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Coal Market Module

of the National Energy Modeling System

Model Documentation 2011

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Update Information

The *Coal Market Module of the National Energy Modeling System Model Documentation 2011* has been updated to include major changes to the Coal Market Module modeling structure for the *Annual Energy Outlook 2011*. The changes include:

- Added an additional supply curve (Rocky Mountain metallurgical coal) for a total of 41 supply curves
- Created and passed an estimate of rail ton-miles for coal rail freight to the Transportation Model of NEMS
- Updated carbon dioxide emission factors for the coal supply curves
- Re-classified Alaska/Washington supply curve as low sulfur coal (previously medium sulfur coal)

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Purpose of This Report

This report documents the objectives and the conceptual and methodological approach used in the development of the National Energy Modeling System's (NEMS) Coal Market Module (CMM) used to develop the *Annual Energy Outlook 2011 (AEO2011)*. This report catalogues and describes the assumptions, methodology, estimation techniques, and source code of the CMM's two submodules. These are the Coal Production Submodule (CPS) and the Coal Distribution Submodule (CDS).

This document has three purposes. It is a reference document providing a description of the CMM for model analysts and the public. It meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its statistical and forecast reports (Public Law 93-275, Federal Energy Administration Act of 1974, Section 57(B)(1), as amended by Public Law 94-385). Finally, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model evaluations, model enhancements, data updates, and parameter refinements as future goals to improve the quality of the module.

Module Summary

The CMM provides annual forecasts of prices, production, and consumption of coal through 2035 for the NEMS. In general, the CPS provides supply inputs that are integrated by the CDS to satisfy demands for coal received from exogenous demand models. The international component of the CDS forecasts annual world coal trade flows from major supply to major demand regions and provides annual forecasts of U.S. coal exports for input to NEMS. Specifically, the CDS receives minemouth prices produced by the CPS, demand and other exogenous inputs from other NEMS components, and provides delivered coal prices and quantities to the NEMS economic sectors and regions.

Archival Media

Archived as part of the National Energy Modeling System production runs.

Model Contact

Information on individual submodules may be obtained from each submodule Model Contact.

Coal Production Submodule

The CPS generates a different set of supply curves for the CMM for each year in the forecast period. The construction of these curves involves three steps for any given forecast year. First, the CPS calibrates a previously estimated regression model of minemouth prices (see Appendix 1.D) to base-year production and price levels by region, mine type, and coal type. Second, the CPS converts the regression equation into continuous coal supply curves. Finally, the supply curves are converted to step-function form, as required by the CMM's Coal Distribution Submodule, and prices for each step are calibrated to base year data (2009 for the *AEO2011*).

Coal Distribution Submodule

The CDS has two primary functions: 1) determine the least-cost supplies of coal to meet a given set of U.S. coal demands by sector and region; and 2) determine the least-cost supplies of coal to meet a given set of international coal demands by sector and region.

Domestic Coal Distribution

The domestic distribution component of the CDS determines the least cost (minemouth price plus transportation cost plus sulfur and mercury allowance costs) supplies of coal by supply region for a given set of coal demands in each demand sector in each demand region using a linear programming algorithm. The transportation costs are assumed to change over time across all regions and demand sectors. These costs are modified over time in response to projected variations in fuel costs, labor costs, the user cost of capital for transportation equipment, and a time trend. The CDS uses the available data on existing coal contracts (tonnage, duration, coal type, origin and destination of shipments) as reported by electricity generators to represent coal under contract up to the contract's expiration date.

International Coal Trade

The international component of the CDS provides annual forecasts of U.S. coal exports and imports in the context of world coal trade for input to NEMS. The model uses 17 coal export regions (including 5 U.S. export regions) and 20 coal import regions (including 4 U.S. import regions) to forecast steam and metallurgical coal flows which are computed by minimizing total delivered cost by a Linear Program (LP) model. The constraints on the LP model are: maximum deliveries from any one export region; sulfur dioxide limits; and international coal supply curves.

Organization of This Report

The report is divided into three sections. The first provides specifics of the CPS, the second described the domestic component of the CDS, and the third section details the international component of the CDS. Within each section, the objectives, assumptions, mathematical structure, and primary input and output variables for each modeling area are described. Descriptions of the relationships within the CMM, as well as the CMM's interactions with other modules of the NEMS integrating system are also provided.

The appendices of each of the three major sections provide supporting documentation for the CMM files. Model abstracts summarizing the features, inputs, and outputs of each model are provided in Appendix A. Within the other Appendices are more detailed descriptions of the CMM input files, parameter estimates, forecast variables, and model outputs. A mathematical description of the computational algorithms used in the respective submodules of the CMM, including model equations and variable transformations, is provided. A bibliography of reference materials used in the development process of each section is also given. Data quality and estimation methods are also described within the Appendices.

List of Acronyms

2SLS:	Two-stage least squares
ACI:	Activated carbon injection
AEO:	Annual Energy Outlook
BOM:	Bureau of Mines
BTU:	British Thermal Unit
CAAA90:	Clean Air Act Amendment of 1990
CDS:	Coal Distribution Submodule
CEUM:	Coal and Electric Utilities Model
CIF:	Cost plus insurance and freight; the FOB cost of coal plus the cost of insurance and freight
CMM:	Coal Market Module
CPS:	Coal Production Submodule
CSTM:	Coal Supply and Transportation Model
CTL:	Coal-to-liquids; references modeled sector in which coal is be converted from a solid to a liquid
DWT:	Deadweight ton (2,240 pounds)
ECP:	Electricity Capacity Planning Submodule
EFD:	Electricity Fuel Dispatch Submodule
EIA:	Energy Information Administration
EMM:	Electricity Market Module
EPA:	Environmental Protection Agency
FERC:	Federal Energy Regulatory Commission
FOB:	Free on Board
ICR:	Information Collection Request
ICTM:	International Coal Trade Model
IFFS:	Intermediate Future Forecasting System
LP:	Linear program or linear programming
MAM:	Macroeconomic Activity Module
NCM:	National Coal Model
NEMS:	National Energy Modeling System
OLS:	Ordinary Least Squares
OML:	Optimization Management Library (linear programming solver)
PCI:	Pulverized coal injection
PIES:	Project Independence Evaluation System
PPI:	Producer price index
PMM:	Petroleum Market Module
PRB:	Powder River Basin
RAMC:	Resource Allocation and Mine Costing Model
RHS:	Right-hand side of linear programming constraints
SO_2:	Sulfur Dioxide
WOCTES:	World Coal Trade Expert System

1. **Coal Production Submodule**

Introduction

Section 1 of the Coal Market Module documentation report addresses the objectives and the conceptual and methodological approach for the Coal Production Submodule (CPS). This section provides descriptions of the assumptions, methodology, estimation techniques, and source code of the CPS. As a reference document, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements to improve the quality of the module.

Model Summary

The modeling approach to regional coal supply curve construction discussed here addresses the relationship between the minemouth price of coal and corresponding levels of capacity utilization at mines, productive capacity, labor productivity, wages, fuel costs, other mine operating costs, and a term representing the annual user cost of mining machinery and equipment. These relationships are estimated through the use of a regression model that makes use of regional level data by mine type (underground and surface) for the years 1978 through 2007. The regression equation, together with projected levels of productive capacity, labor productivity, miner wages, cost of capital, fuel prices, and other mine operating costs, produces minemouth price estimates for coal by region, mine type, and coal type for different levels of capacity utilization.

The measure used for the price of fuel in the *AEO2011* coal pricing model is based on both the price of electricity to industrial consumers and the price of No. 2 diesel fuel to end users. According to data published by the U.S. Department of Commerce, electricity accounted for 86 percent of the fuel consumption at U.S. underground mines in 2002 on a Btu basis and an estimated 21 percent of the fuel consumption at surface mines.[1] Fuel oil (distillate and residual) accounted for 14 percent of the fuel consumption at underground mines in 2002 and 79 percent of the fuel consumption at surface mines. The data used to calculate these percentages exclude estimated consumption of fuels for which the type of fuel consumed is unknown, and small amounts of other fuels consumed at U.S. coal mines, such as motor gasoline, natural gas, and coal.

The CPS generates a different set of supply curves for the NEMS' Coal Market Module (CMM) for each year in the forecast period. The construction of these curves involves three main steps for any given forecast year. First, the CPS calibrates the regression model to base-year production and price levels by region, mine type, and coal type. Second, the CPS converts the regression equation into coal supply curves. Finally, the supply curves are converted to step-function form and prices for each step are adjusted to the year dollars required by the CMM's Coal Distribution Submodule. The completed supply curves are input to the Coal Distribution Submodule (CDS), which finds the least cost solution

[1] U.S. Census Bureau, *2002 Census of Mineral Industries*, *Bituminous Coal and Lignite Surface Mining 2002*, EC902-211-212111(RV) (Washington, DC, December 2004); *Bituminous Coal Underground Mining 2002*, EC02-211-212112(RV) (Washington, DC, December 2004); *Anthracite Mining 2002*, EC02-211-212113 (Washington, DC, October 2004).

(minemouth price plus transportation cost) of satisfying the projected annual levels of domestic and international coal demand.

Model Archival Citation and Model Contact

The version of the CPS documented in this report is that archived for the forecasts presented in the *Annual Energy Outlook 2011*.

Name: Coal Production Submodule
Acronym: CPS
Archive Package: NEMS2011 (Available from the U.S. Energy Information Administration, Office of Electricity, Coal, Nuclear and Renewables Analysis)
Model Contact: Mike Mellish, Department of Energy, EI-34 Washington, DC 20585
(202) 586-2136, or (michael.mellish@eia.gov)

Organization

Section 1 of this report describes the modeling approach used in the Coal Production Submodule. The following can be found within this section:

- The model objectives, input and output, and relationship to other models
- The theoretical approach, assumptions, and other approaches
- The model structure, including key computations and equations.

An inventory of model inputs and outputs, detailed mathematical specifications, bibliography, and model abstract for the CPS are included in Appendices 1.A to 1.E.

Model Purpose and Scope

Model Objectives

The objective of the CPS is to develop mid-term (to 2035) annual domestic coal supply curves for the Coal Distribution Submodule (CDS) of the Coal Market Module (CMM) of the National Energy Modeling System (NEMS). The supply curves relate annual production to the marginal cost of supplying coal. Separate supply curves are developed for each unique combination of supply region, mine type (surface or underground), and coal type.

The model is part of a larger integrated National Energy Modeling System (NEMS). The NEMS is a comprehensive, policy-oriented modeling system with which existing situations and alternative futures for the U.S. energy system can be described.[2] A primary NEMS objective is to delineate the energy, economic, and environmental consequences of alternative energy policies by providing forecasts of alternative mid- and long-term energy futures using a unified system of models. Each production, conversion, transportation, and consumption sector is implemented as a module in the NEMS, and supply and demand equilibration among these sectors is achieved through an integrating framework. Annual forecasts are provided through a 25-year horizon. NEMS is capable of providing forecasts of energy-related activities in the United States at the national and regional level. Moreover, the NEMS will provide comprehensive, integrated forecasts for the *Annual Energy Outlook*.

Classification Plan

The CPS contains two major structural elements that categorize U.S. coal supply by region and typology (i.e., parameters that define coal quality and general mining method).

Coal Supply Regions

Fourteen coal supply regions are represented in the CPS. The coal regions are listed in Table 1.1 and shown in Figure 1.1. The coal supply regions represented include States and regions in which prospective changes in coal use are likely to have the greatest market impacts.

The geographical split for the two Wyoming Powder River Basin (PRB) supply regions is primarily based on differences in the average heat content of the coal reserves in these regions. Production from mines in the Wyoming Northern PRB region have a heat content of approximately 16.8 million Btu per ton[3] (8,400 Btu per pound), and production from mines in the Wyoming Southern PRB region having a slightly higher heat content of about 17.6 million Btu per ton (8,800 Btu per pound). In developing our base-year (2009) input data for the *AEO2011*, the Wyoming Northern PRB supply region included production from the nine Wyoming PRB coal mines located north of the Black Thunder mine, and the Wyoming Southern PRB region included production from the three southernmost mines in Wyoming's PRB (Arch Coal's Black Thunder mine, Peabody's North Antelope/Rochelle mine, and Cloud Peak Energy's Antelope mine). In addition to heat content, the supply curves for the two Wyoming PRB supply regions have slightly different assignments for sulfur and mercury content (see Table 2.1).

Coal Typology

The model's coal typology includes four thermal and three sulfur grades of coal for surface and underground mining. The four thermal grades correspond generally to the three ranks of coal (bituminous, subbituminous, and lignite) and a premium grade bituminous coal used primarily for metallurgical purposes. The three sulfur grades represented are low, medium, and high. The three sulfur content categories are required to model the regulatory restrictions on SO_2 emissions and to accurately estimate projected levels of SO2 emissions for the electric power sector. While each of the coal supply curves represented in the CMM are grouped into one of three sulfur grades, actual sulfur content assignments for each curve are based on regional-level data and, therefore, vary across the supply regions. For example, the average sulfur content of low-sulfur bituminous coal shipments from mines in Central Appalachia in recent years has been about 0.55 pounds per million Btu heat input, while the sulfur content of low-sulfur subbituminous coal shipped from mines in Wyoming's Southern Powder River has averaged less than

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[2] For an overview of the National Energy Modeling System see *The National Energy Modeling System: An Overview 2003*. Energy Information Administration, *The National Energy Modeling System: An Overview 2003* DOE/EIA-0581(2003) (Washington, DC, March 2003).
[3] Unless otherwise specified, tons refer to short tons (2,000 pounds) throughout this document.

0.35 pounds per million Btu heat input. In total, 9 coal types (unique combinations of thermal grade and sulfur content) and 2 mine types (underground and surface) are represented in the CPS (Table 1.1).

For the *AEO2011*, U.S. coal supply is represented through the use of 41 supply curves, reflecting the combination of supply regions, coal types, and mine types (Table 1.1). Because not all coal types are represented in the coal reserve base for each of the 14 supply regions modeled in the CMM, the required number of coal supply curves varies by region. For example, Northern Appalachia is represented with six supply curves, the most of any of the regions, while the Western Interior, Dakota Lignite, and Alaska/Washington regions are each represented with a single supply curve. In some instances, the coal reserves base for a region may contain coal types that are not represented in the CMM, generally because the quantity of available reserves is felt to be of an insufficient quantity to model. An example is the small quantities of low-sulfur, bituminous coal reserves that are not modeled for the Northern Appalachian supply region.[4]

The primary data source for U.S. coal reserves is the demonstrated reserve base (DRB) of coal in the United States. Although the DRB was originally developed by the U.S. Bureau of Mines in 1971, the EIA assumed responsibility for the DRB in 1977 and has since maintained and updated the information for this important database.[5] Over time, the EIA has performed two general types of updates: 1) annual downward adjustments to estimated coal reserves based on reported production from mines; and 2) regional updates to reserve estimates primarily based on new data from State geological surveys.

Model Inputs and Outputs

Model input requirements are grouped into two categories, as follows:

- User-specified inputs
- Inputs provided by other NEMS modules and submodules

User-specified inputs for the base-year include capacity utilization at mines, productive capacity, minemouth coal prices, miner wages, labor productivity, cost of mining equipment, and the price of electricity. Other user-specified inputs required for the NEMS forecast years include annual growth rates for labor productivity and wages, and annual producer price indices for the cost of mining machinery and equipment, iron and steel, and explosives. Inputs obtained from other NEMS modules include coal production for year t-1, the minemouth coal price for years t and t-1, electricity prices, and the real interest rate (Figure 1.2). Appendix 1.C includes a complete list of input variables and specification levels.

The primary outputs of the model are annual coal supply curves (price/production schedules), provided for each supply region, mine type, and coal type.

[4] Energy Information Administration, *U.S. Coal Reserves: 1997 Update*, DOE/EIA-0529(97) (Washington, DC, February 1999).
[5] Energy Information Administration, *Estimation of U.S. Coal Reserves by Coal Type: Heat and Sulfur Content*, DOE/EIA-0529 (Washington, DC, October 1989), p. 5.

Table 1.1. Supply Regions and Coal/Mine Types Used in the NEMS Coal Market Module

Supply Regions	States	Underground Mined Types	Surface Mined Types
Appalachia			
1. "NA"-Northern Appalachia	PA,OH,MD & No.WV	MDP,MDB,HDB	MSB,HSB,HSL
2. "CA"-Central Appalachia	So.WV,VA, East KY, No. TN	CDP,CDB,MDB	CSB,MSB
3. "SA"-Southern Appalachia	AL & So. TN	CDP,CDB,MDB	CSB,MSB
Interior			
4. "EI"-East Interior	West KY, IL, IN & MS	MDB,HDB	MSB,HSB,MSL
5. "WI"-West Interior	IA,MO,KS,AR,OK,TX		HSB
6. "GL"-Gulf Lignite	TX,LA		MSL,HSL
North Great Plains			
7. "DL"-Dakota Lignite	ND & East MT		MSL
8. "PG"-Powder & Green River Basins	West MT & WY	CDB	CSS,MSS
Other West			
9. "RM"-Rocky Mountains	CO & UT	CDP,CDB	CSS
10. "ZN"-Southwest	NM & AZ	MDB	CSB,MSS
11. "AW"-Northwest	AK & WA		CSS

KEY TO COAL TYPE ABBREVIATIONS

SULFUR EMISSIONS CATEGORIES

"C__" -"Compliance": < = 1.2 lbs SO2 per million Btu

"M__" -"Medium": > 1.2, < = 3.33 lbs SO2 per million Btu

"H__" -"High":> 3.33 lbs SO2 per million Btu

MINE TYPES

"_D_" underground mining

"_S_"surface mining

COAL GRADE OR RANK

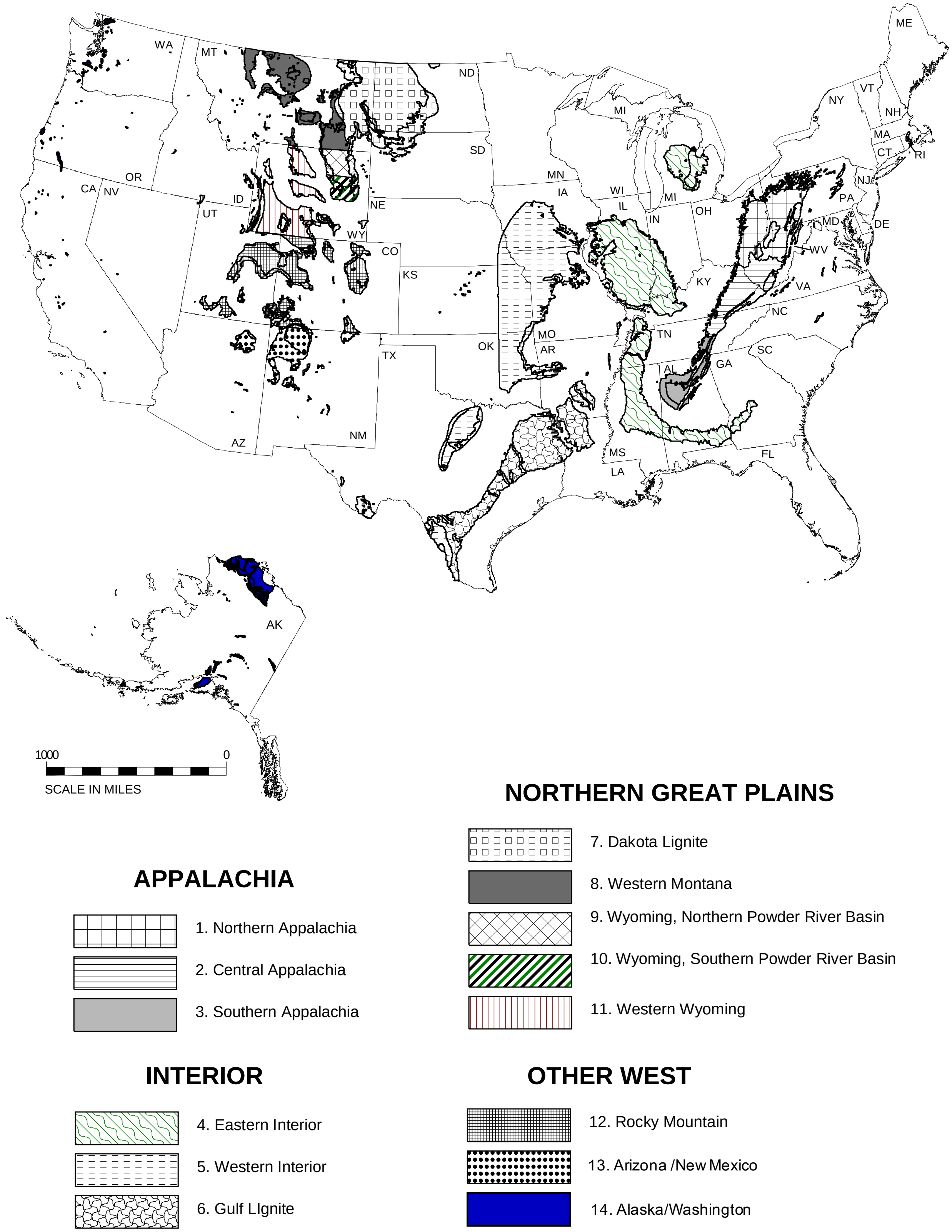
"__P", Premium or metallurgical coal

"__B", Bituminous and anthracite steam coal

"__S", Subbituminous steam coal

__L", Lignite, bituminous gob or anthracite culm steam coal

Figure 1.1. Coal Supply Regions



Source: Energy Information Administration, Office of Electricity, Coal, Nuclear and Renewables Analysis

Relationship to Other Components of NEMS

The model generates regional mid-term (to 2035) coal supply curves. A distinct set of supply curves is determined for each forecast year. The supply curves are required input to the CDS submodule of the CMM, and the NEMS Electricity and Petroleum Market Modules. The information flow between the model and other components of NEMS is shown in Figure 1.2. Information obtained from the CDS and other NEMS modules is as follows:

- Electricity prices by Census division are obtained from the Electricity Market Module (EMM) in year t
- National-level distillate fuel price is obtained from the Petroleum Market Module (PMM) in year t
- Real interest rate is obtained from the Macroeconomic Activity Module (MAM) in year t
- Coal production by CPS supply curve in year t-1
- Minemouth coal prices by CPS supply curve in years t and t-1

Model Rationale

Theoretical Approach

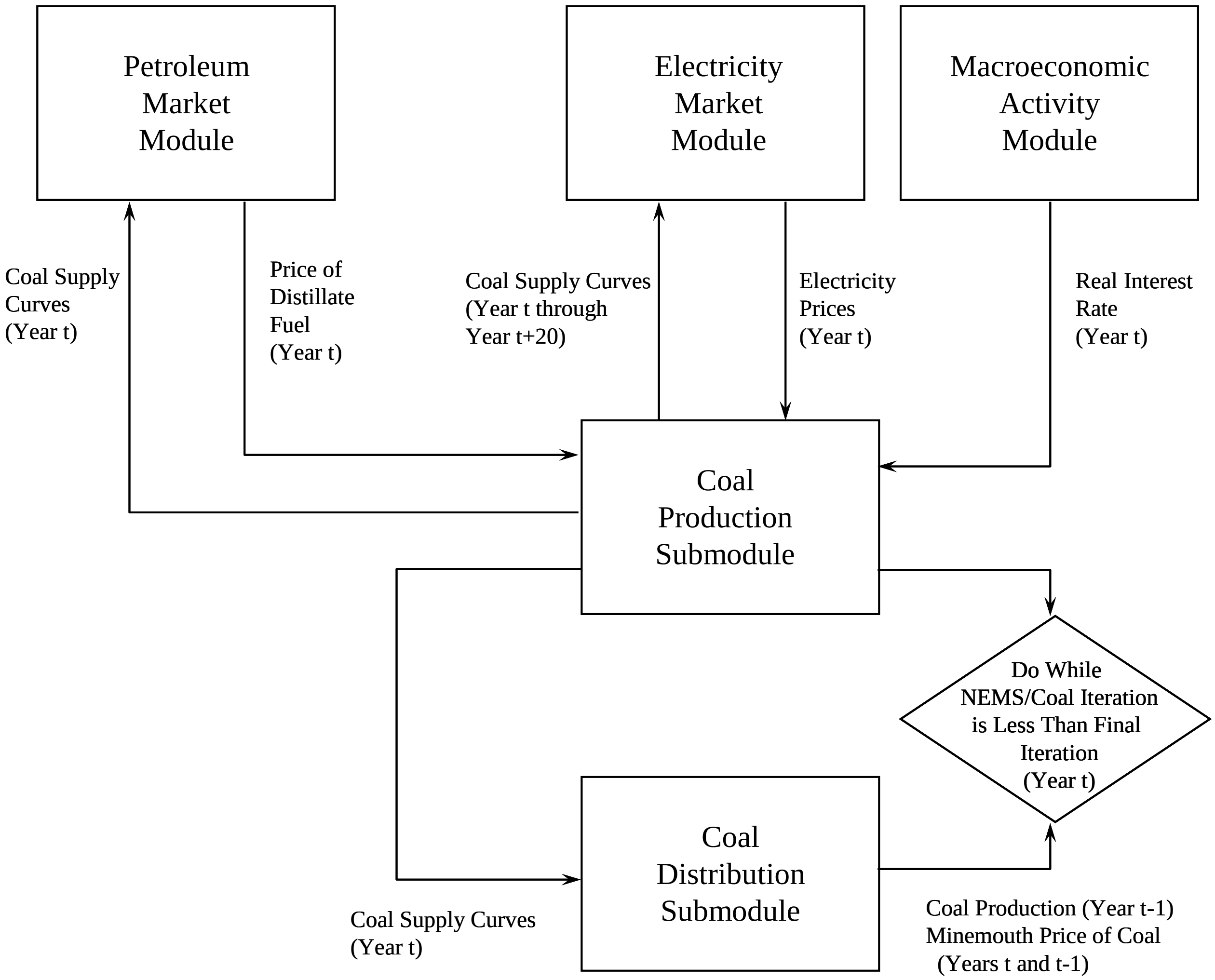
The purpose of the CPS is to construct a distinct set of coal supply curves for each forecast year in the NEMS. The construction of these curves involves three main steps for any given forecast year. First, the CPS calibrates the regression model to base-year production and price levels by region, mine type, and coal type. Second, the CPS converts the regression equation into coal supply curves. Finally, the supply curves are converted to step-function form for input to the CMM's Coal Distribution Submodule, which finds the least cost solution (minemouth price plus transportation cost) of satisfying the projected annual levels of domestic and international coal demand.

The CPS addresses the relationship between the minemouth price of coal and corresponding levels of capacity utilization at mines, productive capacity, labor productivity, wages, fuel costs, other mine operating costs, and a term representing the annual user cost of mining machinery and equipment. These relationships are estimated through the use of a regression model that makes use of annual historical regional level data. The regression equation, together with projected levels of productive capacity, labor productivity, miner wages, capital costs, fuel prices and other mine operating costs, produces minemouth price estimates for coal by region, mine type, and coal type for different levels of capacity utilization.

Underlying Rationale

This section presents the econometric model used to produce coal supply curves for the *AEO2011* forecasts. The primary criteria guiding the development of the coal pricing model were that the model should conform to economic theory and that parameter estimates should be unbiased and

Figure 1.2. Information Flow Between the CPS and Other Components of NEMS



statistically significant. Following economic theory, an increase in output or factor input prices should result in higher minemouth prices, and increases in coal mining productivity should result in lower minemouth prices. In addition, the model should account for a substantial portion of the variation in minemouth prices over the historical period of study.

Background Discussion and Theoretical Foundation

Between 1978 and 2004, the average mine price of coal in the United States, in constant 2005 dollars, fell from $54.11 per ton to $20.74 per ton, a decline of 62 percent (Figure 1.3). During the same period, total U.S. coal production increased by 66 percent, from 670 million tons to 1,112 million tons. The inverse relationship between the production of coal and its price over time is attributable to many factors, including gains in labor productivity and declines in factor input costs. Although minemouth prices and coal mining productivity remained relatively constant between 1999 and 2004, both have changed significantly during the past few years. Between 2004 and 2009, the average U.S. minemouth coal price, in inflation adjusted dollars, rose by 46 percent. During this period, coal mining productivity declined by 18 percent, falling from 6.80 tons per miner hour to 5.61 tons per miner hour.

Productivity has had a profound effect on competition in the U.S. coal industry. Between 1978 and 2004, labor productivity at U.S. mines rose from 1.77 tons per miner hour to 6.80 tons per miner hour, representing an increase of 5.3 percent per year. This growth contributed to a downward shift in costs over time, making additional quantities of coal available at lower prices. A graphical representation of labor productivity and the average price of coal at mines for the unique combinations of region, mine type, and year as represented in the *AEO2011* coal pricing model indicates the strong negative historical correlation between prices and productivity (Figure 1.4).

Figure 1.3. U.S. Coal Production and Prices, 1978-2009

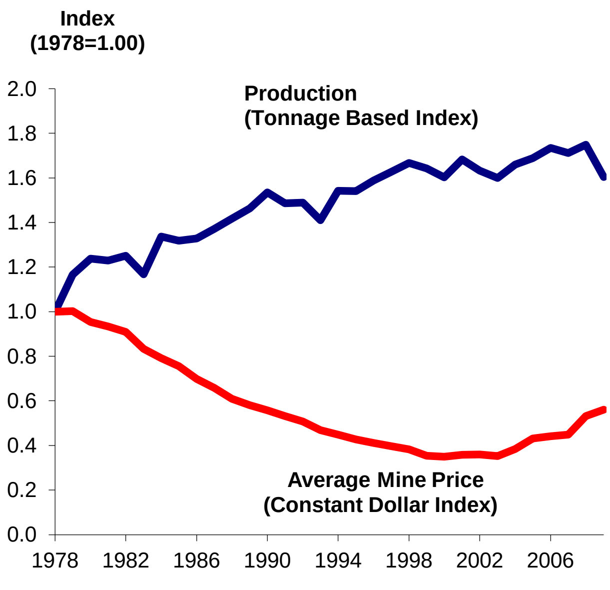
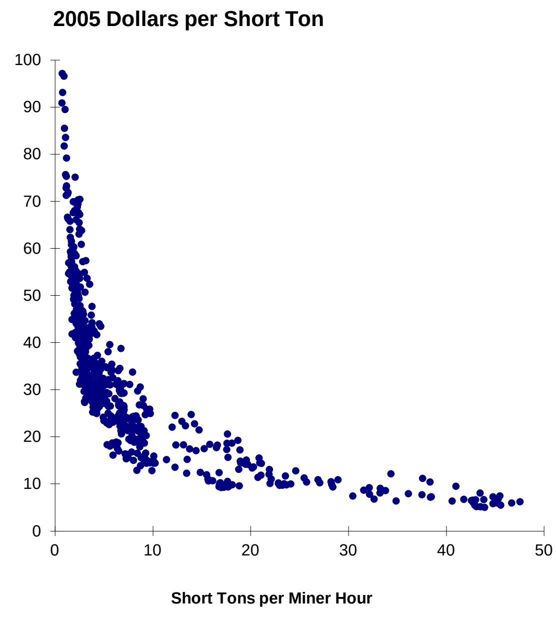


Figure 1.4. Minemouth Coal Prices and Labor Productivity for CMM Regions and Mine Types, 1978-2009



A Model of the Coal Market

The model of the U.S. coal market developed for the CPS recognizes that prices in a competitive market are a function of factors that affect either the supply or demand for coal.[5] The general form of the model is that a competitive market converges toward equilibrium, where the quantity supplied equals the quantity demanded for region i and mining type j in year t:

$$Q_{S,i,j,t}^{S} = Q_{D,i,j,t}^{D} = Q_{i,j,t} \tag{1.1}$$

In this equality, $Q_{i,j,t}$ represents the long-run equilibrium quantity of supply and demand for coal in a competitive market.

The formal specification of the coal pricing model for *AEO2011* is as follows.
For demand,

$$\begin{aligned} Q^D = f\,(&P, ELEC_{t-1}, ELEC\_SHARE_{t-1}, INDUSTRY_{t-1}, OTHPROD_{t-1}, EXPORTS_{t-1}, PGAS_{i,t},\\ &WOP_t, STOCKS_{t-1}, DAYS\_SUP_{t-1}, BTU\_TON_{i,j,t}, SULFUR_{i,j,t}, ASH_{i,j,t}) + e_{D,i,j,t} \end{aligned} \tag{1.2}$$

For supply,

$$\begin{aligned} P = f\,(&(Q_{S,i,j,t}/PRODCAP_{i,j,t}), PRODCAP_{i,j,t}, TPH_{i,j,t}, WAGE_t, PCAP_t, PFUEL_{i,t},\\ &OTH\_OPER_{i,j,t}) + e_{S,i,j,t} \end{aligned} \tag{1.3}$$

The term "Q^S/PRODCAP" is the average annual capacity utilization at coal mines. Throughout the remaining sections and appendices of Section 1, this term is referred to as "CAPUTIL."

<u>The demand-side variables are as follows:</u>

Q^D is the quantity of coal demanded from region i, mine type j, in year t in million tons.

ELEC is U.S. coal-fired electricity generation in billion kilowatthours in year t-1.

ELEC_SHARE is the share of total U.S. electricity generation accounted for by generation at natural-gas-fired power plants in year t-1.

INDUSTRY is U.S. industrial coal consumption (steam and coking) in million short tons for each year t-1.

OTHPROD is the total U.S. coal production in million tons minus coal production for region i and mine type j for each year t-1.

EXPORTS is the level of U.S. coal exports in million tons in year t-1.

PGAS is the delivered price of natural gas to the electricity sector in constant 1992 dollars per thousand cubic feet for region i in year t.

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[5] K. Forbes and C. Minnucci, Science Applications International Corporation, "An Econometric Model of Coal Supply: Final Report," (unpublished report prepared for the Energy Information Administration, December 20, 1996)

WOP is the world oil price in constant 1992 dollars per barrel in year t.

STOCKS is the quantity of coal inventories held at plants in the electric power sector in million tons at the beginning of year t-1.

DAYS_SUP is the average days of supply of coal inventories held at electricity sector plants in year t-1.

BTU_TON is the average heat content of coal receipts at electric power sector plants in million Btu per ton for region i and mine type j, in year t.

SULFUR is the average sulfur content of coal receipts at electric power sector plants specified as pounds of sulfur per million Btu for region i and mine type j, in year t.

ASH is the average ash content of coal receipts at electric power sector plants specified as percent ash by weight for region i and mine type j, in year t.

e^D is a random term representing unaccounted factors in the demand function for region i and mine type j, in year t.

The supply-side variables are as follows:

P is the average minemouth price of coal in constant 1992 dollars per ton for region i and mine type j, in year t.

Q^S is the quantity of coal supplied in million tons from region i, mine type j, in year t.

PRODCAP is the annual coal productive capacity in million tons for region i and mine type j, in year t.

Q^S/PRODCAP (or CAPUTIL)is the average annual capacity utilization (in percent) at coal mines for region i and mine type j, in year t.

TPH is the average annual labor productivity of coal mines in tons per miner hour for region i and mine type j, in year t.

WAGE is the average hourly coal industry wage in constant 1992 dollars, in year t.

PCAP is the annualized user cost of mining equipment in constant 1992 dollars, for mine type j, in year t.

PFUEL is the weighted average of the price of electricity in the industrial sector and the price of No. 2 diesel fuel to end users (excluding taxes) in 1992 dollars per million Btu for region i, in year t.

OTH_OPER is a constant dollar index representing a measure for mine operating costs other than wages and fuel specified by supply region i, mine type j, in year t. Examples of other operating costs include items such as replacement parts for equipment, roof bolts, and explosives.

e^S is a random term representing unaccounted factors in the supply function for region i and mine type j, in year t.

In this model, the amount of coal demanded from region i and mine type j in year t is determined by the minemouth price of coal, electricity generation, industrial coal consumption, coal exports, the price of natural gas, the world oil price, the level of coal stocks, and the heat, sulfur and ash content of the coal. On the supply side of the market, the minemouth price is assumed to be determined by the capacity utilization at mines, productive capacity, the level of labor productivity, the average level of wages, the annualized cost of mining equipment, and the cost of fuel used by mines.

Estimation Methodology

The supply function for coal cannot be evaluated in isolation when the relationship between quantity and price is being studied. The solution is to bring the demand function into the picture and estimate the demand and supply functions together. For the *AEO2011* coal pricing model, the two-stage least squares (2SLS) methodology was selected for estimating the set of simultaneous equations representing the supply and demand for coal.

The rationale for using 2SLS rather than ordinary least squares (OLS) results from the structure of equations (1.2) and (1.3). In equation (1.3), the error term in the supply equation (e^S) affects the minemouth price (P); however, in Equation (1.2), price influences the quantity demanded (Q^D). As a result, the quantity of coal supplied (Q^S) on the right-hand side of the supply equation is correlated with the error term in the same equation. This violates one of the fundamental assumptions underlying the use of OLS, namely, that the error term is independent from the regressors. As a result, the OLS estimator will not be consistent.

In addition, while WAGE, PCAP, PFUEL, OTH_OPER, and TPH are all hypothesized to affect the price of coal, they are also affected by the price of coal. For example, an increase in the price of coal resulting from increased demand for coal may affect the wages paid in the coal industry, the cost of mining equipment, and the price of fuels. Prices may also influence the level of productivity. If prices decrease (increase), marginal mines are abandoned (opened), increasing (lowering) labor productivity. This violates the assumption underlying the use of OLS, making it an inappropriate method by which to estimate the supply function.

An accepted solution to the problem of biased least squares estimators is the use of 2SLS, where the objective is to make the explanatory endogenous variable uncorrelated with the error term.[6] This is accomplished in two stages. In the first stage of the estimation, the endogenous explanatory variables are regressed on the exogenous and predetermined variables. This stage produces predicted values of the endogenous explanatory variables that are uncorrelated with the error term. The predicted values are employed in the second stage of the technique to estimate the relationship between the dependent endogenous variable and the independent variables. The result from the second-stage (structural) equation represents the model implemented in the CMM for *AEO2011*. The first stage (reduced form) equations are used only to obtain the predicted

[6] G.S. Maddala, *Introduction to Econometrics: Second Edition* (New York, MacMillan Publishing Company, 1992), 355-403.

values for the endogenous explanatory variables included in the second stage, effectively purging the demand effects from the supply-side variables.

The structural equation for the coal pricing model was specified in log-linear form using the variables listed above. In this specification, the values for all variables (except for the constant terms) are transformed by taking their natural logarithm. All observations were pooled into a single regression equation. In addition to the overall constant term for the model, intercept dummy variables were included for all regions except Central Appalachia. Slope dummy variables were included for the productivity and productive capacity variables to allow the coefficients for those terms to vary across regions and mine types. The Durbin-Watson test for first-order positive autocorrelation indicated that the hypothesis of no autocorrelation should be rejected. As a consequence, a correction for serial correlation was incorporated. In addition, a formal test indicated that the null hypothesis of homoskedasticity (the assumption that the errors in the regression equation have a common variance) across regions should be rejected, and, as a result, a weighted regression technique to correct for heteroskedasticity in the error term was employed to obtain more efficient parameter estimates. The statistical results of the regression analysis and the equation used for predicting future levels of minemouth coal prices by region, mine type, and coal type are provided in Appendix 1.D.

In general, the results satisfy the performance criteria specified for the model. Indicative of the high R^2 statistic, there is a close correspondence between the predicted and actual minemouth prices (a discussion of how the R^2 statistic is calculated in the TSP statistical package is provided in Appendix 1.D). Moreover, all parameter estimates have their predicted signs and are generally statistically significant.

Average annual seam thickness by region and mine type also was tested as a supply-side variable. The model results, however, did not support the hypothesis that decreases (increases) in seam thickness have exerted upward (downward) pressure on prices.

Labor Productivity

Historically, the U.S. coal mining industry has developed or adopted a number of technological changes in each stage of production and achieved economies of scale that have contributed to overall productivity improvements. Examples include mining equipment and materials handling in underground mines, surface mining equipment and methods, equipment monitoring and automation, and mine planning. In the future, the rate at which productivity will advance is dependent on the mix of relatively new technologies that are contributing to the gains, their individual significance in realizing productivity improvement, and their stage in the technology diffusion cycle.

In addition to gradual improvements in mining equipment and techniques, the U.S. coal industry has also experienced the introduction and penetration of fundamentally new mining systems over time. At underground mines examples include the introduction and gradual diffusion of the continuous mining method that began in the 1940's, and, more recently, the introduction and penetration of longwall mining systems that began in this country in the 1960's. Continuous mining saw its share of total U.S. underground production increase from 2 percent in 1951 to 31 percent in 1961. By 1971, the share of continuous mining coal production was 55 percent, and, in 1990, continuous mining accounted for 64 percent of total underground production.[7] Similarly

[7] J. I. Rosenberg, et. al., *Manpower for the Coal Mining Industry: An Assessment of Adequacy through 2000*, prepared for the U.S. Department of Energy (Washington, DC, March 1979).

longwall mines saw their share of total underground production increase from less than 1 percent in 1966, to 4 percent in 1976, and to approximately 16 to 20 percent by 1982.[8] Recent data collected by EIA showed continuing penetration of the longwall mining technique in the U.S. coal industry for another two decades, with this mining technique's share of underground production rising to 29 percent in 1990 and to a peak of 53 percent in 2002.[9] In 2009, longwall mines accounted for 50 percent of the production from all U.S. underground coal mines. For the future, it's likely that additional penetration of the longwall mining technique will be limited by a number of factors, such as concerns about surface subsidence and reduced availability of new sites with appropriate geologic characteristics and reserve blocks. The fragmentation of reserves and relatively thin coal seams of Central Appalachia are key factors underlying the recent decline in longwall production in this major supply region, where its share of underground production has dropped from a peak of 22 percent in 2002 to 10 percent in 2007. For surface mines, the size and capacity of the various types of equipment used (including shovels, draglines, front-end loaders, and trucks) has gradually increased over time, leading to steady growth in the average productivity of these mines.

Whether technological change represents improvements to existing technologies or fundamental changes in technology systems, the change has a substantial impact on productivity and costs. With few exceptions, transition in the coal industry to new technology has been gradual, and the effect on productivity and cost also has been gradual.[10] The gradual introduction of new technology development is expected to continue during the NEMS forecasting horizon. Potential technology improvements in underground mining during the next several years include larger motors and improved designs of longwall shearers and continuous miners, larger conveyor motors and belt sizes for coal haulage, overall improvements in the design of underground coal haulage systems, better diagnostic monitoring of production equipment for preventative maintenance via the use of sensors and computers, and more precise control of longwall shearers and shields through the use of computer-supported equipment.[11] Potential improvements in surface mining technology include the increased utilization of on-board computers for equipment monitoring, the increased use of blast casting for overburden removal, and the continuation in the long-term trend toward higher capacity equipment (e.g., larger bucket sizes for draglines and loading shovels and larger trucks for overburden and coal haulage).

In the CMM, different rates of productivity improvement are input for each of the 41 coal supply curves used to represent U.S. coal supply. In addition to assumptions about incremental improvements in coal mining technologies over the forecast horizon, the productivity inputs for the CMM also take into consideration the adverse impact on productivity that results as U.S. coal producers gradually move into more difficult to mine coal reserves. A fairly clear-cut example of

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[8] Paul C. Merritt, "Longwalls Having Their Ups and Downs," *Coal*, MacLean Hunter (February 1992), pp. 26-27.

[9] Energy Information Administration (EIA), *Coal Data: A Reference,* DOE/EIA-0064(90) (Washington, DC, November 1991), p. 10; and EIA, Form EIA-7A, "Coal Production Report."

[10] Perhaps the most notable exception has been the dramatic, on-going rise in longwall productivity, following rapidly on the heels of the introduction of a new generation of longwall equipment in the last decade. Between 1986 and 1990, longwall productivity nearly doubled, and although this increase should not be attributed solely to the improvements in longwall technology, the introduction and rapid penetration of the new longwall equipment was unquestionably a major contributing factor.

[11] S. Fiscor, "U.S. Longwall Census 2008," *Coal Age* (February 2009) and prior issues; E.J. Flynn, "Impact of Technological Change and Productivity on the Coal Market," *Issues in Midterm Analysis and Forecasting 2000,* Energy Information Administration, EIA/DOE-0607(2000) (Washington, DC, July 2002); S.C. Suboleski, et. al., *Central Appalachia: Coal Mine Productivity and Expansion (EPRI Report Series on Low-Sulfur Coal Supplies*) (Palo Alto, CA: Electric Power Research Institute (Publication Number IE-7117), September 1991).

a region where mining conditions are becoming increasingly difficult is Wyoming's Powder River Basin, where coal producers are faced with steadily increasing overburden thicknesses as their surface mining operations advance to the west. This situation has faced coal producers in this region ever since the start of major surface mining operations in this region in the early 1970s. For years, advancements in mine equipment, mining techniques, and economies of scale appeared to have been winning out over the increasing overburden thicknesses at mines, as evidenced by steady improvements in coal mining productivity. For example, data collected by EIA and the Mine Safety and Health Administration indicate that coal mining productivity at mines in Wyoming's Powder River Basin rose from 12.18 tons per miner hour in 1978 to 46.77 tons per miner hour in 2001. Since then, however, productivity for this region has leveled off and declined, with the most recent data indicating productivity of 33.38 tons per miner hour in 2009. This seems to be an indication that the more difficult mining conditions in this region are outpacing the advancements in surface coal mining technologies.

In the CMM, the cost effect of labor productivity change for each year is determined using the coal-pricing regression model which incorporates both regional and mine type coefficients. In each forecast year, the regression model determines the change in cost due to the changes in labor productivity and the costs of factor inputs. This calculation is based on exogenous productivity forecasts together with forecasts of the various factor input costs. The costs of factor inputs to mining operations captured by the model include projected and estimated changes in real labor costs, real electricity and diesel fuel prices, other mine operating costs, and the annualized cost of capital over the forecast period.

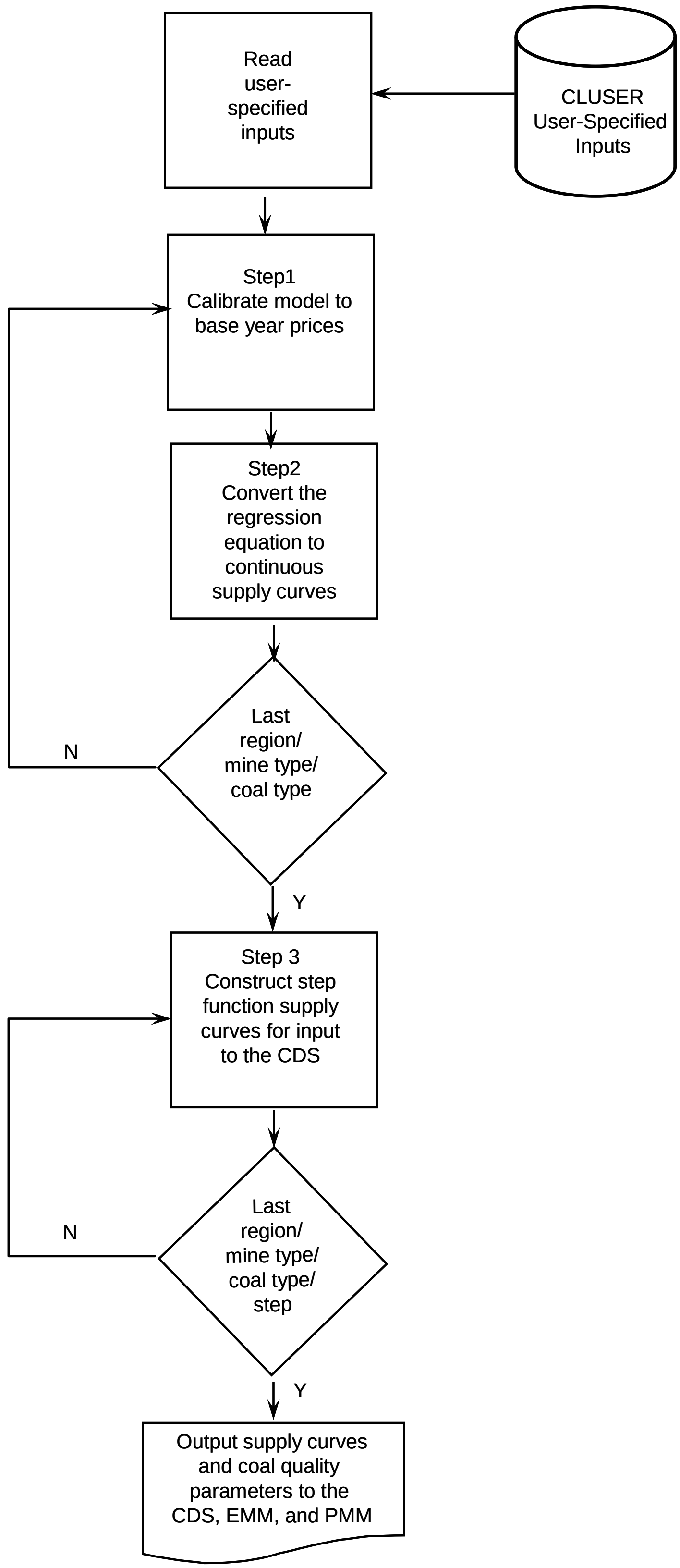
Model Structure

This chapter discusses the modeling structure and approach used by the CPS to construct coal supply curves. The chapter provides a general description of the model, including a discussion of the key relationships and procedures used for constructing the supply curves. A detailed mathematical description of the CPS, showing the estimating equations and the sequence of computations, is provided in Appendix 1.B.

The model constructs a distinct set of supply curves for each forecast year in three separate steps, as follows (see Figure 1.5):

> Step 1: Calibrate the regression model to base-year production and price levels by region, mine type and coal type
>
> Step 2: Convert regression equation to continuous-function supply curves
>
> Step 3: Construct step-function supply curves for input to the CDS

Figure 1.5. CPS Flowchart



Step 1: Model Calibration

To calibrate the model to the most recent historical data, a constant value is added to the regression equation for each CPS supply curve. Thus, when using the base year values of the independent variables, the model solution will equal the base year price as input by the user.

The calibration constants are automatically computed as part of a NEMS run. First, the coal-pricing equation is solved using the base year values for the independent variables. Second, this estimated price is then subtracted from the actual base-year price input by the user. For calibration purposes the simplifying assumption is made that the lagged values of the independent variables (used in those terms of the equation needed to correct for autocorrelation) are the same as the base year values. This assumption obviates the need to provide the model with two years of base data and is believed to yield a reasonable approximation of the "true" calibration constant.

Step 2: Convert Regression Equation to Continuous Supply Curves

A regression equation is used to estimate the relationship between minemouth prices and the projected or assumed values of production, productivity, wages, capital costs, and fuel prices. A distinct supply curve is developed for each combination of region, mine type, and coal type. For the *AEO2011*, the CPS generated a set of 41 separate coal supply curves (see Table 1.1) for each year of the NEMS forecast period.

Following initial base year calibration, the regression equations must be converted into supply curves in which price is represented as a function of production alone. This is accomplished by consolidating all of the non-capacity utilization terms in the regression equation into a single multiplier, computed using the forecast year values of the independent variables. The value of the multiplier is computed by solving the regression equation with the capacity utilization term excluded and all other independent variables equal to their forecast year values. A separate value of the multiplier is computed for each region, mine type, and coal type. Some of the required forecast year values of the various independent variables are supplied endogenously by other NEMS modules, while others, including labor productivity, the average coal industry wage, and the PPI (producer price index) for mining machinery and equipment, steel and iron, and explosives are provided as user inputs. Two different PPI series are used to represent costs of mining equipment: one representing equipment used primarily at underground mines and a second representing equipment used primarily at surface mines.

It should be noted that the subroutine also contains code, currently "commented out," which allows the user to compute the wage values based on inputs from the macroeconomic model; however, currently future wages are computed based on input data from the CLUSER file.

In the CPS, labor productivity is used as a way of capturing the effects of technological improvements on mining costs, in lieu of representing explicitly the cost impact of each potential, incremental technology improvement. In general, technological improvements affect labor productivity as follows: (1) technological improvements reduce the costs of capital; (2) the reduced capital costs lead to substitution of capital for labor; and (3) more capital per miner results in increased labor productivity. As determined by the econometric-based coal-pricing model developed for the CPS, increases in labor productivity translate into lower mining costs on a per-ton basis. Using this approach, exogenous estimates of labor productivity are provided to the CPS for each year of the forecast period. Separate estimates are developed as inputs to the submodule for each region and mining method.

Step 3: Construct Step-Function Supply Curves

The CDS is formulated as a linear program (LP) and cannot directly use the supply curves generated by CPS regression model, whose functional form is logarithmic. Rather, the CDS requires step-function supply curves for input. Using an initial target quantity and percent variations from that quantity, an 11-step curve is constructed as a subset of the full CPS supply curve and is input to the CDS. For each supply curve and year, the CMM uses an iterative approach to find the target quantity that creates the optimal 11-step supply curve given the projected level of demand. The user can vary the length of the steps, and, subsequently, the vertical distances between the steps, by making adjustments to the percent variations from the target quantity via input parameters contained in the CLUSER input file. The selection of step-lengths for the *AEO2011* is based primarily on the premise that the model solution will lie close to the target quantity supplied by the CDS. As a result, the variation from the target quantity is fairly tight on the middle five to seven steps of the curve. The outer four steps are primarily there to assure that there is sufficient supply on the step-function curve to meet any substantial swings in coal demand that might result within a single iteration of NEMS.

The method by which these step-function curves are constructed is as follows. First, the CPS computes 11 quantities by multiplying the target quantity, obtained from the CDS, by the 11 user-specified scalars obtained from the CLUSER input file. The model then computes the prices corresponding to each of the 11 quantities, using the supply curve equations. Finally, prices for each step are adjusted to the year dollars required by the CDS using the GDP chain-type price index supplied by the NEMS Macroeconomic Activity Module. The resulting production and price values are used by the CDS to determine the least cost supplies of coal for meeting the projected levels of annual coal demand.

Appendix 1.A

Submodule Abstract

Model Name: Coal Production Submodule

Model Acronym: CPS

Description: Produces supply-price relationships for 14 coal producing regions, 9 coal types (unique combinations of thermal grade and sulfur content) and 2 mine types (underground and surface) addressing the relationship between the minemouth price of coal and corresponding levels of capacity utilization at coal mines, annual productive capacity, labor productivity, wages, fuel costs, other mine operating costs, and a term representing the annual user cost of mining machinery and equipment. The model serves as a major component in the National Energy Modeling System (NEMS). In the CPS, coal types are defined as unique combinations of thermal and sulfur content. This differs slightly from the NEMS Coal Distribution Submodule, where coal types are defined as unique combinations of thermal content, sulfur content, and mine type.

Purpose of the Model: The purpose of the model is to produce annual domestic coal supply curves for the mid-term (to 2035) for the Coal Distribution Submodule of the Coal Market Module of the NEMS.

Model Update Information: October 2010

Part of Another Model?: Yes, part of the:

- Coal Market Module
- National Energy Modeling System

Model Interface: The model interfaces with the following models:

- Coal Distribution Submodule
- Electricity Market Module
- Macroeconomic Activity Module
- Petroleum Market Module

Official Model Representative:

Office: Electricity, Coal, Nuclear and Renewables Analysis

Division: Coal and Electric Power

Model Contact: Mike Mellish

Telephone: (202) 586-2136

E-mail: michael.mellish@eia.gov

Documentation:

- U.S. Energy Information Administration, *Coal Production Submodule Component Design Report* (draft), May 1992, revised January 1993.

- U.S. Energy Information Administration, *Coal Market Module of the National Energy Modeling System, Model Documentation 2011* DOE/EIA-M060(2011) (Washington, DC, June 2011).

Archive Media and Installation Manual: NEMS11 - *Annual Energy Outlook 2011*

Energy System Described by the Model: Estimated coal supply at various f.o.b. mine costs.

Coverage:

- **Geographic:** Supply curves for 14 geographic regions

- **Time Unit/Frequency:** 1995 through 2035

- **Product(s):** 9 coal types (unique combinations of thermal and sulfur content) and 2 mine types (underground and surface)

- **Economic Sector(s):** Coal producers and importers.

Modeling Features:

- **Model Structure:** The CPS employs a regression model to estimate price-supply relationships for underground and surface coal mines by region and coal type, using projected levels of capacity utilization at coal mines, annual productive capacity, productivity, miner wages, capital costs of mining equipment, fuel prices, and other variable mine supply costs.

- **Modeling Technique:** Three main steps are involved in the construction of coal supply curves:

  - Calibrate the regression model to base-year production and price levels by region, mine type (underground and surface), and coal type
  - Convert the regression equation into supply curves
  - Construct step-function supply curves for input to the CDS

- **Model Interfaces:** Coal Distribution Submodule, Electricity Market Module, Macroeconomic Activity Module, and the Petroleum Market Module.

- **Input Data:** Base year values for U.S. coal production, capacity utilization, productive capacity, productivity, and prices. Base year electricity prices and wages. Heat, sulfur, and mercury content averages, and carbon emission factors by supply curve. Projections of labor productivity, wages, the PPI's for mining machinery and equipment, iron and steel, and explosives.

- **Data Sources:** DOE data sources: U.S. Energy Information Administration: EIA-3, EIA-5, EIA-6A, EIA-7A, EIA-423, and EIA-923 databases. *U.S.* Energy Information Administration, *Electric Power Annual 2009*, DOE/EIA-0348(2009) (Washington, DC, April 2011); *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010); and *State Energy Data System*, Consumption, Price, and Expenditure Estimates (Washington, DC, June 2010), web site www.eia.gov. Non-DOE data sources: Federal Energy Regulatory Commission, FERC-423 database. U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID's: EEU10120006; CEU1021210006; PPI for Mining Machinery and Equipment, Series ID: PCU333131333131; and PPI for Construction Machinery, Series ID: PCU333120333120; PPI for Iron and Steel, Series ID: WPU101; and PPI for Explosives: Series ID: WPU067902. Global Insight, Yield on Utility Bonds. U.S. Census Bureau, *2002 Census of Mineral Industries*, *Bituminous Coal and Lignite Surface Mining: 2002*, EC02-211-212111(RV) (Washington DC, December 2004), *Bituminous Coal Underground Mining: 2002*, EC02-211-212112(RV) (Washington DC, December 2004), and *Anthracite Mining: 2002*, EC02-211-212113 (Washington DC, October 2004).

Computing Environment: See *Integrating Module of the National Energy Modeling System*

Independent Expert Reviews Conducted:

- Barbaro, Ralph and Seth Schwartz. *Review of the Annual Energy Outlook 2003 Reference Case Forecast*, prepared for the U.S. Energy Information Administration (Arlington, VA: Energy Ventures Analysis, Inc., June 2003).

- Eyster, Jerry and Trygve Gaalaas. *Independent Expert Review of the Annual Energy Outlook 2003 Projections of Coal Production, Distribution, and Prices for the National Energy Modeling System's Appalachian, Interior, and Western Supply Regions*, prepared for the U.S. Energy Information Administration (Washington, DC: PA Consulting Group, June 2003).

- Barbaro, Ralph and Seth Schwartz. *Review of the Annual Energy Outlook 2002 Reference Case Forecast for PRB Coal*, prepared for the U.S. Energy Information Administration (Arlington, VA: Energy Ventures Analysis, Inc., August 2002).

- Eyster, Jerry, Trygve Gaalaas and Mark Repsher. *Independent Expert Review of the Annual Energy Outlook 2002 Projections of Coal Production, Distribution, and Prices for the National Energy Modeling System*, prepared for the U.S. Energy Information Administration (Washington, DC: PA Consulting Group, August 2002).

- Suboleski, Stanley C., *Report Findings and Recommendations, Coal Production Submodule Review of Component Design Report*, prepared for the U.S. Energy Information Administration (Washington, DC, August 1992).

- Kolstad, Charles D., *Report of Findings and Recommendations on EIA's Component Design Report Coal Production Submodule*, prepared for the U.S. Energy Information Administration (Washington, DC, July 23, 1992).

Status of Evaluation Efforts Conducted by Model Sponsor: The Coal Production Submodule (CPS) was developed for the National Energy Modeling System (NEMS) during the 1992-1993 period and revised in subsequent years. The version described in this abstract was used in support of the *Annual Energy Outlook 2011*.

Independent expert reviews of the Coal Market Modules (CMM's) *Annual Energy Outlook 2002* and *Annual Energy Outlook 2003* coal forecasts were conducted in August 2002 and June 2003, respectively, by Energy Ventures Analysis, Inc. (EVA) and the PA Consulting Group.

Appendix 1.B

Detailed Mathematical Description of the Model

This appendix provides a detailed description of the model, including a specification of the model's equations and procedures for constructing the supply curves. The appendix describes the model's order of computations and main relationships. The model is described in the order in which distinct processing steps are executed in the program. These steps are as follows:

> Step 1: Calibrate the regression model to base-year production and price levels by region, mine type, and coal type
>
> Step 2: Convert the regression equation into supply curves
>
> Step 3: Construct step-function supply curves for input to the CDS

Indices

i	=	supply region
j	=	mining method (surface or underground)
k	=	coal type
t	=	year
by	=	base year (for the *AEO2011*, the base year was 2009)
z	=	individual step on the step-function supply curves generated by the CPS for input to the Coal Distribution Submodule

Step 1: Initial Calibration

Prior to the processing of inputs, the model calibrates the regression equation to current price levels. First, the equation for the CPS pricing model is used to calculate the minemouth price of coal for the base year as shown in equation 1.B-1. EXP represents the exponential function.

$$
\begin{aligned}
P_{i,j,k,by} = {} & \{EXP\,[(A + \beta_{i,1}) * (1\text{-}rho)]\} * [TPH_{i,j,t=1}{}^{(TPHBM * (1-rho))}] * \\
& CAPUTIL\_HIST_{i,j,k}{}^{[\beta_4 - (\beta_4 * CU\_BY\_SC)] * (1 - rho)} * [PROD\_CAP\_ADJ_{i,j,k}{}^{((\beta_2 + \beta_{j,3}) * (1-rho))}] * \\
& [PRI\_ADJ_{i,j,k}{}^{(-rho)}] * PRODCAP_{i,j,k,by}{}^{(\beta_2 + \beta_{j,3})} * CAPUTIL_{i,j,k,by}{}^{(\beta_4 * CU\_BY\_SC)} * \\
& TPH_{i,j,by}{}^{((\beta_5 + (PCADJ)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8})} * WAGE_{by}{}^{\beta_{j,9}} * PCAP_{j,by}{}^{\beta_{10}} * PFUEL_{i,by}{}^{\beta_{11}} * \\
& OTH\_OPER_{i,j,by}{}^{\beta_{12}} * P_{i,j,k,by}{}^{rho} * PRODCAP_{i,j,k,by}{}^{(-rho * (\beta_2 + \beta_{j,3}))} * \\
& CAPUTIL_{i,j,k,by}{}^{(-rho * \beta_4 * CU\_BY\_SC)} * TPH_{i,j,by}{}^{(-rho * ((\beta_5 + (PCADJ)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} * \\
& WAGE_{by}{}^{(-rho * \beta_{j,9})} * PCAP_{j,by}{}^{(-rho * \beta_{10})} * PFUEL_{i,by}{}^{(-rho * \beta_{11})} * OTH\_OPER_{i,j,by}{}^{(-rho * \beta_{12})}
\end{aligned}
\qquad (1.B\text{-}1)
$$

where CU_BY_SC = $(CAPUTIL_{i,j,k,by} / CAPUTIL\_HIST_{i,j,k})^{\eta}$

Variables

$P_{i,j,k,by}$	- average annual minemouth price of coal for supply region i, mine type j, and coal type k, computed from the regression equation using base year values of the independent variables
A	- overall constant term for the model
TPHBM	- benchmark factor used for calibrating the coal pricing equation to the actual value of the minemouth coal price in year one of the forecast period
$PROD\_CAP\_ADJ_{i,j,k}$	- Factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type
$PRI\_ADJ_{i,j,k}$	- Factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type
$PRODCAP_{i,j,k,by}$	- annual productive capacity of coal mines for supply region i, mine type j, and coal type k for the base year
$CAPUTIL_{i,j,k,by}$	- annual capacity utilization (the ratio of annual production to annual productive capacity) of coal mines for supply region i, mine type j, and coal type k for the base year (modeled as a percentage)
$TPH_{i,j,by}$	- coal mine labor productivity for supply region i and mine type j for the base year
PCADJ	- represents an adjustment to the intercept term for the coal-pricing equation to account for a potential user-specified change in the estimated coefficient for the overall productivity term. The term represents the amount by which the overall parameter estimate (β_5) for the productivity term is to be revised.
$WAGE_{by}$	- average annual wage for coal miners for the base year
$PCAP_{j,by}$	- index for the annual user cost of capital for mine type j, for the base year
$PFUEL_{i,by}$	- weighted annual average of the electricity price and the diesel fuel price for supply region i for the base year
$OTH\_OPER_{i,j,by}$	- constant dollar index representing a measure for mine operating costs other than wages and fuel costs specified for supply region i and mine type j for the base year
$P_{i,j,k,by}$	- average minemouth price of coal for supply region i, mine type j, and coal type k for the base year
$CAPUTIL\_HIST_{i,j,k}$	- representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated for supply region i, mine type j, and coal type k
CU_BY_SC	- scalar used to adjust regression coefficient for the capacity utilization term for levels of average coal-mine capacity utilization that lie outside the range of utilization rates contained in the coal pricing model's historical database
η	- exponent representing the theoretical functional form of the capacity utilization term for levels of capacity utilization that are outside the range

of utilization rates contained in the coal pricing model database (for the *AEO2011*, this term was set at 3.0)

Regression Coefficients

A overall constant for the model

$\beta_{i,1}$ for the intercept dummy variables for each supply region i

β_2 for the productive capacity term

$\beta_{j,3}$ for the productive capacity term by mine type j

β_4 for the capacity utilization term

β_5 for the labor productivity term

$\beta_{i,6}$ for the labor productivity term by supply region i

$\beta_{j,7}$ for the labor productivity term by mine type j

$\beta_{i,j,8}$ for the labor productivity term by supply region i and mine type j

$\beta_{j,9}$ for the labor cost term by mine type j

β_{10} for the user cost of capital term

β_{11} for the fuel price term

β_{12} for the other mine operating costs term

rho for the first-order autocorrelation term

For calibration purposes, base year values of productive capacity, capacity utilization, productivity, labor costs, the fuel price, capital costs, and the average minemouth price are provided as inputs to the equation. Using these base year values, the regression equation is solved for each CPS supply region, mining method, and coal type. Note that for calibration purposes the simplifying assumption is made that the lagged values of the independent variables (used in those terms of the equation needed to correct for autocorrelation) are the same as the base year values. This assumption obviates the need to provide the model with two years of base data, and is believed to yield a reasonable approximation of the “true” calibration constant.

As shown in equation 1.B-2, the calibration constants are determined as the difference between the minemouth price of coal ($P_{i,j,k,by}$) calculated with the CPS pricing equation using base year values for the independent variables and the corresponding base year mine price of coal ($BYP_{i,j,k}$), which is an input to the CLUSER file.

$$CAL\_FACTOR_{i,j,k} = (BYP_{i,j,k} - P_{i,j,k,by}) \qquad (1.B\text{-}2)$$

where

$CAL\_FACTOR_{i,j,k}$ - constant added to the regression equation for each supply region i, mine type j,
and coal type k to calibrate the model to current price levels

$BYP_{i,j,k}$ - average base year mine price for region i, mine type j, and coal type k

$P_{i,j,k,by}$ - price computed from regression equation using base year values of the independent variables, for region i, mine type j, and coal type k for the base year

The calibration constants thus calculated are used to make vertical adjustments to each CPS supply curve. Thus, when using the base year values of the independent variables, the model solution will equal the base year price as specified in the CLUSER file.

Step 2: Convert the Regression Equation into Supply Curves

Following initial base year calibration, the regression equations must be converted into supply curves in which price is represented as a function of capacity utilization alone. This is accomplished by consolidating all of the non-capacity utilization terms in the regression equation into a single multiplier ($K_{i,j,k}$), computed using the forecast year values of the independent variables as shown in equation 1.B-3.

$$K_{i,j,k,t} = \{EXP\ [(A + \beta_{i,1}) * (1\text{-rhorho})]\} * [TPH_{i,j,t=1}^{(TPHBM * (1\text{-rhorho}))}] * \tag{1.B-3}$$

$$CAPUTIL\_HIST_{i,j,k}^{[\beta_4 - (\beta_4 * CU\_FY\_SC)] * (-\text{rhorho})} *$$

$$[PROD\_CAP\_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1\text{-rho}))}] * [PRI\_ADJ_{i,j,k}^{(\text{-rho})}] * PRODCAP_{i,j,k,t}^{(\beta_2 + \beta_{j,3})} *$$

$$TPH_{i,j,t}^{((\beta_5 + PCADJ) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8})} * WAGE_t^{\beta_{j,9}} * PCAP_{j,t}^{\beta_{10}} * PFUEL_{i,t}^{\beta_{11}} *$$

$$OTH\_OPER_{i,j,t}^{\beta_{12}} * P_{i,j,k,t-1}^{\text{rho}} * PRODCAP_{i,j,k,t-1}^{(\text{-rho} * (\beta_2 + \beta_{j,3}))} *$$

$$CAPUTIL_{i,j,k,t-1}^{(\text{-rho} * \beta_4 * CU\_FY\_SC)} * TPH_{i,j,t-1}^{(\text{-rho} * ((\beta_5 + PCADJ) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} *$$

$$WAGE_{t-1}^{(\text{-rho} * \beta_{j,9})} * PCAP_{j,t-1}^{(\text{-rho} * \beta_{10})} * PFUEL_{i,t-1}^{(\text{-rho} * \beta_{11})} * OTH\_OPER_{i,j,t-1}^{(\text{-rho} * \beta_{12})}$$

where

$$CU\_FY\_SC = (CAPUTIL_{i,j,k,t-1} / CAPUTIL\_HIST_{i,j,k})^{\eta}$$

<u>Variables</u>

$K_{i,j,k,t}$	- annual multiplier, specified by supply region i, mine type j, and coal type k, calculated by solving the CPS coal pricing equation for production equal to zero for year t equal to zero and all other independent variables set equal to their forecast year values (for years t and t-1)
A	- overall constant term for the model
TPHBM	- benchmark factor used for calibrating the coal pricing equation to the actual value of the minemouth coal price in year one of the forecast period
$PROD\_CAP\_ADJ_{i,j,k}$	- factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type
$PRI\_ADJ_{i,j,k}$	- factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type
$PRODCAP_{i,j,k,t}$	- annual productive capacity of coal mines for supply region i, mine type j, coal type k, and year t
$TPH_{i,j,t}$	- coal mine labor productivity for supply region i, mine type j, and year t
$WAGE_t$	- average annual wage for coal miners in year t
$PCAP_{j,t}$	- index for the annual user cost of capital for mine type j, in year t

$PFUEL_{i,t}$ - weighted annual average of the electricity price and the diesel fuel price for supply region i and year t

$OTH\_OPER_{i,j,t}$ - constant dollar index representing a measure for mine operating costs other than wages and fuel costs specified for supply region i and mine type j, in year t

$P_{i,j,k,t-1}$ - average minemouth price of coal for supply region i, mine type j, coal type k, and year t-1, as determined in the final NEMS iteration for year t-1

$PRODCAP_{i,j,k,t-1}$ - annual productive capacity of coal mines for supply region i, mine type j, coal type k, and year t-1

$CAPUTIL_{i,j,k,t-1}$ - average annual capacity utilization (the ratio of annual production to annual productive capacity) of coal mines for supply region i, mine type j, coal type k, and year t-1 (modeled as a percentage)

$TPH_{i,j,t-1}$ - coal mine labor productivity for supply region i, mine type j, and year t-1

$WAGE_{t-1}$ - average annual wage for coal miners in year t-1

$PCAP_{j,t-1}$ - index for the annual user cost of capital for mine type j, in year t-1

$PFUEL_{i,t-1}$ - weighted annual average of the electricity price and the diesel fuel price for supply region i in year t-1

$OTH\_OPER_{i,j,t-1}$ - constant dollar index representing a measure for mine operating costs other than wages and fuel costs specified for supply region i and mine type j, in year t-1

$CAPUTIL\_HIST_{i,j,k}$ - representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated for supply region i, mine type j, and coal type k

CU_FY_SC - scalar used to adjust regression coefficient for the capacity utilization term for levels of average coal-mine capacity utilization that lie outside the range of utilization rates contained in the coal pricing model's historical database. This term differs from the CU_BY_SC term referenced in equation 1-B.1 in that it uses the projected levels of capacity utilization in place of the base-year capacity utilization data from the CLUSER input file.

η - exponent representing the theoretical functional form of the capacity utilization term for levels of capacity utilization that are outside the range of utilization rates contained in the coal pricing model database (for the *AEO2011*, this term was set at 3.0)

<u>Regression Coefficients (values provided in Table 1.D-1)</u>

A overall constant for the model

$\beta_{i,1}$ for the intercept dummy variables for each supply region i

β_2 for the productive capacity term

$\beta_{j,3}$ for the productive capacity term by mine type j

β_4 for the capacity utilization term

β_5 for the labor productivity term

$\beta_{i,6}$ for the labor productivity term by supply region i

$\beta_{j,7}$ for the labor productivity term by mine type j

$\beta_{i,j,8}$ for the labor productivity term by supply region i and mine type j

$\beta_{j,9}$ for the labor cost term by mine type j

β_{10} for the user cost of capital term

β_{11} for the fuel price term

rho for the first-order autocorrelation term

A separate value of $K_{i,j,k,t}$ is computed for each region i, mine type j, coal type k, and year t. Some of the required forecast year values of the various independent variables are supplied endogenously by other NEMS modules (see Figure 2), while others, including labor productivity, the average coal industry wage, the PPI (producer price index) for mining machinery and equipment, the PPI for iron and steel, and the PPI for explosives, are provided as user inputs. In place of a user input for the PPI for iron and steel, the CLUSER input file also contains a switch which, if set equal to 1, provides for the use of the related PPI for metals and metal products data (series id: WPI10) supplied by the NEMS Macroeconomic Activity Module.

Incorporating the calibration constant and the production term, the CPS supply curves take on the following form (equation 1.B-4):

$$P_{i,j,k,t} = CAL\_FACTOR_{i,j,k} + [K_{i,j,k,t} * CAPUTIL_{i,j,k,t}{}^{\beta_4}] \tag{1.B-4}$$

where

$P_{i,j,k,t}$	- minemouth price of coal by supply region i, mine type j, and coal type k computed as a function of output ($Q_{i,j,k,t}$)
$CAL\_FACTOR_{i,j,k}$	- constant added to the regression equation for each supply region i, mine type j, and coal type k to calibrate the model to current price levels
$K_{i,j,k,t}$	- annual multiplier, specified by supply region i, mine type j, and coal type k, calculated by solving the CPS coal pricing equation for production equal to zero for year t equal to zero and all other independent variables set equal to their forecast-year values (for years t and t-1)
$CAPUTIL_{i,j,k,t}$	- average annual capacity utilization (the ratio of annual production to annual productive capacity) of coal mines for supply region i, mine type j, coal type k, and year t (modeled as a percentage)
β_4	- regression coefficient for the capacity utilization term

Step 3: Construct Step-Function Supply Curves for Input to the CDS

The CDS is formulated as a linear program (LP) and cannot directly use the supply curves generated by the CPS regression model, whose functional form is logarithmic. Rather, the CDS requires step-function supply curves for input. Using an initial target quantity and percent variations from that quantity, an 11-step curve is constructed as a subset of the full CPS supply curve and is input to the CDS. For each supply curve and year, the CMM uses an iterative approach to find the target quantity that creates the optimal 11-step supply curve given the projected level of demand. The user can vary the length of the steps, and, subsequently, the vertical distances between the steps, by making adjustments to the percent variations from the target quantity via input parameters contained in the CLUSER input file.

The method by which these step-function curves are constructed is as follows. First, the CPS computes 11 quantities corresponding to fixed percentages of a target quantity obtained from the CDS. The model then computes the production corresponding to each of the 11 quantities, using the supply curve equations.

Equation 1.B-5 shows the CPS equation used for generating the prices for the step-function supply curves.

$P_{i,j,k,z,t} = CAL\_FACTOR_{i,j,k} + [K_{i,j,k,t} * CAPUTIL\_HIST_{i,j,k}{}^{(\beta_4 - (\beta_4 * CU\_STEP\_SC)} * (Q_{i,j,k,z,t} / PRODCAP_{i,j,k,t})^{(\beta_4 * CU\_STEP\_SC)}]$ (1.B-5)

where

$CU\_STEP\_SC = ((Q_{i,j,k,z,t} / PRODCAP_{i,j,k,t}) / CAPUTIL\_HIST_{i,j,k})^{\eta}$

<u>Variables</u>

$P_{i,j,k,z}$	- price associated with step z for region i, mine type j, coal type k, and year t specified as a percent variation from the target price.
$CAL\_FACTOR_{i,j,k}$	- calibration constant for each supply curve
$Q_{i,j,k,z}$	- production associated with step z for region i, mine type j, coal type k, and year t (the target quantity is obtained from the CLUSER file for year one of the forecast period and from the CDS for all remaining years of the forecast period)
β_4	- regression coefficient for the capacity utilization term
$K_{i,j,k,t}$	- multiplier for the non-production terms in the regression equation
$PRODCAP_{i,j,k,t}$	- annual productive capacity of coal mines for supply region i, mine type j, coal type k, and year t
$CAPUTIL\_HIST_{i,j,k}$	- representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated for supply region i, mine type j, and coal type k
CU_STEP_SC	- scalar used to adjust regression coefficient for the capacity utilization term for levels of average coal-mine capacity utilization that lie outside the range of utilization rates contained in the coal pricing model's historical database
η	- exponent representing the theoretical functional form of the capacity utilization term for levels of capacity utilization that are outside the range of utilization rates contained in the coal pricing model database (for the *AEO2011*, this term was set at 3.0)

The scalar for the capacity utilization term reflects the basic premise that mining costs will increase substantially as the capacity utilization of coal mines approaches 100 percent. For most combinations of region and mine type, rates of coal-mine capacity utilization rarely approach 100 percent in the historical data series used to estimate the coal-pricing model. In general, the highest rates of capacity utilization are reported by captive lignite operations in Texas, Louisiana and North Dakota. Between 1991 and 2009, the average annual capacity utilization for Texas lignite production ranged from a low of 90.3 percent in 1991 to a high of 98.5 percent in 2006. During this same period, the average annual capacity utilization for surface coal mines in Wyoming's Northern Powder River Basin ranged from a low of 65.1 percent in 1993 to a high of 93.2 percent in 2007.

Equation 1.B-6 shows the CPS equation used for generating the quantities for the step-function supply curves.

$STEP\_Q_{i,j,k,z,t} = Q_{i,j,k,z,t} - Q_{i,j,k,z-1,t}$ (1.B-6)

where

$STEP\_Q_{i,j,k,z,t}$	- quantity associated with step z for region i, mine type j, coal type k, and year t
$Q_{i,j,k,z,t}$	- production associated with step z for region i, mine type j, coal type k, and year t
$Q_{i,j,k,z-1,t}$	- production associated with step z-1 for region i, mine type j, coal type k, and year t

Finally, prices for each step are adjusted to the year dollars required by the CDS using the GDP chain-type price index supplied by the NEMS Macroeconomic Activity Module. The resulting production and price values are used by the CDS to determine the least cost supplies of coal for meeting the projected levels of annual coal demand. The specific outputs provided by the model are described in Appendix 1.C.

Appendix 1.C

Inventory of Input Data, Parameter Estimates,and Model Outputs

Model Inputs

Model inputs are classified into two categories: user-specified inputs and inputs provided by other NEMS components.

CLUSER. User-specified inputs are listed in Table 1.C-1. The table identifies each input, the variable name, the units for the input, and the level of detail at which the input must be specified. Future levels of labor productivity are estimated by the EIA. For the *AEO2011*, productivity improvements are assumed to continue at a reduced rate over the forecast horizon. Rates of improvement are developed based on econometric estimates using historical data by region and by mine type (surface and underground). The average heat and sulfur content values are estimated from data obtained from the EIA-923 database for coal consumed at electric power plants and from the EIA-3 and EIA-5 databases for coal consumed at industrial facilities and coke plants, respectively.

The values for the input variables listed in Table 1.C-1 are contained in the file CLUSER – a single "flat" file – are listed in the order of their appearance in this file. The CLUSER file contains six main groups of data: 1) forecast-year estimates for labor costs, coal-mine productivity, and the PPI's for mining machinery and equipment, iron and steel, and explosives; 2) base-year quantities for production, productive capacity, capacity utilization, prices, and coal quality (heat content, sulfur content, mercury content and carbon dioxide emission factors) by supply curve; 3) share of annual fuel costs at U.S. coal mines represented by electricity and diesel fuel; 4) coefficients for the CPS coal-pricing equation; 5) forecast-year production capacity limitations by supply curve (no near-term constraints on production capacity were input for the *AEO2011*); and 6) capacity utilization trigger points by region and mine type used to determine when to add or retire coal-mining productive capacity. Each trigger point is assigned a unique multiplier used to adjust annual productive capacity either upward or downward.

The indices used in the tables are defined as follows:

i	=	supply region
j	=	mine type (surface or underground)
k	=	coal type
t	=	year
by	=	base year
z	=	individual step on the step-function supply curves generated by the CPS for input to the Coal Distribution Submodule

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
WAGE	Real labor cost escalator	National/year	--	--	EIA projection
L_PROD	Base year productivity	Supply region/ mine type/coal type	Tons/miner hour	$LP_{i,j,by}$	EIA-7A
FR_PROD	Forecast year productivity (as a fraction of L_PROD)	Supply region/ mine type/coal type/year	--	$LP_{i,j,t}$	EIA projection
ADJ_MMP_ MULT	Price adjustment variable (multiplier)	Supply region/ mine type/coal type/year	Scalar	--	EIA estimate
ADJ_MMP_ ADD	Price adjustment variable (additive)	Supply region/ mine type/coal type/year	1987 Dollars/Ton	--	EIA estimate
SBAS_REGION	Alphabetic supply region code	Supply region	--	--	Model definition
NBAS	Number of production records	Supply region	--	--	File definition
CPROD_TYPE	Alphabetic coal type code	Supply region/ coal type	--	--	Model definition
B_PROD	Base year (2009) production (surface and deep)	Supply region/ mine type/coal type	MMTons	$P_{i,j,k,by}$	EIA-*7A*
BTU	Average heat content (surface and deep)	Supply region/ mine type/coal type	MMBtu/ton	--	FERC-423
SULFUR	Average sulfur content (surface and deep)	Supply region/ mine type/coal type	Lbs/MMBtu	--	FERC-423
CAR	Average carbon dioxide emission factor (surface and deep)	Supply region/ coal type	Lbs/MMBtu	--	U.S. EPA
PRI	Base-Year (2009) coal price (surface and deep)	Supply region/ coal type	1987 Dollars/Ton	--	EIA-7A
MERCURY	Average mercury content (surface and deep)	Supply region/ mine type/coal type	Lbs/trillion Btu	--	U.S. EPA
B_CAP_UTIL	Base-Year (2009) capacity utilization of coal mines (surface and deep)	Supply region/ mine type	Fraction	$CAPUTIL_{i,j,k,by}$	EIA-7A

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
B_PROD_CAP	Base-Year (2009) productive capacity (surface and deep)	Supply region/ mine type/coal type	MMTons	$PRODCAP_{i,j,k,by}$	EIA-7A
B_PROD_CAP_ ADJ	Factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content)	Supply region/ mine type/coal type	--	$PROD\_CAP\_ADJ_{i,j,k,by}$	EIA-7A
PRI_ADJ	Factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content)	Supply region/ mine type/coal type	--	$PRI\_ADJ_{i,j,k,by}$	EIA-7A
UTIL_HIST	Representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated (surface and deep)	Supply region/ mine type/coal type	Percent	$CAPUTIL\_HIST_{i,j,k}$	EIA specifica-tion
ELEC_SHARE	Share of total fuel costs at mines represented by electricity	Supply region/ mine type	Fraction	--	U.S. Census Bureau
DIST_SHARE	Share of total fuel costs at mines represented by diesel fuel	Supply region/ mine type	Fraction	--	U.S. Census Bureau
OCONT	Overall constant for CPS regression model	National	--	A	Regression analysis
LUTIL	Pricing model coefficient (capacity utilization term)	National	--	β_4	Regression analysis

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
LPCAP	Pricing model coefficient (cost of capital term)	National	--	β_{10}	Regression analysis
LPFUEL	Pricing model coefficient (fuel price term)	National	--	β_{11}	Regression analysis
LPSTEEL	Pricing model coefficient (other operating costs term)	National	--	β_{12}	Regression analysis
TPH	Pricing model coefficient (overall productivity term)	National	--	β_5	Regression analysis
TPH_DEEP	Pricing model coefficient (mine type productivity term)	Mine type	--	$\beta_{j,7}$	Regression analysis
LPRODCAP	Pricing model coefficient (overall productive capacity term)	National	--	β_2	Regression analysis
RHO	Pricing model coefficient (first-order autocorrelation term)	National	--	rho	Regression analysis
PDUMM	Pricing model adjustment factor applied to overall constant term to account for user-specified revisions of the coefficient for the labor productivity regression variable	National	--	TPHBM	Regression analysis
DEEPRODCAP	Pricing model coefficient (mine type productive capacity term)	Mine type	--	$\beta_{j,3}$	Regression analysis
DEEPWAGE	Pricing model coefficient (mine type labor cost term)	Mine Type	--	$\beta_{j,9}$	Regression analysis
B_WAGE	Base-year hourly wage	National	1987 Dollars/Hour	WAGE	Bureau of Labor Statistics
F_INDEX	Base-year electricity price (industrial sector)	Supply region	1992 Dollars/ MMBtu	--	EIA
SDS	Pricing model coefficients (intercept dummy variables)	Supply region	--	$\beta_{i,1}$	Regression analysis
SDD	Pricing model coefficients (used to adjust intercept terms for underground mines in CPS regions WM, WW and ZN)	Supply region	--	$\beta_{i,1}$	Regression analysis

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
SPROD	Pricing model coefficients (regional productivity terms)	Supply region	--	$\beta_{i,6}$	Regression analysis
DPROD	Pricing model coefficients (regional and mine type productivity terms)	Supply region/ mine type	--	$\beta_{i,j,7}$	Regression analysis
P_EQUIP_ SURF	PPI for construction machinery	Year	Constant dollar index (1992 dollars)	--	Bureau of Labor Statistics
P_EQUIP_ UNDG	PPI for mining machinery and equipment	Year	Constant dollar index (1992 dollars)	--	Bureau of Labor Statistics
PPI_METALS_ SWITCH	Switch to choose either the user specified PPI for iron and steel (set switch to 0) or the NEMS generated PPI for metals and metal products (set switch to 1)	--	--	--	--
P_STEEL	PPI for iron and steel	Year	Constant dollar index (1992 dollars)	--	Bureau of Labor Statistics
P_EXPLO	PPI for explosives	Year	Constant dollar index (1992 dollars)	--	Bureau of Labor Statistics
PCNT_REC	Number of marginal cost curves	National	--	--	File definition
PCNT_ REGION	Numerical supply region identifier	Supply region	--	--	Model definition
PCNT_CTYPE	Numerical coal type identifier	Coal type	--	--	Model definition
PCNT_PRICE	Base-year minemouth coal price	Supply region/ mine type/ coal type	1987 Dollars/ton	--	EIA-7A
PCNT_PROD	Initial target production used to build step-function curves with 11 steps	Supply region/ mine type/ coal type	MMTons	--	EIA-7A
MCNT_REC	Number of marginal cost curves	National	--	--	File definition
MCNT_ REGION	Numerical supply region identifier	Supply region	--	--	Model definition

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
MCNT_CTYPE	Numerical coal type identifier	Coal type	--	--	Model definition
MCNT_PRICE	Initial target price used to build step-function curves with 11 steps	Supply region/ mine type/ coal type	1987 Dollars/ton	$P_{i,j,k,z=1,t}$	EIA-7A
MCNT_PROD	Base year production	Supply region/ mine type/ coal type	MMTons	--	EIA-7A
MCNT_STEP	Variations from the target price used to build step-function curves with 11 steps	National	Fraction	--	EIA estimate
SCLIMIT_CNT	Numerical supply curve code	Supply curve	--	--	Model definition
SCLIMIT_REG	Numerical supply region code	Supply region	--	--	Model definition
SCLIMIT_ REGNAME	Alphabetic supply region code	Supply region	--	--	Model definition
SCLIMIT_ CPSCT	Numerical coal type code	Coal type	--	--	Model definition
SCLIMIT__ CDSCT	Alphabetic coal type code	Coal type	--	--	Model definition
IYR	Supply curve limit	Supply curve	MMTons	--	EIA estimate
SCURVE_ LIMIT_MAX	Maximum supply curve limit	National	MMTons	--	EIA specifica- tion
UTIL_EXP	Real number used to revise the coefficient for the coal pricing model's capacity utilization term for levels of capacity utilization that are outside the upper range of utilization rates contained in the coal pricing model database. This factor (set to 3.0 for the AEO2011) is used for the calculating prices for each of the last six steps of the eleven-step CPS supply curves.	National	--	η	EIA specifica- tion

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
UTIL_EXP_BOT	Real number used to revise the coefficient for the coal pricing model's capacity utilization term for levels of capacity utilization that are outside the lower range of utilization rates contained in the coal pricing model database. This factor (set to 1.0 for the AEO2011) is used for the calculating prices for each of the first five steps of the eleven-step CPS supply curves.	National	--	η	EIA specification
UTIL_MAX_SURF	Upper capacity utilization amount used to trigger additions to surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MAX_UNDG	Upper capacity utilization amount used to trigger additions to underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MID_SURF	Mid-level capacity utilization amount used to trigger additions to surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MID_UNDG	Mid-level capacity utilization amount used to trigger additions to underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MIN_SURF	Lower capacity utilization amount used to trigger retirements of surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MIN_UNDG	Lower capacity utilization amount used to trigger retirements of underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MAX_SURF_ADJ	Factor used to increase surface productive capacity when capacity utilization UTIL_MAX_SURF	Supply region	Fraction	--	EIA specification

Table 1.C-1. User-Specified Inputs Required by the CPS

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
UTIL_MAX_ UNDG_ADJ	Factor used to increase underground productive capacity when capacity utilization. UTIL_MAX_UNDG	Supply region	Fraction	--	EIA specifica- tion
UTIL_MID_ SURF_ADJ	Factor used to increase surface productive capacity when capacity utilization < UTIL_MAX_SURF but. UTIL_MID_SURF	Supply region	Fraction	--	EIA specifica- tion
UTIL_MID_ UNDG_ADJ	Factor used to increase underground productive capacity when capacity utilization < UTIL_MAX_UNDG but. UTIL_MID_UNDG	Supply region	Fraction	--	EIA specifica- tion
UTIL_MIN_ SURF_ADJ	Factor used to retire surface productive capacity when capacity utilization < UTIL_MIN_SURF	Supply region	Fraction	--	EIA specifica- tion
UTIL_MIN_ UNDG_ADJ	Factor used to retire underground productive capacity when capacity utilization < UTIL_MIN_SURF	Supply region	Fraction	--	EIA specifica- tion
MCNT_STEP	Variable use to establish production levels for each of the 11 steps represented on the CPS step-function supply curves	National	Fraction	--	EIA specifica- tion

Inputs Provided by Other NEMS Components. Table 1.C-2 identifies inputs obtained from other NEMS components and indicates the variable name, the units for the input, and the level of detail at which the input must be specified. Electricity prices are obtained from the Electricity Market Module, industrial distillate fuel prices are obtained from the Petroleum Market Module, the real rate of interest on AA public utility bonds are received from the Macroeconomic Activity Module, and production and prices by CPS supply curve are obtained from the Coal Distribution Submodule.

Table 1.C-2. CPS Inputs Provided by Other NEMS Modules and Submodules

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	NEMS Module/ Submodule
PELIN	Average price of electricity in the industrial sector	Supply region/ year	1987 Dollars/ MMBtu	--	EMM
PDSIN	Average price of distillate in the industrial sector	National/year	1987 Dollars/MMBtu	--	PMM
MC_RLRMCORPPUAANS	Real rate on AA-rated public utility bonds	National	Percent	--	MAM
LAG_PMPROD	Total mine value of coal produced in year t-1	Supply region/ mine type/ coal type/year	1987 Dollars	--	CDS
LAG_QPROD	Coal production in year t-1	Supply region/ mine type/ coal type/year	Million tons	--	CDS
MCNT_PROD	Target quantities for years t > 1, used to build step-function curves with 11steps	Supply region/ mine type/ coal type/year	Million tons	--	CDS

Model Outputs

The primary outputs from the model are step-function supply curves provided to the CDS. In addition to the price and quantity values associated with the steps on each of the supply curves, the CPS provides the CDS with coal quality data that include estimates for heat, sulfur and mercury content, and for carbon dioxide emission factors (Table 1.C-3).

Table 1.C-3. CPS Model Outputs

CPS Variable Name	Description	Units	Variable Used in this Report
MCNT_P	Minemouth coal price associated with each CPS supply curve step provided to the CDS	1987 dollars/ton	$P_{i,j,k,z,t}$
MCNT_Q	Length of each CPS supply curve step provided to the CDS	Million tons	$Q_{i,j,k,z,t}$
MCNT_BTU	Average Btu content for each CPS supply curve step provided to the CDS	MMBtu per ton	--
MCNT_SULF	Average sulfur content for each CPS supply curve step provided to the CDS	lbs/MMBtu	--
MCNT_MERC	Average mercury content for each CPS supply curve step provided to the CDS	lbs/Trillion Btu	--
MCNT_CAR	Average carbon dioxide emission factor for each CPS supply curve step provided to the CDS	lbs/MMBtu	--

Endogenous Variables

Variables endogenous to the model are included in Table 1.C-4. Table 1.C-4 includes the variable name used in the report, the corresponding variable name used in the CPS model, a description of the variable, and the variable's units.

Table 1.C-4. CPS: Key Endogenous Variables

CPS Variable Name	Description	Units	Variable Used in this Report
L_PROD	Labor productivity for NEMS forecast year t	Tons/miner hour	$TPH_{i,j,t}$
E_FUEL	Hybrid fuel price (average of industrial electricity and distillate prices) for NEMS forecast year t	1992 dollars/ MMBtu	$PFUEL_{i,j,t}$
D_FUEL	Diesel fuel prices for NEMS forecast year t	1992 dollars/MMBtu	--
R_WAGE	Average coal industry wage for NEMS forecast year t	1992 dollars/ hour	$WAGE_t$
PK	User-cost of mining equipment for NEMS forecast years	Constant dollar index (1992 dollars)	$PCAP_t$
P_OPER_OTH	Cost index representing operating costs other than wages and fuel for NEMS forecast year t	Constant dollar index (1992 dollars)	--
YINT	CPS calibration constant	--	$C_{i,j,k}$
FP	Multiplier for non-production terms in the CPS coal pricing equation	--	$K_{i,j,k,t}$
QTARG	Target quantities for years t > 1, used to build step-function curves with 11 steps	Million tons	$Q_{i,j,k,t}$
SC_PRICE	Prices for each of the steps on the 11-step supply curves input to the CDS	1992 dollars/ton	$P_{i,j,k,z,t}$
SC_QUAN	Quantities for each of the steps on the 11-step supply curves input to the CDS	Million tons	$Q_{i,j,k,z,t}$
LAG_PRI	Minemouth price of coal by supply curve in year t-1	1992 dollars/ton	$MMP_{i,j,k,t-1}$
LAG_PROD	Coal production by supply curve in year t-1	Million tons	$Q_{i,j,k,t-1}$
PROD_CAP	Coal productive capacity by supply curve in year t	Million tons	$PRODCAP_{i,j,k,t}$

Appendix 1.D

Data Quality and Estimation

Development of the CPS Regression Model

The two-stage least squares regression technique was used to estimate the relationship between the minemouth price of coal and the corresponding levels of capacity utilization at mines, productive capacity, labor productivity, wages, fuel costs, other mine operating costs, and a term representing the annual user cost of mining machinery and equipment. In the first stage of the estimation, the endogenous explanatory variables are regressed on the exogenous and predetermined variables. The product of this estimation is predicted values of the endogenous explanatory variables that are uncorrelated with the error term. In turn, these predicted values are employed in the second stage of the technique to estimate the relationship between the dependent endogenous variable and the independent variable(s).

The result from the second stage (structural) equation represents the model implemented in the CMM for the *AEO2011*. The first stage (reduced form) equations are used only to obtain the predicted values for the endogenous explanatory variables included in the second stage, removing the effects on minemouth prices caused by shifts in the demand function.

The structural equation for the coal pricing model was specified in log-linear (constant elasticity) form. In this specification, the values for all variables (except the constant term) are transformed by taking their natural logarithm. The CPS regression model was developed using a combination of cross-sectional and time series data. The model includes annual-level data for thirteen CPS supply regions[12] and two mine types (surface and underground) for the years 1978 through 2007, excluding the years 1986-1990.[13] In all, 450 observations are included (18 observations per year (13 surface and 5 underground) for each of the 25 years represented in the historical data series).

[12]Data for coal mines in the AW (Alaska and Washington) supply region were not included in the regression model. The average mine price of coal for those States is withheld from EIA publications to avoid disclosure of individual company data.

[13] The reason that data for the years 1986 through 1990 were excluded from the regression model was primarily due to lack of good quality data for U.S. coal mining productive capacity for the years 1987 through 1990. For these years, estimates of daily (1987-1989) and annual (1990) productive capacity were collected, but, because the data were not to be published, they did not go through a complete data verification process. Another complicating factor related to the coal mining productive capacity data is that for the years 1978 through 1989 EIA requested that respondents report estimated daily productive capacity on the EIA-7A "Coal Production Report" survey, while for the years 1990 and later survey respondents are asked to report estimated annual productive capacity. Because these are two very different measures of productive capacity, a methodology was developed to convert the earlier daily productive capacity data collected by EIA to annual productive capacity, thus, enabling the use of additional years of data for estimating the regression model. Estimates of annual productive capacity by mine for the years 1978 through 1986 were developed using reported daily productive capacity data by mine, reported number of days worked by mine, and region/mine type estimates for maximum average number of days worked. The maximum average number of days worked represents the highest reported average number of days worked per year by region and mine type during the years 1978 through 1989. Annual productive capacity for mines that reported working less days than the maximum average number of days worked for their region and mine type were calculated by multiplying their reported daily productive capacity by the maximum average number of days worked. Alternatively, if a mine reported working more days than the maximum average number of days worked for their region/mine type, annual productive capacity was calculated by simply multiplying their reported daily productive capacity by their reported number of days worked.

All data were pooled into a single regression equation. In addition to the overall constant term for the model, intercept dummy variables were included for most of the supply regions. Dummy variables were used for the productivity and productive capacity variables to allow slope coefficients to vary across regions and mine types. The Durbin-Watson test for first-order positive autocorrelation indicated that the hypothesis of no autocorrelation should be rejected. As a consequence, a correction for serial correlation was incorporated. In addition, a formal test indicated that the hypothesis of homoskedasticity (the assumption that the errors in the regression equation have a common variance) should be rejected, and, as a result, a weighted regression technique was employed to obtain more efficient parameter estimates.

The two-stage least squares (2SLS) regression equation for the CPS was estimated using the LSQ (general nonlinear least squares multiequation estimator) procedure in TSP 4.5 with the INST option. For a description of the LSQ procedure see the Reference Manual for TSP Version 4.5. The form of the CPS regression equation and the associated regression statistics are presented below and in Table 1.D-1, respectively. The sources for the various historical data series used in the regression model are shown in Tables 1.D-2 and 1.D-3.

Indicative of the high R^2 statistic (see Table 1.D-1), there is a close correspondence between the predicted and actual minemouth prices. The calculation for the adjusted R^2 statistic provided in Table 1.D-1 is documented in the User's Guide for TSP Version 4.5. As indicated in this report, all of the statistics related to the residuals using the 2SLS regression technique are calculated in TSP with the same formulas used for ordinary least squares (OLS). A summary of the calculations used for generating the R^2 and adjusted R^2 statistics in TSP is provided below.

<u>Computation of R^2 with a constant term</u>:

$$R^2 = 1 - \left[\sum e_t^2 / \sum (y_t - \bar{y})^2\right] \qquad (1.D\text{-}1)$$

where

$$e_t = y_t - \hat{y}_t$$

and

$$\hat{y}_t = X_t b$$

Or

$$R^2 = 1 - [SSR / SST]$$

where

$$SSR = \sum e_t^2$$

$$SST = \sum (y_t - \bar{y})^2$$

The adjusted R^2 or $\bar{R}^2$ with a constant term is calculated as follows:

$$\bar{R}^2 = 1 - [SSR / (T - K)] / [SST / (T - 1)] \qquad (1.D\text{-}2)$$

In the above equations,

e_t	residuals
y_t	observed values of the independent variable
$\bar{y}$	mean of the observed values of y_t
$\hat{y}_t$	predicted values of the independent variable
X_t	vector of independent variables
b	estimated regression coefficients
SSR	sum of squared residuals
SST	total sum of squares
T	number of observations in the sample
K	number of independent variables

Based on the regression results shown in Table 1.D-1, the equation used for predicting future levels of minemouth coal prices by region, mine type and coal type for *AEO2011* is:

$$\begin{aligned} P_{i,j,k,t} = {} & CAL\_FACTOR_{i,j,k,t} + [C_{i,j,k,t} * PRODCAP_{i,j,k,t}^{(\beta_2 + \beta_{j,3})} * CAPUTIL_{i,j,k,t}^{\beta_4} * \\ & TPH_{i,j,t}^{((\beta_5 + PCADJ) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8})} * WAGE_t^{\beta_{j,9}} * PCAP_{j,t}^{\beta_{10}} * \\ & PFUEL_{i,t}^{\beta_{11}} * OTH\_OPER_{i,j,t}^{\beta_{12}} * P_{i,j,k,t-1}^{rho} * PRODCAP_{i,j,k,t-1}^{(-rho * (\beta_2 + \beta_{j,3}))} * \\ & CAPUTIL_{i,j,k,t-1}^{(-rho * \beta_4 * CU\_FY\_SC)} * TPH_{i,j,t-1}^{(-rho * ((\beta_5 + PCADJ) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} * \\ & WAGE_{t-1}^{(-rho * \beta_{j,9})} * PCAP_{j,t-1}^{(-rho * \beta_{10})} * PFUEL_{i,t-1}^{(-rho * \beta_{11})} * OTH\_OPER_{i,j,t-1}^{(-rho * \beta_{12})}] \end{aligned} \tag{1.D-3}$$

First Term in Equation 1.D-3 ($CAL\_FACTOR_{i,j,k,t}$)
$CAL\_FACTOR_{i,j,k,t}$ is a constant added to the regression equation for each supply region i, mine type j, and coal type k in each year t to calibrate the model to current price levels. For the *AEO2011*, prices were calibrated to the average annual minemouth coal prices for 2009.

Second Term in Equation 1.D-3 ($C_{i,j,k,t}$)

$$\begin{aligned} C_{i,j,k,t} = {} & e^{(A + \beta_{i,1}) * (1-rho)} * TPH_{i,j,t=1}^{(-PCADJ * (1-rho))} * CAPUTIL\_HIST_{i,j,k}^{[\beta_4 - (\beta_4 * CU\_FY\_SC)] * (-rho)} * \\ & [PROD\_CAP\_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1-rho))}] * [PRI\_ADJ_{i,j,k}^{(-rho)}] \end{aligned} \tag{1.D-4}$$

The first term in equation 1.D-4 ($e^{(A + \beta_{i,1}) * (1\text{-rho})}$) is the intercept for the model, where "A" is an overall constant for the model and the term "$\beta_{i,1}$" represents the regional specific constants for the model.

The second term in equation 1.D-4 ($TPH_{i,j,t=1}^{(PCADJ * (1\text{- rho}))}$) represents a potential user-specified adjustment to the intercept term for the coal-pricing equation to account for changes in the estimated coefficient (β_5) for the overall productivity term. For the *AEO2011*, PCADJ was set equal to zero reflecting the assumption that the estimated relationship between coal mining productivity and minemouth coal prices estimated for the historical period will continue to hold over the *AEO2011* forecast horizon.

The third term in equation 1.D-4 ($CAPUTIL\_HIST_{i,j,k}^{[\beta_4 - (\beta_4 * CU\_FY\_SC)] * (\text{- rho})}$) represents a required adjustment to the intercept term for the coal-pricing equation to account for changes in the parameter estimate (β_4) for the capacity utilization term. In the *AEO2011* forecast scenarios, the coefficient for the capacity utilization term is revised endogenously within the Coal Market Module on the basis of how much the projected levels of capacity utilization vary from the representative historical levels of capacity utilization. This feature was added to the CPS to reflect the premise that coal mining costs will increase substantially as the average capacity utilization of coal mines approaches 100 percent. The term CU_FY_SC is equal to ($CAPUTIL_{i,j,k,t-1}$ / $CAPUTIL\_HIST_{i,j,k}$)$^{\eta}$. In this equation, $CAPUTIL_{i,j,k,t-1}$ is the projected level of capacity utilization for a specific supply curve in year t-1, $CAPUTIL\_HIST_{i,j,k}$ is the representative historical rate of capacity utilization for this same CPS supply curve, and the term η is a user-specified term. For the *AEO2011*, the user-specified term η was set equal to 3.0.

The fourth term in equation 1.D-4 ($PROD\_CAP\_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1\text{-rho}))}$) is used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content). PROD_CAP_ADJ is a user-specified input calculated by dividing base-year (2009) productive capacity for supply region i and mine type j by the estimated base-year (2009) productive capacity for supply region i, mine type j, and coal type k. The latter of these two productive capacity numbers represents data for a specific CPS supply curve, thus the additional coal type dimension for this term.

The fifth term in equation 1.D-4 ($PRI\_ADJ_{i,j,k}^{(\text{-rho})}$) is used to adjust the intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content). PRI_ADJ is a user-specified input calculated by dividing the average base-year (2009) minemouth coal price for supply region i and mine type j by the estimated average base-year (2009) minemouth coal price for supply region i, mine type j, and coal type k. The latter of these two prices represents data for a specific CPS supply curve, thus the additional coal type dimension for this term.

Remaining Terms in Equation 1.D-4

$P_{i,j,k,t}$	average annual minemouth price of coal in constant 1992 dollars for supply region i, mine type j, coal type k in year t
A	overall constant term for the model
$PRODCAP_{i,j,k,t}$	annual productive capacity of coal mines for supply region i, mine type j, coal type k in year t
$CAPUTIL_{i,j,k,t}$	average annual capacity utilization (the ratio of annual production to annual productive capacity) of coal mines for supply region i, mine type j, coal type k in year t (modeled as a percentage)
$TPH_{i,j,t}$	average annual coal mine labor productivity in tons per miner hour for supply region i, mine type j in year t
$WAGE_t$	average hourly wage for coal miners in year t
$PCAP_{j,t}$	index representing the annualized user cost of mining equipment for mine type j, in year t. The index is adjusted to constant 1992 dollars.
$PFUEL_{i,t}$	a weighted average of the annual price of electricity in the industrial sector and the U.S. price of No. 2 diesel fuel (excluding taxes) to end users for supply region i in year t
$OTH\_OPER_{i,j,t}$	constant dollar index representing mine operating costs other than wages and fuel requirements specified by supply region i, mine type j, in year t. Examples of other operating costs include items such as replacement parts for equipment, roof bolts, and explosives.

Regression Coefficients
A overall constant for the model
$\beta_{i,1}$ for the intercept dummy variables for each supply region i
β_2 for the productive capacity term
$\beta_{j,3}$ for the productive capacity term by mine type j
β_4 for the capacity utilization term
β_5 for the labor productivity term
$\beta_{i,6}$ for the labor productivity term by supply region i
$\beta_{j,7}$ for the labor productivity term by mine type j
$\beta_{i,j,8}$ for the labor productivity term by supply region i and mine type j
$\beta_{j,9}$ for the labor cost term by mine type j
β_{10} for the user cost of capital term
β_{11} for the fuel price term
β_{12} for the other mine operating costs term
rho for the first-order autocorrelation term

Table 1.D-1. Regression Statistics for the Coal Pricing Model

Regression Coefficient	Variable	Parameter Estimate	Standard Error	t- Statistic
A	Overall Constant	-2.500	0.550	-4.547*
$\beta_{i=3,1}$	DUM_REG_3 (Southern Appalachia (SA))	0.660	0.129	5.097*
$\beta_{i=5,1}$	DUM_REG_5 (West Interior (WI))	1.036	0.132	7.822*
$\beta_{i=6,1}$	DUM_REG_6 (Gulf Lignite (GL))	-0.387	0.065	-6.001*
$\beta_{i=7,1}$	DUM_REG_7 (Dakota Lignite (DL))	1.300	0.168	7.758*
$\beta_{i=8,1}$	DUM_REG_8 (Western Montana (WM))	3.225	0.509	6.330*
$\beta_{i=9,1}$	DUM_REG_9 (Wyoming, Northern PRB (NW))	3.143	0.427	7.368*
$\beta_{i=10,1}$	DUM_REG_{10} (Wyoming, Southern PRB (SW))	3.522	0.263	13.413*
$\beta_{i=11,1}$	DUM_REG_{11} (Western Wyoming (WW))	1.185	0.310	3.817*
$\beta_{i=12,1}$	DUM_REG_{12} (Rocky Mountain (RM))	0.672	0.061	11.080*
$\beta_{i=13,1}$	DUM_REG_{13} (Arizona/New Mexico (ZN))	0.405	0.065	6.205*
β_2	ln PRODCAP	0.450	NA[a]	NA[a]
$\beta_{j=1,3}$	DUM_MINE_TYPE (Underground) * ln PRODCAP	-0.105	0.050	-2.093**
β_4	ln CAPUTIL	0.437	0.061	7.214*
β_5	ln TPH	-0.390	0.065	-6.038*
$\beta_{i=3,6}$	SA*ln TPH	0.497	0.132	3.782*
$\beta_{i=5,6}$	WI*ln TPH	0.326	0.115	2.846*
$\beta_{i=7,6}$	DL*ln TPH	-0.591	0.075	-7.887*
$\beta_{i=8,6}$	WM*ln TPH	-1.125	0.177	-6.348*
$\beta_{i=9,6}$	NW*ln TPH	-1.159	0.132	-8.803*
$\beta_{i=10,6}$	SW*ln TPH	-1.235	0.090	-13.655*
$\beta_{i=11,6}$	WW*ln TPH	-0.354	0.162	-2.183**
$\beta_{j=1,7}$	DUM_ MINE_TYPE (Underground) * ln TPH	-0.403	0.055	-7.399*
$\beta_{i=1,j=1,8}$	NA * DUM_ MINE_TYPE (Underground) * ln TPH	0.212	0.037	5.724*
$\beta_{i=3,j=1,8}$	SA * DUM_ MINE_TYPE (Underground) * ln TPH	-0.262	0.110	-2.371**
$\beta_{i=4,j=1,8}$	EI * DUM_ MINE_TYPE (Underground) * ln TPH	0.238	0.043	5.600*
$\beta_{j=1,9}$	DUM_ MINE_TYPE (Underground) * ln WAGE	0.166	0.084	1.964**
β_{10}	ln PCAP	0.128	0.034	3.768*
β_{11}	ln PFUEL	0.133	0.027	4.840*
β_{12}	ln OTH_OPER	0.367	0.087	4.233*
rho	Autocorrelation Parameter (Rho)	0.552	0.048	11.406*
	Adjusted R squared	0.997		
	Durbin-Watson Statistic	2.169		
	Number of Observations	378[b]		

NA = Not available. *Significant at one percent. ** Significant at five percent. *** Significant at ten percent.

[a]The coefficient for the productive capacity term was constrained to a level of 0.45, and, thus the standard error is not available for this term. In a similar regression where the productive capacity term was not constrained, the coefficient for the productive capacity term was 0.204.

[b]The combined use of a weighted regression technique and lagged variables results in the loss or dropping of the first two observations for each group of data (combination of region and mine type). The model includes annual-level data for thirteen CPS supply regions and two mine types (surface and underground) for the years 1978 through 2007, excluding data for the years 1986-1991. In all, 378 observations are included (18 observations per year for each of the 21 years represented in the final estimation).

Notes: The endogenous explanatory variables in the regression are PRODCAP, CAPUTIL, TPH, WAGE, PCAP, PFUEL, and OTH_OPER. Instruments excluded from the supply equation are lagged coal-fired electricity generation, lagged natural gas share of total electricity generation, lagged days of supply at electric power sector plants, lagged industrial coal consumption, lagged exports, lagged coal inventories at electric power sector plants, lagged mine price of coal, lagged productive capacity, lagged capacity utilization, lagged mine productivity, lagged fuel price, lagged coal industry wage, lagged index of other mine operating costs, the world oil price, the price of natural gas to the electric power sector, and the average heat, sulfur and ash content for coal received at electric power sector plants.

Table 1.D-2. Data Sources for Supply-Side Variables

Variable	Description	Units	Sources
$P_{i,j,t}$	Average annual minemouth price of coal by CPS supply region and mine type	1992 Dollars per short ton	U.S. Energy Information Administration, Form EIA-7A, "Coal Production Report"
$PRODCAP_{i,j,t}$	Annual coal productive capacity by region and mine type	Million short tons	U.S. Energy Information Administration, Form EIA-7A, "Coal Production Report"
$CAPUTIL_{i,j,t}$	Average annual capacity utilization at coal mines by region and mine type	Percent	U.S. Energy Information Administration, Form EIA-7A, "Coal Production Report"
$TPH_{i,j,t}$	Average annual labor productivity by region and mine type	Short tons per miner hour	U.S. Energy Information Administration, Form EIA-7A, "Coal Production Report"
$WAGE_t$	Average hourly coal industry wage (national level)	1992 Dollars per miner hour	U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID's: EEU10120006 and CEU1021210006
$PCAP_{j,t}$[14]	Annualized user cost of mining equipment (national level)	Constant dollar index (1992 dollars)	**PPI for Mining Machinery and Equipment**: U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU333131333131; **PPI for Construction Machinery**: U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU333120333120; and **Yield on Utility Bonds**: Global Insight.
$PFUEL_{i,t}$	Weighted average annual price of electricity in the industrial sector and the U.S. price of No. 2 diesel fuel (excluding taxes)	1992 Dollars per million Btu	U.S. Energy Information Administration, *Electric Power Annual 2008 - Spreadsheets* (Washington, DC, January 2010), web site www.eia.gov ; EIA, *Petroleum Marketing Annual 2008*, EOE/EIA - 0487(2008) (Washington, DC, August 2009), Table 2; and EIA, *State Energy Data System*, Consumption, Price, and Expenditure Estimates (Washington, DC, August 2009), web site www.eia.gov.
$OTH\_OPER_{i,j,t}$	A constant dollar index representing mine operating costs other than wages and fuel requirements	Constant dollar index (1992 dollars)	**PPI for Iron and Steel**: U.S. Department of Labor, Bureau of Labor Statistics, Series ID: WPU101; **PPI for Explosives**: U.S. Department of Labor, Bureau of Labor Statistics, Series ID: WPU067902.

[14] This variable was calculated as follows:

$$PCAP = (r + \delta - (p_t - p_{t-1})/p_{t-1}) * p_t$$

where

r is a proxy for the real rate of interest, equal to the AA Utility Bond Rate minus the percentage change in the implicit GDP deflator for year t;

In equation form:
$r_t = (\text{AA Utility Bond Rate}_t/100) – [(\text{GDP Deflator}_t – \text{GDP Deflator}_{t-1})/\text{GDP Deflator}_{t-1}]$
δ is the rate of depreciation on mining equipment, assumed to equal 10 percent; and
p_t is the PPI for mining equipment, adjusted to constant 1987 dollars using the GDP deflator for year t.

The three terms represented in the annual user cost of mining equipment are defined as follows:
rp_t is the opportunity cost of having funds tied up in mine capital equipment in year t;
δp_t is the compensation to the mine owner for depreciation in year t; and
$((p_t - p_{t-1})/ p_{t-1})\ p_t$ is the capital gain on mining equipment (in a period of declining capital prices, this term will take on a negative value, increasing the user cost of capital for year t).

Table 1.D-3. Data Sources for Instruments Excluded from the Supply Equation

Data Item	Description	Units	Sources
Total Coal-Fired Electricity Generation	Annual coal-fired net electricity generation	Billion Kilowatthours	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Table 8.2a.
Natural Gas Share of Total U.S. Electricity Generation	Share of total U.S. electricity generation accounted for by generation at natural-gas-fired power plants	Fraction	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Table 8.2a.
Industrial coal consumption	Annual industrial coal consumption (steam and coking)	Million short tons	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Table 7.3.
World Oil Price	Refiner acquisition cost of crude oil: imported	1992 Dollars per barrel	U.S. Energy Information Administration, *Petroleum Marketing Annual 2008*, DOE/EIA-0487(2008) (Washington, DC, August 2009), Table 1.
Price of Natural Gas	Annual average price of natural gas delivered to the electricity sector by CPS supply region	1992 Dollars per thousand cubic feet	U.S. Energy Information Administration, *Electric Power Monthly, March Supplement, Historical Excel Tables*, March 2008, DOE/EIA-0226(2008/03) (Washington, DC, March 2008), Tables 4.9.B and 4.13.B.
Heat content of coal	Average annual heat content of coal for receipts at electric power sector plants by CPS supply region and mine type	Million Btu per short ton	Federal Energy Regulatory Commission, FERC Form 423, “Monthly Report of Cost and Quality of Fuels for Electric Plants” and U.S. Energy Information Administration, Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"
Sulfur content of coal	Average annual sulfur content of coal for receipts at electric power sector plants by CPS supply region and mine type	Pounds of sulfur per million Btu.	Federal Energy Regulatory Commission, FERC Form 423, “Monthly Report of Cost and Quality of Fuels for Electric Plants” and U.S. Energy Information Administration, Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"

Table 1.D-3. Data Sources for Instruments Excluded from the Supply Equation

Data Item	Description	Units	Sources
Ash content of coal	Average annual ash content of coal for receipts at electric power sector plants by CPS supply region and mine type	Percent by weight	Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants" and U.S. Energy Information Administration, Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"
Exports	Annual exports of U.S. coal	Million tons	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Table 7.1.
Other Production	Total U.S. production minus production for the current observation	Million tons	U.S. Energy Information Administration, Form EIA-7A, "Coal Production Report"
Coal Inventories	Coal stocks at the beginning of the year for U.S. electric power sector	Million tons	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Table 7.5.
Days of Coal Supply at Electric Power Sector Plants	Year-end electric power sector coal inventories divided by average daily coal consumption	Days	U.S. Energy Information Administration, *Annual Energy Review 2008*, DOE/EIA-0384(2008) (Washington, DC, June 2009), Tables 7.3 and 7.5.

Appendix 1.E

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Appendix 1.F

Coal Production Submodule Program Availability

The source code for the Coal Production Submodule program is available from the program office:

Office of Electricity, Coal, Nuclear and Renewables Analysis
U.S. Energy Information Administration
EI-34
U.S. Department of Energy
1000 Independence Avenue S.W.
Washington, DC 20585

2. Coal Distribution Submodule -Domestic Component

Introduction

This section of the report presents the objectives of the approach used in modeling domestic coal distribution and provides information on the model formulation and application. Section 2 is intended as a reference document for model analysts, users, and the public. Section 2 conforms to the requirements specified in Public Law 93-275, Section 57(B)(1) as amended by Public Law 94-385, Section 57.b.2.

Model Summary

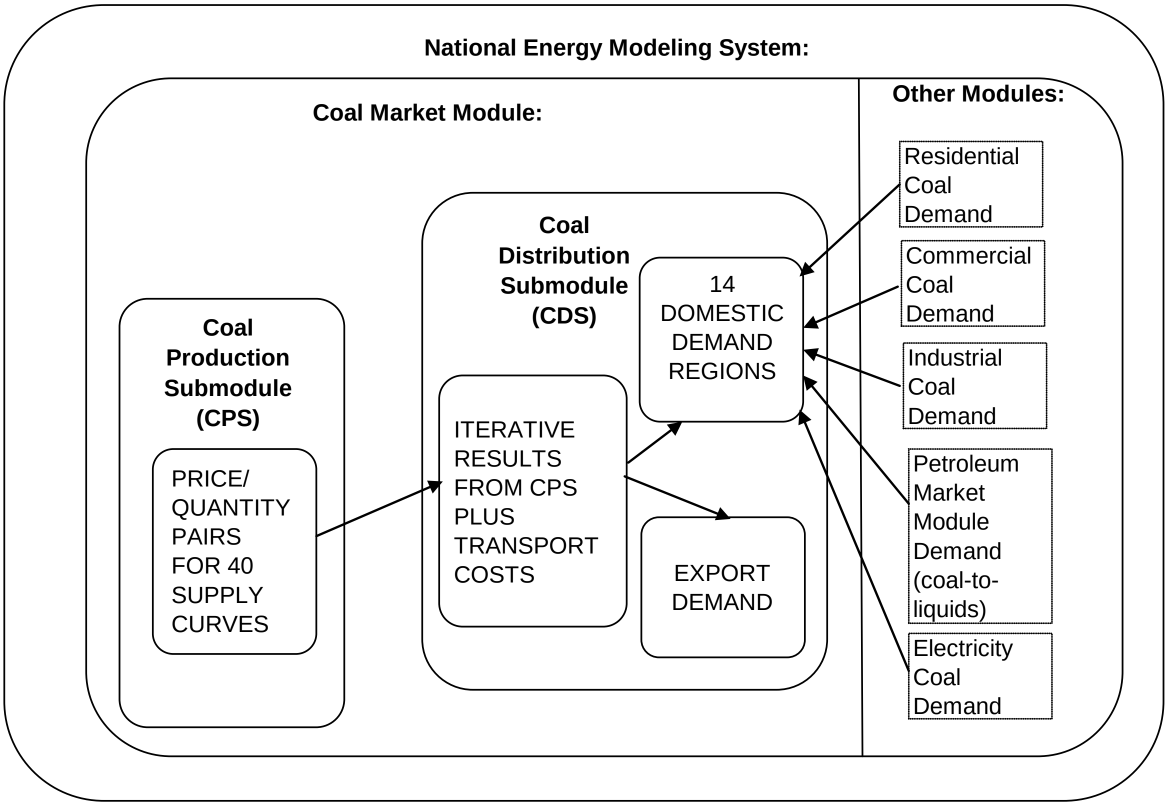
The domestic component of the CDS forecasts coal distribution between 14 U.S. coal supply regions and 16 domestic demand regions. The model consists of a linear program with constraints representing environmental, technical and service/reliability constraints on delivered coal price minimization by consumers. Coal supply curves are input from the CPS, while coal demands are received from the Residential, Commercial, Industrial and Electric Power components of NEMS, with export demands being provided by the international component of the CDS (Figure 2.1).

Model Archival Citation and Model Contact

The version of the CDS documented in this report is that archived for the forecasts presented in the *Annual Energy Outlook 2011*.

Name: Coal Distribution Submodule
Acronym: CDS
Model Contact: Diane Kearney, Department of Energy, EI-34, Washington, DC 20585
(202) 586-2415; (diane.kearney@eia.gov)

Figure 2.1. Model Summary



Organization

This section describes the modeling approach used in the domestic portion of the Coal Distribution Submodule. Within this section, the following are provided:

- The model purpose and scope, its classification structures (including the coal typology adopted, model supply and demand regions and demand sectors and subsectors), model inputs and outputs, and relationship to other NEMS modules and parts of the Coal Market Module

- The theoretical approach, assumptions, major constraints, and other key features

- The structure of the model, including an outline of the CDS computational sequence and input/output flows; a listing of the key computations and equations

This section has six appendices:

- A model abstract (Appendix 2.A)

- A detailed mathematical description of the model (Appendix 2.B)

- A listing of input data, variable and parameter definitions, model output, and their location in reports (Appendix 2.C)

- A discussion of data quality and estimation for model inputs (Appendix 2.D)

- A bibliography of technical references for the model structure and the economic systems modeled (Appendix 2.E)

- A description of CDS program availability (Appendix 2.F).

Model Purpose and Scope

Model Objectives

The purpose of the CDS is to provide annual forecasts (through 2035) of coal production and distribution within the United States. Coal supply in the CDS is modeled using a typology of 12 coal types (discrete categories of heat and sulfur content), 14 supply regions and 16 demand regions. Exogenously generated coal demands within the demand regions are subdivided into 5 economic sectors and 49 economic subsectors. Coal transportation is modeled using sector-specific arrays of interregional transportation prices. Demands are met by supplies that represent the lowest delivered cost on a dollar per million Btu basis. The distribution of coal is constrained by environmental, technical, and service/reliability factors characteristic of domestic coal markets.

As guided by the NEMS planning documents[15], an important design objective in modeling domestic coal distribution is to provide a simple platform that can be rapidly adapted to model policy problems, not all of which may be currently foreseeable. Incorporation of theoretical points-of-view that transcend the fundamental characteristics of the systems modeled was deliberately avoided. The general design strategy can be summarized as follows:

- Start with EIA's coal distribution model from the IFFS modeling system, the Coal Supply and Transportation Model (CSTM)

- Reduce classification detail to the minimum needed to simulate present and potentially important supply and demand patterns and transport routes

[15] Energy Information Administration: EIA Working Group, "Requirements for a National Energy Modeling System" (July 2, 1990), pp. 7, 14, 15. Office of Integrated Analysis and Forecasting: "Draft System Design for The National Energy Modeling System" (January 16, 1991), pp. 3,11; "Working Paper: Requirements for a National Energy System (Draft)" (November 22, 1991), pp. 8, 17; "Working Paper: Requirements for A National Energy Modeling System" (December 12, 1991), pp. 7, 15, 17; "Development Plan for The NEMS" (February 10, 1992), pp. 8, 50, 51. National Research Council, Committee on the National Energy Modeling System, Energy Engineering Board, Commission on Engineering and Technical Systems, "The National Energy Modeling System" (Washington, DC, January 1992), p. 58.

- At the same time, minimize the computational complexity of model functions, thus reducing maintenance requirements and scenario turnaround time while making the model easier to understand

- Design model structure to make maximum use of the limited existing EIA data resources as model input and calibration factors and thereby enhance the transparency of model operation and maximize the consistency of output with EIA data sources.

Classification Plan

The domestic component of the CDS contains four major structural elements that define the geographic and technical scale of its simulation of coal distribution. First is the typology that represents the significant variation in the heat and sulfur content of coal. The geographic categorizations of coal supply and demand comprise two more. The classification of demand into economic subsectors constitutes the fourth classification element. Each is discussed in turn below.

Coal Typology

The coal typology contains 3 sulfur and 4 thermal grades of coal with surface and underground mining to produce the framework shown in Table 1.1 in Section 1. By applying this typology to coal reserves in the 14 supply regions, the 41 coal supply sources used in the *AEO2011* result.

Coal Supply and Demand Regions

Fourteen coal supply regions in the CMM distinguish coalfields by coal quality, typical mine prices and differential access to domestic markets as represented by the 16 demand regions. There are four supply regions east of the Mississippi River that contain 23 of the 41 coal supply sources used for the *Annual Energy Outlook 2011* (Table 1.1 in Section 1). The eight supply regions west of the Mississippi River contain the remaining 12 coal sources. Production from each supply curve (and the associated heat, sulfur and ash content) as used in the *AEO2011* is shown in Table 2.1.

The 16 CMM domestic demand regions (Figure 2.2) represent the nine Census divisions, four of which have been divided to represent distinct sub-markets with special characteristics (Table 2.2). The South Atlantic Census division has been partitioned to create a special market region for Georgia and Florida, which have low-cost access to western supply regions via the Mississippi River system and the Gulf of Mexico. Ohio is given separate region status because of its proximity to North Appalachian coal (from Ohio), and its greater distance from the East Interior and western coalfields. Similarly, Alabama and Mississippi are separated from the other East South Central states (Kentucky and Tennessee) because of their access to South Appalachian coal, and because most coal consumption in Kentucky and Tennessee is supplied from the Central Appalachian and East Interior regions. The Mountain Census division is subdivided to create a separate demand region for Idaho, Montana, and Wyoming, in which utilities are more highly dependent on coal from the Northern Great Plains. Within the Mountain Census division, Colorado, Utah, and Nevada are also separated from Arizona and New Mexico in order to better represent transportation costs. The coal demand regions can easily be aggregated into Census divisions which are subsequently aggregated into the electricity regions by the NEMS Electricity Market Module.

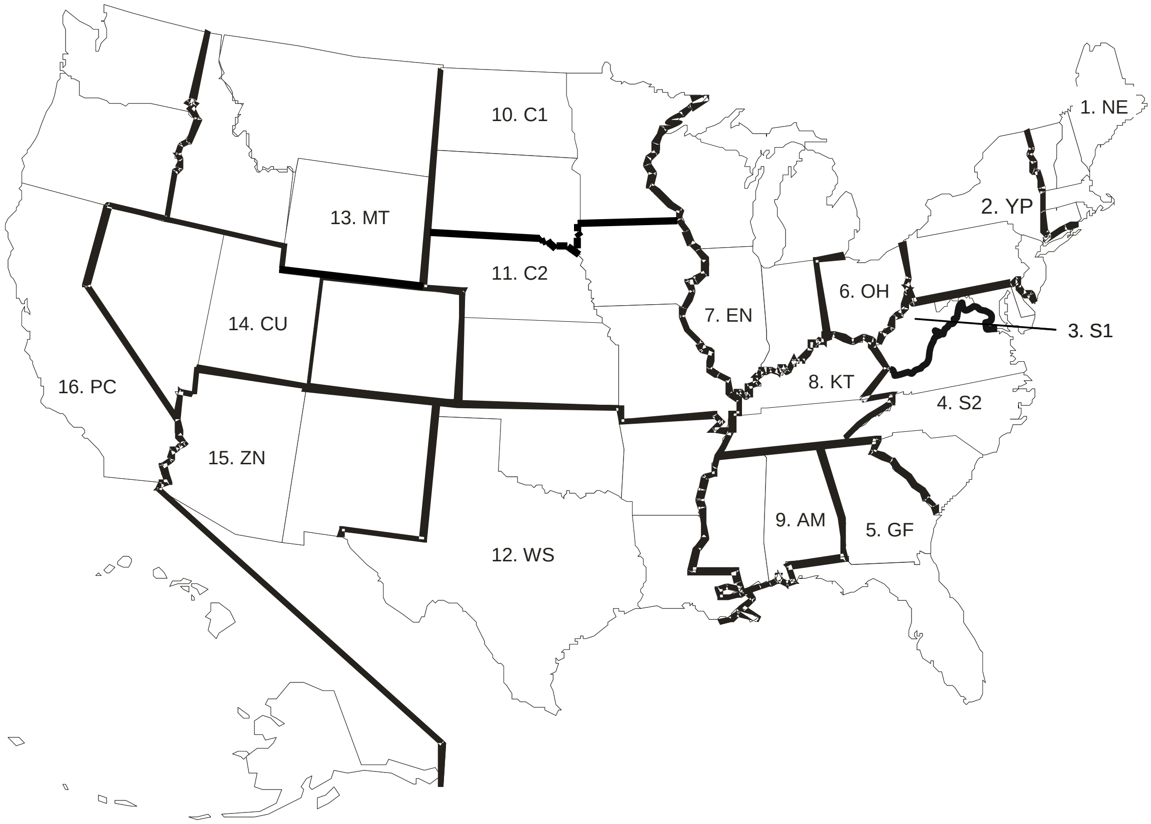
Table 2.1. Average Coal Quality and Production by Supply region and Type, 2009

CMM Supply Region	Coal Type	Production (million tons)	Average MMBtu/Ton	Average lbs Sulfur/MMBtu	Sulfur % by Weight	Average Ash %
1. "NA" (North Appalachia = PA, OH, MD, No. WV)	MDP	4.6	26.33	0.68	0.89	6.29
	MDB/MSB	48.3	25.32	1.33	1.68	8.24
	HDB/HSB	74.6	24.75	2.60	3.21	8.03
	HSL	12.4	12.25	3.01	1.84	45.77
2. "CA" (Central Appalachia = So. WV, VA, East KY, No. TN)	MDP	38.0	26.33	0.67	0.88	6.23
	CDB/CSB	25.8	24.86	0.54	0.68	9.41
	MDB/MSB	132.9	24.75	0.91	1.12	10.13
3. "SA" (South Appalachia = AL, So. TN)	CDP	8.8	26.33	0.52	0.68	7.89
	CDB/CSB	0.7	24.66	0.49	0.61	10.11
	MDB/MSB	9.7	24.06	1.25	1.50	11.44
4. "EI" (East Interior = IL, IN, West KY, MS)	MDB/MSB	14.1	22.71	1.08	1.23	7.21
	HDB/HSB	88.8	22.84	2.60	2.97	8.31
	MSL	3.4	10.21	0.92	0.47	15.24
5. "WI" (West Interior = KS, MO, AR, OK, TX, bituminous)	HSB	1.6	22.24	2.12	2.36	12.38
6. "GL" (TX, LA, lignite only)	MSL	23.5	13.35	1.24	0.83	14.94
	HSL	15.2	12.38	2.60	1.61	19.54
7. "DL" (ND, MT, lignite only)	MSL	30.3	13.30	1.12	0.75	9.02
8. "WM" (MT, bituminous and subbituminous)	CDS	0.8	19.22	0.39	0.37	8.78
	CSS	18.9	18.29	0.39	0.36	6.14
	MSS	19.5	17.18	0.78	0.67	9.35
9. "NW" (WY, Northern Powder River Basin)	CSS	170.7	16.84	0.37	0.31	5.08
	MSS	4.0	16.14	0.74	0.60	8.56
10. "SW" (WY, Southern Powder River Basin)	CSS	242.4	17.57	0.32	0.28	4.94
11. "WW" (WY, Other basins, excluding Powder River Basin)	CDS	3.5	18.65	0.62	0.58	8.79
	CSS	4.7	19.06	0.47	0.45	8.90
	MSS	5.8	19.25	0.85	0.82	7.88
12. "RM" (Rocky Mtn. - CO, UT)	CDP	N/A	26.28	0.52	0.68	N/A
	CDB	43.9	22.80	0.42	0.48	7.75
	CSS	6.1	20.18	0.42	0.42	7.99
13. "ZN" (Arizona/New Mexico- AZ, NM)	CSB	7.4	21.50	0.59	0.64	10.56
	MSS	18.7	18.27	0.92	0.84	18.52
	MDB	6.5	19.36	0.68	0.65	19.60
14. "AW" (Alaska/Washington- AK, WA)	CSS	1.9	16.16	0.31	0.25	7.42

* = less than 50,000 tons of production

N/A = not applicable

Figure 2.2. CMM -- Domestic Coal Demand Regions



Region Code	Region Content
1. NE	CT,MA,ME,NH,RI,VT
2. YP	NY,PA,NJ
3. S1	WV,MD,DC,DE
4. S2	VA,NC,SC
5. GF	GA,FL
6. OH	OH
7. EN	IN,IL,MI,WI
8. KT	KY,TN

Region Code	Region Content
9. AM	AL,MS
10. C1	MN,ND,SD
11. C2	IA,NE,MO,KS
12. WS	TX,LA,OK,AR
13. MT	MT,WY,ID
14. CU	CO,UT,NV
15. ZN	AZ,NM
16. PC	AK,HI,WA,OR,CA

Table 2.2. CMM -- Domestic Coal Demand Regions

Region	Census Division Name	Census Division Number Code	States Included
1. NE	New England	1	CT, MA, ME, NH, RI, VT
2. YP	Middle Atlantic	2	NY, PA, NJ
3. S1	South Atlantic	5	WV, MD, DC, DE
4. S2	South Atlantic	5	VA, NC, SC
5. GF	South Atlantic	5	GA, FL
6. OH	East North Central	3	OH
7. EN	East North Central	3	IN, IL, MI, WI
8. KT	East South Central	6	KY, TN
9. AM	East South Central	6	AL, MS
10. C1	West North Central	4	ND, SD, MN
11. C2	West North Central	4	IA, NE, MO, KS
12. WS	West South Central	7	TX, LA, OK, AR
13. MT	Mountain	8	MT, WY, ID
14. CU	Mountain	8	CO, UT, NV
15. ZN	Mountain	8	AZ, NM
16. PC	Pacific	9	AK, HI, WA, OR, CA

Coal Demand Sectors and Subsectors

In the CDS, domestic coal demands are further divided into six major sectors and 49 subsectors, part or all of which may be utilized in each demand region in each forecast year. The six major coal demand sectors are Electricity generation, Industrial Steam, Industrial Coking, Industrial Coal-to-liquids (CTL), Residential/Commercial, and Exports. Electricity generation includes generation from utilities, independent power producers, and combined heat and power facilities whose main purpose is the sale of electricity. The Industrial Steam sector includes other combined heat and power facilities as well as industrial consumers of steam from coal. The Industrial Coking sector includes metallurgical and by-product coke ovens. The CTL sector includes facilities where coal is converted to liquid petroleum products. The Residential and Commercial sectors together represent less than one percent of coal demand, so they are modeled together in order to more closely model distribution patterns.

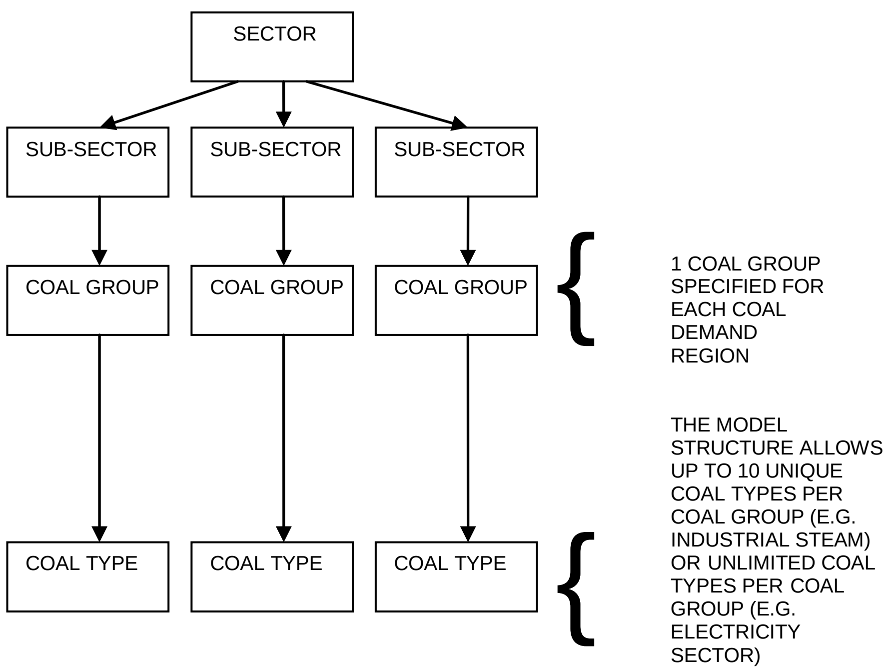
Coals of different types and quality, geographic availability, and prices tend to be associated with satisfying demands of particular sectors. These coals may not necessarily represent the least expensive option for a sector when factors such as quality or type are not considered, however. If minimization of costs alone is used to determine which coals satisfy a sector's coal demand, many historical and forecasted flows would not be accurately depicted in the model. The CMM determines the mix of coals used to satisfy demand based on minimization of cost within a linear program (LP). One option to handle these examples of seemingly uneconomic coal choices is to include many constraints within the LP specifying which coals are available for consumption by certain sectors while making others unavailable. The addition of such constraints, however, would increase the model structure's complexity. In order to avoid this, subsectors are defined for each economic sector. For the non-electricity sectors, consumption by the subsectors is mainly allocated based on historical distribution patterns. The subsectoral detail used in the *Annual Energy Outlook 2011* is shown in Table 2.3.

Table 2.3. Domestic CMM Demand Structure - Sectors and Subsectors

Sector	Number of Demand Subsectors
1. Residential/Commercial	2
2. Industrial Steam	3
3. Industrial Metallurgical	2
4. Industrial Coal-to-liquids	1
5. Export	6
6. Electricity	35
Total Number of Subsectors	49

For all of the subsectors, a “coal group” is defined for each demand region. Each of these coal groups references a particular set of coal types. An example of a coal type is medium sulfur, surface-mined, bituminous coal from Northern Appalachia. Some of the coal groups allow unlimited choices of coal types while others are more restrictive and only allow a choice of two or three. For example, for the coking coal subsectors, only metallurgical grade coal is permitted. In general, the Electricity sector is allowed to use coal from any of the non-metallurgical grade coal supply supply curves modeled in the CMM. (The Electricity sector is further constrained in other ways, for example, sulfur limitations in the model structure. For more information, see “Constraints Limiting the Theoretical Approach” and “Environmental Constraints.”) A general schematic of the sectoral structure present in the coal model is displayed in Figure 2.3.

Figure 2.3. General Schematic of Sectoral Structure



The Electricity sector is divided into 35 subsectors. Each subsector represents a particular plant configuration generally describing the type of emission control technology employed at a group of plants. The specific categorization shown in Table 2.4 was introduced in the *Annual Energy Outlook 2004*. Previously there were only seven sectors, defined by plant age, sulfur use limitations, and scrubbing capability. (For more information regarding the previous subsectoral classification, please refer to the Coal Market Module Documentation, February 2003.) The expansion of the subsectors from 7 to 35 improves the communication between the Electricity Capacity Planning Module (ECP) and the CMM. Coal demands are sent from the electricity model in this level of detail, so the CMM does not need to disaggregate the demands into subsectors itself.

In a mercury-constrained scenario, once a mercury control technology is chosen, the model does not allow a subsequent retrofit decision to be made to "undo" the previous choice. Since pilot tests indicate that there are no mercury removal benefits, selective non-catalytic reduction systems (SNCRs) in combination with flue gas desulfurization equipment are not represented in the model as a mercury control option. Also, a plant that is unscrubbed is only allowed to upgrade to wet flue gas desulfurization equipment within the model structure (as opposed to dry flue gas desulfurization equipment). Items highlighted in grey in Table 2.4 indicate configurations which are not considered viable mercury removal options in the *AEO2011* although they are still present in the model structure.

The Industrial Steam sector is divided into three subsectors. Although the subsectors in the industrial sector are less formalized than in the electricity sector, the basic premise is the same. As in the electricity sector, technical requirements of certain facilities limit the types of coal that may be used. For example, “stoker” industrial steam coals are shipped to older industrial boilers that require – for technical reasons – coal fuels with relatively low ash and high thermal energy content. Industrial pulverized coal boilers can accept lower quality coals in terms of ash and Btu content. In addition, there are a wide variety of other specialized technologies, for example coal-fired fluidized-bed steam boilers, Portland cement kilns, and anthracite coals used as sewage filtration medium.

The Industrial Coking sector is also divided into two subsectors.   This division allows the CMM to better approximate historical consumption patterns for each demand region, as a unique coal group (i.e., set of supply curves) is assigned to each of the two subsectors. For instance, 80 percent of the coking demand for the Middle Atlantic region may be satisfied by the first subsector specifying coal group “X.” The remaining 20 percent of the coking demand for the Middle Atlantic region may be satisfied by the second subsector specifying coal group “Y.”

Since there are no historical flows for the CTL sector, the CTL sector does not require subsectors in order to represent consumption. Each new CTL facility is assumed to have a capacity of 50,000 barrels per day of liquid fuels and is located in areas where existing refineries are present. The CTL market is not limited to specific coals but chooses its fuel based upon minimization of costs. The Petroleum Market Module (PMM) sends demands to the CMM according to its five PMM regions. The CMM assigns coal demand regions to each of these PMM regions. For the regions PMM1, PMM2, PMM3, and PMM5, 100 percent of the CTL demand is mapped to the coal demand regions YP, EN, WS, and PC, respectively. PMM4’s CTL demand is allocated equally to the CW and MT coal demand regions.

CTL facilities are modeled in the PMM as indirect liquefaction “co-co” facilities, meaning they produce both liquid fuels (of which 57 percent is assumed to be diesel and 43 percent is naphtha) and electricity. Each modeled plant is assumed to produce 845 MW of electricity (300 MW for the grid and 545 MW for the conversion process) and is capable of producing 50,000 barrels of liquids per day. Coal-biomass-to-liquids (CBTL) facilities are also modeled. These facilities assumed capacity is 602 MW (150 MW for the grid and 452 MW for the conversion process) and are capable of producing 30,000 barrels of liquid fuels per day. Eighty percent of the energy required is assumed to come from coal while the remaining 20 percent comes from biomass. The proportion and type of liquid fuels produced from CBTL facilities are the same as CTL facilities.

The four subsectors used for export coals are established in much the same way as the industrial sectors. U.S. coal exports tend to be among the most expensive in international markets, even on a dollar per million Btu basis, but are bought because of their high quality, reliable availability, and historical role as a method of balancing foreign trade accounts. The United States is still considered an important exporter of premium coking coals (which have the same characteristics as premium coking coals in domestic markets). The other export subsectors are for steam coals, which require special coal quality definitions different from domestic steam coals.

In summary, the CDS contains two residential/commercial subsectors, three industrial steam and two domestic coking coal subsectors, one coal-to-liquid sector, three export metallurgical and three export steam subsectors and 35 electricity subsectors, making 49 in all.

Relationship to Other Models

The domestic component of the CDS relates to other NEMS modules as the primary iterating unit of the Coal Market Module, receiving demands from other non-coal modules and sending delivered coal prices, Btu contents, and tonnages framed in inter-regional coal distribution patterns specific to the individual NEMS economic sectors (Figure 2.4). This information is shared between the CDS and other NEMS modules via "include files." Table 2.C-1 in Appendix 2.C lists information that is shared between the CDS and the CPS or the CDS and other models within NEMS. When the CMM's programming code (written in Fortran) is compiled, these files are automatically included by the compiler. Within the CMM, the domestic distribution component of the CDS interacts with other parts of the CMM. In the first iteration of each annual forecast, it receives coal supply curves from the CPS. Price and quantity output describing the CMM's simulation of domestic coal production, distribution and exports by economic sector is sent to the NEMS integrating module. These outputs include: (1) minemouth, transportation and delivered prices; (2) regional/sectoral coal supplies in trillion Btu and millions of tons by coal heat and sulfur content categories; and (3) energy conversion factors (million Btu per short ton) and sulfur values (pounds of sulfur per million Btu). The domestic distribution portion of the CDS relates to other CMM components using its own set of 16 domestic demand regions, but aggregates all final outputs to the NEMS integrating model into the 9 Census divisions, which are a superset of the CMM's domestic demand regions.

Both the CMM and the EMM have input files that are defined at the unique plant unit level and then aggregated to the plant type level. Coal contracts, coal diversity constraints, transportation rates, and coal supply curves are represented in both models. The CMM also passes transportation rates and coal supply curves to the PMM for the purpose of coal-to-liquids (CTL) modeling. (This modeling change was first introduced for the *AEO2007*. In previous AEO's only a simplified representation of coal supply curves was passed to the PMM.) The detail shared between the three models stems from a goal of improving overall NEMS convergence and convergence speed.

Input Requirements from NEMS

The CDS obtains electricity sector coal demand by forecast year and estimates of future coal demand in subsequent years from the EMM for each of the 16 CDS demand regions and 35 electricity subsectors.

The CDS receives annual U.S. coal export demands from CDS's international component. These demands represent premium metallurgical demand, and bituminous and subbituminous steam coal demands. Export demands are also disaggregated, but only to the 8 domestic demand regions of the CMM that contain ports-of-exit. This regional structure allows the CDS to forecast domestic mining and transportation costs to terminals in different regions of the U.S. and for exports to overseas markets in northern and southern Europe, South America, the Pacific Rim of Asia, and Canada.

Residential/commercial, industrial steam and coking coal demands, specified for each of the nine Census divisions, are sent from the Residential, Commercial and Industrial Demand modules, respectively. Coal, once an important transportation fuel, is now restricted to use in a handful of steam engines pulling excursion rides. Therefore, there is no transportation demand sector in the CDS.

The CTL and CBTL (XTL) sectors represent a potential technology that could become economic when low-sulfur distillate prices are high. Demands for XTL are specified by the PMM's five demand regions. The relationship between the PMM demand regions and the CMM demand regions is shown below in Table 2.5. The modeling of XTL is simplified by only allowing certain coal demand regions to participate in the XTL sector.

The transition from Census divisions and PMM regions to the more detailed domestic CDS demand regions is accomplished using static demand shares specific to the Residential/Commercial, Industrial Steam, Industrial Metallurgical, and Industrial Coal-to-liquids sectors. These shares are updated annually and are found in the CDS input files. The demand for U.S. coal exports is received from the international component of the CDS and is disaggregated into the domestic CDS demand regions according to static shares found in the international portion of the CDS.

Other CDS inputs include transportation rates (clrates.txt) and coal contracts (clcont.txt) for the electricity sector (both discussed in Chapter 3), a parameters file (clparam.txt) which includes regional and sectoral indices and labels, as well as parameters used to calibrate minemouth prices and transportation rates. The parameter input file also defines "coal groups"—groups of coal types that specify the coal Btu and sulfur categories that may be used to satisfy demand in different subsectors. Shares restricting the amount of subbituminous and lignite coal used to satisfy particular electricity subsector demands in certain regions are provided in input files as well.

Output Requirements for Other NEMS Components

The CDS provides detailed input information to the EMM including coal contracts, coal diversity information (subbituminous and lignite coal constraints), transportation rates, and coal supply curves. The EMM uses this information to develop expectations about future coal prices and coal availability and allows the EMM to make improved projections of coal planning decisions.

Ultimately, the CDS still provides the least cost delivered prices for each coal type in each CDS demand region to the EMM. These prices allow the EMM to determine the comparative advantage of coal in relation to that of other fuels and are used for the EMM's dispatching decisions. After receiving the EMM demands, the CDS supplies them with the least cost available coal supplies and reports the resulting distribution pattern, production tonnages and minemouth,

Table 2.4. Electricity Subsectors

Sector Code	SECTOR CHARACTERISTICS			
	General Classification	Flue Gas Desulfurization Equipment	NO_x Control Equipment	Additional Mercury Controls
1.B1	Bag house	NA	Any	NA
2.B2	Bag house	NA	Any	SC
3.B3	Bag house	Wet scrubber	NA	NA
4.B4	Bag house	Wet scrubber	NA	SC
5.B5	Bag house	Wet scrubber	Selective Catalytic Reduction	NA
6.B6	Bag house	Wet scrubber	Selective Catalytic Reduction	SC
7.B7	Bag house	Dry Scrubber	Any	NA
8.B8	Bag house	Dry Scrubber	Any	SC
9.C1	Cold side electrostatic precipitator	NA	Any	NA
10.C2	Cold side electrostatic precipitator	NA	Any	FF
11.C3	Cold side electrostatic precipitator	NA	Any	SC/FF
12.C4	Cold side electrostatic precipitator	Wet scrubber	NA	NA
13.C5	Cold side electrostatic precipitator	Wet scrubber	NA	FF
14.C6	Cold side electrostatic precipitator	Wet scrubber	NA	SC/FF
15.C7	Cold side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	NA
16.C8	Cold side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	FF
17.C9	Cold side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	SC/FF
18.CX	Cold side electrostatic precipitator	Dry Scrubber	NA	NA
19.CY	Cold side electrostatic precipitator	Dry Scrubber	NA	FF
20.CZ	Cold side electrostatic precipitator	Dry Scrubber	Selective Catalytic Reduction	SC/FF
21.H1	Hot side electrostatic precipitator	NA	Any	NA
22.H2	Hot side electrostatic precipitator	NA	Any	FF
23.H3	Hot side electrostatic precipitator	NA	Any	SC/FF
24.H4	Hot side electrostatic precipitator	Wet scrubber	NA	NA
25.H5	Hot side electrostatic precipitator	Wet scrubber	NA	FF
26.H6	Hot side electrostatic precipitator	Wet scrubber	NA	SCFF
27.H7	Hot side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	NA
28.H8	Hot side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	FF
29.H9	Hot side electrostatic precipitator	Wet scrubber	Selective Catalytic Reduction	SC/FF
30.HA	Hot side electrostatic precipitator	Dry Scrubber	Any	NA
31.HB	Hot side electrostatic precipitator	Dry Scrubber	Any	FF
32.HC	Hot side electrostatic precipitator	Dry Scrubber	Any	SC/FF
33.PC	New Pulverized Coal			
34.IG	New Integrated Gasification Combined Cycle			
35.IS	Integrated Gasification Combined Cycle with Sequestration			

(Shaded) No longer considered mercury control option in NEMS although still present in modeling structure.

SC = Spray Cooling
FF = Fabric Filter
NA = Not Applicable

Figure 2.4. General Relationship to Other NEMS Modules

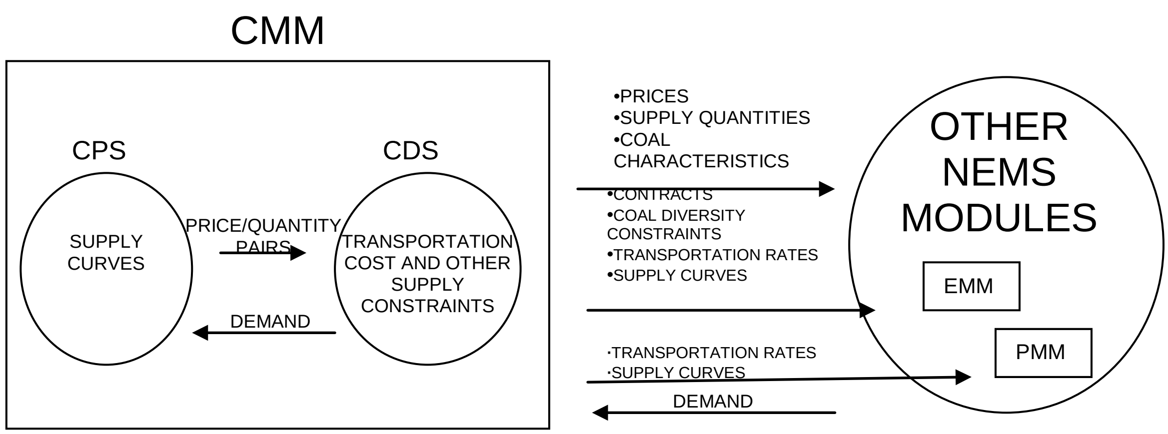


Table 2.5. PMM Demand Region Composition for the CTL and CBTL Sectors

PMM DEMAND REGION	COAL DEMAND REGIONS
I	YP
II	EN
III	WS
IV	CW,MT
V	PC

transport, and delivered prices to NEMS for the electricity generation sector after aggregating the output to the Census division level. The CDS provides delivered prices and volumes for coal supplied to the residential, commercial and industrial sectors by Census division. Prices and volumes are reported by regional origin and Btu/sulfur content. These values are reported to the residential, commercial and industrial models via the NEMS integrating module. The domestic component of the CDS can provide export coal quantities and f.a.s. port-of-exit prices by export supply region and coal sulfur/Btu content.[16]

The CDS also provides detailed input information to the PMM including transportation rates and coal supply curves. The PMM uses this information to develop expectations about future coal prices and coal availability and allows the PMM to determine the economic feasibility of constructing a coal-to-liquids facility by estimating delivered coal prices for specific quantities of coal. In scenarios where allowance prices are modeled (for more information, see section entitled “Environmental Constraints ”), allowance prices for SO_2 and mercury are sent to the PMM and are considered in the overall cost of the coal fuel supplied. Emissions from CTL facilities are

[16] F.a.s. prices, literally, "free alongside ship", mean that these prices include all charges incurred in U.S. territory except loading on board marine transport. This meaning is generally observed even when, as in the case of some exports to Mexico and Canada, they do not literally leave by water transport.

assumed to be identical to that for IGCC. Additional details of coal-to-liquids modeling are provided in the Petroleum Market Module Documentation.

The output for the domestic component of the CDS falls into two categories:

- Outputs produced specifically for the NEMS system, characteristically in aggregate form and presented in tables that span the forecast period. These reports are primarily designed to meet the output requirements of the *Annual Energy Outlook* and its *Supplement*.

- Detailed reports produced in a set for a single forecast year. These reports provide detail on sectoral demands received, regional and national coal distribution patterns, transportation costs, and reporting of regional and supply curves-specific production. Any or all of these reports can be run for any year in the model forecast horizon. These reports are designed to meet requirements for detailed output on special topics, and for diagnostic and calibration purposes.

Model Rationale

Theoretical Approach

Each year, coal is transported from mines to consumers thousands of individual transportation routes. Subject to certain constraints peculiar to its industrial organization, the behavior of the coal industry is demand driven and highly competitive. Coal transportation, while far from perfectly competitive in all cases, is a competitive industry when viewed at the national scale. Given this overall picture, it is appropriate to model coal distribution with the central assumption that markets are dominated by the power of consumers acting to minimize the cost of coal supplies. Since the late 1950's, coal supply and distribution has been modeled with this central assumption, using linear programming and/or heuristic solution algorithms that determine the least cost pattern of supply to meet national demand.

The CDS employs a linear program to determine the least cost set of supplies to meet overall national coal demand. The detailed pattern of coal production, transportation, and consumption is simplified in the CDS as consisting of about 200 annual demands (the exact number depends on the forecast year and scenario modeled) satisfied from up to 41 coal supply curves.

Constraints Limiting the Theoretical Approach

The picture of a highly competitive coal mining industry serving consumers with significant market power is correct, but substantially incomplete. It fails to show powerful constraints on consumer minimization of delivered coal costs that transform the observed behavior of the industry. These major constraints can be categorized:

- Environmental constraints

- Technological constraints

- Transportation constraints

The deregulation of electricity generation and the increasing uncertainty about the long-term environmental acceptability of coal combustion have combined to remove some of the constraints imposed on coal modeling by long-term contracts and other “security of supply” agreements that tended to reduce the role of cost minimization in domestic coal markets. Environmental regulation and technological inflexibility combine to restrict the types of coal that can be used economically to meet many coal demands, thus reducing the consumer's range of choice. Supply reliability and local limits on transportation competition combine to restrict where, in what quantity, and for how long a technically and environmentally acceptable coal may be available. The synergistic action of these constraints produces a pattern of coal distribution which differs from unconstrained delivered cost minimization.

Environmental Constraints

The CMM is capable of modeling compliance with emissions limits established by the Clean Air Act Amendments of 1990 (CAAA90), CAIR and CAMR. The role of modeling these environmental constraints is shared by the Coal Distribution Submodule (CDS) and the Electricity Market Module (EMM). In particular, there are three ways in which these constraints may be met: fuel switching, purchasing emissions allowances, and scrubber and other technology retrofits. The CMM determines any change in the mix of coals needed to comply with the various constraints, i.e. fuel switching, and also determines an allowance price which influences the EMM’s retrofit decisions.

CAIR was vacated by the courts but then temporarily reinstated in December 2008, so it is modeled in *AEO2011*. CAMR was also vacated by the courts in February 2008, and it is not modeled in *AEO2011*. However, with or without CAMR, many States are planning to implement mercury rules on their own. For those States, the effects of state laws are approximated and modeled for *AEO2011*. These plants are required to implement Maximum Achievable Control Technology and remove 90 percent of the mercury content of the coal consumed. The discussion related to mercury below primarily describes how mercury is capable of being modeled in a scenario where CAMR is implemented.

The CDS is formulated as a linear programming problem. It allows supply decisions to be made while simultaneously satisfying the emission requirements. Electricity demand, in Btus, originates from the EMM and is specified by plant unit. The CDS provides coal prices, sulfur content, mercury content, and SO_2 and mercury allowance prices. Hence, fuel switching between coal types needed to reach compliance is determined by the CMM.

The CMM coal typology for domestic supply sources provides three grades of coal sulfur content: low, medium, and high. Phase II of the Clean Air Act Amendments of 1990 imposes a permanent annual cap on SO_2 emissions of 8.95 million tons of SO_2 for all existing generating units with an output capacity of greater than 25 megawatts as well as new generating units. This translates to approximately 1.2 pounds of SO_2 per million Btu of heat input. The first phase of CAIR is assumed to begin in 2010 and supersedes the provisions of CAAA90, initially capping the emissions of affected states to 3.6 million tons. The second phase of CAIR would restrict affected states to 2.5 million tons beginning in 2015. (The NO_x provisions of CAIR are modeled only in the EMM.)

In addition to sulfur content, the CMM includes mercury (Hg) content information. Hg content data for coal by supply region and coal type, in units of pounds of Hg per trillion Btu, were derived from shipment-level data reported by electricity generators to the EPA in its 1999 Information Collection Request (ICR). Data input to the CMM were calculated as weighted averages specified by supply region, coal rank, and sulfur category. CAMR, though not modeled in AEO2011, establishes nation-wide emissions limits on mercury, the first phase of whichset at 38 tons per year beginning in 2010. If modeled, a second phase limit of 15 tons per year would become effective in 2018.

A sulfur penalty and mercury penalty calculation (only applies when CAMR is modeled) are represented by constraint rows in the linear program of the CDS. The sulfur constraint limits the level of sulfur credits expended so as not to exceed the limits on emissions established by the CAAA90 and CAIR. Likewise, if CAMR is modeled, the mercury constraint limits the amount of mercury contained in the coal supplied. The dual variable for each constraint represents the corresponding penalty level (allowance price) for each pollutant.

The year-to-year change in the sulfur allowance bank can be adjusted to keep the sulfur penalty within a set of dynamically adjusted upper and lower bounds (which are provided by the ECP). These upper and lower bounds can be adjusted in each model year. Hence, the CMM is influenced by the ECP when it derives its annual SO_2 allowance price projections.

In the case of mercury, activated carbon injection (ACI) during the coal combustion process may be used on an incremental basis to achieve various levels of Hg emission reductions. With either CAMR or when mercury is modeled as a MACT (as in *AEO2011*), the cost of removing Hg using activated carbon is added to the transportation cost and is included in the coal model's LP objective function. Each cost represents the amount spent on activated carbon to remove one ton of Hg and corresponds to a particular coal generation plant configuration, coal demand region, and Hg reduction quantity range. The amount of Hg removed using activated carbon is added to the mercury cap within the mercury constraint row. This adjustment to the mercury constraint row allows the CMM greater flexibility and accuracy in meeting the coal demands.

The CDS supplies the Electricity Fuel Dispatch (EFD) Submodule with coal prices, average sulfur and mercury content for these 35 coal subsectors, and the penalty costs. Using these inputs, the EFD determines the appropriate mix of fuel demands based on regulatory and technological costs.

The CDS provides additional information to the ECP regarding contracts, subbituminous and lignite coal market share limitations, transportation rates (and supply curves from the CPS), and other miscellaneous output. This data provides the ECP with improved expectations of coal prices and coal availability in the forecast years. The ECP submodule uses this information as well as output from other supply submodules to project capital decisions for the electricity markets. In addition to determining new generation capacity, the ECP submodule decides whether to retire coal units or to retrofit existing coal generation units with sulfur dioxide scrubbers. The ECP also estimates sulfur dioxide emissions.

Emissions from coal-to-liquids facilities, which are assumed to generate electricity that is sold to the grid as well as liquid products, are subject to the restrictions of CAIR and CAMR. The PMM adds the cost of allowances to its fuel costs when making its CTL planning decisions. The emissions of CTL plants, similar to IGCC, are low relative to other coal technologies, due to the removal of 99 percent of potential sulfur dioxide and 95 percent of potential mercury emissions.

In the other subsectors that do not involve electric power generation, domestic environmental and technical constraints (with their foreign market equivalents for coal exports) combine to restrict choices. These constraints are modeled using the coal groups. In the industrial and residential/commercial sectors, demand is received from other NEMS components in aggregated form and is subdivided into sulfur categories.

In summary, the CMM determines the projected mix of coals and performs allowance price calculations. While the ECP also calculates allowances prices, it is responsible for the SO_2 scrubber retrofit decisions and, in the case of mercury, other technology investment decisions. The PMM considers the cost of emission allowances when making its planning decisions.

Technological Constraints

Technological constraints restrict the suitability of coals in different end uses. Coal deposits are chemically and physically heterogeneous; end-use technologies are engineered for optimal performance using coals of limited chemical and physical variability. The use of coals with sub-optimal characteristics carries with it penalties in operating efficiency, maintenance cost, and system reliability. Such penalties range from the economically trivial to the prohibitive, and must be balanced against any savings from the use of less expensive coal.

Precise modeling of the technological constraints on coal cost minimization would require an enormously detailed model, using large quantities of engineering data that are not in the public domain. A simplified approach is adequate for most public policy analyses and is mandated by data availability constraints. Technological constraints on coal choice are simply addressed in the CDS by subdividing sectoral demands into subsectoral detail representing the more important end-use technologies, and by then restricting supplies to these subsectors to one or more of the CMM coal types using the "coal group" definitions. For the electricity sector, the “coal groups” have been relaxed to allow the coal model greater flexibility in satisfying the demands.

It is sometimes necessary to restrict regional demands to specific coal sources. In the case of demands for lignite, gob or anthracite culm, which contains the lowest heat content per ton of the coals modeled in the CMM, transportation over any significant distance creates the double risk of significant Btu loss and spontaneous combustion. In the CDS, such demands can be restricted to demand regions conterminous with the appropriate supply regions.

Again, the advent of deregulation and the increasing importance of electricity generation costs have produced a willingness to overlook some of the less threatening types of damage that can occur from using coals which differ from a boiler’s design specification. Many plants have learned that, with relatively minor investments, newer plants can be easily transferred from bituminous to subbituminous coal. The transportation rate model structure accounts for an increase in expenses when subbituminous coal is used beyond historical levels. (See “Transportation Cost Constraints” below.)

Technical constraints are also represented in the model for certain electricity subsectors and demand regions by modeling diversity constraints for lignite and subbituminous coals. The diversity constraints establish bounds for use of these types of coals. The bounds are established for particular electricity subsector/demand region combinations based on historical patterns of use of lignite and subbituminous coals. Over the forecast, these bounds become considerably less restrictive for subbituminous coals and have all but disappeared for all sectors by 2025. For *AEO2011*, the lignite diversity constraints either allow plant units within an electricity subsector unlimited use of lignite coal or prevent lignite coal from being used at all.

Transportation Cost Constraints

Minimization of delivered coal costs may be constrained by the market power of railroads, the dominant transport mode. Railroad rates for coal have historically reflected substantial market power in many regions; they still may in most of the northeastern United States and at locations where alternative coal sources and/or multiple common carriers are lacking. Coal consumption facilities have a typical economic life of from 25 to 50 years; once built they are immovable. The resulting price elasticity of demand often enables a coal carrier to extract economic rents.

Nationwide, shipping costs for contract deliveries to electric utilities represented 29 percent of delivered costs in 1984 and only 25 percent in 1987, but amounted to 40 percent of delivered costs to utilities in the South in 1987, and half of delivered costs in the West.[17] In 1999, shipping costs represented about 33 percent of delivered costs to utilities. In some current cases, transport costs have exceeded 80 percent of delivered costs.[18] In 1998, coal accounted for 27.3 percent of carloads, 45.5 percent of tonnage, and 22.9 percent of revenue for Class I railroads.[19]

Coal distribution modeling mandates recognition that coal transportation rates only approach marginal costs of service in the presence of intermodal competition. Further, the difference between cost and price can be significant, not merely on a route-specific basis, but at the national level. Because coal transportation rates may not be determined exclusively by costs or distance, estimation of route-specific transport rates (i.e., when required for topical analyses) is done exogenously. Since thousands of transport routes may be in use in any year, endogenous estimation of a reasonably complete set of route-specific costs would impose unacceptable model execution and maintenance burdens.

In the CDS, domestic transportation rates are inferred by subtracting historical average minemouth prices from historical average delivered prices. Since coal-to-liquids facilities do not currently exist, CTL transportation rates are based upon historical transportation rates to the electricity sector. For each of the 49 subsectors within the six major economic sectors (electric power generation, industrial steam generation, domestic metallurgical production, residential/commercial consumption, coal-to-liquids, and exports), a set of transportation prices connects the 16 demand regions with each of the 41 supply curves. In principle, there are thus 16*41*49=32,144 coal transportation routes and associated prices in the model. In practice, the number of useable routes is substantially less, since many of the origin/destination possibilities represent routes that are economically impractical now and in the foreseeable future.

Alaska produces coal for its own consumption and export, but has never "imported" coal from the contiguous States or overseas. Its only feasible coal transportation connection in the CDS is with the Pacific Northwest region. No other approach is reasonable in such cases, since estimates of

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[17] Energy Information Administration, *Trends in Contract Coal Transportation, 1979-1987*, DOE/EIA-0549 (Washington, DC, September 1991), p. ix.

[18] In 1990 Georgia Power purchased over 1.5 million short tons of Wyoming coal at a delivered cost of $26.48 per short ton, of which the reported minemouth cost at the Caballo Rojo mine in Wyoming was $4.00 per short ton, or 15.1 percent.

[19] Association of American Railroads, *The Rail Transportation of Coal*, January 2000.

transport costs cannot be made for routes that have never been used and where required infrastructure does not exist. A different type of example is provided by the metallurgical coal sector. Not all of the model's supply regions contain coal reserves suitable for making metallurgical coke using current technologies. Similarly, not all demand regions contain coking coal demands. Where there can be neither supply nor demand, coal transportation rates are set to dummy values to prohibit their use. This method allows easy modification of the rates should technological change or economic development produce possibilities where none now exist.

For the electricity sector, an increase over historical volumes for certain transportation routes and coal types may occur in the forecast as generation demand increases and demand changes due to environmental and cost pressures. In certain cases, this incremental volume will require an increase in shipping distance within a demand region. This increase in shipping distance has been reflected in second tier transportation rates for certain routes. For a plant that has never used coal from a particular supply curve, the model structure provides the capability to model transportation only at a higher second tier rate.

A higher, second tier transportation rate is also used for subbituminous coal. This transportation rate is a proxy for the operation costs associated with the use of subbituminous coal, including fouling/slagging, derates, and other production problems that are not currently accounted for in the electricity model. The net effect of the second tier transportation rate is to add roughly $0.10 per million Btu (measured in 2000 dollars) to the transportation rate for incremental volumes of subbituminous coal.[20]

Domestic transportation rates in the CDS vary significantly between the same supply and demand regions for different economic sectors. This difference is explained by the following factors:

- Both supply and demand regions may be geographically extensive, but the particular sectoral or subsectoral demands may be focused in different portions of the demand region, while the different types of coal used to meet these demands may be produced in different parts of the supply region.

- Different coal end-uses require coal supplies that must be delivered within a narrow range of particle sizes. Special loading and transportation methods must be used to control breakage for these end uses. Special handling means higher transportation rates, especially for metallurgical, industrial, and residential/commercial coals.

- Different categories of end-use consumers tend to use different size coal shipments, with different annual volumes. As with most bulk commodity transport categories, rates charged tend to vary inversely with both typical shipment size and typical annual volumes.

- Since the Staggers Rail Act of 1980, Class I railroads have been free to make coal transportation contracts that differ in contract terms of service and in the sharing of capital cost between carrier and shipper. Where previously the carrier assumed the expense of providing locomotive power, rolling stock, operating labor and supplies, right-of-way maintenance, and routing and scheduling, more

[20] The estimated cost of switching to subbituminous coal, $0.10/mmBtu, was derived by Energy Ventures Analysis, Inc. and recommended for use in the CMM as part of an Independent Expert Review of the *Annual Energy Outlook 2002*'s Powder River Basin production and transportation rates.

recent "unit train" contracts reflect the use of dedicated locomotive power, rolling stock, and labor operating trains on an invariant schedule. Often the shipper wholly or partly finances these dedicated components of the total contract service. In such cases, the actual costs and services represented by the contract may cover no more than right-of-way maintenance, routing and scheduling. Particular interregional routes may vary widely in the proportion of total coal carriage represented by newer cost sharing and older tariff-based contracts.

Model Structure

The domestic component of the CDS forecasts the quantities of coal needed to meet regionally and sectorally specified coal demands. It provides the Btu and sulfur content of all coal delivered to meet each demand. It also provides annual forecasts of minemouth and delivered coal prices by sector and region. Marginal delivered coal prices by demand sector and plant type are provided to the EMM to be used in formulating regional and sector-specific electricity demands for coal. Additionally, the CDS projects the regional distribution of coal supply by sector, region, mine type, and coal type based on future electricity and non-electricity coal demand. Transportation costs can be summarized independently by coal supply region, coal rank and sulfur content for regional or sectoral transportation analysis.

The model code that performs domestic coal distribution tasks in the CMM consists of 15 subroutines, eight sources of input and five output files. The interaction of these components is outlined below and in the accompanying flowcharts.

Computational Sequence and Input/Output Flow

The controlling submodule in the coal distribution code is called "CDS".[21]The functions of subroutine "CDS" are shown in Figure 2.5, which also provides an overview of the operations of the domestic coal distribution code as a whole. "CDS" controls ten other subroutines:

- "CREMTX" creates the linear programming matrix containing the coal demands, supplies, and transport activities. It is called on the first iteration and the first year the model is run.
- "RDCLHIST" reads coal data (minemouth prices, production by supply curve, and regional production) for historical years from the input file, “CLHIST.”
- "CREVISE" revises the linear programming matrix after the initial iteration and calls the linear programming solver, OML, in each forecast year.
- "RETSOL" retrieves the linear program solution produced by OML and sends the appropriate sub-parts of the solution to "INPREP","DEMREP","PRDREP" and "CEXPRT".

21 To avoid confusion in the following discussion, subroutine and file names are always written in quotation marks, e.g., "CDS", "EMMOUT".

- "INPREP" creates the demand reports that record sectoral demands received from other NEMS components and the international component of the CDS. "INPREP" writes output describing the demands it has calculated from the input common block names and physical files described above. Non-electricity and electricity demand reports, plus an electricity demand summary report are written to the physical file "CLCDS". These reports appear at the head of the year-specific detailed CDS output that consists of approximately 17 reports available for each forecast year. Using these reports it is possible to determine exactly what demands the CDS has solved for in a given forecast year, since this output is written before the linear program is called by the "CDS" subroutine.

- "DEMREP" generates coal demand reports that describe demand, transportation, and distribution of coal from supply to demand region by economic sector, with fully adjusted transport rate data provided in both dollars per ton and dollars per million Btu. One of these year-specific reports, the "Detailed Supply and Price Report," provides a full description of coal type, demand quantity, individual participants, and minemouth, transportation, and delivered costs for an entire run, in the order of the 16 domestic CDS demand regions. This is the most detailed report currently available from the CDS, and generally requires 30 to 50 pages per forecast year (divided into 14 regional subreports). Reports generated by "DEMREP" are written to the physical file "CLCDS".

- "PRDREP" generates coal production reports that describe the quantities of coal produced by coal type from each coal supply curve in each supply region. Accompanying production quantities in millions of tons are associated minemouth prices. The definition for each coal type that is assigned to individual coal supply curves defines a sulfur and Btu category, but values of sulfur and Btu that are specific to each supply curve (and which are taken from the FERC Form 423 and the EIA 423) are also available, and are used by both the CDS and the EMM to calculate precise dollars per million Btu prices and sulfur contents (in lbs of sulfur per million Btu). The coal production reports are written on physical file "CLCDS".

- "CEXPRT" generates reports from the export portion of the linear program.

- "CPSHR" writes non-electric coal price output to the common block name "PQ", and delivered coal prices, sulfur and Btu assignments for coals assigned to electricity demands to the common block name "COALOUT". "CPSHR" writes prices, sulfur, and Btu content for coal meeting electricity demands to a physical file named "CLCDS". As the name implies, "CLDEBUG" contains output describing the iteration-by-iteration output of the CDS that is used in resolving problems that arise in the operation of the CMM and/or other NEMS models with which it interacts.

- "CBFOUT" is called both directly from the subroutine “CDS” and also from the “RDCDSIN” and calculates Btu conversion factors, an important process since the Coal Market Module mimics actual industry behavior in modeling the mining and shipping of coal in short tons, but demands are met in terms of least delivered cost per million Btu. This conversion is conceptually important since production, transportation, and delivery data are required to be reported in both physical units and trillion Btu. The conversions accomplished in "CBFOUT" are reported to the common block name "COALOUT".

The subroutine "CDS" calls the above subroutines in the same order in which they are discussed above. Subroutine "CREMTX" also calls other subroutines:
"RDCDSIN," "RDCEXIN," "RCMMDB,""COALDEFS," and "WRCINDB" (Figure 2.6):

- "RDCDSIN" reads input files containing calibration factors for the CDS, and calls "CMAPSR," "CDSINT," and "CBFOUT."
- "RDCEXIN" reads input files containing calibration factors for the international portion of the CDS. These inputs are described in Section 3 - Coal Distribution Submodule -International Component, Appendix 3.C.

The subroutine "CDSINT" called by subroutine "RDCDSIN" initializes all arrays and reads input data from four physical files. These input units are as follows:

- "CLPARAM" which contains parameters that order the assignment of demands, assign coal type labels and sectoral names, and provides important adjustments to minemouth and transportation prices, as well as constraining the types of coal that can be used to fill demands in different economic sectors and regions. (The contents of "CLPARAM" and other physical input files are described in greater detail in Appendix 2.C of this report.)

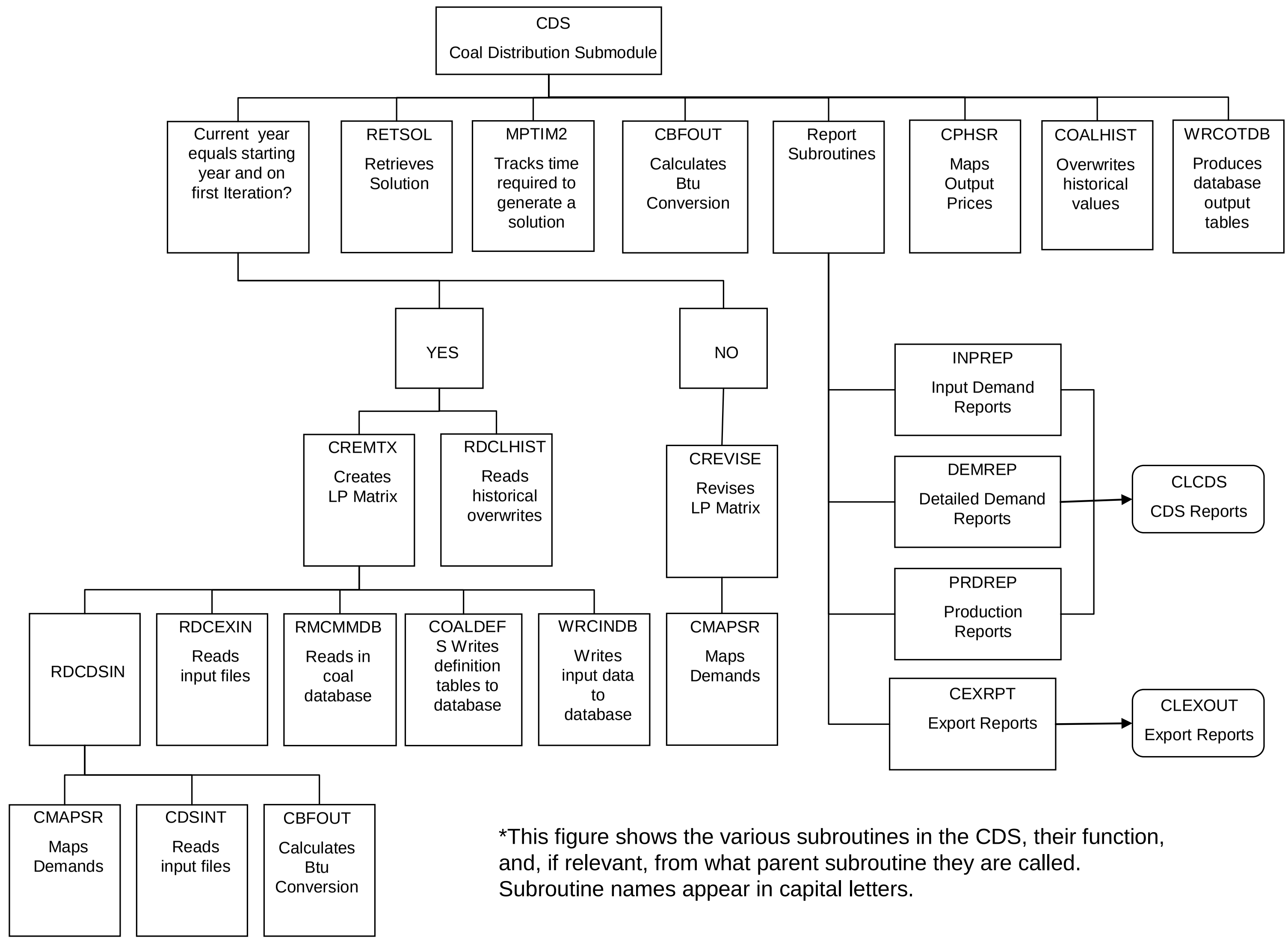
- "CLNODES" contains supply and demand region name labels.

- "CLRATES" contains a large matrix of transportation rates defined by economic subsector, coal supply, and demand regions. These rates are specified in 1987 dollars and are adjusted to provide rates in the dollar year used in any run, as well as adjustments specific to the economic sector and forecast years. These last two adjustments are accomplished by parameters found in "CLPARAM" that are discussed in Appendix 2.C.

- "CLCONT" contains data defining electricity coal distributions that are assigned to constrain the selection of coal sources by the CDS solution algorithm. Beginning with *AEO2005*, a modification was made so that these minimum flows are able to follow a plant unit even if it upgrades (acquiring new emission control equipment). This data file also contains profiles associated with each plant, defining its transportation rate structure and its ability to use subbituminous and lignite coals. The nature of this input and its use is also discussed in Appendix 2.C.

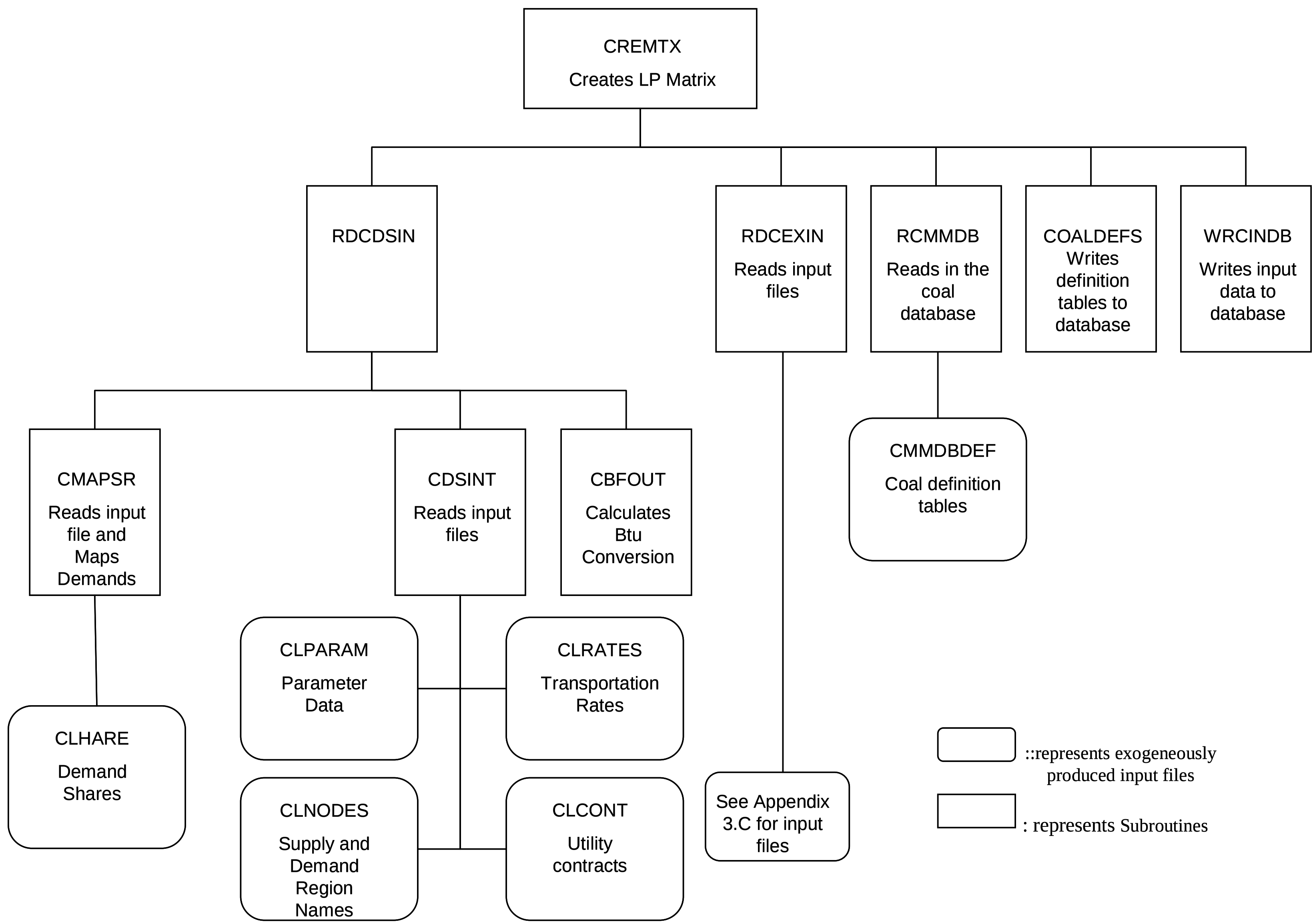
The "CMAPSR" subroutine creates the regionally and sectorally distinct demands for which the CDS solves. It does not, however, prioritize these demands, nor does it perform the important step of modifying the demands to reflect the constraints imposed by existing electricity coal contracts. Both these processes are accomplished by subroutine "CREMTX", which is described in association with the discussion of Figures 2.5 and 2.6. "CMAPSR" reads common block names "PQ" (which contains the non-electricity coal demands) and the physical file "CLSHARE" (which contains the shares disaggregating non-electricity demands from Census division to CDS demand region level).

Figure 2.5 Structure of CDS Subroutines – Overview*



*This figure shows the various subroutines in the CDS, their function, and, if relevant, from what parent subroutine they are called. Subroutine names appear in capital letters.

Figure 2.6. Functions of Subroutine – “CREMTX”



Key Computations and Equations

The CDS uses a linear programming (LP) formulation to find minimum cost coal supplies to meet domestic sectoral coal demands received from the Electricity Market Module, the Residential, Commercial and Industrial Demand Modules and international demands as determined in the international component of the CDS. The linear program for the domestic component of the CDS selects the coal supply sources for all coal demands in each domestic CDS demand region, subject to the constraint that all demands are met.

The domestic component of the CDS orders input data, solves the LP model, and provides the required outputs to the CPS and to other modules of the NEMS. The initial matrix and objective function are inputs. However, most of the coefficients in the model change over time. For example, the objective function represents the cost of delivering coal from supply regions to demand regions, and its coefficients include minemouth prices, transportation rates and coal demands specified by heat and sulfur content, all of which may vary. Similarly, coefficients in the constraint matrix, which include the electricity coal contracts, also change within the forecast horizon. Appendix 2.B provides mathematical description of the objective function and equations of the constraint matrix, and of the equations that derive the revised coefficients for the LP model. Appendix 2.C describes model inputs, parameter estimates and model output. Appendix 2.D describes data quality and estimation. The model relies on Optimization and Modeling Library (OML) software, a proprietary mathematical programming package, to create and store coefficients in a database, solve the problem, and retrieve the solution. The OML subroutines are summarized in Appendix 3.E of Section 3 of this documentation report.

Transportation Rate Methodology

Inter-regional coal transportation rates are calculated exogenously and read by subroutine "CDSINT" from the physical file "CLRATES". "CLRATES" contains rates for each possible combination of 49 economic subsectors, 16 demand regions and 41 supply curves. The input rate array contained in "CLRATES" is prepared by subtracting minemouth prices from the EIA Form 7A, "Coal Production Report" from sector-specific delivered prices from the Form EIA-3, "Quarterly Coal Consumption Report – Manufacturing Plants" (for the industrial steam and residential/commercial sectors), from the Form EIA-5, "Quarterly Coal Consumption and Quality Report, Coke Plants" for the domestic coking coal sector, from the Form EM-545 for coal exports, and from the EIA-423, “Monthly Cost and Quality of Fuels for Electric Plants Report” (for non-utilities in the Electricity sector), and Form FERC 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants" (for utilities in the Electricity sector).

For the electricity sector only, a two tier transportation rate structure is used for those regions which, in response to rising demands or changes in demands, may expand their market share beyond historical levels. The first tier rate is representative of the historical average transportation rate. The second tier transportation rate is used to capture the higher cost of expanded shipping distances in large demand regions. The second tier may also be used to capture costs associated with the use of subbituminous coal at units that were not originally designed for its use. This cost is estimated at $0.10 per million Btu (2000 dollars).

Coal transportation costs, both first- and second-tier rates, are modified over time by two regional (east and west) transportation indices. The indices are measures of the change in average transportation rates, on a tonnage basis, that occurs between successive years for rail and multi-mode coal shipments. An east index is used for coal originating from eastern supply regions while a west index is used for coal originating from western supply regions. The indices are calculated econometrically as a function of railroad productivity, the user cost of capital of railroad equipment (east only), investment (west only), diesel fuel price (east only), and the western share of national coal demand (west only). Although the indices are derived from railroad information, they are universally applied to all coal transportation rates within the CMM. In the *AEO2011* reference case, eastern coal transportation rates are projected to remain flat between 2009 and 2035, and western rates are projected to rise by 6 percent. See Appendix 2.D for more information regarding the methodology and assumptions used to derive the transportation rate indices.

For the case of increased shipping distances, the second tier transportation rate is calculated by assuming a geographic centroid for the relevant demand region, estimating an approximate distance, and where possible using ton-mile data from the FERC Form 580, "Interrogatory on Fuel and Energy Purchase Practices," to calculate a new dollars per ton transportation rate. For subbituminous coals, $0.10 per million Btu (2000 dollars) is assumed to be, on average, representative of the added difficulty of using subbituminous coal.[22] These difficulties include slagging/fouling problems, impacts on heat rates, and other operation costs. For subbituminous coals, the second tier rate is simply the first tier rate plus this adder of $0.10 per million Btu. For certain supply/demand region pairs, the second tier rate may include both the $0.10 per million Btu adjustment as well as a geographic adder.

[22] $0.10/mmBtu, the estimated cost of switching to subbituminous coal, was derived by Energy Ventures Analysis, Inc., and recommended for use in the CMM as part of an Independent Expert Review of the *Annual Energy Outlook 2002*'s Powder River Basin production and transportation rates. Barbaro, Ralph and Seth Schwartz. *Review of the Annual Energy Outlook 2002 Reference Case Forecast for PRB Coal*, prepared for the Energy Information Administration (Arlington, VA: Energy Ventures Analysis, Inc., August 2002)

Appendix 2.A

Submodule Abstract

Model Name: Coal Distribution Submodule -Domestic Component

Model Acronym: CDS

Description: United States coal production, national coal transportation industries.

Purpose: Forecasts of annual coal supply and distribution to domestic markets.

Model Update Information: October 2010

Part of Another Model:

- Coal Market Module
- National Energy Modeling System

Model Interface: The model interfaces with the following models: within the Coal Market Module the CDS interfaces with the Coal Production Submodule. Within NEMS, the CDS receives industrial steam and metallurgical coal demands from the NEMS Industrial Demand Module, coal-to-liquids demands from the NEMS Petroleum Market Module, residential demands from the NEMS Residential Demand Module, commercial demands from the NEMS Commercial Demand Module, and electricity sector demands from the NEMS Electricity Market Module. The CDS also receives macro-economic variables from the NEMS Macro-Economic Activity Module.

Official Model Representative:

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Documentation:

- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System*, DOE/EIA-M060(2011) (Washington, DC, June 2011).

- U.S. Energy Information Administration, *Overview of the Coal Market Module of the National Energy Modeling System*, April 1992.

Archive Media and Installation Manual: NEMS11 - *Annual Energy Outlook 2011.*

Energy System Described by the Model: Coal demand distribution at various demand regions by demand

Coverage:

- **Geographic:** United States, including Hawaii, Puerto Rico, and the U.S. Virgin Islands.

- **Time unit/Frequency:** 1990 through 2035 (with structure available through 2050)

- **Basic products involved:** Bituminous, subbituminous and lignite coals in steam and metallurgical coal markets.

- **Economic Sectors:** Forecasts coal supply to 2 Residential/Commercial, 3 Industrial, 2 domestic metallurgical, 1 Coal-to-liquids, 6 Export, and 35 Electricity subsectors to 16 domestic demand regions.

Special Features:

- All data on demands are exogenous to the CDS.

- Supply curves (there are 41 supply sources) depicting coal reserve base are exogenous to CDS and are reported in the CDS from 14 coal supply regions.

- CDS currently contains no descriptive detail on coal transportation by different modes and routes. Transportation modeling consists only of sector-specific rates between demand and supply curves that are adjusted annually for factor input cost changes.

- CDS output includes tables of aggregated output for NEMS system and approximately 6 single-year reports providing greater regional and sectoral detail on demands, production distribution patterns, and rates charged.

- Coal imports are calculated endogenously.

- CDS reports minemouth, transport and delivered prices, coal shipment origins and destinations (by region and economic subsector), coal Btu and sulfur levels.

Modeling Features:

- **Structure:** The CDS uses 41 coal supply sources representing 12 types of coal produced in 14 supply regions. Coal shipment costs to consumers are represented by transportation rates specific to NEMS sector and supply curve/demand region pair, based on historical differences between minemouth and delivered prices for such coal movements. In principle there are up to 31,360 such rates for any forecast year; in practice there are less since many rates are economically infeasible and a unique transportation rate is not derived for each of the 35 electricity sectors. Coal supplies are delivered to up to 49 demand subsectors in each of the 16 demand regions. A single model run represents a single year, but up to 46 consecutive years (1990-2035) may be run in an iterative fashion. Currently, the NEMS system provides demand input for the 1990-2035 period. (Note: many of the input files have been structurally extended to 2050, but assumptions about activity between 2035 and 2050 are not considered valid.)

- **Modeling Technique:** The model utilizes a linear programming that minimizes the estimated delivered cost to all demand sectors.

- **Model Interfaces:**

— The NEMS residential, commercial, and industrial models provide estimates of coal demand for those sectors, while the NEMS Petroleum Market Module provides demands for the coal-to-liquids sector, and the NEMS Electricity Market Module provides demands for the electricity generation sectors. The CDS provides the NEMS with coal production estimates, Btu conversion factors, and estimated minemouth, transportation and delivered costs for coal supplies to meet the demands.

— The CDS interfaces with the international component of the CDS to receive coal export demands.

— The CDS interfaces with the Coal Market Module's Coal Production Submodule to receive supply curves that specify the minemouth price in relation to the quantity demanded. In turn, the CPS receives production quantities from the CDS that are used to revise its prices, if necessary, for subsequent iterations.

- **Input Data:**

— **Physical:**

— — *Demand shares by sector and region:* (1) residential/commercial (trillion Btu); (2) industrial steam coal (trillion Btu): (3) industrial metallurgical coal (trillion Btu); (4) industrial coal-to-liquids (trillion Btu) (5) import supplies (millions of short tons)

— — *Coal contracts for electricity sector:* (1) coal demand regions; (2) supply regions; (3) coal quality (Btu and sulfur content); (4) contract historical volumes (trillion Btu); (5) contract profiles for each forecast year

— — *Coal quality data for supply curves:* (1) million Btu per short ton; (2) lbs. sulfur per million Btu; (3) lbs. of mercury per trillion Btu; (4) lbs. of carbon dioxide emitted per million Btu

— — Coal quality specifications for regional subsectoral demands in electricity generation and other sectors

— **Economic:**

— — Supply curves relating minemouth prices to cumulative production levels

— — *Transportation rates:* (1) 1987 dollars per short ton; (2) specified by subsector, differ by sector; (3) differ also by supply curve and demand region pair

— — *Transportation rate escalation factors:* (1) endogenous; (2) regional (eastern and western railroads); (3) based on estimates of railroad productivity, the producer price index for rail equipment, contract duration, and distance (for western railroads only); (4) used to escalate and de-escalate transportation rates by forecast year

— — *Minemouth price adjustments:* (1) can be made by supply region and forecast year; (2) currently used only by forecast year; (3) used to adjust for productivity change

— — *Transportation rate adjustments (not used in AEO2011):* (1) can be used by demand sector and demand region; (2) derived from off-line program that subtracts base year minemouth costs from delivered costs reported in Forms EIA-3 and -5, and FERC Form 423 to produce transport rate, calculates ratio between model rate and rate from forms, preserve ratio as model parameter; (3) used to calibrate rates in model

- **Data Sources:**

— Form EIA-3, "Quarterly Coal Consumption and Quality Report, Manufacturing and Transformation/Processing Coal Plants and Commercial and Institutional Users "
— Form EIA-5, "Quarterly Coal Consumption and Quality Report, Coke Plants"
— Form EIA-7A, "Coal Production and Preparation Report"
— FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
— Form EIA-423, “Monthly Cost and Quality of Fuels for Electric Plants Report”
— Form EIA-923, “Power Plant Operations Report”
— FERC Form 580, "Interrogatory on Fuel and Energy Purchase Practices"
— U.S. Department of Commerce, Form EM-545
— U.S. Department of Commerce, Form IM-145
— Association of American Railroads, *AAR Railroad Cost Indices* (Washington, DC, quarterly)
— Rand McNally and Co., *Handy Railroad Atlas of The United States* (Chicago, IL, 1988)
— Caplan, Abby, et al, eds., *1996-1997 Fieldston Coal Transportation Manual* (Washington, DC, 1996)

- **Output Data:**

— **Physical:** Forecasts of annual coal supply tonnages (and trillion Btu) by economic sector and subsector, coal supply region, coal Btu, coal sulfur content, coal mercury content, and demand region

— **Economic:** Forecasts of annual minemouth, transportation and delivered coal prices by coal type, economic sector, coal demand and supply regions

Computing Environment: See *Integrating Module of the National Energy Modeling System*

Inhouse or Proprietary:

Inhouse

Independent Expert Reviews Conducted:

Independent expert reviews were conducted for the Component Design Report, which was reviewed by Dr. Charles Kolstad of the University of Illinois and by Dr. Stanley Suboleski of the Pennsylvania State University during 1992 and 1993.

An independent expert review was conducted in 2002 by PA Consulting Group and Energy Ventures Analysis, Inc. The focus of the review was on forecasted levels of production supplied from the Powder River Basin and transportation rates. Some of the recommendations were incorporated into the *Annual Energy Outlook 2003*. As a result of the review, some transportation rates were re-estimated, a two tier transportation rate structure was introduced, and two coal demand regions were redefined. The coal demand regions that were redefined included MT and ZN. Previously, Nevada, Colorado, and Utah were included in MT. The change included adding these states to ZN.

In 2003, PA Consulting Group and Energy Ventures Analysis, Inc. were asked to review the entire coal forecast of the *Annual Energy Outlook 2003*. Based on their recommendations, an additional coal demand region, CU, was added for the *Annual Energy Outlook 2004* which includes Colorado, Utah, and Nevada.

Status of Evaluation Efforts Conducted by Model Sponsor: No formal evaluation efforts other than the above reviews have been made at the date of this writing.

Last Update: The CDS is updated annually for use in support of each year's *Annual Energy Outlook*. The version described in this abstract was updated in October 2007.

Appendix 2.B

Detailed Mathematical Description of the Model

The CDS model is specified as a Linear Program (LP) in which the total costs of coal supply, including production, transportation, and the cost of satisfying environmental constraints, are minimized. The CDS receives production costs iteratively from the CPS. These production costs are limited in scope to the neighborhood of the solution. The iterative relationship between the CPS and the CDS allows non-linear supply curve information calculated in the CPS to be approximated by a linear form in the CDS. Costs of transportation from supply to demand regions are added to the production costs. The costs of limiting sulfur dioxide emissions and other pollutants for certain scenarios (i.e. mercury and carbon dioxide) can be modeled in the cost minimization LP. Based on these total costs, the model calculates the optimum pattern of supply required to satisfy demand.

Mathematical Formulation

The table of column activity definitions and row constraints defined in the CDS linear program incorporates assumptions described in Model Rationale in Section 2 and variable definitions that are described in Appendix 2.C in Table 2.C-1. The general structure of the LP matrix is shown as a block diagram in Table 2.B-1.

The block diagram format depicts the matrix as made up of sub-matrices or blocks of similar variables, equations, and coefficients. The first column in the diagram contains descriptions of the rows of equations in the model. The subsequent columns define sets of variables for the production and transportation of coal. Other columns are necessary to represent contracts, coal diversity constraints, SO_2, mercury, and carbon dioxide constraints. Contracts represent binding agreements between coal suppliers and generators. Coal diversity constraints represent technical constraints limiting the use of certain types of coal within particular plant types in certain demand regions. These constraints are currently limited to the use of subbituminous and lignite coals. Environmental constraints represent caps that may be present in certain scenarios. The columns referencing activated carbon define certain specialized activities in which activated carbon may be used by power generators to reduce emissions of mercury. The activated carbon features are only used in scenarios where a mercury cap is in place such as when modeling the effects of the the Clean Air Mercury Rule (CAMR). However, CAMR was vacated by the courts in February 2008, so it is not actively modeled in the reference case of the *Annual Energy Outlook 2011*. (In lieu of CAMR, a Maximum Achievable Control Technology (MACT) is modeled in the Electricity Market Module, requiring certain regions to achieve 90 percent mercury removal where states within those regions have moved to restrict mercury emissions on their own.)

The various rows of the matrix include the objective function, the demand, production, contracts, diversity, sulfur, mercury, carbon, and activated carbon rows. The objective function row, which is considered a free row, is set up as a linear programming cost minimization problem. Other free rows, used to collect information from the model solution, are present in the LP structure but are not depicted in the diagram below. However, they are described in the section titled, “Row and Column Structure of the Coal Market Module” within this appendix. The column labeled Row Type, shows the equations to be maximums, minimums, or equalities. Each block within the table is shown with representative coefficients for that block. These coefficients are applied to the quantities (typically in trillion Btus) specified by their column intersections. The last column labeled RHS contains symbols that represent the physical limitations such as supply capacities, demands, or minimum flows.

The CDS matrix currently contains about 6,900 rows (equations) and 35,000 columns (activities). The block diagram in Table 2.B-1 is a way of showing the matrix structure in a single table.

The mathematical specification for the CDS optimization program incorporates within its structure the optimization program for international coal flows, which is discussed in Section 3 of this document.

Table 2.B-1. CDS Linear Program Structure -- Domestic Component

Coal Distribution Submodule Block Diagram

	PRODUCTION	TRANSPORTATION VECTORS: 1ST TIER			TRANSPORTATION VECTORS: 1ST TIER W/ ACTIV CARBON			TRANSPORTATION VECTORS			CONTRACT ESCAPE VECTORS		DIVERSITY ESCAPE VECTORS		MERC. PRICE CAP	MERC. ESCAPE VECTOR	ACTIV. CARBON VECTOR	CARBON EMISSION VECTOR	Row Type	RHS
MASK	P(SR)(U)(M)(S)	1(SR)(U)(M)(R)(DR)(PT)(C)			(ACSTEP)(SR)(U)(M)(R)(DR)(PT)(C)			T(SR)(U)(M)(R)(DR)(SEC)(C)			SCRUBBED: F(SR)(DR)X(C)	UNSCRUB.: C(SR)(DR)X(C)	DSS(DR)(PT)	DSL(DR)(PT)	MERCEV*	MOREHGXX	ACIXSS (ACSTEP)Y	CARBONXX		
COAL RANK		SUB	LIG	OTHER	SUB	LIG	OTHER						SUB	LIG						
SECTOR		ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	CTL	NON-ELEC./ NON-CTL	2ND TIER ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	ELEC.	ELEC.		
Objective	+p	$+t_0$	$+t_0$	$+t_0$	$+t_1$	$+t_1$	$+t_1$	$+t_2$	$+t_2$	$+t_2$	+9.9	+9.9	+15	+15	+ CAP	+20	+v	+EMETAX	--	MIN
Demand Rows:																				
D.(DR)(PT)		+1	+1	+1	+1	+1	+1												EQ	D
D.(DR)(SEC)									+1										EQ	D
Contract Rows:																				
SCRUBBED: F(SR)(DR)X(C)		+1	+1	+1	+1	+1	+1				-1								GE	B_1
UNSCRUBBED: C(SR)(DR)X(C)		+1	+1	+1	+1	+1	+1					-1							GE	B_2
Production Row: S@(SR)(U)(M)(C)	+1	-1	-1	-1	-1	-1	-1												EQ	0
Productive Capacity Constraint: X@(SR)(U)(M)(C)	+1																		LE	PCAP
Diversity Rows:																				
Subbituminous: DVS(DR)(PT)		+1			+1								-1						LE	B_3
Lignite: DVL(DR)(PT)			+1			+1								-1					LE	B_4
Transportation Row by scrubbed and unscrubbed: T(SR)(DR)(C)		+1	+1	+1	+1	+1	+1			-1									LE	T
Sulfur Dioxide Constraint: SULFPEN1 and SULFPEN2		+s	+s	+s	+s	+s	+s	+s											LE	S
Mercury Constraint: MERCP01		+m	+m	+m	+m	+m	+m	+m							-1	-1			LE	M
Activated Carbon Row: ACIXXXXY		+a	+a	+a	+a	+a	+a	+a									-10		LE	0
Carbon Constraint: CARBONXX		+c	+c	+c	+c	+c	+c	+c										-1	EQ	0

a = tons of activated carbon required per trillion Btu (mercury scenarios only)
B1 = scrubbed contracts for electricity sector
B2 = unscrubbed contracts for electricity sector
B3 = subbituminous coal bound
B4 = lignite coal bound
c = carbon content
CAP = mercury allowance price limit (only certain mercury scenarios)
D = coal demand
EMETAX = carbon allowance price (only carbon scenarios)
m = mercury content
M = mercury emissions limit (only mercury scenarios)
PCAP = productive capacity limit for supply curve
p = production cost
s = sulphur dioxide content
S = sulphur dioxide emissions limit
T = 1st tier transportation rate bound
t_0 = 1st tier transportation cost
t_1 = 1st tier transportation cost plus cost of activated carbon injection (mercury scenarios only)
t_2 = incremental cost of 2nd tier transportation cost above 1st tier transportation cost
v = dollars per lb of activated carbon (mercury scenarios only)

Objective Function

The objective of the LP is to minimize delivered costs of coal, including the costs associated with moving coal from supply regions to demand regions. The objective function below defines the costs being minimized by the CDS. The costs include production, transportation, activated carbon (mercury scenarios), costs associated with a mercury cap (specific mercury scenarios), carbon (carbon scenarios), and escape vector costs. Activated carbon costs are relevant in mercury scenarios where activated carbon is injected during the coal combustion process in order to achieve various levels of mercury emissions reduction. In certain scenarios where a mercury allowance price is constrained, a mercury cap cost is included in the LP objective function. The presence of a volume in the mercury cap cost column indicates that the allowance price calculated by the coal LP is higher than the mercury cap. The cost associated with carbon emissions is only relevant in carbon scenarios. This cost is included in the objective function to allow the coal model's regional distributions to be influenced when carbon limits are present. Escape vectors are a mechanism to allow the model to ignore a constraint by paying a large penalty. Escape vectors are a useful tool in identifying errors in assumptions or conflicting constraints and do not represent the true cost associated with coal deliveries. Iteratively, the escape vectors assist in gently pushing the model towards a feasible solution. When a feasible solution is obtained, the escape vectors are no longer active. The objective function is defined as:

$$\Sigma_{i,r,t,u,s}\,[Qp_{i,r,s,t,u} * P_{i,r,s,t,u}] + \Sigma_{i,j,p,r,t,u,v}\,[Qt_{\,i,j,p,r,t,u,v} * T_{i,j,p,r,t,u,v}] + \Sigma_{i,j,k,r,t,u}\,[Q2t_{\,i,j,k,rt,u} * T_{i,j,k,r,t,u}] + \Sigma_{v}\,[A_{v} * x_{v}] + [H * y] + [C * z] + \text{escape vector costs} \qquad (2.B\text{-}1)$$

where the indexes are defined as follows:

Index Definitions

Index Symbol	Description
(i)	Coal supply region
(j)	Coal demand region
(k)	Demand subsector
(p)	Plant configuration (index p is a subset of index k)
(r)	Coal rank
(s)	Supply curve step
(t)	Mine type
(u)	Sulfur level
(v)	Activated carbon supply curve step
(w)	Scrubbed or unscrubbed electricity plant type

where the columns are defined as:

Column Definitions

Column Notation		Description
$Qp_{i,r,s,t,u,}$	=	Quantity of coal from step s of the coal supply curve produced from coal supply region i, of sulfur level u, mine type t, and rank r. Corresponds to Block Diagram Column: P(SR)(U)(M)(S).

$Qt_{i,j,p,r,t,u,v}$ = Total quantity of coal transported from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for the electricity plant type p, and activated carbon step v (if relevant to scenario).
Corresponds to Block Diagram Columns:
1(SR)(U)(M)(R)(DR)(PT)(C) and
(ACSTEP)(SR)(U)(M)(R)(DR)(PT)(C)

$Q2t_{i,j,k,r,t,u}$ = Total quantity of coal transported from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for the demand subsector k for the non-electricity sectors **or**
Total quantity of coal transported at 2nd tier transportation rate from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for the demand subsector k for the electricity sector
Corresponds to Block Diagram Columns:
T(SR)(U)(M)(R)(DR)(PT)(C)

A_v = Total quantity of activated carbon from activated carbon supply curve step v.
Corresponds to Block Diagram Column:
ACIXSS(ACSTEP)Y

H = Quantity of mercury getting mercury cap price (only relevant for specific mercury scenarios)
Corresponds to Block Diagram Column:
MERCEV

C = Quantity of carbon emitted from coal

And the incremental costs assigned to the column vectors are defined as:

P = Production or minemouth price
T = Transportation price (plus cost of activated carbon, if relevant to scenario)
x = Cost of activated carbon
y = Mercury allowance price cap
z = Carbon tax

The escape vector costs correspond to the costs associated with the columns: F(SR)(DR)X(C), C(SR)(DR)X(C), DSS(DR)(PT), DSL(DR)(PT), and MOREHGXX. These costs are high so that they are chosen only as a last resort in order to keep the model feasible. By assisting in maintaining feasibility in early model runs, the linear supply curves can be moved along the supply functions in search of an optimal, minimum cost solution that is feasible without the escape vectors.

Row Constraints

The rows interact with the columns present in the objective function to define the feasible region of the LP and are defined below.

SUPPLY BALANCE

EQUATIONS: For specific i,r,t,and u: $\Sigma_s Qp_{i,r,s,t,u} - \Sigma_{j,k,v} Qt_{i,j,k,r,t,u,v} = 0$ (2.B-2)

DEFINITION: Balance the coal produced from each supply region with the coal transported.

CORRESPONDING ROW IN BLOCK DIAGRAM: S@(SR)(U)(M)(C)

PRODUCTIVE CAPACITY LIMIT

CONSTRAINTS: For specific i,r,t,and u: $\Sigma_s Qp_{i,r,s,t,u} \leq PCAP_{i,r,t,u}$ (2.B-3)

DEFINITION: Prevents coal production by supply curve from exceeding its productive capacity limit (PCAP).

CORRESPONDING ROW IN BLOCK DIAGRAM: X@(SR)(U)(M)(C)

DEMAND BALANCE

EQUATIONS: For specific j and k: $\Sigma_{i,r,t,u,v} Qt_{i,j,k,r,t,u,v} = D_{j,k}$ (2.B-4)

DEFINITION: Balance the coal transported with the coal demanded by coal demand region and subsector.

CORRESPONDING ROWS IN BLOCK DIAGRAM: D.(DR)(PT) and D.(DR)(SEC)

CONTRACT FLOWS

CONSTRAINTS:

For specific i, j, r, t, u: $\Sigma_{p,v,w} Qt_{i,j,p.r,t,u,v,w}$ – escape vector quantity $\geq B_{i,j,r,t,u,w}$, (2.B-5)

where "B" equals contract quantity and "w" indicates whether plant type p is scrubbed or unscrubbed.

DEFINITION: Require minimum quantities of coal, "B", of a specific coal quality from particular supply regions to satisfy electricity contracts from particular demand regions for scrubbed and unscrubbed plants.

CORRESPONDING ROWS IN BLOCK DIAGRAM: F(SR)(DR)X(C) and C(SR)(DR)X(C)

DIVERSITY REQUIREMENTS

CONSTRAINTS: For a specific j, p, and r (subbituminous or lignite only), where "B" equals subbituminous or lignite coal limit:

$$\Sigma_{i,t,u,} Qt_{i,j,p,r,t,u} \leq B_{j,p,r} \quad (2.B\text{-}6)$$

DEFINITION: Limits the amount of subbituminous and lignite coal used to satisfy demand in certain electricity demand subsectors and regions.

CORRESPONDING ROWS IN BLOCK DIAGRAM: DVS(DR)(PT) and DVL(DR)(PT)

TRANSPORTATION RATE RESTRICTIONS

CONSTRAINTS: $\Sigma_p(Qt_{i,j,p,r,t,u} - Qt2_{i,j,p,r,t,u}) \leq T_{i,j,r,t,u}$ (2.B-7)

DEFINITION: Limits the amount of coal that may be transported at rates applicable to historical flow levels for the electricity sector for a specific i, j, p, r, u, and t, where "T" is the amount of coal capable of being transported at the current rates (first tier rates). Additional transportation flows are assumed to require additional cost (second tier rates) in order to expand coal deliveries in these regions.

CORRESPONDING ROW IN BLOCK DIAGRAM: T(SR)(DR)(PT)(C)

SULFUR DIOXIDE EMISSION RESTRICTIONS
CONSTRAINTS:
sulfur dioxide emissions
from imports $+ \Sigma_{i,j,p,r,t,u} [s_{i,r,t,u} * Qt_{i,j,p,r,t,u}] \leq S$ (2.B-8)
DEFINITION: For relevant years, restrict the sulfur levels of coal in the electricity sector such that the sulfur dioxide emissions limit is met, where "s" equals the sulfur dioxide content of the coal and "S" equals the emissions limit. For more detail on sulfur dioxide emissions from imports, see "3. Coal Distribution submodule – International Component."
CORRESPONDING ROW IN BLOCK DIAGRAM: SULFPEN1 and SULFPEN2

MERCURY EMISSION RESTRICTIONS
CONSTRAINTS:
$\Sigma_{i,j,k,r,t,u} [m_{i,r,t,u} * Qt_{i,j,k,r,t,u}]$ – H – escape vector quantity $\leq$ M (2.B-9)
DEFINITION: Limits the quantity of mercury present in coal (adjusted with the plant removal rate and use of activated carbon) to be less than or equal to the coal mercury emissions limit, "M". Coefficient $m_{i,,t}$ is the mercury content of coal. Some mercury scenarios cap the compliance costs. In these scenarios, additional "allowances" are available at the allowance cap. "H" is the volume of additional allowances purchased at the cap price. Escape vectors are not active in the final solution but allow feasibility to be maintained in early iterations.
CORRESPONDING ROW IN BLOCK DIAGRAM: MERCP01

ACTIVATED CARBON SUPPLY CURVE
CONSTRAINTS:
$\Sigma_{i,j,p,r,t,u,v} [a_{p,v} * Qt_{i,j,p,r,t,u,v}] - 10 * \Sigma_v A_v \leq 0$ (2.B-10)
DEFINITION: Balances the activated carbon used in association with the electricity sector transportation vectors with the activated carbon supply curves. Coefficient $a_{p,v}$ represents tons of activated carbon per trillion Btu for plant configuration p and activated supply curve step v. "A_v" represents the total quantity of activated carbon from activated carbon supply curve step v.
CORRESPONDING ROW IN BLOCK DIAGRAM: ACIXXXY

CARBON TAX
CONSTRAINTS:
$\Sigma_{i,j,p,r,t,u} [c_{i,j,p,r,t,u} * Qt_{i,j,p,r,t,u}] - C \leq 0$ (2.B-11)
DEFINITION: Balances the carbon emissions, "C", associated with the electricity sector transportation vectors with the carbon emissions being "paid for" with the carbon penalty price. The coefficient $c_{i,j,p,r,t,u}$ represents the carbon content of coal.
CORRESPONDING ROW IN BLOCK DIAGRAM: CARBONXX

Output Variables

$X_{i,j,k,r,t,u,v}$ = Quantity of coal rank r, sulfur level u, and mine type t that is transported from coal supply region i to coal import region j for coal demand sector k and activated carbon step v (if relevant to the scenario).

$U_{i,k,t}$ = Finalized (solution) delivered price (minemouth plus transportation cost) of coal from mine type t to demand sector k in demand region j. This variable is the final optimized value from the CDS.

Table 2.B-2. Row and Column Structure for the Domestic Component of the Coal Market Module

Each column and row of the linear programming matrix is assigned a name identifying the activity or constraint that it represents. A mask defines the general or generic name of a set of related activities or constraints. For example, the mask ‘P(SR)(R)(U)(M)(SP)’ defines the general name of all activities representing the production of coal. The names of specific activities or constraints are formed by inserting into the mask appropriate members of notational sets identified by the mask. For instance, the production of coal in Northern Appalachia, of bituminous rank, of low sulfur content, from underground mines, and from existing mines (step 1 of a supply curve) is represented by the column vector P(NA)(B)(C)(U)(1).

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
ACIXSS(ACSTEP)Y	Column	Volume of activated carbon (in lbs) injected to reduce mercury emissions; column bounds on this vector are present specifying how much activated carbon is available at each step
ACIXXXXY	Row	Assigns activated carbon requirement (lbs of activated carbon per trillion Btu) for each activated carbon step in transportation column
(ACSTEP)(SR)(U)(M)(DR)(PT)(C)	Column	Volume of coal transported in association with the use of activated carbon for particular activated carbon supply curve step (ACSTEP), from supply region (SR), sulfur level (U), minetype (M), to demand region (DR) for plant type (PT) of coal type (C)
1(SR)(U)(M)(R)(DR)(PT)(C)	Column	Transportation at 1st tier rate for electricity sector from supply region (SR), sulfur level (U), mine type (M), coal rank (R) to demand region (DR) for plant type (PT) of coal type (C)
C(SR)(DR)X(C)	Column	Escape vector allowing contracts to be ignored for supply region (SR) to demand region (DR) of coal type (C) for the unscrubbed electricity subsectors, if infeasibility is encountered. Not active in final solution.
C(SR)(DR)X(C)	Row	Contract constraint from supply region (SR) to demand region (DR) of coal type (C) for the unscrubbed electricity subsectors.
CARBONXX	Column	Assigns carbon tax to coal in carbon scenario and influences patterns of coal

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
		use in electricity sector
CARBONXX	Row	Assigns carbon content to electricity sector transportation rates
D.(DR)(SEC)	Row	Coal demand from demand region (DR) for demand subsector (SEC)
DSL(DR)(PT)	Column	Escape column vector for lignite diversity constraint for demand region (DR) and electricity plant type (PT). Not active in final solution.
DSS(DR)(PT)	Column	Escape column vector for subbituminous diversity constraint for demand region (DR) and electricity plant type (PT). Not active in final solution.
DVL(DR)(PT)	Row	Coal diversity constraint for lignite coal, demand region (DR), electricity subsector (PT).
DVS(DR)(PT)	Row	Coal diversity constraint for subbituminous coal, demand region (DR), electricity subsector (PT).
F(SR)(DR)X(C)	Column	Escape vector allowing contracts to be ignored for supply region (SR) to demand region (DR) of coal type (C) for the scrubbed electricity subsectors if infeasibility encountered. Not active in final solution.
F(SR)(DR)X(C)	Row	Contract constraint from supply region (SR) to demand region (DR) of coal type (C) for the scrubbed electricity subsectors
FAB(DR)(C)	Row (free)	Used to calculate average heat content of coal used in electricity sector by demand region (DR) and coal type (C)
FAC(DR)(C)	Row (free)	Used to calculate total carbon (million metric tonnes of carbon equivalent) of coal by demand region (DR) and coaltype (C) for electricity sector
FAM(DR)(C)	Row (free)	Calculates uncontrolled total mercury in coal (in lbs) by demand region (DR) and coal type (C) for the electricity sector
FHG(DR)(PT)	Row (free)	Calculates total mercury emissions from coal in consideration of use of emission control technology (controlled emissions) by demand region (DR) and electricity plant type (PT)
FP(SR)(U)(R)	Row (free)	Calculates coal production from supply region (SR), sulfur level (U), and coal rank (R)
HOURS	Row (free)	Estimates number of miner hours

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
		required to produce coal from a supply region (SR)
LB(CR)L1	Row (free)	Calculates millions of tons of coal used for CTL by census region (CR)
LC(CR)L1	Row (free)	Determines total carbon present in coal used for CTL by census region (CR)
LCEN(CR)L1	Row (free)	Calculates total trillion Btu of coal used in CTL by census region (CR)
LIQUPMM(PMM)	Row (free)	Determines coal used for CTL by PMM region (PMM)
LP(M)(DR)(PMM)L	Row (free)	Sums CTL coal distribution by minetype (M), demand region (DR), and PMM region (PMM)
LP(SR)(U)(M)(R)(PMM)	Row (free)	Sums CTL coal distribution by supply region (SR), sulfur level (U), minetype (M), coal rank (R), and PMM region (PMM)
MERCAC01	Row (free)	Calculates total amount of mercury tons removed using activated carbon injection
MERCEV	Column	Provides upper bound for mercury allowance price
MERCP01	Row	Mercury penalty constraint for electricity sector (mercury scenarios only)
MOREHGXX	Column	Escape vector allowing more mercury to be emitted if tight mercury constraint causes infeasibility. Not active in final solution.
P(SR)(U)(M)(S)	Column	Coal production in supply region (SR), sulfur level (U), mine type (M), and step (S)
S@(SR)(U)(M)(C)	Row	Coal production in supply region (SR) of sulfur level (U), mine type (M), and coal type (C)
SULFPEN	Row	Sulfur penalty constraint for electricity sector
T(SR)(U)(M)(R)(DR)(SEC)(C)	Column	For electricity sector, the volume transported at 2nd tier rate (rate required to expand coal flows into this region) and, for non-electricity sectors, total transportation volume from supply region (SR), sulfur level (U), minetype (M), rank (R), to demand region (DR), subsector (SEC), of coal type (C)
WAGES	Row (free)	Estimates total wages required to produce coal
X@(SR)(U)(M)(C)	Row	Coal production capacity limit for supply region (SR) of sulfur level (U), mine type (M), and coal type (C)

where

DR	**U.S. DEMAND REGIONS**	
NE		CONNECTICUT, MASSACHUSETTS, MAINE, NEW HAMPSHIRE, RHODE ISLAND, VERMONT
YP		NEW YORK, PENNSYLVANIA, NEW JERSEY
S1		WEST VIRGINIA, DELAWARE, DISTRICT OF COLUMBIA, MARYLAND
S2		VIRGINIA, NORTH CAROLINA, SOUTH CAROLINA
GF		GEORGIA, FLORIDA
OH		OHIO
EN		ILLINOIS, INDIANA, MICHIGAN, WISCONSIN
KT		KENTUCKY, TENNESSEE
AM		ALABAMA, MISSISSIPPI
C1		NORTH DAKOTA, SOUTH DAKOTA, MINNESOTA
C2		IOWA, NEBRASKA, MISSOURI, KANSAS
WS		TEXAS, OKLAHOMA, ARKANSAS, LOUISIANA
MT		MONTANA, WYOMING, IDAHO
CU		COLORADO, UTAH, NEVADA
ZN		ARIZONA, NEW MEXICO
PC		ALASKA, HAWAII, WASHINGTON, OREGON, CALIFORNIA

SR	**SUPPLY REGIONS**	
NA		PENNSYLVANIA, OHIO, MARYLAND, WEST VIRGINIA (NORTH)
CA		WEST VIRGINIA (SOUTH), KENTUCKY (EAST), VIRGINIA, TENNESSEE (NORTH)
SA		ALABAMA, TENNESSEE (SOUTH)
EI		ILLINOIS, INDIANA, KENTUCKY (WEST), MISSISSIPPI
WI		IOWA, MISSOURI, KANSAS, OKLAHOMA, ARKANSAS, TEXAS (BITUMINOUS)
GL		TEXAS (LIGNITE), LOUISIANA
DL		NORTH DAKOTA, MONTANA (LIGNITE)
WM		WESTERN MONTANA (SUBBITUMINOUS)
NW		WYOMING, NORTHERN POWDER RIVER BASIN (SUBBITUMINOUS)
SW		WYOMING, SOUTHERN POWDER RIVER BASIN (SUBBITUMINOUS)
WW		WESTERN WYOMING (SUBBITUMINOUS)
RM		COLORADO, UTAH
ZN		ARIZONA, NEW MEXICO
AW		WASHINGTON, ALASKA

CR	**CENSUS REGION**
1	NEW ENGLAND
2	MIDDLE ATLANTIC
3	EAST NORTH CENTRAL
4	WEST NORTH CENTRAL
5	SOUTH ATLANTIC
6	EAST SOUTH CENTRAL
7	WEST SOUTH CENTRAL

8 MOUNTAIN
9 PACIFIC

PMM **PETROLEUM MARKET MODULE REGIONS**
1 REGION 1
2 REGION 2
3 REGION 3
4 REGION 4
5 REGION 5

R **COAL RANK**
L Lignite
S Subbituminous
B Bituminous
P Premium

U **SULFUR GRADE**

C	Low:	≤ 1.2 lbs SO_2 per million Btu
M	Medium:	> 1.2 but ≤3.33 lbs SO_2 per million Btu
H	High:	>3.33 lbs SO_2 per million Btu

M **MINE TYPE**
D Underground Mining
S Surface Mining

S **STEPS**
N1 1ST STEP
N2 2ND STEP
N3 3RD STEP
N4 4TH STEP
N5 5TH STEP
N6 6TH STEP
N7 7TH STEP
N8 8TH STEP

SEC **SUBSECTOR**
1 RESID/COM = RESIDENTIAL/COMMERCIAL DEMAND
2 RESID/COM
3 IND STEAM 1
4 IND STEAM 2
5 IND STEAM 3
6 COKING 1
7 COKING 2
8 COAL-TO-LIQUIDS
9 METALLURGICAL 1 EXPORT
10 METALLURGICAL 2 EXPORT
11 METALLURGICAL 3 EXPORT
12 STEAM 1 EXPORT
13 STEAM 2 EXPORT
14 STEAM 3 EXPORT
15 ELECTRICITY – B1

16 ELECTRICITY – B2
17 ELECTRICITY – B3
18 ELECTRICITY – B4
19 ELECTRICITY – B5
20 ELECTRICITY – B6
21 ELECTRICITY – B7
22 ELECTRICITY – B8
23 ELECTRICITY – C1
24 ELECTRICITY – C2
25 ELECTRICITY – C3
26 ELECTRICITY - C4
27 ELECTRICITY - C5
28 ELECTRICITY - C6
29 ELECTRICITY - C7
30 ELECTRICITY - C8
31 ELECTRICITY - C9
32 ELECTRICITY - CX
33 ELECTRICITY - CY
34 ELECTRICITY - CZ
35 ELECTRICITY - H1
36 ELECTRICITY - H2
37 ELECTRICITY - H3
38 ELECTRICITY - H4
39 ELECTRICITY - H5
40 ELECTRICITY - H6
41 ELECTRICITY - H7
42 ELECTRICITY - H8
43 ELECTRICITY - H9
44 ELECTRICITY - HA
45 ELECTRICITY - HB
46 ELECTRICITY - HC
47 ELECTRICITY - PC
48 ELECTRICITY - IG
49 ELECTRICITY - IS

PT **PLANT TYPE**

See SUBSECTORS #15-49 above or Table 2.6 for more details

ACSTEP **ACTIVATED CARBON SUPPLY CURVE STEPS**

Step 1

C **COAL GROUPS**

1 Premium and Bituminous
2 Subbituminous
3 Lignite
" " None

Appendix 2.C

Inventory of Input Data, Parameter Estimates, and Model Outputs

Input: Data Requirements

Input to the domestic component of the CDS is read from eight input data files. These files and their contents are listed below.

CLRATES. This file contains the basic coal transportation rates used in the CDS. The input transportation rates are in 1987 dollars, organized as lines, each containing 16 rates (one for each non-electricity economic subsector in the model and two for the electricity sector). Each line represents a possible supply curve and demand region pair in the model. At the left hand side of the file, the regional two letter abbreviations are shown, with the supply region on the left and the demand region immediately to the right. Rates are differentiated only for the major sectors, so that in each line of 16 rates, two residential/commercial rates are followed by 3 industrial subsector rates, 2 metallurgical subsector rates, 1 coal-to-liquids rate, 6 export subsector rates and 2 electricity sector rates. For the electricity sector rates, the second electricity sector rate listed is always greater or equal to the first rate. A transportation rate profile is assigned for each plant in the electricity sector in the clcont file. This profile determines when the second rate takes effect. Where supply/demand region pairs are economically very unlikely (i.e., there is no historical record or current prospect of coal moving between these two regions), dummy rates of 999.99 are entered.

This file also contains input information for the calculation of a transportation fuel surcharge for both domestic production and imports. The following information is provided separately for domestic production and imports: a flag to turn the surcharge on or off, average distances by supply region and coal demand region, tons per carload by supply and demand region, trigger prices at which the surcharge becomes effective by supply and demand region, the incremental increase in the trigger price at which a higher surcharge is applied, and the cost per mile per car by supply region and coal demand region.

The clrates file also contains a single national percentage designating the portion of the base transportation rates that already contain the fuel surcharge. For instance, a 90.0 would indicate that on average only 90 percent of the movements are assumed to be subject to the fuel surcharge in the base year (2009). A 100.0 indicates that 100 percent of the coal shipments and their corresponding rates are assumed to already include the fuel surcharge. In the second example, this means that the model will adjust every base year transportation rate downward by the full value of the fuel surcharge for that year and route. By doing this, the model tries to limit double-counting of the fuel surcharge in subsequent forecast years. (For *AEO2011*, 100 percent of the coal shipments were assumed to have been assessed a fuel surcharge in the base year.)

CLSHARE. This file contains rational numbers used to create demand shares that distribute demands received at the Census division level of aggregation over the 16 CDS demand regions. The shares are organized in 10 columns representing the 9 Census divisions plus a 10th column (reserved in case it is decided to model California as a separate region). The CDS demand regions are represented by the rows. The first 16 rows contain rational numbers used to disaggregate industrial demands. The second set of 16 rows contains the shares for residential/commercial demands. The third set of 16 rows contains the shares for metallurgical demands followed by a matrix assigning coal demand regions to the PMM demand region. These shares are allocated based on assumptions of where coal supply sources and demand centers for coal-to-liquids would most likely be.

Next, an array representing supplies of imported coal in millions of tons (variable: TONN). This input is indexed by Census division (variable: ICEN), domestic CDS demand region (variable: ICDS), and by the sector (variable: ISEC1) to which the demand pertains (i.e., "1"= Electric imports, "2"= Industrial imports, and "3"= Metallurgical imports). Each indexed group contains 41 numbers, one for each year beginning in 1990 and ending in 2050. Beginning with *AEO2006*, imports are endogenous so this structure is no longer being used.

The next matrix has a 16 by 7 structure. The rows represent the demand regions while the columns represent the sectors, i.e. residential/commercial (2 columns), industrial (3 columns), metallurgical sectors (2 columns), and coal-to-liquids (1 column). Each number (FRADI) represents the fraction of demand designated to a particular demand region. Columns 1 and 2 should sum to 1 (or 0 if there is no demand) for each demand row. Also, Columns 2, 3, and 4 should sum to 1 (or 0 if there is no demand) for each demand row as should Columns 5 and 6. For example, if the first number, FRADI(1,1) equals .02, then 2 percent of the residential/commercial demand for demand region 1 is designated for residential use. Likewise, .98, or 98 percent, is designated for commercial use.

16 additional rows can be found in the next matrix. Each of these rows represents a year of activity from 1989 to 2007. The data is stated in trillion Btu and is represented by the variable STKHIS. There are three columns. The first represents coking sectors, the second represents the electricity sector, and the third represents the industrial sectors. This information is used to update any electricity sector stock changes and is used to calibrate the CMM model to match historical data prior to 2008. The model calculates the stocks based on differences between successive years. 2007 is the last forecast year in which this methodology is used. The next three groups of data inputs following this methodology represent a new method for adjusting stocks and calibrating to the Short-Term Energy Outlook coal production numbers for *AEO2011*.

“Stock adjustments by coal demand region for electricity sector” enables the modeler to designate the coal demand regions where the stock adjustments are apportioned. For instance, for the *AEO2011*, for the year t, 720 trillion Btus are input for the stock calculation. Fifty percent of which are allocated to the S2 coal demand region, 20 percent to C2, 20 percent to WS, 10 percent to MT, 10 percent to CU, and 10 percent to ZN. These percentages do not need to sum to 100.

The next section, “STEO adjustments for electricity,” specifies by year and region (Appalachia (1), Interior(2), and West(3)), the minimum levels of production in million short tons required to calibrate to the Short-Term Energy Outlook. As a practical rule of thumb, only two of the three regions should be required to meet a minimum production level in order to avoid over-constraining the model in any particular year. The next section “Supply region mapped to aggregate region for stocks” maps each of the 14 supply regions to one of the three subtotaled regions, either the Appalachian, Interior or West region.

The next data entry designates the base year of the model. For *AEO2011*, this is 2009.

The remaining matrices in this file are not currently being used by the CMM.

CLEXEXS. The first set of values in this file refers to the percentage of each exporter's capacity that can be supplied to any one importer and is identified with the variable name exshare. This file also contains U.S. coal export demands for the historical years of the forecast period. Each group of demands contains numbers representing annual demands (1990-2011) for coal exports in trillion Btu. These groups have five indices at the left. From left to right these indices are (1) the domestic CDS demand region index, (2) the domestic CDS economic subsector, (3) the international CDS demand sector, (4) the CDS coal group from which supplies may be drawn (The organization of "coal groups" is explained below in the discussion of the "CLPARAMS" input file), and (5) the international coal export region to which they pertain. The next group of inputs represents lower bounds and growth rates required to smooth the export forecast.

CLCONT. This file contains data describing electricity coal contracts, coal contract profiles, coal diversity profiles and transportation rate profiles for both domestic production and imports.

The first section of the file contains a list of 260 "contract profile" indices with corresponding contract profiles, one for each year of the forecast. The contract profiles extend through 2050. These profiles determine whether minimum flows of a particular supply region's coal will be maintained or decline over the forecast horizon.

For domestic production only, the next section contains "transportation profiles." The transportation profiles determine whether a plant will always get the first tier transportation rate or whether it will be assigned a second tier transportation as well. The second tier rate only will become effective if modeled volumes exceed historical flows. If the second tier rate takes affect it is only applied to the volume in excess of this shipment level. (By default, all new plants are subject to the second tier rate for their coal shipments.)

For domestic production only, the transportation profile section is followed by the "subbituminous diversity profiles" and then the "lignite diversity profiles." These two sections determine what proportion of a plant's consumption can be comprised of subbituminous coal and lignite coal, respectively. In the next section, a subbituminous diversity profile is established for new or unidentified coal units by demand region. Unidentified coal units are those which may be present in the electricity model's plant input file but are not listed in the clcont file. For *AEO2011*, new and unidentified plants are allowed unlimited use of subbituminous coal.

The next section maps international exporting regions to a unique supply curve number and supply region number.

In the final section of the clcont file, 3787 records are listed. The following information is provided on each line: plant identification number, plant unit number, plant name, plant state, supply curve number, contract profile index, subbituminous diversity index, lignite diversity index, transportation rate index, and a coal consumption quantity (in trillion Btu). Each of the indices refers to a similarly named profile mentioned above. For imports, 'dummy' values are provided for the subbituminous diversity index, lignite diversity index, and transportation rate index. These 'dummy' values are not actually used for imports.

For both domestic production and imports, contracts are specified by coal type, supply region, demand region, and whether the units have flue gas desulfurization equipment or not. Those units having flue gas desulfurization equipment are referred to as "scrubbed." The process for determining the level of contracts for a given forecast year involves a series of calculations utilizing the data entered in the clcont file. First, the historical proportion of consumption satisfied at the entire plant unit by each coal type/supply region combination is calculated for each plant unit. Second, a profile percentage indicating the proportion of the historical quantity still under contract in the current forecast year is multiplied by the share calculated in the first step. Third, the resulting calculated minimum contract share is multiplied by the demand (specified by plant unit) received from the electricity model. Finally, this information is aggregated by coal type, supply region, demand region, and whether the units specified in the contract have flue gas desulfurization equipment or not. As the forecast year changes, this minimum flow is subject to change as the contract profiles and electricity demand change. For domestic production, the resulting calculated minimum flow is the right-hand-side of the F(SR)(DR)X(C) row in the LP for the scrubbed sector or the C(SR)(DR)X(C) row for the unscrubbed sector. (See Section 2 Table 2.B-1. CDS Linear Program Structure – Domestic Component in Appendix 2.B.) For imports, the resulting calculated minimum flow is the right-hand-side of the F(ISR)(DR)I1 row in the LP for the scrubbed sector or the C(ISR)(DR)I1 row for the unscrubbed sector. (See Section 3 Table 3.B-1. CDS Linear Program Structure – International Component in Appendix 3.B.)

The following example depicts a hypothetical situation in which only two scrubbed plant units comprise a demand region.

	Source of data, if applicable	Scrubbed Plant Unit 1	Scrubbed Plant Unit 2	Total
Step 1. Calculation of supply curve historical share				
Historical consumption of supply curve "X" @ unit (trillion Btu):	clcont	100	80	
Historical total plant unit consumption (all supply curves, trillion Btu):	clcont	150	200	
Calculated share:		100/150=0.67	80/200=0.40	
Step 2: Apply profile percentage				
Profile for forecast year, T:	clcont	0.80	0.50	
Adjusted share for forecast year, T:		0.67*0.80=0.53	0.40*0.50=0.20	
Step 3. Calculation of minimum flow for each unit				
Electricity demand for plant unit for forecast year, T (trillion Btu):	electricity model	170	210	
Minimum flow by plant unit for forecast year, T (trillion Btu):		170*0.53=90	210*0.20=42	
Step 4. Total contract value, specified by scrubbed/unscrubbed categorization, demand region, and supply curve (trillion Btu)				90+42=132

The contract, or minimum flow, in this hypothetical example, used in the LP for this forecast year, demand region, scrubbed sector, and supply curve “X” combination is 132 trillion Btu (or 90 plus 42).

For the diversity profiles for domestic coal production, the process is similar except the level of aggregation (Step 4) is different. Here, the diversity profiles are specified by plant type (Table 2.4) and demand region. The resulting value becomes the right-hand-side for the rows DVS(DR)(PT) for subbituminous and DVL(DR)(PT) for lignite coals.

Again, for the transportation profiles for domestic coal production, the process is similar, but the information is aggregated based on supply region, demand region, plant type and coal type. For those transportation profiles indicating a second tier rate, the calculated value becomes the right-hand-side for the row T(SR)(DR)(PT)(CT) and represents the bound on the first tier transportation rate. In other words, any production from supply curve “X” transported to demand region “Y” for plant type “Z” in excess of this “bound” must get the more expensive second tier rate.

CLNODES. This file contains labels for coal distribution origins and destinations, that is, two-letter and full alphabetic designations for the supply and demand regions in the model.

CLPARAM. This file contains 11 arrays and vectors. They are described and identified in the order of their appearance:

"COAL" contains labels for the CMM coal types.

"BSRZR" is used to adjust transportation rates by the 49 economic subsectors and 16 demand regions. For *AEO2011*, "BSRZR" is set to 1.0 for all subsectors and demand regions and has no effect on the forecast.

“BSZR_UTIL” enables the calibration of delivered electricity coal prices to historical data. Each number represents a single forecast year beginning in 1990 and ending in 2050.
“MINERS BY SUPPLY REGION FOR MINEBYR” is the base year data from which subsequent coal mine employment for the forecast years is calculated.

"SECTORS" is a column vector of alphabetic labels for the 49 economic subsectors in the CDS.

“IFED" and “IFED2” assign the 16 domestic CDS demand regions to the 9 Census divisions.

"ISEC" assigns the 49 CDS economic subsectors to the 6 NEMS economic sectors (Residential/Commercial, Industrial steam, Industrial metallurgical, Coal-to-liquids, Exports, and Electricity sectors).

“IPMM” and “IPMM2” assign the 16 domestic CDS demand regions to the 5 PMM regions.

"KCNUR" is indexed with the demand region numbers and their two-letter alphabetic abbreviations. The array assigns coal groups to residential/commercial, industrial steam, metallurgical, and coal-to-liquids economic subsectors which are represented, in that order, by the first eight columns of integers.

The next few lines appearing before “Transportation escalator coefficients” define the initial investment value for the west transportation escalator, the base year for the investment value, and the increase in investment given an incremental change in ton-miles. Likewise, the initial PPI for railroad equipment value is specified is specified for the east transportation escalator, the base year for the PPI, and the incremental adjustments required given a change in ton-miles.

The transportation escalator coefficients are listed next.

Inputs for the transportation escalator are listed in columns below the transportation index coefficients. For *AEO2011*, only east and west productivity are actively used in the model.

"NUMEAST" and "NUMEASTSC" are defined next.

The next section shows average distances for western sourced coal, but this data input is currently not used in the *AEO2011*.

"BTR" previously defined rail transportation cost escalators. (“BTR” is not used in the *AEO2011*.)

"CSDISC" is used to adjust minemouth prices to reflect regional labor productivity changes during the forecast period. "CSDISC" is indexed by the two-letter alphabetic code abbreviations for the 14 CMM coal supply regions, with each group containing a value for each of the 61 years (1990-2050).

"KCUR is used to assign coal groups to the 49 electricity subsectors. This parameter is indexed by demand region.

"ICSET" is used to define the coal groups, listing the coal sources included in each coal group. The structure of the array provides a row for each coal group, with the permitted coal sources indexed by supply region number (1 through 14) and coal type (1 through 8). Coal types are indexed in the order in which they occur in the CLPARAM array "COAL" (q.v., above).

CLHIST. This file contains historical overwrite information for production and prices for years 1998-2009.

CMMDBDEF. This file contains the coal database definition tables. Changes in the number of records within a definition most likely require a corresponding change to the cldbdef include file and a recompilation of the orcltabs.f source code

Table C-1. Parameter and Variable List for CDS

Variable	Include File	Definition
ABSULF(4,MNUMYR)	coalrep	Appalachia bituminous coal (million tons)
ABSULF_BTU(4,MNUMYR)	coalrep	Appalachia bituminous coal (trillion Btu)
ACMERC(MNUMYR)	coalrep	Tons of mercury removed using activated carbon
ALLCOALS(41)	cdscom2l	Supply coal type combinations (e.g. NACDB, NAMDB,etc.)
APPCDS=3	cdsparms	Number of CMM supply regions in Appalachia
APSULF(4,MNUMYR)	coalrep	Appalachian premium coal (million tons)
ASTN(MAXTNAM)	cdsrevise	Assigned tons
ASTR(MAXTNAM)	cdsrevise	Assigned trillion Btu
BASEYR	parametr	Base calendar year corresponding to CURIYR = 1
BSRZR(NTOTSECT,NDREG)	cdscom2l	Rail route multipliers by demand region; read in from clparam.txt; currently set to 1.0
BSRZR_UTIL(NFYRS)	cdscom2l	Input from clparam.txt; used to calibrate delivered utility coal prices
BTR(NSREG+1, NFYRS)	cdscom2l	Network rail rate multiplier; currently not used in the model
BTUTZR(NUTSEC,NDREG)	cdscom1l	Btu conversion factor for utility sectors (million Btu/ton)
BTW(NFYRS)	cdscom2l	Network water rate multiplier; currently not used in the model
C_ECP_BTU(MX_SO2T,NUTSEC+1,NDREG)	uso2grp	Trillion Btus by sulfur category, utility sector, and coal demand region
C_ECP_PRC(MX_SO2T,NDREG)	uso2grp	Coal price by sulfur category and by coal demand region ($/mmBtu)
C_ECP_SO2(MX_SO2T,NDREG)	uso2grp	SO2 content by sulfur category and coal demand region (lbs/mmBtu)
CBTU(NSREG, NCOALTYP)	cdscom2l	Carbon factor by supply region and coal type
CDSIN(NDREG,MNUMCR)	cdsshr	Industrial sector share factors (read in from clshare.txt)
CDSMC(NDREG,MNUMCR)	cdsshr	Metallurgical coal sector share factors (read in from clshare.txt)
CDSRC(NDREG,MNUMCR)	cdsshr	Residential/commercial sector share factors (read in from clshare.txt)
CDTN(MAXTNAM)	cdsrevise	Calculated delivered price/ton
CDTR(MAXTNAM)	cdsrevise	Calculated delivered price/MMBtu
CDYRS(NMAXCTRK,NFYRS)	cdscom2l	Utility contract demand (trillion Btu)
CESIO	omlbuf	Memory required by coal LP model
CLITR	cdscpsp	Coal iteration
CLMAXITR	cdscpsp	Maximum number of coal iterations allowed
CLSULF(NSREG,4,3,MNUMYR)	coalrep	Coal production by supply region (million tons)
CLSULF_BTU(NSREG,4,3,MNUMYR)	coalrep	Coal production by supply region (trillion Btu)
CLSYNGQN(17,MNUMYR)	coalout	Coal synthetic natural gas quantity
CNCSET=10	cdsparms	Number of coals available within a set
CNTR(MAXTNAM)	cdsrevise	Contract trillion Btu (lower bounds)
COAL(NSREG,NCOALTYP)	cdscom2l	Coal type code (e.g. CSS (low sulfur/surface/subbituminous))
COALIYR	cdscom1l	Internal year index
COALPRICE(MNUMLR,MNUMYR)	coalrep	Coal price ($/short ton)

Table 2.C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
COALPROD(MNUMCR,MNUMLR, MNUMYR)	coalrep	Coal distribution (million short tons)
COALPROD2(MNUMCR,MNUMLR, MNUMYR)	coalrep	Coal distribution including exports(million short tons)
COAL2GAS(MNUMCR,MNUMYR)	coalrep	Coal-to-gas (mainly Great Plains plant) in trillion Btus
COF(10)	cdscom2l	Coefficients for transportation equation
CPSB(3,MNUMYR)	coalout	Coal minemouth price in ($/ton)
CPSBF(NSREG,NFYRS)	cdscom1l	Total minemouth price ($/ton)
CPSFLG	cdscpsp	=0 before the CPS submodule is called and 1 afterwards
CQDBFB(MNUMCR,NEMSEC,MNUMYR)	coalout	Coal consumption (trillion Btu)
CQDBFT(MNUMCR,NEMSEC,MNUMYR)	coalout	Coal conversion factor for consumption (million Btu/ton)
CQEXP	cdscom1l	Total export demand (trillion Btu)
CQSBB(3,MNUMYR)	coalout	Coal production (East,West Miss, U.S.) (trillion Btu)
CQSBFB(NSREG,NFYRS)	cdscom1l	Coal production by CDS supply regions (million Btu)
CQSBFT(NSREG,NFYRS)	cdscom1l	Conversion factor for coal production (million Btu/ton)
CQSBT(3,MNUMYR)	coalout	Coal Btu conversion factor for production (million Btu/ton)
CRTN(MAXTNAM)	cdsrevise	Calculated rate/ton
CSDISC(NSREG,NFYRS)	cdscom2l	Productivity adjustment factors
CT_USED(16,32)	cdsshr	Coal type used
CTRK_INDX(2,NCOALTYP, NSREG,NTOTDREG)	cdscom2l	Index for contracts (e.g. =1 for 1st contract, 2 for 2nd contract, etc.)
CURITR	ncntrl	Current iteration index
CURIYR	ncntrl	Current iteration year index
DEMDEX(MAXTNAM)	cdsrevise	Index needed for sorting
DEMKEY(MAXTNAM)	cdsrevise	Key (8 digits demand, supply, sector, and coal type)
DEMRGN(NTOTDREG)	cdscom2l	Demand region (e.g. NE, YP, etc.)
DFCLOSE(DBFILE)	dfinc2	Function which terminates processing of a database file
DFMCBND(BNDNAME,CNAME,LVALUE,UVALUE)	dfinc2	Creates or changes a bound value
DFMCRTP(RNAME,TYPE)	dfinc2	Declares or changes the row type
DFMCVAL(CNAME,RNAME,VALUE)	dfinc2	Creates or changes a value for a row/column intersection
DFMEND()	dfinc2	Function which terminates matrix processing
DFMINIT(DB,MODE)	dfinc2	Initializes a database for matrix processing
DFOPEN(DBFILE,ACTFILE)	dfinc2	Opens the datafile for the LP problem
DFPINIT(DB,DBFILE,ACTPROB)	dfinc2	Initializes processing of the LP problem in the current database
DPTR(MAXTNAM)	cdsrevise	Decision price
DTJL(NMAXPART,NMAXDJOB)	cdscom2l	Coal demand requirement by coal type for the nonutility sector (million tons)

Table C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
DVCONT(90, NFYRS)	cdscom2l	Contract constraint
DVLBND	cdscom2l	Upper bound for lignite
DVSBND	cdscom2l	Upper bound for subbituminous coal
EDYRS(NMAXEXPT,NFYRS)	cdscom1l	Export demand (trillion Btu)
EMCOALPROD(numcoalch4regs+1,2,MNUMYR)	emission	Coal production by emission regions plus US
EMELBNK(MNUMYR)	emission	Available banked sulfur dioxide allowances
EMELPSO2(MNUMYR)	emission	CMM sulfur dioxide emission allowance price
EMETAX(1,MNUMYR)	emission	Carbon tax for coal
EMISS=4	cdsparms	Number of supply regions East of the Mississippi River
EMLIM(4,MNUMYR)	emission	Emission constraints for CO2, SOX, NOX, and Hg
EMRFSA(MNUMYR)	emission	SO2 emissions limit
ESCAL	cdscom2l	Transportation rate escalator
ESCAL97	cdscom2l	Used as an escalator for transportation rates
FCNTR(MAXTNAM)	cdsrevise	Requested contract
FCRL	ncntrl	Final convergence and reporting loop switch (1=converged, 0 = unconverged)
FILE_MGR	cdsfmgr	File manager
FIRSTFLG	cdscpsp	Flag which is always set equal to 1
FIRSYR	ncntrl	First forecast year index (e.g. 2)
FRADI(NOTSEC,NDREG)	cdscom2l	Fraction for allocating demands to resid/comm, industrial, metallurgical and coal to liquids sectors
FRCSTYR=2	cdsparms	Number of look-ahead years for production capacity expansion (not currently in use in the model)
IBSULF(4,MNUMYR)	coalrep	Interior bituminous coal (million tons)
IBSULF_BTU(4,MNUMYR)	coalrep	Interior bituminous coal (trillion Btu)
ICC(NMAXCTRK)	cdscom2l	Coal set index number for contracts
ICD(NMAXCTRK)	cdscom2l	Contracted demand region
ICS(NMAXCTRK)	cdscom2l	Index of supply region for contract
ICSETC(NCSET,CNCSET)	cdscom2l	The coaltype component of the member of a coal set (e.g. coaltype =1); paired with ICSETS
ICSETS(NCSET,CNCSET)	cdscom2l	The supply region component of the member of a coal set (e.g. 11); paired with ICSETC
ICY(NMAXCTRK)	cdscom2l	Part of contract file; 4th column; indicates coaltype (values 1-8)
IDC(90)	cdscom2l	=L for lignite or S for subbituminous; part of constraint input file in clparam.txt
IDD(90)	cdscom2l	demand region (values 1-16); part of lignite and subbituminous constraint input file in clparam.txt
IDLCNT(NMAXDJOB)	cdscom2l	Contract line number
IDLR(NMAXDJOB)	cdscom2l	Index of demand region for nonutility sectors
IDLZ(NMAXDJOB)	cdscom2l	Index of demand sector for nonutility sectors
IDS(90)	cdscom2l	electricity sector; part of lignite and subbituminous constraint input file in clparam.txt
IFED(NTOTDREG)	cdscom2l	Converts CDS demand region index to census division index

Table 2.C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
ILSULF(4,MNUMYR)	coalrep	Interior lignite coal (million tons)
IMPBTU(10,3,NFYRS)	cdscom1l	Import total by census divisions (trillion Btu)
IMPBTUC(NDREG,3,NFYRS)	cdscom1l	Import total by CDS demand regions (trillion Btu)
IMPINDSW	cdscom1l	Value is set to ‘1’ if minimum import quantity for industrial sector is specified, otherwise is ‘0’
IMPMAXSW	cdscom1l	Value is set to ‘1’ if maximum import quantity for total imports is specified, otherwise is ‘0’
IMPMETSW	cdscom1l	Value is set to ‘1’ if minimum coking coal import quantity is specified, otherwise is ‘0’
IMPMINSW	cdscom1l	Value is set to ‘1’ if minimum import quantity for total sector is specified, otherwise is ‘0’
IMPSEC=3	cdsparms	Number of import sectors (utility, metallurgical, industrial)
IMPTON(10,3,NFYRS)	cdscom1l	Import total by census divisions (million tons)
IMPTONC(NDREG,3,NFYRS)	cdscom1l	Import total in by CDS demand regions (million tons)
INDMIN	cdscom1l	Minimum million short tons of imports for the industrial sector
IND_TESC(4,MMUMYR,NDREG)	cdscom1l	Transportation escalator (after adjusting for surcharge) for the industrial sector
INLANDTR(3,17,NDREG,4)	cdscom1l	Inland transportation rates for imports after adjusting for surcharge
INTCDS=6	cdsparms	CMM supply regions belonging to Appalachia (1-3) and the Interior (4-6)
IRETOPT	cdscom2l	Optimal solution flag returned from the LP (0 indicates feasibility; 1 indicates infeasibility)
ISCRUB=7	cdsparms	Integer representing number of scrubbed sectors
ISEC(NTOTSECT)	cdscom2l	Converts detailed 21 demand sectors to 6 sectors (resid/comm, industrial, metallurgical, coal-to-liquids, exports, and electricity)
ISTJ(NMAXPART,NMAXDJOB)	cdscom2l	Index of supply region by route and demand job
ISUL(NCOALTYP)	cdscom2l	Coal type sulfur
ISVC(NMAXCURV)	cdscom2l	Coal type index
ISVR(NMAXCURV)	cdscom2l	Supply region index
IUNIT	cdsfmgr	Unit for WRITE statement
IUNITDB	cdsfmgr	Unit to WRITE to the debug file
IUNITDS	cdsfmgr	Unit to WRITE to the CDS file
KCNUR(NOTSEC,NDREG)	cdscom2l	Indices of coal sets for nonutility demands
KCUR(NUTSEC,NDREG)	cdscom2l	Indices of coal sets for utility demands
L_PROD(NSREG,2,MNUMYR)	cdscom2l	Labor productivity (tons/hour) assumptions; read in from cluser.txt
LABPRODGROWTH(MNUMYR)	coalrep	Growth in labor productivity from 2001
LASTYR	ncntrl	Last forecast year index (e.g. 36)
LCTNO(MAXTNAM)	cdsrevise	Contract line number
LCVBTU(MNUMPR,MNUMYR)	coalout	Coal supply curve heat content (mmBtu/ton)
LCVELAS(MNUMPR,MNUMYR)	coalout	Elasticity of coal supply curve for coal-to-liquids

Table C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
LCVTONP(MNUMPR,MNUMYR)	coalout	Coal supply curve delivered price ($/ton)
LCVTONQ(MNUMPR,MNUMYR)	coalout	Coal supply curve production (million tons)
LIGCONST	cdscom2l	Lignite constraint in clparam.txt
LIQUCARB(MNUMCR,MNUMYR)	coalout	Carbon content of coal to coal-to-liquids (kilograms/mmBtu)
LIQUSULF(MNUMPR,MNUMYR)	coalout	Sulfur content of coal to coal-to-liquids (lbs/mmBtu)
LTRNTON(MNUMPR,MNUMYR)	coalout	Transportation rate ($/ton)
MAPCDS(NDREG)	cdsshr	Maps census regions to coal demand regions
MAPCEN(NDREG+1)	cdsshr	Maps coal demand regions to census regions
MAPSTEO(NSREG)	cdscom1l	Maps supply regions to one of: Appalachia, Interior, or West
MAXDNAM=550	cdsrevise	Names of demand rows
MAXPNAM=250	cdsrevise	Names of production activities
MAXTNAM=3500	cdsrevise	Names of transportation activities
MC_ECIWSP(MNUMYR)	macout	Empl Cost Index, private wages & manufacturing salary; 1989 = 1.00
MC_PCWGDP(-2:MNUMYR)	macout	Implicit GDP deflator; 1987 = 1.00
MC_WPI14(MNUMYR)	macout	Producer price index for transportation equipment
MCNT_BTU(600)	cdscpsp	BTU conversion (marginal cost curve)
MCNT_CAR(600)	cdscpsp	Carbon factor (marginal cost curve)
MCNT_CTYPE	cdscpsp	Coal type (marginal cost curve)
MCNT_FRAC(600)	cdscpsp	Mine type (marginal cost curve)
MCNT_P(600,8)	cdscpsp	Coal price for each step (marginal cost curve)
MCNT_PRICE(600)	cdscpsp	Minemouth price (marginal cost curve)
MCNT_PROD(600)	cdscpsp	Production (marginal cost curve)
MCNT_Q(600,8)	cdscpsp	Coal quantity for each step (marginal cost curve)
MCNT_REC	cdscpsp	Number of record (marginal cost curve)
MCNT_REGION	cdscpsp	Supply region (marginal cost curve)
MCNT_STEP(8)	cdscpsp	Step size
MCNT_SULF(600)	cdscpsp	Sulfur level (marginal cost curve)
MDLZ(NMAXCTRK)	cdscom2l	Index of contract sector
METMIN	cdscom1l	Minimum million short tons of imports for the coking coal sector
MET_TESC1(4.MNUMYR,NDREG)	cdscom1l	Coking coal sector transportation escalator after adjusting for surcharge
MNUMCR=11	parametr	Census regions (9 + CA + US)
MNUMLR=17	parametr	Coal supply regions (16 + US)
MNUMYR=61	parametr	Maximum number of forecast years
MNUMXR=11	parametr	Coal export regions (10 + US)
MPTN(MAXTNAM)	cdsrevise	Minemouth price/ton
MPTR(MAXTNAM)	cdsrevise	Minemouth price/trillion Btu
MTJ(NMAXDJOB)	cdscom2l	Number of routes for job
MX_IMPCOAL=35	cdsparms	Maximum number of coal import supply curve/step combinations for thermal coal
MX_ISCST=58	cdsparms	Total supply curve/step combinations for import supply curves
MX_ISCV=12	cdsparms	Maximum number of coal import supply curves for thermal coal
MX_NCOALS=41	cdsparms	Maximum number of US coal supply curves

Table 2.C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
NCESIO=200000	omlbuf	Size of workspace for coal matrix
NCOALS	cdscom2l	Number of supply region/coaltype combinations; currently 36
NCOALTYP=8	cdsparms	Number of coal types per supply region
NCSET=41	cdsparms	Number of coal sets available
NCUTSET=12	cdsparms	Number of utility coal sets
NDREG=16	parametr	Coal demand regions
NDV	cdscom2l	Number of lignite and subbituminous constraints in clparam.txt
NEMSEC=7	cdsparms	Number of NEMS sectors (NTOTSECT + imports)
NFYRS=MNUMYR	cdsparms	Number of forecasted years
NMAXCTRK=350	cdsparms	Maximum number of contracts
NMAXCURV=300	cdsparms	Maximum number of supply curves
NMAXDJOB=900	cdsparms	Maximum number of demand jobs
NMAXEXPT=50	cdsparms	Maximum number of export demands
NMAXPART=20	cdsparms	Maximum number of participants per demand job
NMAXSTEP=4000	cdsparms	Maximum number of curve steps
NOCONTR	cdscom2l	Number of contracts in contract file
NODES(5,60)	cdscom2l	Supply and demand region abbreviations; NODES(1,1-14)= supply regions; NODES(1,12-24)= demand regions
NONUTIL=NOTSEC+NXPSEC	cdsparms	Number of detailed nonutility sectors (R1,R2,IP,IS,IO,M1,M2,L1,and X1-X6)
NOTSEC=8	cdsparms	Number of residential/commercial, industrial, metallurgical, and coal-to-liquids sectors
NSREG=14	cdsparms	Number of coal supply regions
NTOTDREG=16	cdsparms	Total number of demand regions
NTOTSECT=21	cdsparms	Total number of demand sectors (R1,R2,IP,IS,IO,M1,M2,L1,X1-X6, and U1-U7)
NUMPTYPE=3	cdsparms	Number of plant types
NUMSTYPE=3	cdsparms	Number of coal types (low-, medium-, and high-sulfur)
NUMSULFLVL=3	cdsparms	Number of sulfur categories (low, medium, and high)
NUTSEC=35	cdsparms	Number of electricity sectors
NXPSEC=6	cdsparms	Number of export sectors
ODTRATE(NSREG,NCOALTYP,NTOTDREG, NTOTSECT)	cdscom1l	Transportation rates from clrates.txt
PABSULF(4,MNUMYR)	coalrep	Price of Appalachian bituminous coal ($/ton)
PALSULF(4,MNUMYR)	coalrep	Price of Appalachian lignite coal ($/ton)
PAPSULF(4,MNUMYR)	coalrep	Price of Appalachian premium coal ($/ton)
PCLCM(MNUMCR,MNUMYR)	ampblk	Price of coal for the commercial sector ($/mmBtu)
PCLCM(MNUMCR,MNUMYR)	mdblk	Coal price for commercial sector ($/mmBtu)
PCLEL(MNUMCR,MNUMYR)	ampblk	Price of coal for the electricity sector ($/mmBtu)

Table C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
PCLEL(MNUMCR,MNUMYR)	mdblk	Coal price for electricity sector ($/mmBtu)
PCLEX(MNUMCR,MNUMYR)	coalrep	Coal export price ($/mmBtu)
PCLIN(MNUMCR,MNUMYR)	ampblk	Price of coal for the industrial sector ($/mmBtu)
PCLIN(MNUMCR,MNUMYR)	mdblk	Coal price for industrial sector ($/mmBtu)
PCLRFPD(MNUMPR,MNUMYR)	coalout	Price of coal for coal-to-liquids ($/mmBtu)
PCLRS(MNUMCR,MNUMYR)	ampblk	Price of coal for the residential sector ($/mmBtu)
PCLRS(MNUMCR,MNUMYR)	mdblk	Coal price for residential sector ($/mmBtu)
PCLSULF(NSREG,4,3,MNUMYR)	coalrep	Coal price by supply region ($/ton)
PCNT_BTU(600)	cdscpsp	BTU conversion (capacity curve)
PCNT_CAR(600)	cdscpsp	Carbon factor (capacity curve)
PCNT_CTYPE	cdscpsp	Coal type (capacity curve)
PCNT_FRAC(600)	cdscpsp	Mine type (capacity curve)
PCNT_P(600,8)	cdscpsp	Coal price for each step (capacity curve)
PCNT_PRICE(600)	cdscpsp	Minemouth price (capacity curve)
PCNT_PROD(600)	cdscpsp	Production (capacity curve)
PCNT_Q(600,8)	cdscpsp	Coal quantity for each step (capacity curve)
PCNT_REC	cdscpsp	Number of record (capacity curve)
PCNT_REGION	cdscpsp	Supply region (capacity curve)
PCNT_SULF(600)	cdscpsp	Sulfur level (capacity curve)
PD(NSREG)	cdscom2l	Production for deep mines (million tons)
PDUTZR(NUTSEC,NDREG)	cdscom1l	Utility delivered price by utility sector ($/million Btu)
PIBSULF(4,MNUMYR)	coalrep	Price of Interior bituminous coal ($/ton)
PILSULF(4,MNUMYR)	coalrep	Price of Interior lignite coal ($/ton)
PINLANDTR(3,17,NTOTDREG,USINTLDR)	cdscom1l	Inland transportation rates for imports (pre-surcharge adjustment)
PMCIN(MNUMCR,MNUMYR)	ampblk	Price of coal for the metallurgical sector ($/mmBtu)
PMCIN(MNUMCR,MNUMYR)	mdblk	Metallurgical coal price for industrial sector ($/mmBtu)
PMN(NSREG,NCOALTYP)	cdscom2l	Value of coal from a region ($/ton)
PMPROD(NSREG,NCOALTYP)	cdscom1l	Value of coal from a supply region (including adjustment for premium coal)
PMPRODR(NSREG,NCOALTYP,NFYRS)	cdscom1l	Value of coal from a supply region (including adjustment for premium coal) for a given year
PMTD(NSREG,MNUMYR)	cdscom1l	Underground coal production in million short tons
PMTD_BTU(NSREG,MNUMYR)	cdscom1l	Underground coal production in trillion Btu
PMTDP(NSREG,MNUMYR)	cdscom1l	Price of underground coal production ($/mmBtu)
PMTS(NSREG,MNUMYR)	cdscom1l	Surface coal production in million short tons
PMTS_BTU(NSREG,MNUMYR)	cdscom1l	Surface coal production in trillion Btu
PMTSP(NSREG,MNUMYR)	cdscom1l	Price of surface coal production ($/mmBtu)
PRCONVB(MNUMCR,4,MNUMYR)	cdscom1l	Trillion Btus for either electricity, industrial, coking coal, or total sectors but excludes imports; used to calculate conversions factor for prices where imports are excluded
PRCONVT(MNUMCR,4,MNUMYR)	cdscom1l	Million short tons for either electricity, industrial, coking coal, or total sectors but excludes imports; used to calculate conversions factor for prices where imports are excluded
PREMBTU=26.27	cdsparms	Btu conversion factor for premium coal
PRTDBGC	ncntrl	Print debug

Table 2.C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
PS(NSREG)	cdscom2l	Production for surface mines (million tons)
PSRMT(NSREG,2)	cdscom2l	Production by supply region and minetype
PSRMTYR(NSREG,2,NFYRS)	cdscom2l	Production by supply region, minetype, and forecast year (extra variable not in use)
PSRNG(NMAXCURV)	cdscom2l	Minemouth price in 1987 $/ton
PTARG(16,2,16)	cdscpsp	Target price
PWBSULF(4,MNUMYR)	coalrep	Price of western bituminous coal ($/ton)
PWLSULF(4,MNUMYR)	coalrep	Price of western lignite coal ($/ton)
PWSSULF(4,MNUMYR)	coalrep	Price of western subbituminous coal ($/ton)
QCLCM(MNUMCR,MNUMYR)	qblk	Quantity of coal for commercial sector (trillion Btu)
QCLCML(MNUMCR)	cdsces	Lagged commercial production (trillion Btu)
QCLEL(MNUMCR,MNUMYR)	qblk	Quantity of coal for electricity sector (trillion Btu)
QCLIN(MNUMCR,MNUMYR)	qblk	Quantity of coal for industrial sector (trillion Btu)
QCLINL(MNUMCR)	cdsces	Lagged industrial production (trillion Btu)
QCLNHNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with high emission standards (can burn any type of coal)
QCLNLNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with low emission standards (can only burn low sulfur coal)
QCLNMNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with medium emission standards (can burn low sulfur or medium sulfur coal)
QCLOHNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with high emission standards (can burn any type of coal)
QCLOLNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with low emission standards (can only burn low sulfur coal)
QCLOMNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with medium emission standards (can burn low or medium sulfur coal)
QCLRS(MNUMCR,MNUMYR)	qblk	Quantity of coal for residential sector (trillion Btu)
QCLRSL(MNUMCR)	cdsces	Lagged residential production (trillion Btu)
QCLSBNR(NDRGG,MNUMYR)	coalemm	Demand for coal at scrubbed units (trillion Btu)
QCLSN(MNUMCR,MUNMYR)	qblk	Quantity of coal synthetics (trillion Btu)
QDIN1R(NDREG)	cdscom1l	Industrial demand (trillion Btu)
QDL(NMAXDJOB)	cdscom2l	Coal demand per demand job in trillion Btu
QDL11R(NDREG)	cdscom1l	Coal-to-liquid coal demand (trillion Btu)
QDMT1R(NDREG)	cdscom1l	Metallurgical coal demand (trillion Btu)
QDRC1R(NDREG)	cdscom1l	Residential/commercial demand (trillion Btu)
QDUTZR(NUTSEC,NDREG)	cdscom1l	Utility demand by utility sector (trillion Btu)
QMCIN(MNUMCR,MNUMYR)	qblk	Quantity of metallurgical coal (trillion Btu)
QMCINL(MNUMCR)	cdsces	Lagged metallurgical coal production (trillion Btu)
QPROD(NSREG, NCOALTYP)	cdscom1l	Coal production (including adjustment for premium coal)
QPRODR(NSREG,NCOALTYP,NFYRS)	coalcds	Coal production (including adjustment for premium coal) by year

Table C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
QPRODS(NSREG, NCOALTYP)	cdscom2l	Straight 35-curve production (excluding adjustment for premium coal)
R_WAGE(NSREG,MNUMYR)	cdscom2l	Real wage by supply region and forecast year
RPTN(MAXTNAM)	cdsrevise	Transportation rate/ton
RPTR(MAXTNAM)	cdsrevise	Transportation rate/trillion Btu
RQTN(MAXTNAM)	cdsrevise	Required tons
RQTR(MAXTNAM)	cdsrevise	Required trillion Btu
RSBTU(NMAXCURV)	cdscom2l	Btu content (million Btu/ton)
SBTU(NSREG, NCOALTYP)	cdscom2l	Btu conversion factor by supply region and coal type (million Btu/ton)
SECNAM(NTOTSECT)	cdscom2l	Demand sector name (e.g. R1,R2,IP,IS,etc); input from clparam.txt
SECTOR(3,NTOTSECT)	cdscom2l	Sector name (e.g. RESID/COMM1, IND. PREM, etc.)
SO2_PCB=0.980	cdsparms	1.0 minus fraction of sulfur left in ash, bituminous coal
SO2_PCL=0.960	cdsparms	1.0 minus fraction of sulfur left in ash, lignite coal
SO2_PCS=0.940	cdsparms	1.0 minus fraction of sulfur left in ash, subbituminous coal
SO2TX(MAXTNAM)	cdsrevise	SO2 penalty ($/mmBtu)
SOUTZR(NUTSEC,NDREG)	cdscom1l	SO2 content for utility sectors (lb/million Btu)
SSUL(NSREG, NCOALTYP)	cdscom2l	Sulfur level by supply region and coal type
STARTYR=6	cdsparms	First year the coal model LP should solve; set to 1995
SUBCONST	cdscom2l	Subbituminous constraint in clparam.txt
STOCKREG(1995:1989 + MNUMYR)	cdscom1l	Total stocks; used to adjust emissions limits
STOCKSH(NDREG,1995:1989 + MNUMYR)	cdscom1l	Share of total annual stocks associated with a particular region
SULFCONT	cdscom2l	Sulfur content (considers the sulfur removed at plant) (lbs/mmBtu)
SULFPEN	cdscom2l	Row name for sulfur constraint
SUPNO(16,32)	cdscom2l	Supply curve number
SUPRGN(NSREG)	cdscom2l	Supply region
SURCHARGEI(4,NDREG,MNUMYR)	cdscom1l	Fuel surcharge for imports
SURCHART1(NSREG,NDREG,MNUMYR)	cdscom1l	Fuel surcharge for first tier electricity transportation rates
SURCHART2(NSREG,NDREG,MNUMYR)	cdscom1l	Fuel surcharge for second tier electricity transportation rates
SURFLAG	cdscom1l	If ‘1’, indicates that a surcharge is applicable to domestic shipments
SURFLAGI	cdscom1l	If ‘1’, indicates that a surcharge is applicable to imports
SUR_ADJ	cdscom1l	If SURFLAG equals ‘1’, indicates share of base year transportation rates that already include a fuel surcharge
TIJL(NMAXPART,NMAXDJOB)	cdscom2l	Coal assigned by coal type (million tons)
TMPMBTU(MNUMYR)	cdscom1l	Average mercury emissions in tons of mercury per mmBtu
TONN(10,25,3,NFYRS)	cdscom1l	Import tonnage (million tons)
TOTALHOURS(NFYRS)	cdscom2l	Total labor hours by forecast year
TOTALWAGES(NFYRS)	cdscom2l	Total wages by forecast year
TOTLABPROD(MNUMYR)	coalrep	Total labor productivity in a given forecast year (tons/hour)

Table 2.C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
TOTPROD(NFYRS)	cdscom2l	Total production by forecast year
TRN_INDX(NUTSEC,NCOALTYP,NSREG,NTOTDREG)	cdscom2l	Index indicating whether transportation vector is required (0=Not required; 1=Required)
TRUBND1(NSREG,NCOALTYP,NTOTDREG, NUTSEC)	cdscom1l	Maximum volume of coal that may get the first tier transportation rate by scrubbed and unscrubbed
TSPMBTU(MNUMYR)	cdscom1l	Average sulfur dioxide emissions in tons of sulfur dioxide per mmBtu
UCMERC(NUTSEC,MNUMYR)	cdscom1l	Uncontrolled mercury emissions
UCSO2(NUTSEC,MNUMYR)	cdscom1l	Uncontrolled sulfur dioxide emissions
UPEBYR	uso2grp	End banking year (year banked allowance cannot be used)
UPSLWFCTR	uso2grp	SO2 penalty price lower bound factor (currently 0.00)
UPSYEAR	uso2grp	Year to start creating SO2 penalty price bounds (currently 1999)
UPTPSO2(MNUMYR+1)	uso2grp	Target SO2 penalty price
USINTLDR=4	cdsparms	International U.S. demand regions (UI,UE,UG, and UN)
USPLIT=6	cdsparms	Utility coal types for reporting (old, new, scrubbed, and low-, medium-, and high-sulfur)
UTCONS	coalrep	Utility coal consumption (trillion Btu)
UTPSO2	coalrep	Utility potential SO2 emissions (million tons)
WAGEGROWTH(MNUMYR)	coalrep	Growth in wages from 2001
WAGEPHOUR(MNUMYR)	coalrep	Total wage per hour by year
WBSULF(4,MNUMYR)	coalrep	West bituminous coal (million tons)
WFCBND(COLNAME,LOBOUND,UPBOUND)	wfinc2	Change column bounds
WFCMASK(MASK,NAME)	wfinc2	Get LP variable name
WFCNAME(INDEX,NAME)	wfinc2	Retrieves a column name
WFCRHS(ROWNAME,VALUE)	wfinc2	Changes righthand side value
WFDEF(MODEL,LEN,MODLNAME)	wfinc2	Defines the model space for the LP problem
WFINSRT(FILENAME,DECKANME)	wfinc2	Loads the starting basis for the LP problem
WFLOAD(ACTFILE,ACTPROB)	wfinc2	Loads the matrix for the LP problem into memory
WFOPT()	wfinc2	Optimizes the model
WFPUNCH(FILENAME,DECKANME)	wfinc2	Saves the current basis into a standard format file
WFRNAME(INDEX,NAME)	wfinc2	Retrieves a row name
WFSCOL(NAME,SELECT,STAT,SOLVAL)	wfinc2	Retrieves solution values for a column vector
WFSET(MODEL)	wfinc2	Sets matrix
WFSROW(NAME,SELECT,STAT,SOLVAL)	wfinc2	Retrieves solution values for a row
WLSUF(4,MNUMYR)	coalrep	West lignite coal (million tons)
WMCF(4,MNUMYR)	coalrep	Metallurgical coal world flows (million tons)
WSCF(4,MNUMYR)	coalrep	Steam coal world flows (million tons)

Table C-1. Parameter and Variable List for CDS (continued)

Variable	Include File	Definition
WSSULF(4,MNUMYR)	coalrep	West subbituminous coal (million tons)
WTCF(4,MNUMYR)	coalrep	Total coal world flows (million tons)
XC(NCSET)	cdscom2l	Contract demand (trillion Btu)
XT(NCSET)	cdscom2l	Utility demand (trillion Btu)
YEARPR	ncntrl	For reporting, year dollars (e.g. 2001)

Output and Composition of Reports

Current output from the domestic component of the CDS falls into three categories:

- The NEMS system currently generates five domestic coal reports in the NEMS table array (Tables 16 and the *Supplement to the Annual Energy Outlook* tables 109,110, 111 and 115).

- An output file (@.CLCDS) that currently contains 5 year-specific detailed reports. These reports are intended for use in model diagnosis, calibration and to provide detailed output for special studies. Only those currently operational are reviewed in this appendix. For diagnostic purposes, the reports in this file may be generated for each iteration of the CDS.

- A second file (@.CLDEBUG) contains output showing the performance of the CDS Fortran code and is used for diagnostic purposes.

NEMS Tables

Prices and quantities produced by the CDS occur throughout the NEMS tables. However, the bulk of domestic CDS output is reported in five NEMS tables dedicated entirely to coal: Tables 15, 120, 121, 122, 123, 124 and 125. These reports can be found at http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html for Table 15 and http://www.eia.doe.gov/oiaf/aeo/supplement/index.html for the other reports. These reports are organized to show selected NEMS coal quantities and prices for each year in the forecast period. Table 15, "Coal Supply, Disposition, and Prices" shows:

- Production east and west of the Mississippi River and for the Appalachian, Interior and Western regions, and the national total in millions of short tons

- Imports, exports, and net imports, plus total coal supply in millions of short tons

- Sector consumption for the residential/commercial, industrial steam, industrial coking, and electricity sectors plus total domestic consumption in millions of short tons

- Annual discrepancy (including the annual stock change)

- Average minemouth price in dollars per ton (the dollar year is provided)

- Sectoral delivered prices in dollars per ton for the industrial steam, industrial coking, and electricity sectors, and the weighted average for these three sectors

- Average free-alongside-ship price for exports, i.e., the dollar-per-ton value of exports at their point of departure from the United States..

Table 120, "Coal Production and Minemouth Prices By Region," provides annual summaries of national distribution aggregated supply regions, plus subtotals for five subregions: "Appalachia", "Interior", "Western", "East of the Mississippi River", and "West of the Mississippi River". In the lower half of the table, minemouth prices are shown in dollars per ton for the same regions and subtotals

Table 121, "Coal Production by Region and Type" lists production in millions of short tons per forecast year by supply region by coal rank and sulfur level.

Table 122, "Coal Prices by Region and Type" lists minemouth prices for each forecast year by supply region by coal rank and sulfur level.

Tables 123, 124 and 125 show international coal trade projections for coal by international supply regions to the Europe/Mediterranean region, Asia, and the Americas.

Other outputs from the CDS occur in a number of NEMS tables. National coal production, consumption, and exports are reported in quadrillion Btu in NEMS Table 1 (http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html), as is the minemouth price of coal in dollars per ton (Table 15). Annual energy consumption for the Residential, Commercial, Industrial (both industrial steam and coking consumption are shown) and the Electric Power sector in quadrillion Btu are shown in NEMS Table 2. Table 3 gives delivered coal prices for these same sectors in dollars per million Btu. NEMS Table 128 in the *Supplement to the Annual Energy Outlook* (http://www.eia.doe.gov/oiaf/aeo/supplement/supref.html) shows Btu conversion rates for coal production (east and west of the Mississippi River, and the national average), and for coal consumed in the domestic NEMS sectors (Residential/Commercial, Industrial, Coking, and Electricity sectors).

Single Year Detailed Reports

The first report which is output to the CDS file is the Census Division Report, which shows sectoral statistics by Census division and for the Nation. The statistics reported are production in millions of tons, demand in trillion Btu, and the sectoral average Btu conversion factor. The minemouth, transportation, and delivered prices are shown in dollars per ton, and the delivered price is also shown in dollars per million Btu. No prices are shown for imported coal since it is not priced in the model. The next report, the Detailed Demand and Price Report, describes each demand met by the model in the year described and shows each increment of supply that contributes to every demand in millions of tons. The demands are shown in millions of short tons and trillion Btu. This report also contains the adjusted minemouth price for each participant, the origin of the coal shipped, the type of coal shipped, and the associated transportation rate. Average prices and total quantities are provided for the major sectors in each demand region. This report is about 14 pages in length, depending on the year and scenario reported (usually one page per demand region).These reports are currently followed by a series of three single-page regional summary production reports. The first shows regional production and minemouth price (in millions of short tons and dollars per ton, respectively) by mine type. The second shows the same items by coal rank, while the third shows them by coal sulfur level.

These summary reports are followed by the Detailed Coal Production Report, showing the production, minemouth price, total energy content and Btu conversion factor for each coal supply source used in the reported year. This report is also formatted as a spreadsheet, with the coal types shown as rows and the supply regions as columns.

Appendix 2.D

Data Quality and Estimation

Development of the CDS Transportation Index

In *AEO2011*, coal transportation costs, both first- and second-tier rates, are modified over the forecast horizon by two regional (east and west) transportation indices. The indices, calculated econometrically, are measures of the change in average transportation rates, on a tonnage basis, that occurs between successive years for coal shipments. The methodology used to formulate these indices was first revised for the *AEO2009*. In the *AEO2011*, an east index is used for coal originating from eastern supply regions, while a west index is used for coal originating from western supply regions. The east index is a function of railroad productivity, the user cost of capital for railroad equipment, and national average diesel fuel price. The user cost of capital for railroad equipment is calculated from the producer price index for railroad equipment, projected to remain flat in real terms, and accounts for the opportunity cost of money used to purchase equipment, depreciation occurring as a result of use of the equipment (assumed at 10 percent per year), less any capital gain associated with the worth of the equipment. The west index is a function of railroad productivity, gross capital expenditures for Class I railroads, and western share of national coal consumption. The indices are universally applied to all domestic coal transportation movements within the CMM. In the *AEO2011* reference case, eastern coal transportation rates are projected to be flat in 2035 and western rates are projected to be 6 percent higher in 2035 compared to 2009.

Background

Transportation rates can be expected to change over time as market conditions change. Historically, the majority of transportation agreements involved contracts that extended over many years. Despite the length of these contracts, escalator clauses were typically employed allowing rates to change in accordance with changing market conditions. In addition shorter contracts, which have become more prevalent, provide an opportunity for both parties involved to renegotiate their positions more frequently. The transportation indexing methodology used in *AEO2011* is needed within the CDS to simulate the changes that may occur in real coal transportation rates over the forecast horizon.

Prior to the *Annual Energy Outlook 1997 (AEO97)*, transportation indexing factors were derived from index data published by the Association of American Railroads. Beginning in *AEO97* and extending through *AEO2004*, an indexing methodology based on the producer price index (PPI) for the transportation of coal via rail was used. The PPI for coal transportation tracks the national average change in prices received by railroads for the transportation of coal. A statistical regression model was fitted to the PPI for coal rail transportation. The independent variables used in the formulation were intended to account for the input costs that would affect transportation rates over time and in the *AEO97* formulation included: trend (as a proxy for productivity), the price of No. 2 distillate fuel to the industrial sector, the PPI for transportation equipment, and the national average wage rate. (For more information regarding this formulation, see "Forecasting Annual Energy Outlook Coal Transportation Rates" by Jim Watkins in *Issues in Midterm Analysis and Forecasting 1997*.) For *AEO2004*, the PPI for rail transportation equipment was substituted for the PPI for transportation equipment as one of the independent variables. The PPI for rail transportation equipment was also converted to the user cost of capital of transportation equipment for use in the regression. In addition, for *AEO2004*, the average rail wage replaced the national average wage rate in the econometric formulation.

For *AEO2005*, the methodology used to derive the transportation index was again revised. The principal goals of the development of a revised transportation escalator for *AEO2005* were a statistically significant regression that included East and West regional differentiation and an improved representation of productivity. Although the factors that affect costs in the East and West are largely the same, there is evidence suggesting the weights of these factors on transportation costs differ for these two regions. For instance, Western coal traffic tends to be associated with longer hauls than Eastern traffic. Hence, the effect of distance on the change in average transportation cost for Western traffic is assumed to be more influential. In addition to the incorporation of a regional component, an improved representation of productivity was also an objective. In previous formulations of the transportation index, time trend served as a proxy for productivity. Time trend is not amenable to the development of sensitivity cases in which productivity falls or increases; therefore an alternative was sought.

For *AEO2009*, the methodology for the transportation index was once again revised. This same basic methodology is used in the *AEO2011*. A revision was required because the FERC 580 survey, the basis for the *AEO2005* methodology, only includes a sample of coal shipments to electric utilities. As deregulation lowered the number of utilities nationwide, this sample size dropped even more. So, an update of the historical information for the dependent variable (transportation rate), distance, and contract information, all previously derived from the FERC Form 580, would not be representative of all coal shipments. The revised *AEO2009* (and *AEO2011*) methodology combines the historical FERC Form 580 information through 1999 (supplemented with information from the Surface Transportation Board's Carload Waybill Sample) with the average transportation rates inferred from the FERC Form 423, EIA 423 surveys, and EIA-7A surveys for the years 2000 through 2005 to approximate the dependent variable of the equation. The current methodology *AEO2011*is based on data through 2006.

Theoretical Approach

The general intent of the transportation index is to account for the variables that are correlated with or impact non-inflationary changes in average coal transportation rates over time. The approach taken to develop a revised formulation included a review of the factors contributing to historical changes in transportation rates, the development of a list of potential predictive variables, and the actual development of a regression model.

While coal is transported by rail, barge, truck, and conveyor, the most frequently used form of transportation for coal is rail. In 1980, 59 percent of coal was transported by rail alone. In 2010, rail made up about 70 percent of all domestic coal shipments. Currently, all modes of coal transportation are aggregated within the CDS. In addition, limited data resources are available for the less dominant modes of coal transport. For these reasons, the regression is formulated with a railroad focus.

The Staggers Act of 1980 partially deregulated the railroad industry allowing greater flexibility in the prices charged to rail customers. Since 1980 and through the 1990's, competitive pressures between rail companies inspired productivity improvements both related to and independent of the consolidation of the rail industry and the reduction of redundancies in the rail network. As the rail industry consolidated, many jobs were eliminated and replaced with investments in capital equipment. Unit trains, as long as 110 railcars and dedicated to the servicing of a single destination, contributed to improvements in average train speed and fuel economy. Larger, more powerful locomotives and the use of lighter aluminum rail cars, rather than those made entirely of steel, have also had a beneficial impact on productivity. Bigger rail cars, capable of holding 100 tons each, longer train sets, and double tracking are also among the improvements cited by the rail industry.

The Clean Air Act Amendment of 1990 (CAA90) imposed sulfur dioxide emissions limits on the electric power industry. As a result, more low sulfur western coal was being used and shipped to locations much further away than previously thought practical. This coal, lower in thermal content than typical eastern bituminous coals, previously was regarded as too high in moisture content and too volatile to transport long distances. Also, transportation rates from western supply regions became increasingly competitive to help western coal penetrate eastern markets. Lower competitively priced transportation rates coupled with low western minemouth prices and lower sulfur content made many generators interested in at least trying western subbituminous coal. For *AEO2011* for the West transportation index, an increasing share of western coal required to satisfy national coal demand is assumed to be negatively correlated with transportation rates.

The railroad industry is capital intensive and requires investments in the purchase and servicing of equipment such as freight cars, land, inventory, and structures such as tracks. Without investments in capital structure, many productivity improvements would not have occurred in the historical period. For this reason, some representation of investment was deemed to be a necessity for the current formulation. For the east regression, the PPI for rail transportation equipment was transformed into a user cost of capital for rail equipment by accounting for the interest rate, depreciation, and any capital gain or loss associated with the investment. Unlike productivity, which is expected to push prices downward, with all other variables held constant, an increase in the user cost of capital tends to increase transportation rates. For the west, the same term did not prove significant. Instead, gross capital expenditures for Class I railroads was used as a proxy for western railroad investments.

While diesel fuel historically has represented a fairly small share, 9 percent[23], of the railroad operating costs and fixed charges, recent years' high fuel costs are assumed to have an increasing impact on overall transportation costs. The diesel fuel price is included as an explanatory variable for the eastern formulation for 2001 through 2006. Diesel fuel prices did not appear to be significant for the western formulation and do not have an effect on the formula for the east in the years prior to 2001.

For the dependent variable, calculated prices from the Coal Transportation Rate Database (CTRDB) were used to develop the index for the historical period from 1980 to 1999. This data was based on the FERC 580 Form in combination with supplemental data from the Surface Transportation Board's Carload Waybill Sample. Multi-mode shipments were included with rail since rail travel is frequently a component of multi-mode shipments. For the time period, 2000 through 2006 average transportation rates were inferred from the FERC Form 423 and EIA-423 surveys and the EIA Form 7A. The 423 surveys provide delivered price information for the electricity sector while minemouth prices are obtained from the EIA-7A survey. The difference between the delivered prices and minemouth price is assumed to be the transportation rate. The resulting data series was merged with the CTRDB data by rebasing both series to their respective 1999 values (indexed to 1.00).

[23] Association of American Railroads, *AAR Railroad Cost Indexes* (September 2003), p. 4.

The regression analysis relies on the following explanatory variables: productivity, user cost of capital of railroad equipment (east), investment dollars (west), diesel fuel price (east), and western share of national coal demand (west). These were chosen due to their ability to explain the historical time period, their availability, the ability to develop reasonable estimates of their future values for NEMS, and their ability to generate a statistically reasonable regression.

Equation Specification

EAST INDEX = f(PRODUCTIVITY, USER COST OF CAPITAL OF RAILROAD EQUIPMENT, DIESEL FUEL PRICE)

and

WEST INDEX = f(PRODUCTIVITY, INVESTMENT DOLLARS, WESTERN SHARE OF NATIONAL COAL DEMAND)

Variables:

EAST and WEST INDEX, the dependent variables, are the values of the transportation price index in year t for coal originating East of the Mississippi River and West of the Mississippi River, respectively. For the historical data series (1980 through 1999), this value is calculated from the yearly average transportation rates (dollars per ton) calculated from the CTRDB for rail and multi-mode shipments of coal originating from eastern supply sources for the East index and from western supply sources for the West index. The CTRDB nominal dollars per ton is subsequently divided by the chain-weighted implicit gross domestic product (GDP) deflator to convert the rate to real 1987 dollars, and has a value of 1 in 1999 because it was rebased to 1999.

The CTRDB represents only a subset of the electric power industry. The CTRDB, is mainly based on the FERC 580 Form, "Interrogatory on Fuel and Energy Purchase Practices," which collects information from jurisdictional utilities (investor-owned utilities that sell electric power at wholesale prices to other utilities) owning at least one power plant of 50 MW or more. The FERC 580 collects coal shipment information and transportation costs related to contract shipments between coal utilities and coal producers and brokers of one year or greater in duration on a biannual basis. This database is also supplemented with data from the Surface Transportation Board's Carload Waybill Sample.

For 1998 through 2006, transportation rate data were imputed using the difference between the delivered price of coal to the electricity sector on the FERC and EIA-423 and the minemouth prices from the EIA-7A. This methodology was not used for earlier years due to the unavailability of data before 1998. For this series, data were rebased so that 1999 equals 1.00 and then merged with the CTRB data for the years 1999 through 2006.

PRODUCTIVITY is defined as billion ton-miles per employee per year for Class I railroads classified as Western carriers for 1980 through 1999. This variable has not been converted to an index. The ton-miles and employee information is derived from data collected by the Association of American Railroads (AAR) and annual reports from the major four largest freight railroads and represents productivity for these railroads’ entire freight traffic, not just coal.

Ton-miles per employee is calculated by multiplying the total revenue tons by the average length of haul for all freight shipments divided by the number of railroad employees for Class I railroads. Class I railroads are defined by the Surface Transportation Board as those line haul freight railroads whose earning adjusted annual operating revenues for three consecutive years exceeds 250 million dollars.[24] The definition of Class I railroads has changed over time as the revenue criteria has changed and railroads enter and exit the railroad industry. Class I railroads generate the majority of the revenue and move the majority of the freight in the rail industry. In performing the calculation, east tons and average haul are calculated from shipments originating in the East while west tons and average haul are calculated from shipments originating in the West. In calculating the number of Eastern employees, the following railroad companies were included in the historical series: CSX Transportation, Norfolk Southern, Consolidated Rail, Illinois Central, and Florida East Coast Railway Company. In calculating the number of Western employees, the following railroad companies were included in the historical series: Union Pacific, Burlington Northern & Santa Fe, Southern Pacific, Atchison, Topeka & Santa Fe, Chicago & North Western, Grand Trunk Corporation, Soo Line Railroad, and Kansas City.

USER COST OF CAPITAL OF RAILROAD EQUIPMENT (UCC) is calculated from the producer price index (PPI) for railroad equipment. The PPI is obtained from the Bureau of Labor Statistics series WPS144. The user cost of capital is intended to capture the true cost of purchasing transportation equipment. The user cost of capital accounts for the opportunity cost of money used to purchase the equipment, depreciation occurring as a result of use of the equipment (assumed at 10 percent), less any capital gain associated with the worth of the equipment. The formula to convert the PPI to a user cost of capital is the following:

$$UCC_t = (r_t + \delta - (p_t - p_{t-1})/p_{t-1}) * p_t$$

where

r_t is a proxy for the real rate of interest, where r_t = ((AA Utility Bond Rate$_t$ + greenhouse gas risk premium)/100) – [GDP Deflator$_t$ – GDP Deflator$_{t-1}$)/GDP Deflator$_{t-1}$];

δ is the rate of depreciation on railroad equipment, assumed to equal 10 percent per year;

and

p_t is the PPI for railroad equipment, adjusted to constant 1987 dollars using the GDP deflator for year t.

The three terms represented in the annual user cost of railroad equipment are defined as follows:

rp_t is the opportunity cost of having funds tied up in railroad equipment in year t;

δp_t is the compensation to the railroad company for depreciation in year t; and

$((p_t - p_{t-1})/ p_{t-1}))\ p_t$ is the capital gain on railroad equipment (in a period of declining capital prices, this term will take on a negative value, increasing the user cost of capital for year t).

[24] Surface Transportation Board, Statistics of Cl I Frt Rrs 2003.pdf, web site http://www.stb.dot.gov.

INVESTMENT is calculated from the gross capital expenditures of Class I railroads in a given year, sourced from the *U.S. Census Bureau Statistical Abstract*. These gross capital expenditures include expenditures on equipment, roadway, and structures.

WESTERN SHARE OF NATIONAL TOTAL COAL PRODUCTION is the total proportion of coal produced that is supplied from west of the Mississippi River. This rising share since 1980 has been correlated with declining transportation rates through and including 2005 as the west sought to increase its market share. This variable is assumed to be correlated with changes in transportation rates in the projection period.

RHO: In conducting the regression for the East and West index, the Durbin Watson statistic indicated autocorrelation was present. Autocorrelation indicates that some portion of the error term is capable of being forecasted but is not represented by the independent variables in the equation. A correction for autocorrelation, rho, was incorporated into the equations procedure in TSP 4.5 with the AR1 option for first-order correlation.

A semi-log linear specification was used to develop the West econometric formula. Using ordinary least squares (OLS) regression and correcting for autocorrelation, the following equations were derived:

$$\text{EAST INDEX} = [\text{EAST INDEX}_{t-1}^{rho_e} + (A_E * (1 - rho_e)) + (B1 * \text{productivity}_t) - (B1 * rho_e * \text{productivity}_{t-1}) + (B2 * \text{uccrequ}_t) - (B2 * rho_e * \text{uccrequ}_{t-1}) + (B3 * \text{DUM05} * \text{diesel fuel price}_t) - (B3 * rho_e * \text{DUM05} * \text{diesel fuel price}_{t-1})]/\text{EAST INDEX}_O$$

$$\text{WEST INDEX} = [\text{WEST INDEX}_{t-1}^{rho} * \exp(A_W * (1 - rho_w)) + (B5 * \text{invest}_t) - (B5 * rho_w * \text{invest}_{t-1}) + (B4 * \text{productivity}_t) - (B4 * rho_w * \text{productivity}_{t-1}) + (B6 * \text{DUM} * \text{wshnatl}_t) - (B6 * rho_w * \text{DUM} * \text{wshnatl}_{t-1})]/\text{WEST INDEX}_O$$

where

A_E = constant term
B1 = the regression coefficient for productivity
B2 = the regression coefficient for the user cost of capital
B3 = the regression coefficient for the diesel fuel price
DUM05 = 1 if year 2005, else 0
rho_e= correction for autocorrelation
EAST $INDEX_O$ = the value of EAST INDEX in the base year of the forecast (2009)
A_W = constant term
B5 = 0the regression coefficient for investment
B4 = the regression coefficient for productivity
B6 = the regression coefficient for the western share of national coal demand
DUM = 1 for years < 2006, but 0 for 2006
rho_w = correction for autocorrelation

WEST $INDEX_O$ = the value of WEST INDEX in the base year of the forecast (2009)
uccrequ = user cost of capital for railroad equipment
wshnatl = western share of national coal demand for 1981-2005
invest = Class I railroad investment dollar index

Table 2.D-1. Statistical Regression Results

	EAST INDEX	WEST INDEX
Method of estimation:	Ordinary Least Squares	Ordinary Least Squares
Number of observations:	27 (years 1980-2006)	26 (years 1981-2006)
Mean of dependent variable:	1.29086	0.262376
Standard deviation of dep. var.:	.216717	0.335155
Sum of squared residuals:	.131569	0.045453
Variance of residuals:	0.598043^{-02}	0.216443^{-02}
Standard error of regression:	0.077333	0.0465223
R^2:	0.892330	0.984019
Adjusted R^2:	0.872753	0.980975
Rho:	0.361206	0.547600
Durbin-Watson:	1.77288	1.85383
Schwarz B.I.C.:	-29.710825.3577	-37.9701
Log likelihood:	37.856133.5973	46.1153

EAST INDEX

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*	*P-value*
Constant	1.59107	0..120371	13.2180	[0.000]
Productivity	-0.124193	.013626	-9.11410	[0.000]
User cost of capital for rail equipment	0.011394	0.486063^{-02}	2.34421	[0.019]
Diesel fuel price	0.077039	0.010463^{-02}	7.36320	[0.000]
Rho	0.361206	0.203607	1.77403	[0.076]

WEST INDEX

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*	*P-value*
Constant	0.632603	0.132541	4.77287	[0.000]
Productivity	-0.111765	0.010056	-11.1148	[0.000]
Western share of national coal demand for years less than 2006	-0.264830	0.087420	-3.02939	[0.002]
Investment	0.434937	0.154393	2.81707	[0.005]
Rho	0.547600	0.232696	2.35329	[0.019]

Table 2.D-2. Data Sources for Transportation Variables

Variable	Units	Historical Data	Forecasted Data
Transportation Rate	No units (index)	**1980-1999**:Derived from U.S. Energy Information Administration, Coal Transportation Rate Database (CTRDB); **2000-2006**: imputed from difference between delivered prices on FERC/EIA Form 423 and minemouth prices from EIA-7A	Forecasted endogenously from econometric equation.
Productivity	Billion Freight Ton-Miles/Employee	Derived from data from the Association of American Railroads and Class I Railroads' Annual 10-K Reports	Projected to remain flat from 2009 levels
User Cost of Capital for Rail Equipment	No units (index)	Derived from the PPI for rail equipment from Bureau of Labor Statistics (Series WPS144).	PPI for rail equipment was assumed to change proportionately with year-over-year changes in national coal ton-miles (estimated by model)
Gross Capital Expenditures (includes equipment, roadway, and structures) for Class I railroads	Million Dollars	U.S. Census Bureau, *Census Bureau Statistical Abstract*, (Washington, DC, various editions), web site http://www.census.gov/compendia/statab/	Changes proportionately with year-over-year change in national coal ton-miles (estimated by model)
Western share of national coal demand	Percentage	Energy Information Administration, *Annual Energy Review 2007*, (Washington, DC, June 2007), Table 3.3, web site http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf	Linked to model output
Diesel Price	Dollars per million Btu	U.S. Energy Information Administration, *Annual Energy Review 2007*, (Washington, DC, June 2007), Table 3.3, web site http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf	The coefficient in changed to zero in order to avoid double-counting the effects of the fuel surcharge discussed below.

Table 2.D-3: Historical Data Used to Calculate East Index

Year	Productivity (East ton-miles/East employees)	UCC Rail Equip	Diesel Fuel Price (nominal dollars per mmBtu)	Transportation Rate (1987 dollars, 1999=1.00)	GDP Deflator
1980	1.75	12.63	5.90	1.43	0.74
1981	1.82	21.39	7.17	1.58	0.81
1982	1.82	25.11	6.79	1.58	0.86
1983	2.24	24.54	5.96	1.61	0.89
1984	2.48	24.53	5.93	1.62	0.92
1985	2.52	21.81	5.69	1.48	0.95
1986	2.63	20.35	3.45	1.49	0.97
1987	3.11	21.30	3.97	1.45	1.00
1988	3.40	18.26	3.61	1.47	1.03
1989	3.54	14.44	4.22	1.39	1.07
1990	3.94	16.62	5.23	1.37	1.11
1991	4.09	16.99	4.67	1.34	1.15
1992	4.32	18.13	4.46	1.20	1.18
1993	4.66	16.80	4.34	1.24	1.21
1994	5.07	15.75	3.99	1.12	1.23
1995	5.35	14.44	4.04	1.14	1.26
1996	5.68	16.89	4.91	1.14	1.28
1997	6.07	19.96	4.63	1.14	1.30
1998	6.20	17.08	3.56	1.05	1.32
1999	6.04	17.54	4.21	1.00	1.34
2000	6.59	17.54	6.74	0.99	1.37
2001	6.94	17.27	6.07	1.24	1.40
2002	7.47	16.48	5.49	1.15	1.42
2003	7.78	14.37	6.81	0.91	1.45
2004	8.52	10.14	8.96	0.96	1.50
2005	8.35	4.40	12.88	1.29	1.54
2006	8.34	10.96	15.11	1.51	1.59

Table 2.D-4: Historical Data Used to Calculate West Index

Year	Productivity (West ton-miles/West employees)	Investment (1987 dollars, 1981= 1.00)	Western Share of National Coal Demand	Transportation Rate (1987 dollars, 1999=1.00)	GDP Deflator
1981	2.50	1.00	0.24	1.89	0.81
1982	2.57	0.97	0.24	1.96	0.86
1983	2.98	0.93	0.24	1.96	0.89
1984	3.31	1.19	0.24	2.15	0.92
1985	3.32	1.15	0.29	2.04	0.95
1986	3.64	1.13	0.23	2.13	0.97
1987	4.41	1.12	0.24	1.94	1.00
1988	4.88	1.12	0.26	1.73	1.03
1989	5.18	1.11	0.26	1.65	1.07
1990	5.47	1.06	0.30	1.57	1.11
1991	5.78	1.06	0.32	1.34	1.15
1992	6.21	1.04	0.31	1.33	1.18
1993	6.54	1.04	0.36	1.25	1.21
1994	7.20	1.05	0.36	1.19	1.23
1995	8.03	1.07	0.39	1.17	1.26
1996	8.64	1.15	0.37	1.10	1.28
1997	8.58	1.18	0.36	1.09	1.30
1998	8.71	1.24	0.38	1.02	1.32
1999	9.43	1.30	0.42	1.00	1.34
2000	10.11	1.30	0.42	0.92	1.37
2001	10.72	1.31	0.43	0.87	1.40
2002	11.00	1.30	0.44	0.87	1.42
2003	11.49	1.39	0.45	0.83	1.45
2004	11.94	1.42	0.48	0.83	1.50
2005	11.71	1.53	0.51	0.89	1.54
2006	11.97	1.54	0.53	0.97	1.59

For the projection period, the explanatory values are assumed to have varying impacts on the calculation of the indices. For both the east and the west indices, investment is assumed to occur in response to changes in demand. This is measured by the change in ton-miles, as calculated by the model. If national ton-miles increase, the terms representing investment (for both the east and the west) are assumed to increase. Likewise, if ton-miles decrease, investment may decline. This assumption is derived partly from the assertion by railroads that they will be hesitant to make investments in capacity unless the demand is already present. Industry documents indicate that capital programs are correlated with the revenue received. Changes in ton-miles are naturally correlated with changes in revenue. In addition, other analysis has concluded that transportation investment is more sensitive to business cycles than other businesses. An increase in ton-miles necessitates investment to expand capacity and alleviate congestion, and a decline in ton-miles will similarly discourage investments.

Historically, cost savings derived from improvements in productivity have been accompanied by declining transportation rates. For both the east and the west, any related financial savings due to productivity improvements through 2035 are assumed to be retained by the railroads and are not passed on to shippers in the form of lower transportation rates. For that reason, productivity is held flat for the projection period for both regions. For the east, for the projection period, diesel fuel is removed from the equation in order to avoid double-counting the influence of diesel fuel costs with the impact of the fuel surcharge program.

Fuel Surcharge

Major coal rail carriers have implemented fuel surcharge programs in which higher transportation fuel costs have been passed on to shippers. While the programs vary in their design, the Surface Transportation Board (STB), the regulatory body with limited authority to oversee rate disputes, has recommended that the railroads agree to develop some consistencies among their disparate programs and has likewise recommended closely linking the charges to actual fuel use. The STB has cited the use of a mileage-based program as one means to more closely estimate actual fuel expenses.

A fuel surcharge program was incorporated into the coal transportation rates for the first time in *AEO2007* and was based on BNSF Railway Company's mileage-based program for all regions. For *AEO2011*, the methodology is based on BNSF Railway Company's mileage-based program for western coal sources and for the east, the methodology is base on CSX Transportation's mileage-based program. The surcharge becomes effective when the projected nominal distillate price to the transportation sector exceeds $1.25 per gallon for the west and $2.00 per gallon for the east. For the west, for every $0.06 cent per gallon increase above $1.25, a $0.01 per carload mile is charged, and for the east, every $0.04 cent per gallon increase above $2.00, a $.01 per gallon fee is assessed. The number of tons per carload and the number of miles vary with each supply and demand region combination and are a pre-determined model input. The final calculated surcharge (in constant dollars per ton) is added to the escalator-adjusted transportation rate.

For *AEO2011*, it was assumed that the base year (2009) transportation rates already included an assessed fuel surcharge. For *AEO2011*, the model calculates the fuel surcharges for 2009 and subtracts it from the corresponding base year transportation rate. These modified, lower, base year transportation rates are used in subsequent forecast years and the fuel surcharges and transportation escalators for a specific forecast year are applied to these lower rates.

CDS Data Sources

EIA maintains a number of annual surveys of coal production and distribution. The agency also has access to several data surveys collected for the Federal Energy Regulatory Commission (FERC) that report the fuel purchase and delivery practices of the Nation's electricity sector. Other information comes from Census Bureau forms reporting coal imports and exports. Data from the Association of American Railroads, the Surface Transportation Board, the Mine Safety and Health Administration, and State agency reports of mining activity supplement these sources.

- Form EIA-3, "Quarterly Coal Consumption and Quality Report, Manufacturing and Transformation/Processing Coal Plants and Commercial and Institutional Users," surveys heat, sulfur and ash content of coal receipts delivered to industrial steam, commercial, and institutional coal consumers by consumption location and state of origin.

- Form EIA-5, “Quarterly Coal Consumption and Quality Report, Coke Plants,” surveys volatility, sulfur and ash content of coal receipts delivered to coke plants by consumption location and state of origin.

- Form EIA-7A,"Coal Production and Preparation Report," covers coal producers and coal preparation plants and reports production, minemouth prices, coal seams mined, labor productivity, employment, stocks, and recoverable reserves at mines.

- Form EIA-423, “Monthly Cost and Quality of Fuels for Electric Plants Report,” covers electric non-utility plants with capacity of 50 MW or more and reports delivered cost, receipts, ash, Btu, sulfur ("As Received" basis), and sources. Beginning for 2008 data, Form EIA-923 replaces the EIA-423.

- FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants," covers electric utility plants with capacity of 50 MW or more and reports delivered cost, receipts, ash, Btu, sulfur ("As Received" basis), and sources. Beginning for 2008 data, Form EIA-923 replaces the EIA-423.

- Form EIA-923, “Power Plant Operations Report,” collects information from regulated and unregulated electric power plants in the United States. Data collected include electric power generation, energy source consumption, end of reporting period fossil fuel stocks, as well as the quality and cost of fossil fuel receipts.

- FERC Form 580, "Interrogatory on Fuel and Energy Purchase Practices", was a biennial survey of investor-owned utilities selling electricity in interstate markets and having capacity over 50 MW; coverage of contractual base tonnage, tonnage shipped, ash, Btu, sulfur and moisture ("As Received" basis), minemouth price, freight charges, coal source and destination, shipping modes, transshipments (if any), and distances.

- Form EM 545 from the U.S. Census Bureau records coal exports by rank, value and tonnage from each port district. The U.S. Census Bureau’s Form IM 145 reports imports by rank, value, tonnage, and port district.

- The Carload Waybill Sample, administered by the Surface Transportation Board, contains confidential information on a sample of waybills from those railroads that terminate at least 4,500 cars per year. The data collected includes origin, destination, tons, commodity type, revenue, and distance information. This information has been used to supplement EIA’s CTRDB database.

Data Gaps

The resources that are available to support the NEMS CPS and CDS include a series of databases derived from a variety of surveys that are valuable for their national scope and Census-like coverage. However, as shown in Table 2.D-5, no data from mines are routinely collected on the quality of coal produced at the mine or the minemouth price for coals of different quality levels.

The EIA-923 has replaced the FERC Form 423 and the EIA-423 and now asks for mine origin information in addition to coal quality information. By doing this, in some instances, it is possible to infer some coal quality information for particular mines when the respondents have specific knowledge of their coal supplier. The EIA-923 together with the forms EIA-3 and EIA-5 (which provide state origin information) provide some coal quality data that assists in assigning coal quality information to coal supply regions.

While EIA publishes data identifying the tonnage of exported coal mined in each State and the Department of Commerce collects data on the tonnage exported (by port district), there are no available data to identify the tonnage from each mining State that is exported at each port of exit. Coals consumed by surveyed sectors (electricity, industrial, commercial/institutional and coking coal) are known to differ in quality from coals delivered to sectors currently unsurveyed (the residential, export metallurgical and export steam sectors). The EIA-7A requests information about export quantities. Where the coal quality characteristics of the mine can be inferred from information gathered on the EIA-923, some coal quality characteristics for exports can be likewise deduced. Consumption in the unsurveyed sectors currently accounts for a small percentage of production.

The difference between delivered costs as shown on the EIA-923, EIA-3, EIA-5, and EM 545 and minemouth costs as shown on Form EIA-7A in the most recent available historical year is used to estimate transportation rates. (Although commodity cost and delivered cost are available on the EIA-923, transportation rates are not currently calculated from the EIA-923 alone due to insufficient or incomplete information from the respondents.) The use of this method allows estimation of different rates from each supply curve to each sector in each demand region, but—even if data for more remote historical years were used—can do little to provide transportation rates for routes that have not been used. More than half the routes indicated by the CDS supply and demand region classification structures have not been used for coal transport in significant quantities in recent years. In the version of the CDS documented here, rates for these routes have been synthesized using available data on tariff rates and analytical judgment, while others that are unlikely to be used are given dummy values that prevent their use.

The general availability of coal-related data that were used to build and calibrate the CDS for the *Annual Energy Outlook 2011* is summarized in Table 2.D-5.

Table 2.D-5. Survey Sources Used to Develop CMM Inputs

	Electricity	Industrial	Coking	Commercial/ Institutional[1]	Export	Import	Mine
Prices:							
Minemouth Prices							EIA-7A
Delivered Prices	EIA-923	EIA-3	EIA-5	EIA-3	EM 545[2]	EIA 3,5,923	
Transportation:							
Transportation Mode	EIA-923	EIA-3	EIA-5	EIA-3			
Origin	EIA-923	EIA-3	EIA-5	EIA-3	EIA-7A	IM 145[2]	EIA-7A
Destination	EIA-923	EIA-3	EIA-5	EIA-3	EM 545[2]	EIA 3,5,923	
Tonnage:							
Production					EIA-7A		EIA-7A
Receipts	EIA-923	EIA-3	EIA-5	EIA-3		EIA 3,5,923 and IM 145[2]	
Distribution	EIA-923	EIA-3	EIA-5	EIA-3	EM 545[2]	EIA 3,5,923 and IM 145[2]	
Consumption	EIA-923	EIA-3	EIA-5	EIA-3			
Contract Information	EIA-923					EIA-923	
Quality:							
Rank	EIA-923	EIA-3	EIA-5	EIA-3	EM 545[2]	EIA 3,5,923	EIA-7A
Heat Content	EIA-923	EIA-3		EIA-3		EIA 3,923	
Sulfur Content	EIA-923	EIA-3	EIA-5	EIA-3		EIA 3,5,923	
Ash Content	EIA-923	EIA-3	EIA-5	EIA-3		EIA 3,5,923	
Mercury Content	EIA-923	EIA-3	EIA-5	EIA-3		EIA 3,5,923	
Volatile Matter			EIA-5				

Notes:
1 Commercial/Institutional replaces Residential/Commercial and excludes residential information.
2 The EM 545 and the IM 145 are reports from the U.S. Bureau of Census.

Appendix 2.E

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Appendix 2.F

Coal Distribution Submodule Program Availability

The source code for the CDS program is available from the program office:

Office of Office of Electricity, Coal, Nuclear and Renewables AnalysisOffice of Electricity, Coal, Nuclear and Renewables Analysis
EI-34
U.S. Energy Information Administration
U.S. Department of Energy
1000 Independence Avenue S.W.
Washington, DC 20585
Telephone: (202) 586-2415

3. **Coal Distribution Submodule — International Component**

Introduction

The purpose of Section 3 of the Coal Market Module documentation is to define the objectives of the modeling approach used to forecast international coal trade in the Coal Distribution Submodule (CDS), to describe the basic approach, and to provide information on the model formulation and application. It is intended as a reference document for the model analysts, users, and the public. The report conforms to requirements specified in Public Law 93-275, Section 57(B)(1) (as amended by Public Law 94-385, Section 57.b.2).

Model Summary

The international component of the CDS projects coal trade flows from 17 coal-exporting regions (5 of which are in the United States) to 20 importing regions (4 of which are in the United States) for 3 coal types—coking, low-sulfur bituminous, and subbituminous. The model consists of exports, imports, trade, and transportation components. The major coal exporting countries represented include: the United States, Australia, South Africa, Canada, Indonesia, China, Colombia, Venezuela, Poland, the countries of the Former Soviet Union, and Vietnam. Beginning with the *AEO2006*, the structure of the international component of the CDS has been updated to endogenously model U.S. imports. The U.S. import algorithm is integrated with the domestic component of the CDS.

Model Archival Citation and Model Contact

The version of the CDS documented in this report is that archived for the forecasts presented in the *Annual Energy Outlook 2011*.
Name: Coal Distribution Submodule-International Component
Acronym: CDS
Archive Package: NEMS11 (Available from the U.S. Energy Information Administration, Office of Electricity, Coal, Nuclear and Renewables Analysis)
Model Contact:

Diane Kearney, Department of Energy, EI-34, Washington DC 20585
(202) 586-2415 or (Diane.Kearney@eia.gov)

Organization

This section of the report describes the modeling approach used in the International Component of the CDS used to project international coal trade. Subsequent sections of this report describe the following:

- The model objective, input and output, and relationship to other models
- The theoretical approach, assumptions, and other approaches
- The model structure, including key computations and equation

An inventory of model inputs and outputs, detailed mathematical specifications, bibliography, and model abstract are included in the Appendices.

Model Purpose and Scope

Model Objectives

The objective of the international component of the CDS is to provide annual forecasts (through 2035) of world coal trade flows.

Coal exports in the international area of the CDS is modeled using 3 coal types, premium bituminous, low-sulfur bituminous, and subbituminous coals (Table 3.1). These coal types represent unique combinations of heat and sulfur content. There are 17 geographic export regions (Table 3.2) including 5 U.S. export regions, 2 Canadian export regions, and 10 additional major coal exporting countries. The 5 U.S. coal export regions in the CMM (Figure 3.2) include the Northern Interior, the East Coast, the Gulf Coast, the Southwest and West, and the Non-Contiguous U.S. These U.S. regions represent aggregations of ports-of-exit through which exported coal passes on its way from domestic export regions to foreign consumers. For instance, the Northern Interior includes 12 ports of exit including locations ranging from Boston, MA to Great Falls, MT. The Non-Contiguous U.S. region is only represented by two ports of exit, Anchorage and Seward, AK. These domestic port districts are identified in Table 3.2.

The coking and steam sectors define the international coal import sectors. The CMM coal types available to satisfy imports for the two international coal sectors are listed in Table 3.1. There are 20 coal import regions represented in the CMM (Table 3.3). The coal import regions for the U.S. are the same as the coal export regions except that the Southwest and West is excluded. Canada is split into two coal import regions, Eastern and Interior. The remaining 14 coal import regions are represented as either individual countries or groups of two or more countries.

The U.S. share of world coal markets is defined as a linear optimization problem and is solved simultaneously with the domestic coal forecast.

Four key user-specified inputs are required. They include coal import requirements, coal export curves, transportation costs, and constraints (Figure 3.1). The primary outputs are annual world coal trade flows.

Relationship to Other Modules

The model generates regional forecasts for U.S. coal exports. These international U.S. export requirements are shared with to the domestic portion of the CDS so that sufficient production is allocated to U.S. exports. The CDS also projects U.S. imports required to satisfy coal demand in the U.S. established by the industrial and electricity models.

. **Table 3.1. CDS International Coal Export Types and Demand Sectors**

Coal Export Type	Heat Content (million Btu per short ton)	Sulfur Content (Pounds sulfur per million Btu)	Corresponding NEMS CPS/CDS Coal Types	Demand Sector
Premium	>=25	<1.67	MDP, CDP	Coking or Steam
Low-Sulfur Bituminous	>=20 but < 25	<1.67	CDB, CSB, MDB, MSB	Steam
Subbituminous	<=15 but < 20	<0.60	CSS	Steam

Note: For definitions of NEMS CPS/CDS coal types see Table 1.1 of this report

Figure 3.1. International Component Inputs/Outputs

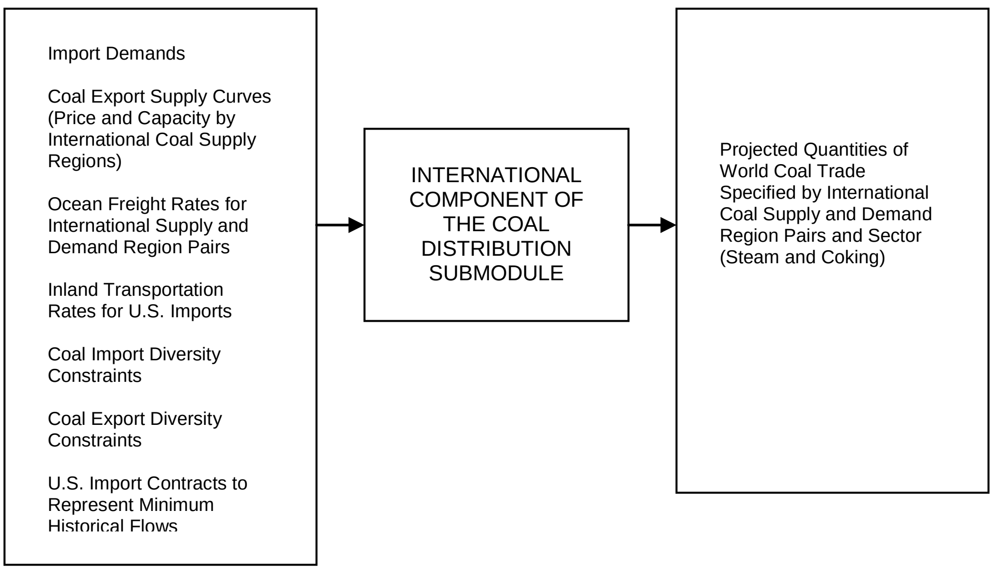


Figure 3.2. U.S. Export and Import Regions Used in the CDS

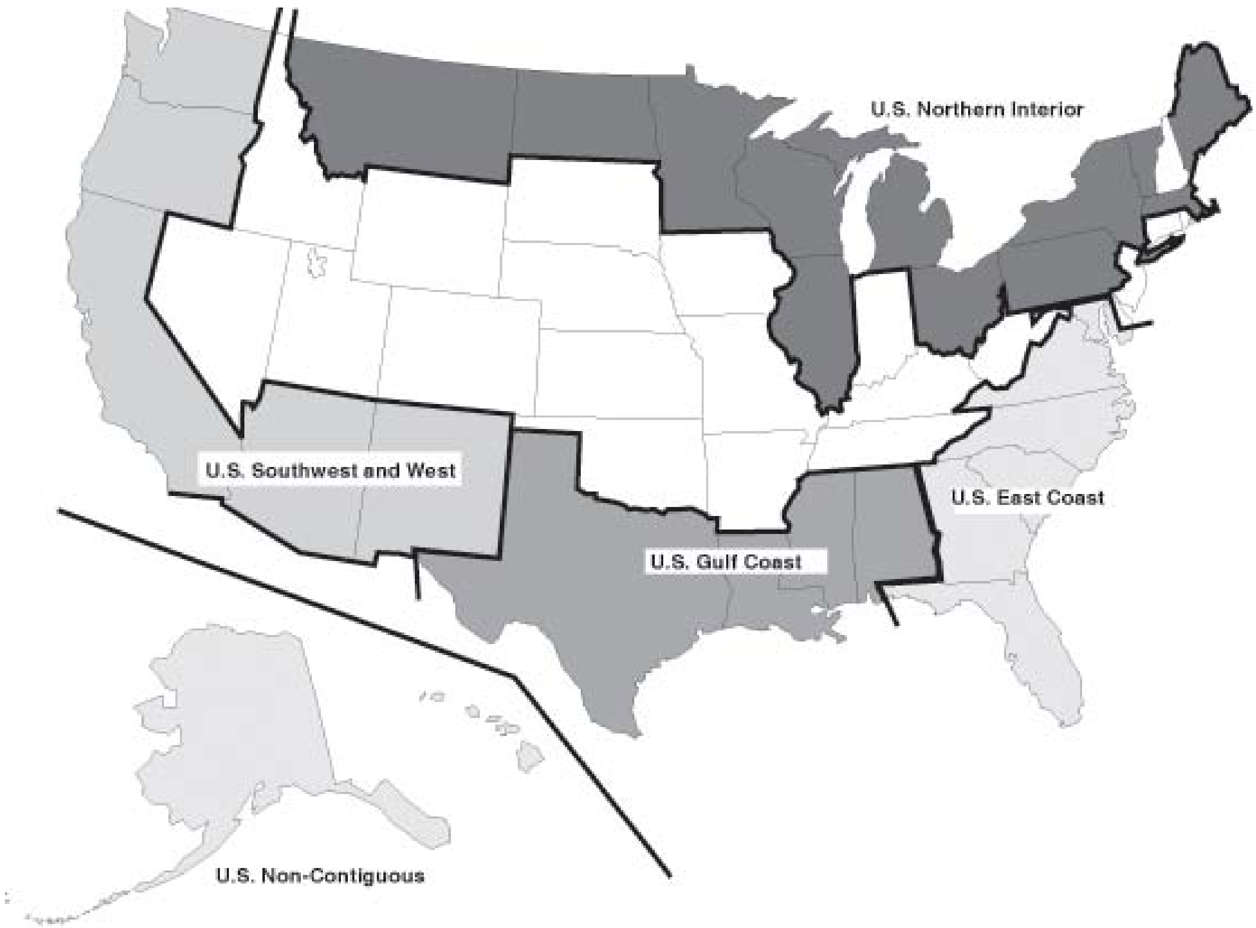


Table 3.2. CDS Coal Export Regions

Export Regions	Domestic Port Districts
1 U.S. Interior (I)	Boston, MA
	Portland, ME
	St. Albans, VT
	Buffalo, NY
	Ogdensburg, NY
	New York, NY
	Philadelphia, PA
	Detroit, MI
	Cleveland, OH
	Duluth, MN
	Pembina, ND
	Great Falls, MT
2 U.S. East Coast (E)	Baltimore, MD
	Norfolk, VA
	Charleston, SC
	Savannah, GA
	Miami, FL
	San Juan, PR
	US Virgin Islands
	Tampa, FL
3 Gulf Coast (G)	Mobile, AL
	New Orleans, LA
	Houston-Galveston, TX
	Laredo, TX
	El Paso, TX
4 Southwest and West (W)	Nogales, AZ
	San Diego, CA
	Los Angeles, CA
	San Francisco, CA
	Stockton, CA
	Richmond, CA
	Portland, OR
	Seattle, WA
5 U.S. Non-Contiguous (A)	Anchorage, AK
	Seward, AK
6 Australia	NA
7 Canada, Western	NA
8 Canada, Interior	NA
9 South Africa	NA
10 Poland	NA
11 Eurasia (exports to Europe)	NA
12 Eurasia (exports to Asia)	NA
13 China	NA
14 Colombia	NA
15 Indonesia	NA
16 Venezuela	NA
17 Vietnam	NA

NA = Not applicable.

Table 3.3. CDS Coal Import Regions

Import Regions	Countries
1 U.S. East Coast (E)	NA
2 U.S. Gulf Coast (G)	NA
3 U.S. Northern Interior (I)	NA
4 U.S. Non-Contiguous (N)	NA
5 Canada, Eastern	NA
6 Canada, Interior	NA
7 Scandinavia	Denmark
	Finland
	Norway
	Sweden
8 United Kingdom/Ireland	NA
9 Germany/Austria	NA
10 Other NW Europe	Belgium
	France
	Luxembourg
	Netherlands
11 Iberia	Portugal
	Spain
12 Italy	NA
13 Med./E.Europe	Algeria
	Bulgaria
	Croatia
	Egypt
	Greece
	Israel
	Malta
	Morocco
	Romania
	Tunisia
	Turkey
14 Mexico	NA
15 South America	Argentina
	Brazil
	Chile
	Peru
	Puerto Rico
16 Japan	NA
17 East Asia	North Korea
	South Korea
	Taiwan
18 China/Hong Kong	NA
19 ASEAN	Malaysia
	Philippines
	Thailand
20 Indian sub/S. Asia	Bangladesh
	India
	Iran
	Pakistan
	Sri Lanka

NA = Not applicable.

Model Rationale

Theoretical Approach

The core of the international component of the CDS is a linear programming optimization model. This LP finds the pattern of coal production and trade flows that minimizes the production and transportation costs of meeting a set of regional net import requirements. The basic underlying assumption regarding the modeling of international coal trade in the CDS is that the international coal market is essentially a perfectly competitive market. The key conditions of a perfect market are that there are no real significant barriers to entry and exit on the export side, there are a large number of buyers and sellers, and no single buyer or seller controls enough of the market so as to be able to exert pricing power.

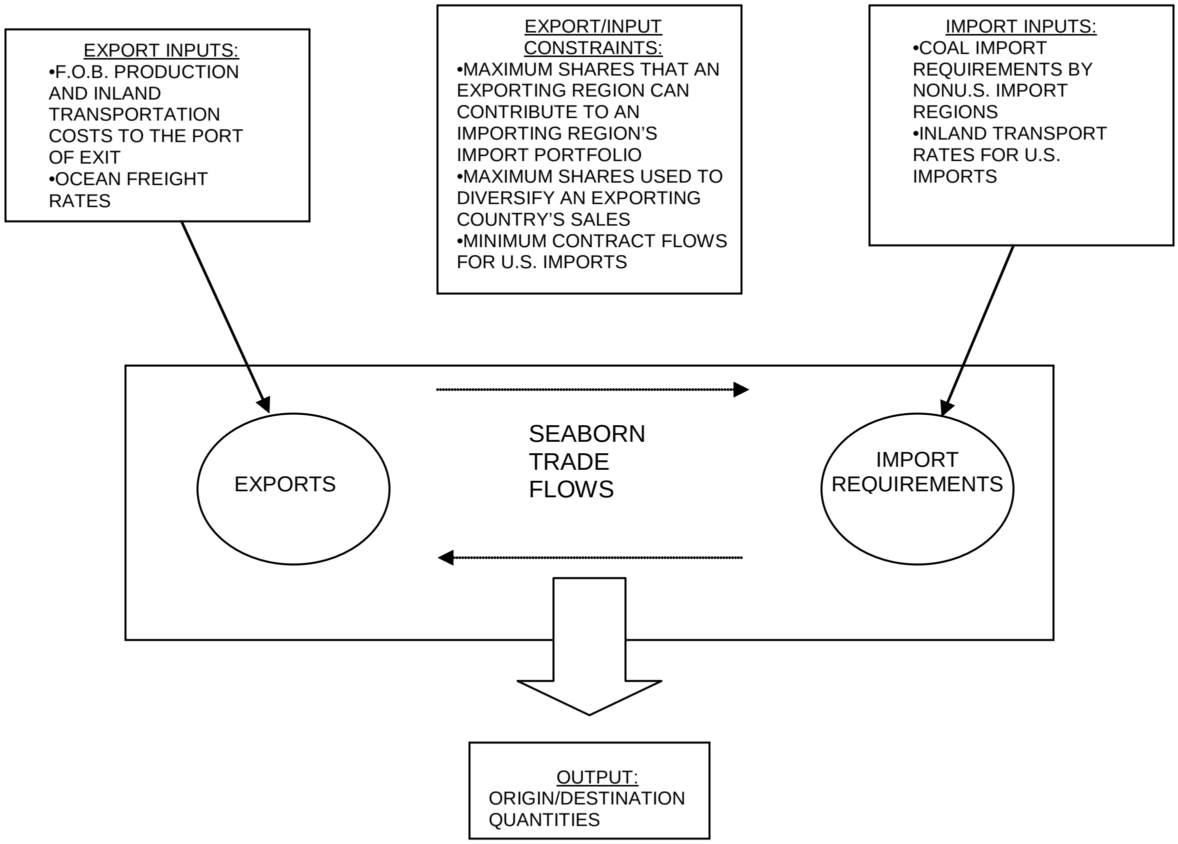
While a perfectly competitive market is the basic underlying assumption used for modeling international coal trade in the CMM, the model solution is subject to a number of key constraints:

- Export capacity of export regions
- Maximum share that any importing region can take from one exporting region. Coal buyers (importing regions) will tend to spread their purchases among several suppliers in order to reduce the impact of supply disruption, even though this will add to their purchase costs.
- Maximum share that any exporting region will sell to one importing region. Coal producers (exporting regions) will choose not to rely on any one buyer, and will diversify their sales.
- Sulfur dioxide emission limits for U.S. imports. U.S. coal imports are subject to SO_2 emission regulations as set forth under CAAA90 and CAIR. This is modeled by intersecting emissions from thermal imports in the electricity sector with the sulfur dioxide emissions constraint in the domestic component of the CDS
- Mercury emission limits for U.S. coal imports. In scenarios where mercury emissions are restricted, imports are subject to the same limits as U.S. coal. When relevant, this is modeled by intersecting emissions from thermal imports in the electricity sector with the mercury row constraint in the domestic component of the CDS.
- Minimum ("contract") flows for U.S. imports. These minimum flows are based on coal receipts data for existing U.S. power plants collected on EIA-923, "Power Plant Operations Report."

Model Structure

The international component of the CDS is specified as part of the overall CDS Linear Program (LP). It satisfies import requirements at all points at the minimum overall "world" coal cost plus transportation cost (Figure 3.3). From the output of the model it is possible to determine an optimum pattern of supply.

Figure 3.3. Overview of the International Component of the CDS



The geographical representation of the "world" is a set of coal export regions (Table 3.2) and coal import regions (Table 3.3). Each coal export region has a quantity of coal available for export, in which this amount available is price dependent. The cost associated with each quantity of coal available for export includes (1) mining costs; (2) representative coal preparation costs, which vary according to export region, coal type, and end-use market; and (3) inland transportation costs (prior to export). This model is driven by fixed (input) coal import requirements for all regions except the U.S. For the U.S., import requirements are derived endogenously, i.e. determined by the model. Diversity constraints limit the portion of a region's imports, by sector, that can be met by each of the individual export regions. If utilized, subbituminous constraints can limit the amount of subbituminous coal that a specific region can import. Each import region may also be restricted to a certain level of sulfur dioxide emissions. Importing countries may be constrained by a maximum expectation of high sulfur coal as a share of their total imports. In scenarios where emissions limits for SO_2, mercury, and/or carbon dioxide are specified for the U.S., imports are also subject to those constraints. Minimum contract constraints for U.S. imports may also be specified. The linear program minimizes the costs associated with exporting coal from one region to an importing region while considering the constraints described above.

Appendix 3.A

Submodule Abstract

Model Name: Coal Distribution Submodule - International Component

Model Acronym: CDS

Description: The international component of the CDS projects coal trade flows from 17 coal-exporting regions (5 of which are in the United States) to 20 importing regions (4 of which are in the United States) for 3 coal types - premium bituminous, low-sulfur bituminous, and subbituminous. The model consists of exports, imports, trade flows, and transportation components. The major coal exporting countries represented include: the United States, Australia, South Africa, Canada, Indonesia, China, Colombia, Venezuela, Poland, Vietnam, and the countries of the Former Soviet Union. The CDS determines the optimal level of coal imports used to satisfy U.S. coal demand for the industrial and electricity sectors.

Purpose: Forecast international coal trade. Provide U.S. coal export and import forecasts to the domestic component of the Coal Distribution Submodule.

Model Update Information: October 2010

Part of Another Model: Yes, part of

- Coal Market Module
- National Energy Modeling System

Model Interface: The model can interface with the following models:

- Coal Distribution Submodule – Domestic Component

Official Model Representative:

Office: Electricity, Coal, Nuclear and Renewables

Division: Coal and Electric Power

Model Contact: Diane Kearney

Telephone: (202) 586-2415

E-mail: (Diane.Kearney@eia.gov)

Documentation:

- *Coal Export Submodule Component Design Report*, U.S. Energy Information Administration, April 1993.

- U.S. Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System*, DOE/EIA-M060(2011) (Washington, DC, June 2011).

Archive Media and Installation Manual:

NEMS11 - *Annual Energy Outlook 2011*

Energy System Described by the Model: World coal trade flows (Coking and Steam)

Coverage:

- **Geographic:** 17 export regions (5 of which are in the United States) and 20 import regions (4 of which are in the United States)

- **Time Unit/Frequency:** Each run represents a single forecast year. Model can be run for any forecast year for which input data are available.

- **Products:** Coking, low-sulfur bituminous coal, and subbituminous coal

- **Economic Sector(s):** Coking and steam

Modeling Features:

- **Model Structure:** Satisfies coal import requirements at the lowest cost given specified export supply curves and transportation.

- **Modeling Technique:** The model is a Linear Program (LP), which satisfies import requirements at all points at the minimum overall "world" coal cost plus transportation cost and is embedded within the Coal Market Module..

- **Special Features:** The model is designed for the analysis of legislation concerned with SO_2 emissions.

- **Input Data:**

  Non-DOE sources—SSY Consultancy and Research, McCloskey Coal Information, Ltd., International Energy Agency. Published trade and business journal articles, including *Platts: International Coal Report, Energy Publishing: Coal Americas*, *Financial Times: International Coal Report*, *McCloskey Coal Report, and World Coal*.

— Coal Import Requirements (Non-U.S.)
— Coal Export Supply Curves
— Ocean Freight Rates
— Diversity Constraints
— Sulfur Emission Constraints
— Subbituminous and High-Sulfur Coal Constraints

DOE sources

- U.S. import inland transportation rates are imputed from similar distanced origin/destination pairs found in the domestic component of the CDS.
- Coal minimum historical flows ("contracts") for electricity sector: (1) coal import regions; (2) international export regions; (3) contract historical volumes (trillion Btu); (4) contract profiles for each forecast year

Computing Environment: See *Integrating Module of the National Energy Modeling System*

Independent Expert Reviews Conducted:

- Kolstad, Charles D., "Report of Findings and Recommendations on EIA's Component Design Report Coal Export Submodule," prepared for the U.S. Energy Information Administration (Washington, DC, April 9, 1993).

Status of Evaluation Efforts Conducted by Model Sponsor: The international component of the CDS is a model developed for the National Energy Modeling System (NEMS) during the 1992-1993 period and revised in 1994. In 2005, the international component of the CDS was revised to include endogenous representation of U.S. imports. The version described in this abstract was used in support of the *Annual Energy Outlook 2011*. No subsequent evaluation effort has been made as of the date of this writing.

Appendix 3.B

Detailed Mathematical Description of the Model

The international component of the CDS is specified as part of the overall CDS Linear Program (LP). It satisfies import requirements at the minimum overall "world" coal cost plus transportation cost. The model output provides an optimum pattern of trade flows.

The geographical representation of the "world" is a set of coal export regions and coal import regions. Each coal export region has a quantity of coal available for export, in which this amount available is price dependent. The cost associated with each quantity of coal available for export is inclusive of (1) mining costs; (2) representative coal preparation costs, which vary according to export region, coal type, and end-use market; and (3) inland transportation costs. For U.S. imports, an additional U.S. inland transportation rate is specified. This represents the cost of moving the imported coal from its port of entry to its point of consumption. The model is driven by fixed (input) coal non-U.S. import requirements. For the first time in the *AEO2006*, the CDS was modified to allow U.S. import requirements to be endogenously determined. The import requirements must be satisfied at the minimum overall cost.

The mathematical specification for the international coal trade optimization program incorporates the following modeling enhancements. The capability of accounting for changes in exchange rates over time is provided for by allowing for the vertical adjustment of coal export supply curves. The reduced cost of supplying coking quality coal to the steam coal market, based on a reduction in coal preparation requirements, is provided for through the adjustment of ocean transportation costs for shipments of coking quality coal to the steam coal market. The model can account for limits on total SO_2 emissions by coal import region through the incorporation of a model constraint. A restriction regarding the maximum permissible sulfur content of coal shipments to an import region as well as restrictions on total coal shipments by coal import region/coal export region pairs can be accounted for in the model as flow constraints, but it is not currently used in the *AEO2011*. In addition, changes in U.S. policies regarding emission limits for SO_2 and mercury and their impacts on U.S. coal imports can be represented. For *AEO2011*, minimum flow ("contract") constraints were added to the model structure for coal imports to the U.S. electricity sector.

Mathematical Formulation

The table of column activity definitions and row constraints defined in the international coal trade matrix incorporate assumptions described in Model Rationale in Section 3 and variable definitions which are described in this section. The general structure of the matrix is shown as a block diagram in Table 3.B-1.

The block diagram format depicts the matrix as made up of sub-matrices or blocks of similar variables, equations, and coefficients. The first column of Table 3.B-1 contains the description of the sets of equations and the equation number as defined later in this section. Subsequent columns define sets of variables for the production, transportation, import, and export of coal. The table column labeled "Row Type," shows the equations to be maximums, minimums, or equalities. Each block within the table is shown with representative coefficients for that block, most typically either a (+/-) 1.0. The last table column, labeled "RHS," an abbreviation for right-hand side, contains symbols that represent the constraint limit

Table 3.B-1. CDS Linear Program Structure – International Component

Coal Distribution Submodule Block Diagram																					
		INTERNATIONAL PRODUCTION FOR SEABORNE EXPORTS		TRANSPORTATION VECTORS								U.S. IMPORTS ONLY				EXPORT VECTORS ONLY			IMPORT VECTOR		
		NON-U.S. PRODUCTION		U.S. PRODUCED/CONSUMED COAL	U.S. IMPORTS INLAND TRANSPORTATION			U.S. EXPORTS INLAND (PRIOR TO EXPORT) TRANSPORTATION	U.S. EXPORTS INTERNATIONAL FREIGHT RATES	NON-U.S. EXPORTS INTERNATIONAL FREIGHT RATES		MERC. PRICE CAP	MERC. ESCAPE VECTOR	ACTIV. CARBON VECTOR	CARBON EMISSION VECTOR	U.S.	U.S.	NON-U.S.	U.S. AND NON-U.S.		
	COLUMN MASK / ROW MASK	PX (ISR) (IS) (STEPS)		SEE CDS LINEAR PROGRAM STRUCTURE -- DOMESTIC COMPONENT FOR DETAIL	(UP)(STEPS)(PT)(ISR)T(DR)	O(UP)I(SN)(ISR)T(DR)	O(UP)M(SN)(ISR) C(DR)	T(USR)(UXSR)X(UXS)(CT)	TX(DR)X(UXS)(IDR)(IS)	TX(ISR)-(IDR)(IS)		MERCEV	MOREHGXX	ACIXSS(STEPS)Y	CARBONXX	TX(DR)X(UXS)(IDR)(IS)	EXP(ISR)	EXP(ISR)	IMP(IDR)(IS)		RHS
Sector:		Thermal	Metallurgical	All	Electricity	Industrial	Metallurgical	All	All	Thermal	Metallurgical	Electricity	Electricity	Electricity	Electricity	Historical Export Bounds	Export Quantity	Export Quantity	Import Quantity		
Objective		+p	+p	+t	+t	+t	+t	+t	+f	+f	+f	+ CAP	+20	+v	+EMETAX						MIN
U.S. IMPORTS STRUCTURE ONLY																					
U.S. Import Demand Rows:	Electricity: D.(DR)(PT)			+1, for electricity vectors	+1															EQ	D
	Industrial: D.(DR)I(SN)			+1, for industrial vectors		+1														EQ	D
	Metallurgical: D.(DR)M(SN)			+1, for metallurgical vectors			+1													EQ	D
U.S. Inland Transportation and International Freight (to U.S.) Balance Rows:	Thermal: TTU(UP)(ISR)XX				+1	+1				-1, if (IDR)=U(UP)										EQ	0
	Metallurgical: TCU(UP)(ISR)XX						+1				-1									EQ	0
Sulfur Dioxide Constraint:	SULFPEN1 (East U.S. demand regions) OR SULFPEN2 (West U.S. demand regions)			+s, for electricity vectors	+s															LE	S
Mercury Constraint:	MERCP01			+m, for electricity vectors	+m							-1	-1							LE	M
Activated Carbon Row:	ACIXXXXY			+a, for activated carbons electricity vectors	+a, for activated carbon vectors only									-10						LE	0
Carbon Constraint:	CARBONXX			+c, for electricity vectors	+c										-1					EQ	0
Historical Flow Constraints:	IMPSTMIN				+mmtons/ trill Btu	+mmtons/ trill Btu	+mmtons/ trill Btu													GE	T_1
	IMPSTMAX				+mmtons/ trill Btu	+mmtons/ trill Btu	+mmtons/ trill Btu													LE	T_2
	IMPMETSW						+mmtons/ trill Btu													GE	T_3
	IMPINDSW					+mmtons/ trill Btu														GE	T_4
	Scrubbed plants: F(ISR)(DR)I1				+1															GE	T_5
	Unscrubbed plants: C(ISR)(DR)I1				+1															GE	T_6
WORLD TRADE STRUCTURE																					
Non-U.S. Production/Shipping Balance	SXX(ISR)(IDR)T	+1								-1										EQ	0
	SXX(ISR)(IDR)C		+1								-1									EQ	0
Non-U.S. Import Demand Rows:	Thermal : DX.(IDR)T								+1, where (S)='T'	+1										EQ	D
	Mettalurgical : DX.(IDR)C								+1, where (S)='C'		+1									EQ	D
U.S. and Non-U.S. Demand Balance:	BDX.(IDR)(IS)									-1, if (IS)='T'	-1, if (IS)='C'								+1	EQ	0
U.S. and Non-U.S. Import Diversity Constraint:	VI(IDR)(IS)(ISR)									+1, if (IS)='T'	+1, if (IS)='C'								-IC	LE	0
U.S. Supply Balance (U.S. exports):	BSXUS															+1	-1			EQ	0
Non-U.S. Supply (Exports) Balance:	BSX(ISR)	+1																-1		EQ	0
U.S. Export Supply Balance:	SDX(UXSR)(UXS)								-1							+1				EQ	0
U.S. Export Demand Balance:	D.(UXSR)X(UXS)							+1								-1				EQ	0
Export Diversity Constraint:	Non-U.S.: VE(ISR)(IDR)(IS)									+1, if (IS)='T'	+1, if (IS)='C'							-EC		LE	0
	U.S.: VE(ISR)(IDR)(IS)								+1								-EC			LE	0

REFERENCE FOR MASK COMPONENTS

(CT): U.S. coaltype number; e.g., 1-8
(DR): U.S.domestic coal demand regions; e.g., NE, YP, SA, GF, OH, EN, KT, AM, CW, WS, MT, CU, ZN, PC
(IDR): internation demand regions; e.g. NE, NI, SC, BT, GY, OW, PS, ITL, RM, MX, LA, JA, EA, CH, AS, IN, UE, UG, UI, UN
(IS): international sector; T or C
(ISR): international supply regions; e.g., NW, NI, CL, VZ, PO, RE, RA, SF, IN, HI, AU
(PT): U.S. electricity plant types; e.g., B1-B8, C1-C9, CX-CY, H1-H9, HA-HC, PC, IG, IS
(SN): sector number; e.g. 1-4
(STEPS): supply curve step numbers; e.g., 1-8
(UP): U.S. ports; e.g., E, I, G, N
(USR): U.S. domestic supply regions; e.g., NA, CA, SA, EI, WI, GL, DL, WM, NW, SW, WW, RM, ZN, AW
(UXS): U.S. export subsector number; e.g., 1-8
(UXSR): U.S. international coal supply regions=(DR)

REFERENCE FOR COEFFICIENTS (per trillion Btu)

a: tons of activated carbon required of coal (mercury scenarios only)
c: carbon content
CAP: mercury allowance price limit (only certain mercury scenarios)
EC: export share
EMETAX: carbon allowance price (only carbon scenarios)
f: freight cost
IC: import share
m: mercury content
p: production costs
s: sulfur dioxide content
t: domestic/land transportation costs
v: dollars per pound of activated carbon (mercury scenarios only)

REFERENCE FOR RIGHTHAND SIDE (RHS) VALUES

D: coal demand
M: mercury emissions limit
S: sulfur dioxide emissions limit
T_1: minimum for total U.S. imports (million short tons)
T_2: maximum for total U.S. imports (million short tons)
T_3: minimum for total U.S. metallurgical imports (million short tons)
T_4: minimum for total U.S. industrial imports (million short tons)
T_5: minimum for U.S. electricity imports for scrubbed plants
T_6:minimum for U.S. electricity imports for unscrubbed plants

Objective Function

The goal of the objective function is to minimize delivered costs (i.e., minemouth production, preparation, and inland transportation costs plus freight transportation costs) for moving coal from international export regions to international import regions and has been defined as

$$\Sigma_{i,s,t}\ PX_{i,s,t} * P_{i,s,t} + \Sigma_{i,j,t}\ TX_{i,j,t} * F_{i,j,t} + \Sigma_{i,j,m,t,v,z}\ UI_{i,j.m,t,v,z} * T_{i,j,m,t,v,z} \qquad (3.B\text{-}1)$$

(For the U.S., the objective function is linked to the U.S.'s domestic portion of the CDS's objective function primarily through the row constraints (3.B-2), (3.B-4)-(3.B-7), (3.B-17) and (3.B-19) described below. The U.S. production costs and inland transportation costs for U.S. domestically produced coal (for exports and domestic consumption) are not shown in (B-1) because they are accounted for in the domestic portion of the CDS documentation.) The mercury price cap, mercury escape vector, activated carbon vector, and carbon emission vectors are also not represented in (3.B-1) for the same reason.

The indexes for the objective function, the rows, and the columns are defined below.

Index Definitions

Index Symbol	Description
(i)	International supply regions for coal exports
(j)	International import regions
(k)	U.S. coal export sub-sectors (correspond to U.S. export sectors in domestic component of CDS)
(m)	U.S. domestic subsector, either plant type for the electricity sector or sector number for the industrial and metallurgical sectors
(s)	Step on curve for coal export supply curve for non-U.S. international export regions
(t)	International coal sector (thermal or coking)
(u)	U.S. export supply curve representing one of eight possible U.S. coal types (different combinations of rank, mining method, and sulfur content) in combination with one of 16 possible export regions
(v)	Activated carbon supply curve step
(z)	U.S. coal export sub-regions and U.S. coal import sub-regions. These sub-regions are equivalent to the demand regions in the domestic portion of the CDS and include NE, YP, SA, GF, OH, EN, KT, AM, CW, WS, CU, MT, ZN, and PC.

Column Definitions

Column Notation	Description
EXP_i	Sum of coal exported from U.S. or non-U.S. international export region i.
$F_{i,j,t}$	Cost of freight transportation for coal from export region i to coal import region j for international coal sector t. This includes the freight costs for U.S.-sourced exports.
$IMP_{j,t}$	Sum of coal imported for international coal sector t to international import region j (U.S. or non-U.S.).
$P_{i,s,t}$	Cost from step s of the export supply curve for coal from export region i for international coal sector t. This applies for non-U.S. international import regions only.
$PX_{i,s,t}$	Quantity of coal from step s of export supply curve in non-U.S. export region i for international sector t.
$T_{i,j,m,t,v,z}$	Cost of inland transportation (within U.S.) for imported coal to the U.S. from export region i to coal international import region j, for U.S. domestic subsector m, for activated carbon supply curve step v, for international coal sector t, and U.S. domestic coal import region z.
$TX_{i,j,t}$	Quantity of coal transported from U.S. or non-U.S. export region i to import region j for international sector t.
$UI_{i,j.m,t,v,z}$	Quantity of coal imported into the U.S. from export region i to coal international import region j, for U.S. domestic subsector m, for activated carbon supply curve step v, for international coal sector t, and U.S. domestic coal import region z.
$UX_{k,z}$	Quantity of coal exported for U.S. export sub-sector k from U.S. coal export sub-region z.
$Qt_{k,u,z}$	Quantity of coal from U.S. export supply curve u transported to U.S. coal export sub-region z and U.S. export sub-sector k.

Row Constraints

The rows interact with the columns to define the feasible region of the LP and are defined below:

U.S. IMPORTS STRUCTURE ONLY

U.S. IMPORT
EQUATIONS: non-imported coal + $\Sigma_{i,v}$ $UI_{i,j.m,t,v,z} = D_{j,m,t,z}$ (3.B-2)

where $D_{j,m,t,z}$ represents the U.S. coal imports for coal import region j, U.S. subsector m, for international coal sector t, and for U.S. domestic coal demand region z.

Definition: Specifies the level of coal imports by import region j that must be satisfied for domestic coal subsector m.
CORRESPONDING ROWS IN BLOCK DIAGRAM: D.(DR)(PT), D.(DR)I(SN) and D.(DR)M(SN)

BALANCE OF U.S. INLAND TRANSPORTATION AND INTERNATIONAL FREIGHT TO U.S.
EQUATIONS: $TX_{i,j,t} - \Sigma_{m,v,z} UI_{i,j.m,t,v,z} = 0$ (3.B-3)

Definition: For j equal to U.S. importing regions, the row balances coal freighted to U.S. international import region j from international (non-U.S.) export region i for international sector t (thermal or coking).
CORRESPONDING ROWS IN BLOCK DIAGRAM: TTU(UP)(ISR)XX and TCU(UP)(ISR)XX

SULFUR DIOXIDE EMISSION RESTRICTION CONSTRAINTS:

SO_2 emissions from
non-imported coal $+ \Sigma_{i,j,m,t,v,z} [s_{i,,t} * UI_{i,j.m,t,v,z}] \leq S$ (3.B-4)

Definition: For t equal to thermal coal, and for the subscript m representing electricity subsectors only, this row restricts the sulfur dioxide levels of coal in the U.S. electricity sector such that the sulfur dioxide emissions limit, "S," is met and "$s_{i,t}$" equals the sulfur dioxide content of the coal from international supply region i in sector t.. For more detail on sulfur dioxide emissions from non-imported coal, see "2. Coal Distribution Submodule – Domestic Component."
CORRESPONDING ROW IN BLOCK DIAGRAM: SULFPEN1 and SULFPEN2

MERCURY EMISSION RESTRICTION CONSTRAINTS:

mercury emissions
from non-imported coal $+ \Sigma_{i,j,m,t,v,z} [m_{i,t} * UI_{i,j.m,t,v,z}] - H -$ escape vector quantity $\leq M$ (3.B-5)

Definition: For relevant years, for t equal to thermal coal, and for subscript m representing electricity subsectors only, this row limits the quantity of mercury present in coal (adjusted with the plant removal rate and use of activated carbon to be less than or equal to the coal mercury emissions limit, "M". Coefficient $m_{i,t}$ is the mercury content of coal. Some alternative mercury scenarios may cap the compliance costs. In these scenarios, additional "allowances" are available at the allowance cap. "H" is the volume of additional allowances purchased at the cap price. Escape vectors are not active in the final solution but allow feasibility to be maintained in early iterations. For more detail on mercury emissions from non-imported coal, see "2. Coal Distribution Submodule – Domestic Component."
CORRESPONDING ROWS IN BLOCK DIAGRAM: MERCP01

ACTIVATED CARBON SUPPLY CURVE CONSTRAINTS:

activated carbon used
with non-imported coal $+ \Sigma_{i,j,m,t,v,z} [a_{p,v} * UI_{i,j.m,t,v,z}] - 10 * \Sigma_v A_v \leq 0$ (3.B-6)

Definition: Balances the activated carbon used in association with the electricity sector transportation vectors with the activated carbon supply curves. Coefficient $a_{p,v}$ represents tons of activated carbon per trillion Btu for plant configuration p and activated supply curve step v. "A_v" represents the total quantity of activated carbon from activated carbon supply curve step v. For more detail on activated carbon use from non-imported coal, see "2. Coal Distribution Submodule – Domestic Component."
CORRESPONDING ROWS IN BLOCK DIAGRAM: ACIXXXXY

CARBON TAX CONSTRAINTS:

carbon emissions
from non-imported coal $+ \Sigma_{i,j,m,t,v,z} [c_{i,m} * UI_{i,j.m,t,v,z}] – C \leq 0$ (3.B-7)

Definition: Balances the carbon emissions, "C", associated with the electricity sector transportation vectors with the carbon emissions being "paid for" with the carbon penalty price. Coefficient $c_{i,m}$ is the carbon content of coal from non-U.S. export region i and U.S. domestic subsector m. For more detail on carbon emissions from non-imported coal, see "2. Coal Distribution Submodule – Domestic Component."
CORRESPONDING ROWS IN BLOCK DIAGRAM: CARBONXX

HISTORICAL FLOW CONSTRAINTS:

MINIMUM IMPORT EQUATION: $\Sigma_{i,j,m,t,v,z} UI_{i,j.m,t,v,z} \geq T_1$ (3.B-8)
Definition: Sets minimum value (T_1) for all U.S. imports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: IMPSTMIN

MAXIMUM IMPORT EQUATION: $\Sigma_{i,j,m,t,v,z} UI_{i,j.m,t,v,z} \leq T_2$ (3.B-9)
Definition: Sets maximum value (T_2) for all U.S. imports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: IMPSTMAX

MINIMUM METALLURGICAL IMPORT EQUATION: $\Sigma_{i,j,m,t,v,z} UI_{i,j.m,t,v,z} \geq T_3$ (3.B-10)
Definition: For subscript t set equal to coking coal and m representing metallurgical subsectors only, sets minimum value (T_3) for metallurgical imports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: IMPMETSW

MINIMUM INDUSTRIAL IMPORT EQUATION: $\Sigma_{i,j,m,t,v,z} UI_{i,j.m,t,v,z} \geq T_4$ 3.B-11) (
Definition: For subscript t set equal to thermal coal and m representing industrial subsectors only, sets minimum value (T_4) for industrial imports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: IMPINDSW

MINIMUM ELECTRICITY IMPORT EQUATION: $\Sigma_{i,j,m,t,v,z} UI_{i,j.m,t,v,z} \geq T_5$ or T_6 (3.B-12)
Definition: For subscript t set equal to thermal coal, m representing electricity subsectors only, sets minimum value (T_5 for scrubbed or T_6 for unscrubbed plants) for electricity imports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: F(ISR)(DR)I1 AND C(ISR)(DR)I1

<u>WORLD COAL TRADE ROWS</u>

NON-U.S. PRODUCTION/SHIPPING BALANCE
EQUATIONS: $\Sigma_s PX_{i,s,t} - \Sigma_j TX_{i,j,t} = 0$ (3.B-13)

Definition: Balance of coal produced in international (non-U.S.) export region i with the coal shipped from export region i for international sector t (thermal or coking).
CORRESPONDING ROWS IN BLOCK DIAGRAM: SXX(ISR)(IDR)T and SXX(ISR)(IDR)C

NON-U.S. IMPORT
EQUATIONS: $\Sigma_i \, TX_{i,j,t} = D_{j,t}$ (3.B-14)

where,
$D_{j,t}$ represents the coal imports for import region j for international coal sector t.
Definition: Specifies the level of coal import requirement by import region j that must be satisfied for international coal sector t (thermal or coking).
CORRESPONDING ROWS IN BLOCK DIAGRAM: DX(IDR)T and DX(IDR)C

U.S. AND NON-U.S. FREIGHT/IMPORT BALANCE
EQUATIONS: $\Sigma_i \, TX_{i,j,t} - IMP_{j,t} = 0$ (3.B-15)

Definition: Balance of total coal imported to international import regions j with quantity freighted to import region j for international sector t.
CORRESPONDING ROWS IN BLOCK DIAGRAM: BDX.(IDR)(IS)

U.S. AND NON-U.S. IMPORT
CONSTRAINTS: $TX_{i,j,t} - IC_{i,j,t}*IMP_{j,t} < 0$ (3.B-16)

Definition: Import constraint specifying that only a certain share of imports for an import region j can come from export region i. $IC_{i,j,t}$ is the proportion of coal imports flowing to internatonal import region j that can come from export region i for international coal sector t.
CORRESPONDING ROWS IN BLOCK DIAGRAM: VI(IDR)(IS)(ISR)

U.S. AND NON-U.S. PRODUCTION/EXPORT BALANCE
EQUATIONS: $a\Sigma_s \, PX_{i,s,t} + b\Sigma_{k,z} \, UX_{k,z} - EXP_{i,t} = 0,$ (3.B-17)
where a = 0 and b = 1, for U.S.; a = 1 and b = 0 for non-U.S.; and where k is a subset of t.

Definition: Balance of coal produced for export from international export region i with total exported from i for international sector t.
CORRESPONDING ROWS IN BLOCK DIAGRAM: BSXUS and BSX(ISR)

U.S. EXPORT BALANCE
EQUATIONS: $\Sigma_{k,z} \, UX_{k,z} - \Sigma_j \, TX_{i,j,t} = 0,$ (3.B-18)

where z is a subset of i and k is a subset of t.
Definition: Balance of total U.S. coal transported overseas with U.S. coal exported. The U.S. export requirement is bounded. The bounds assumed are based on historical levels of exports.
CORRESPONDING ROWS IN BLOCK DIAGRAM: SDX(UXSR)(UXS)

U.S. EXPORT BALANCE
EQUATIONS: $\Sigma_u \, Qt_{k,u,z} - UX_{k,z} = 0$ (3.B-19)

Definition: Balance of coal transported within U.S. from U.S. coal supply curves to meet export requirements from U.S. export sub-regions z and U.S. export sub-sectors k. The U.S. export requirements are bounded. The bounds are based on historical levels of exports.

CORRESPONDING ROWS IN BLOCK DIAGRAM: D.(UXSR)X(UXS)

U.S. AND NON-U.S. EXPORT CONSTRAINT
CONSTRAINTS: $TX_{i,j,t} - EC_{i,j,t} * EXP_i < 0$ (3.B-20)

Definition: Export constraint limiting the amount of export coal from an international export region i that can be shipped to a particular import region j. $EC_{i,j,t}$ is the proportion of coal exports flowing from internatonal export region i that can be shipped to import region j for international coal sector t.
CORRESPONDING ROWS IN BLOCK DIAGRAM: VE(ISR)(IDR)(IS)

Table 3.B-2. Row and Column Structure of the International Component of the Coal Market Module

Each column and row of the linear programming matrix is assigned a name identifying the activity or constraint that it represents. A mask defines the general or generic name of a set of related activities or constraints. For example, the mask ‘PX(ISR)(IS)’ defines the general name of all activities representing the production of coal from international export regions. The names of specific activities or constraints are formed by inserting into the mask appropriate members of notational sets identified by the mask. For instance, the production of coal in Australia is defined as PX(AS)(T).

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
ACIXSS(STEPS)Y	Column	Volume of activated carbon (in pounds) injected to reduce mercury emissions; column bounds on this vector are present specifying how much activated carbon is available at each step
ACIXXXXY	Column	Assigns activated carbon requirement (pounds of activated carbon per trillion Btu) for each activated carbon step in transportation column
BDX(IDR)(IS)	Row	Imports balance row for international import region (IDR) for international coal sector (IS)
BSX(ISR)	Row	Export balance row for export region (ISR)
BSXUS	Row	Balance row for U.S. exports
CARBONXX	Column	Assigns carbon tax to coal in carbon scenario and influences patterns of coal use in electricity sector
CARBONXX	Row	Assigns carbon content to electricity sector transportation columns
C(ISR)(DR)I1	Row	Sets minimum level for U.S. electricity imports for unscrubbed plants by export region (ISR) to U.S. demand region (DR)
D.(DR)I(SN)	Row	Coal demand from demand region (DR) for industrial sector, I, and sector number (SN)
D.(DR)M(SN)	Row	Coal demand from demand region (DR) for metallurgical sector, M, and sector number (SN)
D.(DR)(PT)	Row	Coal demand from demand region (DR) for electricity plant types (PT)
D.(UXSR)X(UXS)	Row	Export balance row for U.S. export sub-region (UXSR) of U.S. export sub-sector (UXS)

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
DX.(IDR)C	Row	Import row for import region (IDR) and international coking coal sector
DX.(IDR)T	Row	Import row for import region (IDR) and international thermal coal sector
EXP(ISR)	Column	Sum of exports from export region (ISR)
F(ISR)(DR)I1	Row	Sets minimum level for U.S. electricity imports for scrubbed plants by export region (ISR) to U.S. demand region (DR)
IMP(IDR)(IS)	Column	Sum of imports from import region (IDR) for international coal sector (IS)
IMPINDSW	Row	Sets minimum level for industrial imports for a given year
IMPMETSW	Row	Sets minimum level for metallurgical imports for a given year
IMPSTMAX	Row	Sets maximum level for total imports for a given year
IMPSTMIN	Row	Sets minimum level for total imports for a given year
MERCEV	Column	Provides upper bound for mercury allowance price
MERCP01	Row	Mercury penalty constraint for electricity sector
MOREHGXX	Column	Escape vector allowing more mercury to be emitted if tight mercury constraint causes infeasibility. Not active in final solution.
OII(SN)(ISR)T(DR)	Column	U.S. import volume transported within the U.S. for use in the industrial steam sector
OIM(SN)(ISR)C(DR)	Column	U.S. import volume transported within the U.S. for in the metallurgical sector
PX.(ISR)(IS)(STEPS)	Column	Supply of exports for non-U.S. international export region (ISR) for international coal sector (IS) and supply curve step (STEPS)
SDX(UXSR)(UXS)	Row	Row balancing the sum of coal transported from the export subsectors (UXS) from the international U.S. export region (UXSR) with the total exported from the U.S. export region (UXSR)
SULFPEN1	Row	Sulfur penalty constraint for the east for electricity sector
SULFPEN2	Row	Sulfur penalty constraint for the west for electricity sector
SXX(ISR)(IDR)C	Row	Row balancing the supply of coal

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
		exports from international export region (ISR) to international import region (IDR) for coking coal
SXX(ISR)(IDR)T	Row	Row balancing the supply of coal exports from international export region (ISR) to international import region (IDR) for thermal coal
TCU(UP)(ISR)XX	Row	Row balancing the quantity of imported coking coal transported inland from U.S. port (UP) from international export region (ISR) to that freighted to the port from international export region (ISR)
TTU(UP)(ISR)XX	Row	Row balancing the quantity of imported thermal coal transported inland from U.S. port (UP) from international export region (ISR) to that freighted to the port from international export region (ISR)
T(USR)(UXSR)X(UXS)(CT)	Column	U.S. export volume transported internally from U.S. export regions - where coal is produced - (USR) to U.S. export sub-regions (UXSR) for U.S. export sub-sectors for coal type (CT)
TX(DR)X(UXS)(IDR)(IS)	Column	U.S. export transportation volume from U.S. export sub-region (DR), to international import region (IDR), for U.S. export sub-sector (UXS), for international export sector (IS)
TX(ISR)-(IDR)(IS)	Column	Export volume transported from non-U.S. export region (ISR) to international import region (IDR) for international export sector (IS)
UX(UXSR)-X(UXS)	Column	Export volume for U.S. export sub-region (UXSR) and U.S. export sub-sector (UXS). Export volume must lie between an upper and lower bound derived from historical volumes.
VE(ISR)(IDR)(IS)	Row	Diversity export constraint on international export region (ISR) to import region (IDR) for international export sector (IS)
VI(IDR)(IS)(ISR)	Row	Diversity import constraint on import region (IDR) for international export sector (IS) from export region (ISR)

where,

CT **U.S. DOMESTIC COAL TYPE** (CT's pairing with a U.S. supply region designates the supply curve and rank.)

1	LOW SULFUR AND UNDERGROUND MINING METHOD
2	MEDIUM SULFUR AND UNDERGROUND MINING METHOD
3	HIGH SULFUR AND UNDERGROUND MINING METHOD
4	LOW SULFUR AND SURFACE MINING METHOD
5	MEDIUM SULFUR AND SURFACE MINING METHOD
6	HIGH SULFUR AND SURFACE MINING METHOD
7	METALLURGICAL COAL
8	WASTE COAL OR MISSISSIPPI LIGNITE

DR or UXSR	**U.S. EXPORT SUB-REGIONS AND/OR U.S. IMPORT REGIONS**
NE	CONNECTICUT, MASSACHUSETTS, MAINE, NEW HAMPSHIRE, RHODE ISLAND, VERMONT
YP	NEW YORK, PENNSYLVANIA, NEW JERSEY
SA	WEST VIRGINIA, DELAWARE, DISTRICT OF COLUMBIA, MARYLAND, VIRGINIA, NORTH CAROLINA, SOUTH CAROLINA
GF	GEORGIA, FLORIDA
OH	OHIO
EN	ILLINOIS, INDIANA, MICHIGAN, WISCONSIN
KT	KENTUCKY, TENNESSEE
AM	ALABAMA, MISSISSIPPI
CW	MINNESOTA, IOWA, NORTH DAKOTA, SOUTH DAKOTA, NEBRASKA, KANSAS, MISSOURI
WS	TEXAS, OKLAHOMA, ARKANSAS, LOUISIANA
MT	MONTANA, WYOMING, IDAHO
CU	COLORADO, UTAH, NEVADA
ZN	ARIZONA, NEW MEXICO
PC	ALASKA, HAWAII, WASHINGTON, OREGON, CALIFORNIA

IDR	**INTERNATIONAL IMPORT REGIONS**
NE	East Coast Canada
NI	Interior Canada
SC	Scandinavia
BT	United Kingdom, Ireland
GY	Germany, Austria
OW	Other Northern Europe
PS	Iberian Peninsula
IT	Italy (thermal and coking)
RM	E. Europe and Mediterranean
MX	Mexico
LA	South America
JA	Japan
EA	East Asia
CH	China, Hong Kong
AS	ASEAN
IN	Indian Subcontinent, S. Asia
UE	US Eastern
UG	US Gulf
UI	US Interior
UN	US Noncontiguous

IS **INTERNATIONAL COAL SECTORS**

C	Coking
T	Thermal

ISR **INTERNATIONAL EXPORT REGIONS**

NA	Canada (alternate for Canada)
NW or W	West Coast Canada
NI or N	Interior Canada (thermal only)
CL or C	Colombia (thermal only)
VZ or Z	Venezuela (thermal only)
PO or P	Poland
RE or E	Former Soviet Union (exports to Europe)
RA or R	Former Soviet Union (exports to Asia)
SF or S	Southern Africa
IN or I	Indonesia
HI or H	China
AU or A	Australia
VT or T	Vietnam
US	US
UA	US All
UG	US Gulf
UI	US Interior
UN	US Noncontiguous
UW	US West coast
UE	US East coast

PT **PLANT TYPE** (see CDS – Domestic Component, page 68)

SN **U.S. IMPORT SUB-SECTOR NUMBERS**

1 – 3	FOR INDUSTRIAL IMPORTS
1 – 2	FOR METALLURGICAL IMPORTS

STEPS **INTERNATIONAL EXPORT SUPPLY CURVE STEPS or ACTIVATED CARBON STEP**

1	Step 1
2	Step 1
3	Step 3
4	Step 4
5	Step 5
6	Step 6
7	Step 7
8	Step 8
9	Step 9
0	Step 10

UP **U.S. PORT REGION**

G	US Gulf
I	US Interior
N	US Noncontiguous
E	US East coast

USR **U.S. COAL SUPPLY REGIONS**

NA PENNSYLVANIA, OHIO, MARYLAND, WEST VIRGINIA (NORTH)
CA WEST VIRGINIA (SOUTH), KENTUCKY (EAST), VIRGINIA, TENNESSEE (NORTH)
SA ALABAMA, TENNESSEE (SOUTH)
EI ILLINOIS, INDIANA, KENTUCKY (WEST), MISSISSIPPI
WI IOWA, MISSOURI, KANSAS, OKLAHOMA, ARKANSAS, TEXAS (BITUMINOUS)
GL TEXAS (LIGNITE), LOUISIANA
DL NORTH DAKOTA, MONTANA (LIGNITE)
WM WESTERN MONTANA (SUBBITUMINOUS)
NW WYOMING, NORTHERN POWDER RIVER BASIN (SUBBITUMINOUS)
SW WYOMING, SOUTHERN POWDER RIVER BASIN (SUBBITUMINOUS)
WW WESTERN WYOMING (SUBBITUMINOUS)
RM COLORADO, UTAH
ZN ARIZONA, NEW MEXICO
AW WASHINGTON, ALASKA

UXS **U.S. EXPORT SECTORS**

1 Metallurgical Export 1
2 Metallurgical Export 2
3 Metallurgical Export 3
4 Steam 1 Export
5 Steam 2 Export
6 Steam 3 Export

USXR **U.S. EXPORT SUB-REGIONS AND/OR U.S. IMPORT REGIONS**

See DR.

Appendix 3.C

Inventory of Input Data, Parameter Estimates, and Model Outputs

Model Inputs

The inputs required by the international component of the CDS are divided into two main groups: user-specified inputs and inputs provided by other NEMS components. The required user-specified inputs are listed in Table 3.C-1. In addition to identifying each input, this table indicates the variable name used to refer to the input in this report, the units for the input, and the level of detail at which the input needs to be specified.

The user-specified inputs to the international component of the CDS are contained in six different input files. These files and their contents are listed below.

CLEXSUP. This file contains the step-function coal export supply curves for all non-U.S. export regions. The first column contains the international export region and step identifier. The next seven columns contain the variables:
1) FOBYR, the export FOB price of coal (minemouth price plus inland transportation cost) in 1992 dollars per metric ton for 1992;
2) CAPYR, the estimated coal export capacity in million metric tons for 1992;
3) CV, the heat content in thousand Btus per pound for all forecast years;
4) SULCON, the sulfur content in percent sulfur by weight for all forecast years;
5) IMPMERC, the mercury content in pounds per trillion Btu;
6) IMPCO2, the carbon dioxide content in pounds of carbon dioxide per million Btu; and
7) SCALAR, a scalar that permits the user to adjust the international coal export supply curves over time at rates that vary from the price path for U.S. export coal.

The remaining columns contain estimates of export prices (FOBYR) and capacities (CAPYR) for each of the coal export supply steps represented in the CDS for the remaining forecast years (typically specified at 5-year intervals).
Some additional calculations are required to convert input data from the file to units consistent with the linear program. They include:

- Conversion of FOBYR to 1987 dollars per trillion Btu using the following calculation:
  FOBYR * 12.6 thousand Btu per pound of coal equivalent / CV * 1987 GDP deflator/
  1992 GDP deflator / 27.78 mmBtu per metric ton of coal equivalent

  or equivalently,

  FOBYR * 1987 GDP deflator/ 1992 GDP deflator/ 2204.623 pounds per metric ton/ CV * 10^3

- Conversion of CAPYR, coal export capacity, to trillion Btu using the following calculation:

CAPYR * CV /12.6 thousand Btu per pound of coal equivalent * 27.78 mmBtu per metric ton of coal equivalent

or equivalently,

CAPYR * 2204.623 pounds per metric ton * CV / 10^3.

- Conversion of SULCON to thousand tons of SO_2 per trillion Btu by the following calculation:

  SULCON * 10.0 / CV.

- Conversion of IMPCO2 to million metric tons of carbon per quadrillion Btu by the following calculation:

  IMPCO2 * 12.0/ 44.0 /2.204623

  or equivalently,

  IMPCO2 * 12.0/ 44.0/ 2204.623 pounds per metric ton * 10^3.

CLEXDEM. This file contains the non-U.S. coal import requirements (variable: DEMAND) by international CDS import region and sector for the years 1990 through 2050 (typically specified at 5-year intervals). The first column in the file indicates the year for the import requirements contained in each row of the file. The remaining columns contain the coal import requirements in million metric tons of coal equivalent for each specific combination of international CDS import region (including the U.S.) and demand sector (e.g., JAC represents coking coal imports to Japan, and JAT represents thermal coal imports to Japan). Prior to use in the LP, the import requirements are converted to trillion Btu by the following calculation: DEMAND * 27.78 million Btu per metric ton of coal equivalent.

CLEXFRT. This file contains a matrix of ocean transportation rates (variable: FREIGHT) for coal shipments. The transportation rates are specified by international CDS import region, export region, and demand sector (coking and thermal). Each column heading represents a specific international CDS import region, and each row represents a specific combination of international CDS export region and demand sector. The rates are specified in 1992 dollars per metric ton. Prior to use in the LP, the ocean transportation rates are converted to 1987 dollars per million Btu.

This file also contains inland transportation rates (variable: INLANDTR), in 1987 dollars per short ton, for U.S. imports. These rates represent the transportation cost from the initial import entry to the U.S. coal import region and are specified by the electricity, industrial, and metallurgical sectors. This file also allows includes optional switches to set minimum and/or maximum import levels. If a switch is equal to "1", the minimum/maximum constraint is in use.

CLEXEXS. This file contains international requirements for U.S. coal export levels for the historical and *Short-Term Energy Outlook* years of the forecast.[25] Each row includes five indices at the left followed by a set of numbers representing annual U.S. coal exports in trillion Btu for the years 1990 through 2011. From left to right these indices are (1) the domestic CDS demand

[25] In general, the Energy Information Administration's *Short-Term Energy Outlook* provides forecasts of U.S. coal exports for the period extending two years beyond the most recently published set of annual historical data.

region, (2) the international CDS demand sector, (3) the domestic CDS economic subsector, (4) the CDS coal group from which supplies may be drawn (The organization of "coal groups" is explained in the discussion of the "CLPARAMS" input file in Appendix 2.C of Section 2 of the CMM Model Documentation), and (5) the international coal export region to which they pertain.

CLEXIMS. This file contains the coal import diversity constraints specified as percent of the total coal imports. Each column heading represents a specific combination of international CDS import region and demand sector (coking and thermal), and each row represents a specific international CDS export region. The constraints limit the portion of an import region’s import requirement by sector that can be met by each of the individual export regions. For example, an input of 40 for the JAT import region/sector and US export region combination indicates that only 40 percent of Japan’s annual imports of thermal coal can be met by U.S. coal suppliers.

CLEXSO2. This file contains the constraints for high-sulfur coal, subbituminous coal, and sulfur dioxide emissions. The first column of the file identifies the specific constraints as follows: **High Sulfur Percent** (variable: HSPCT)**:** portion of an international CDS import region’s thermal coal import requirement that can be met by high-sulfur coal; **Subbituminous Percent:** portion of an international CDS import region’s thermal coal import requirement that can be met by subbituminous coal; **Percent Low-Sulfur Coal Scrubbed:** portion of an international CDS import region’s low-sulfur coal import requirement that is scrubbed; **Percent High-Sulfur Coal Scrubbed:** portion of an international CDS import region’s high-sulfur coal import requirement that is scrubbed; **Sulfur Cap:** cap on sulfur dioxide emissions specified in thousand metric tons. The remaining columns contain the corresponding data for each of the constraints for each international CDS import region. These constraints were not used for the *AEO2011* forecasts.

CLCONT. See Section 2’s Appendix 2.C.

Model Outputs

The international component of the CDS provides annual forecasts of U.S. coal exports and imports to the domestic distribution area of the NEMS Coal Market Module. The key output from international area of the CDS, listed in Table 3.C-2, is world coal trade flows by coal export region/coal import region/coal type/coal demand sector (in trillion Btu). Conversion factors convert output from trillion Btu to short tons for report writing purposes.

Table 3.C-1. User-Specified Inputs

CDS Variable	Input	Specification Level[a]	Input Units
CAPYR	Coal export capacity	Coal export region/coal sector/export supply curve step/forecast year	Million metric tons
CV	Btu conversion assignment for coal export supply curve	Coal export region/coal sector/export supply curve step	Thousand Btu per pound of coal
DEMAND	Coal import requirement (Non-U.S.)	Coal import region/coal demand sector/forecast year	Million metric tons of coal equivalent
EXPSHARE	Exporter diversity constraints	Coal export region/coal import region	Percentage
FOBYR	Coal export prices (FOB port of exit)	Coal export region/coal sector/export supply curve step/forecast year	1992 dollars per metric ton
FREIGHT	Ocean freight rates	Coal export region/coal import region/coal sector/coal demand sector	1992 dollars per metric ton
HSMAX[b]	Maximum share of high-sulfur coal imports	Coal import region/forecast year	Fraction
HSPCT[b]	SO_2 emissions "pass-through" rate	Coal import region/coal demand sector/forecast year	Fraction
INLANDTR	Inland coal transportation rates for U.S. coal imports	U.S. sector/U.S. domestic demand region/international export region/U.S. port of entry	1987 dollars per short ton
IMPMERC[c]	Mercury content assignment for coal export supply curve	Coal export region/coal type	Pounds of mercury per trillion Btu
IMPSHARE	Importer diversity constraints	Coal export region/coal import region	Percentage
IMPCO2[c]	Carbon dioxide content assignment for coal export supply curve	Coal export region/coal type	Pounds of CO_2 per million Btu
LSPCT[b]	SO_2 emissions "pass-through" rate	Coal import region/coal demand sector/forecast year	Fraction
MAXSUL[b]	Limit on total SO2 emissions for international trade	Coal import region/forecast region	Thousand metric tons
SCALINT	Price adjustment factor for non-U.S. export supply curves	Coal export region/coal type/export supply curve step/forecast year	Scalar
SUBMAX[b]	Maximum share of subbituminous coal imports	Coal import region/forecast year	Fraction
SULCON[c]	Sulfur content assignment for coal export supply curve	Coal export region/coal type	Thousand metric tons of SO_2 emissions per metric ton of coal equivalent

[a]For example, inputs specified at the coal export region/coal sector/forecast year level require separate values for each export region, coal type, and forecast.
[b]These variables are not currently used.
[c]Used for U.S. imports.

Table 3.C-2. Outputs

Input	CDS Variable	Specification Level[a]	Units
World coal trade flows	SOLVAL	Coal export region/coal import region/coal sector/coal demand sector/forecast year	Trillion Btu

Appendix 3.D

Data Quality and Estimation

Non-U.S. Coal Import Requirements are import volumes specified by CDS international coal import region and demand sector (coking and thermal). Annual import requirements are assumed to be equal to domestic coal demand less domestic supply (domestic production minus exports). In the CDS, non-U.S. coal import requirements by region and international import sector are an exogenous input, and are typically specified at 5-year intervals. Published information such as announced and planned additions/retirements of coal-fired generating plants, coke plants, and coal mining capacity are used to adjust the annual input data for coal import requirements. Annual coal import requirements for the years not specified in the CLEXDEM input file are determined by linear interpolation.

Coking coal requirements represent the consumption of coal at coke plants to produce coal coke. Coal coke is used primarily as a fuel and as a reducing agent in smelting iron ore in a blast furnace. Coal coke is also consumed at foundries and in the production of sinter. Thermal coal demands correspond to coal consumed for electricity generation, industrial applications (excluding the use of coking coal at coke plants), space heating in the commercial and residential sectors, and for the production of coal-based synthetic gas and liquids. The direct use of coal at blast furnaces for the manufacture of pig iron is also categorized as thermal coal demand.

Coal Export Supply Inputs are potential export supplies specified on a tranche-by-tranche (steps on supply curve) basis in the clexsup.txt input file to enable users to build up a stepped supply curve. Up to ten tranches are allowed for the major price sensitive suppliers. Coal qualities (sulfur, mercury, carbon dioxide and Btu content) cannot vary between tranches.

With each update of the *AEO*, the export FOB price of coal (FOBYR) for the international base year (2009) is updated on the basis of available data on average annual prices for coal exports and imports as reported by the EIA, the International Energy Agency, South Africa's Department of Minerals and Energy, and other statistical agencies and organizations. For international export supply regions and coal types where data for average annual coal export prices are either limited or unavailable, prices are updated on the basis of changes in reported prices for other coal export regions. Further adjustments are made to calibrate the model to base year trade flows.

The FOBYR and CAPYR variables together represent the supply curves for each of the modeled supply regions. For the base year, the paired variables represent estimates of current coal supply potential while projection years consider known capacity plans and capacity potential both in regards to mine capacity expansions (for exported coal), reserves, inland transportation upgrades, and port capacity upgrades or limitations. Limited availability and consistent sources of reliable international data present a difficulty in updating these assumptions. The update of these curves ultimately requires some judgment on the part of the modeler. In general, the slope of these supply curves is assumed to be similar to those of the United States. The SCALINT variable allows productivity assumptions to differ from those of the United States for the various supply curves. Assumptions about the elasticity of coal export supply for each exporting country determine the prices associated with steps on the supply curves representing new mine capacity.

International Freight Shipping Costs start from a matrix of feasible export routes, and taking into account the maximum vessel sizes that can be handled at export and imports piers and through canals, a matrix of maximum vessel sizes allowable on each route is generated. Freight rates are then calculated on the basis of route distance and vessel size, using the following set of formulas:

<u>Handysize (vessel size < 55,000 dwt)</u>

Rate (1992 dollars/tonne) = (2.5 + 1.5D) * (1992 GDP deflator/1997 GDP deflator)

<u>Panamax (vessel size ≥ 55,000 but < 80,000 dwt)</u>

Rate (1992 dollars/tonne) = (1.2 + 1.3D) * (1992 GDP deflator/1997 GDP deflator)

<u>Capesize (vessel size ≥ 80,000 dwt)</u>

Rate (1992 dollars/tonne) = (1.3 + 0.9D) * (1992 GDP deflator/1997 GDP deflator)

where

D = distance in thousand nautical miles (1 nautical mile = 6076.115 feet)
Tonne = metric ton (2204.623 pounds)
dwt = deadweight ton (2240 pounds)

Users can adjust freight rates using an add-factor matrix to take account of backhaul savings, canal tolls, slow unloading terms, etc. This add-factor matrix incorporates a $2.00/t "washery credit" which is subtracted from every freight rate between a coking coal supplier and a thermal coal buyer.

U.S. Import Inland Transportation Rates for origin (port of entry) and destination (domestic coal demand regions) pairs are estimated using information about domestic shipping rates for comparable distances. Transportation rates were also adjusted in order to improve estimates of historical import volumes.

Appendix 3.E

Optimization and Modeling Library (OML) Subroutines and Functions

This appendix provides a summary of the OML routines that are called by the CDS to set up the database, revise coefficients, solve the LP model, and retrieve the solution. OML is a proprietary software package developed by KETRON Management Science.

DFOPEN:	Opens the data file for the LP problem
DFPINIT:	Initializes processing of the LP problem in the current database
DFMINIT:	Initializes a database for matrix processing
DFMEND:	Terminates matrix processing
DFCLOSE:	Terminates processing of a database file
WFDEF:	Defines the model space for the LP problem
WFLOAD:	Loads the matrix for the LP problem into memory
WFINSRT:	Loads the starting basis for the LP problem
WFOPT:	Optimizes the model
WFPUNCH:	Saves the current basis into a standard format file
DFMRRHS:	Retrieves a right-hand side value
DFMCRHS:	Creates or changes a right-hand side value
DFMRBND:	Retrieves a bound value
DFMCBND:	Creates or changes a bound value
DFMCVAL:	Creates or changes a coefficient for a row/column intersection
DFMMVAL:	Changes a coefficient for row/column intersection if it exists
DFMCRTP:	Declares or changes the row type
WFSCOL:	Retrieves solution values (e.g., activity, input cost, reduced cost) for a column vector
WFSROW:	Retrieves solution values (e.g., activity, dual values) for a row
WFRNAME:	Retrieves a row name
WFCNAME:	Retrieves a column name.

Appendix 3.F

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