Coal Market Module

of the National Energy Modeling System

Model Documentation 2008

October 2008

Prepared by:

Coal and Electric Power Division
Office of Integrated Analysis and Forecasting
Energy Information Administration
Update Information

The Coal Market Module of the National Energy Modeling System Model Documentation 2008 has been updated to include major changes to the Coal Market Module modeling structure for the Annual Energy Outlook 2008. The changes include:

- Revised code to remove fuel surcharge from base year transportation rates
Contents

Executive Summary ........................................................................................................... vii

List of Acronyms................................................................................................................ ix

1. Coal Production Submodule

Introduction .......................................................................................................................... 1
  Model Summary ............................................................................................................... 1
  Model Archival Citation and Model Contact ................................................................. 2
  Organization ................................................................................................................... 2

Model Purpose and Scope ............................................................................................... 3
  Model Objectives .......................................................................................................... 3
  Classification Plan ...................................................................................................... 3
  Model Inputs and Outputs ......................................................................................... 7
  Relationship to Other Components of NEMS ......................................................... 7

Model Rationale ............................................................................................................. 9
  Theoretical Approach ................................................................................................. 9
  Underlying Rationale ............................................................................................... 9

Model Structure ............................................................................................................. 17
  Step 1: Model Calibration ......................................................................................... 17
  Step 2: Convert Regression Equation to Continuous Supply Curves ...................... 17
  Step 3: Construct Step-Function Supply Curves ...................................................... 19

Appendix 1.A. Submodule Abstract .............................................................................. 21
Appendix 1.B. Detailed Mathematical Description of the Model .................................. 25
Appendix 1.C. Inventory of Input Data, Parameter Estimates, and Model Outputs .......... 33
Appendix 1.D. Data Quality and Estimation .................................................................. 45
Appendix 1.E. Bibliography ......................................................................................... 55
Appendix 1.F. Coal Production Submodule Program Availability .............................. 57

Tables

1.1. Supply Regions and Coal/Mine Types Used in the NEMS Coal Market Module ...... 5
1.1.C-1. User-Specified Inputs Required by the CPS ..................................................... 34
1.1.C-2. CPS Inputs Provided by Other NEMS Modules and Submodules ................. 41
1.1.C-3. CPS Model Outputs ....................................................................................... 42
1.1.C-4. CPS: Key Endogenous Variables .................................................................. 43
1.1.D-1. Regression Statistics for the Coal Pricing Model .......................................... 50
1.1.D-2. Data Sources for Supply-Side Variables ...................................................... 51
1.1.D-3. Data Sources for Instruments Excluded From the Supply Equation .............. 52
2. Coal Distribution Submodule - Domestic Component

Introduction ................................................................................................................. 59
  Model Summary ................................................................................................. 59
  Model Archival Citation and Model Contact ......................................................... 59
  Organization ......................................................................................................... 60

Model Purpose and Scope ......................................................................................... 63
  Model Objectives ................................................................................................. 63
  Classification Plan ............................................................................................... 63
  Relationship to Other Models .............................................................................. 71

Model Rationale ......................................................................................................... 75
  Theoretical Approach ......................................................................................... 75
  Constraints Limiting the Theoretical Approach ............................................... 75

Model Structure ......................................................................................................... 81
  Computational Sequence and Input/Output Flow .............................................. 81
  Key Computations and Equations .................................................................... 86
  Transportation Rate Methodology .................................................................. 86

Appendix 2.A. Submodule Abstract ......................................................................... 89
Appendix 2.B. Detailed Mathematical Description of the Model ......................... 93
Appendix 2.C. Inventory of Input Data, Parameter Estimates, and Model Outputs 107
Appendix 2.D. Data Quality and Estimation ......................................................... 123
Appendix 2.E. Bibliography .................................................................................. 135
Appendix 2.F. Coal Distribution Submodule Program Availability .................... 139

Tables

2.1. Average Coal Quality and Production by Supply Region and Type, 2006 .......... 65
2.2. CMM – Domestic Coal Demand Regions ....................................................... 67
2.3. Domestic CMM Demand Structure–Sectors and Subsectors ......................... 68
2.4. Electricity Subsectors .................................................................................... 70
2.5. PMM Demand Region Composition for the CTL Sector ................................ 73
2.B-1.CDS Linear Program Structure – Domestic Component .......................... 95
2.B-2.Row and Column Structure for the Domestic Component of the Coal Market Module 100
2.C-1.Parameter and Variable List for CDS ....................................................... 112
2.D-1.Statistical Regression Results .................................................................. 129
2.D-2.Data Sources for Transportation Variables .............................................. 130
2.D-3.Historical Data to Calculate East Index .................................................... 130
3. Coal Distribution Submodule - International Component

Introduction .................................................................................................................. 141
Model Summary ........................................................................................................... 141
Model Archival Citation and Model Contact ............................................................... 141
Organization ................................................................................................................. 141

Model Purpose and Scope ....................................................................................... 143
Model Objectives ....................................................................................................... 143
Relationship to Other Modules ................................................................................ 143
Model Rationale .......................................................................................................... 147
Theoretical Approach ................................................................................................. 147

Model Structure ........................................................................................................ 148

Appendix 3.A. Submodule Abstract .......................................................................... 153
Appendix 3.B. Detailed Mathematical Description of the Model ................................ 157
Appendix 3.C. Inventory of Input Data, Parameter Estimates, and Model Outputs .... 171
Appendix 3.D. Data Quality and Estimation ................................................................. 175
Appendix 3.E. Optimization and Modeling Library (OML) Subroutines and Functions 177
Appendix 3.F. Bibliography ......................................................................................... 179

Tables

3.1. CDS International Coal Export Types and Demand Sectors .............................. 143
3.2. CDS Coal Export Regions .................................................................................. 145
3.3. CDS Coal Import Regions .................................................................................. 145
3.B-1. CDS Linear Program Structure – International Component ....................... 156
3.C-1. User-Specified Inputs ...................................................................................... 172
3.C-2. Outputs ............................................................................................................. 172

Figures

3.1. U.S. Export and Import Regions Used in the CDS ........................................... 144
3.2. International Component Inputs/Outputs ......................................................... 144
3.3. Overview of the International Component of the CDS .................................... 148
Executive Summary

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 2008 (AEO2008). 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 2030 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 (2006 for the AEO2008).

**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 utility coal contracts (tonnage, duration, coal type, origin and destination of shipments) 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
SO2: 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, the costs of factor inputs (mine labor and fuel), 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 2005. The regression equation, together with projected levels of productive capacity, labor productivity, miner wages, fuel prices, and the cost of capital, 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 AEO2008 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. 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 (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 2008*.

Name: Coal Production Submodule  
Acronym: CPS  
Archive Package: NEMS2008 (Available from the Energy Information Administration, Office of Integrated Analysis and Forecasting)  
Model Contact: Mike Mellish, Department of Energy, EI-82, Washington, DC 20585  
(202) 586-2136, or (mmellish@eia.doe.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 2030) 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. 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.

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 restrictions on SO2 emissions specified by the Clean Air Act Amendments of 1990 and the Clean Air Interstate Rule. 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 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 AEO2008, U.S. coal supply is represented through the use of 40 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 Northwest 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 are the small quantities of low-sulfur, bituminous coal reserves that are not modeled for the Northern Appalachian supply region.³

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 1974, the EIA assumed responsibility for the DRB in 1977 and has since maintained and updated the information for this important database. The two general types of updates performed by the EIA over time have been: 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.

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

<table>
<thead>
<tr>
<th>Supply Regions</th>
<th>States</th>
<th>Underground Mined Types</th>
<th>Surface Mined Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appalachian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. &quot;NA&quot;-Northern Appalachia</td>
<td>PA, OH, MD &amp; No. WV</td>
<td>MDP, MDB, HDB</td>
<td>MSB, HSB, HSL</td>
</tr>
<tr>
<td>2. &quot;CA&quot;-Central Appalachia</td>
<td>So. WV, VA, East KY, No. TN</td>
<td>MDP, CDB, MDB</td>
<td>CSB, MSB</td>
</tr>
<tr>
<td>3. &quot;SA&quot;-Southern Appalachia</td>
<td>AL &amp; So. TN</td>
<td>CDP, CDB, MDB</td>
<td>CSB, MSB</td>
</tr>
<tr>
<td>Interior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. &quot;EI&quot;-East Interior</td>
<td>West KY, IL, IN &amp; MS</td>
<td>MDB, HDB</td>
<td>MSB, HSB, MSL</td>
</tr>
<tr>
<td>5. &quot;WI&quot;-West Interior</td>
<td>IA, MO, KS, AR, OK, TX</td>
<td></td>
<td>HSB</td>
</tr>
<tr>
<td>6. &quot;GL&quot;-Gulf Lignite</td>
<td>TX, LA</td>
<td></td>
<td>MSL, HSL</td>
</tr>
<tr>
<td>Northern Great Plains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. &quot;DL&quot;-Dakota Lignite</td>
<td>ND &amp; East MT</td>
<td></td>
<td>MSL</td>
</tr>
<tr>
<td>8. &quot;WM&quot;-Western Montana</td>
<td>West MT</td>
<td>CDS</td>
<td>CSS, MSS</td>
</tr>
<tr>
<td>9. &quot;NW&quot;-Northern Wyoming</td>
<td>WY, Northern Powder River Basin</td>
<td></td>
<td>CSS, MSS</td>
</tr>
<tr>
<td>10. &quot;SW&quot;-Southern Wyoming</td>
<td>WY, Southern Powder River Basin</td>
<td></td>
<td>CSS</td>
</tr>
<tr>
<td>11. &quot;WW&quot;-Western Wyoming</td>
<td>WY</td>
<td>CDS</td>
<td>CSS, MSS</td>
</tr>
<tr>
<td>Other West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. &quot;RM&quot;-Rocky Mountain</td>
<td>CO &amp; UT</td>
<td>CDB</td>
<td>CSS</td>
</tr>
<tr>
<td>13. &quot;ZN&quot;-Southwest</td>
<td>NM &amp; AZ</td>
<td>MDB</td>
<td>CSB, MSS</td>
</tr>
<tr>
<td>14. &quot;AW&quot;-Northwest</td>
<td>AK &amp; WA</td>
<td></td>
<td>MSS</td>
</tr>
</tbody>
</table>

**KEY TO COAL TYPE ABBREVIATIONS**

**SULFUR EMISSIONS CATEGORIES**

- "C__" - "Low": \( \leq 1.2 \) lbs SO2 per million Btu
- "M__" - "Medium": \( > 1.2, \leq 3.33 \) lbs SO2 per million Btu
- "H__" - "High": \( > 3.33 \) lbs SO2 per million Btu

**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 Integrated Analysis and Forecasting
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, minememouth 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. Inputs obtained from other NEMS modules include coal production for year t-1, the minememouth 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.

Relationship to Other Components of NEMS

The model generates regional mid-term (to 2030) 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
- Minememouth coal prices by CPS supply curve in years t and t-1
Figure 1.2. Information Flow Between the CPS and Other Components of NEMS

Petroleum Market Module

Coal Supply Curves (Year t)

Price of Distillate Fuel (Year t)

Coal Production (Year t - 1)

Minemouth Price of Coal (Years t and t-1)

Electricity Market Module

Coal Supply Curves (Year t through Year t+20)

Electricity Prices (Year t)

Electricity Prices (Year t)

Macroeconomic Activity Module

Real Interest Rate (Year t)

Coal Production Curves (Year t)

Coal Distribution Submodule

Do While NEMS/Coal Iteration is Less Than Final Iteration (Year t)

Coal Production (Year t-1)

Minemouth Price of Coal (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, the costs of factor inputs (mine labor and fuel), 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 and fuel prices, produce 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 AEO2008 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 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 2000 dollars, fell from $47.77 per ton to $18.34 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 have remained relatively constant since 1999, both changed significantly in 2005, with the average U.S. minemouth coal price rising by 13 percent and productivity declining by almost 7 percent. In 2006, changes in these two coal industry metrics moderated, with the average minemouth price rising by 2 percent and mining productivity falling by about 2 percent.

Unless otherwise specified, tons refer to short tons (2,000 pounds) throughout this document.
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 AEO2008 coal pricing model indicates the strong historical correlation between prices and productivity (Figure 1.4).

**Figure 1.3. U.S. Coal Production and Prices, 1978-2006**

![Graph of U.S. Coal Production and Prices](image)

**Figure 1.4. Minemouth Coal Prices and Labor Productivity for CMM Regions and Mine Types, 1978-2006**

![Graph of Minemouth Coal Prices and Labor Productivity](image)

### 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. 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:

\[ Q_{i,j,t}^S = Q_{i,j,t}^D = Q_{i,j,t} \]  

(1.1)

In this equality, \( Q_{i,j,t} \) represents the long-run equilibrium between supply and demand for coal in a competitive market.

The formal specification of the coal pricing model for AEO2008 is as follows.

---

For demand:

\[ Q^D = f (P, \text{TRAN}, \text{ELEC}, \text{ELEC\_SHARE}, \text{INDUSTRY}, \text{OTHPROD}, \text{EXPORTS}, \text{PGAS}, \text{WOP}, \text{STOCKS}, \text{BTU\_TON}, \text{SULFUR}, \text{ASH}) + e^D \]  

\[ (1.2) \]

Supply:

\[ P = f ((Q^S/\text{PRODCAP}), \text{PRODCAP}, \text{TPH}, \text{WAGE}, \text{PCAP}, \text{PFUEL}) + e^S \]  

\[ (1.3) \]

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.”

The demand-side variables are as follows:

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

TRAN is a producer price index for the costs of transporting coal in region i to the region where it is consumed for each year t. The index is adjusted to constant 1992 dollars.

ELEC is U.S. fossil-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 fossil-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.

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.

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.

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

STOCKS is the quantity of coal inventories held by U.S. electric utilities in million tons at the beginning of year t.

BTU\_TON is the average heat content of coal receipts at electric utility 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 utility 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 utility 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.

\( e^S \) 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, the cost of transporting the coal to market, electricity generation, industrial output, 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 AEO2008 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, 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. 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 AEO2008. The first stage (reduced form) equations are used only to obtain the predicted 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. Similarly 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. 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. 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 15 percent in 2006. 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. The gradual introduction of new

---

8 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
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 shearsers 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 shearsers and shields through the use of computer-supported equipment.

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).

Technological developments during the NEMS time horizon are expected to consist of incremental improvements to existing technology rather than the introduction of new technologies. Because of the complexity in representing explicitly in the model the cost impact of each potential technology improvement, the effect of incremental technology change is captured indirectly through its estimated net effect on labor productivity. Since technology developments in the mining industry reduce costs primarily by impacting productivity, exogenous estimates of labor productivity that reflect the estimated net effect of technological improvement are provided to the model in each forecast year. Separate estimates are input to the model for each region and mining method. The cost effect of the labor productivity change for each succeeding 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 prices 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):

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

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 AEO2008, the CPS generated a set of 40 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
Figure 1.5. CPS Flowchart

Read user-specified inputs

Step 1
Calibrate model to base year prices

Step 2
Convert the regression equation to continuous supply curves

Last region/mine type/coal type

Y

Step 3
Construct step function supply curves for input to the CDS

Last region/mine type/coal type/step

N

Output supply curves and coal quality parameters to the CDS, EMM, and PMM

Y
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, 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 AEO2008 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.
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, and the cost of factor inputs (mine labor, mining equipment, and fuel). 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 2030) for the Coal Distribution Submodule of the Coal Market Module of the NEMS.

Model Update Information: February 2008

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: Integrated Analysis and Forecasting
Division: Coal and Electric Power
Model Contact: Mike Mellish
Telephone: (202) 586-2136
E-mail: mmellish@eia.doe.gov


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 2030
- 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, and fuel prices.
- 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

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

Independent Expert Reviews Conducted:

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 2007.

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 AEO2008, the base year was 2006)
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.

\[
P_{i,j,k,by} = \{\text{EXP} \left[ (A + \beta_{i,1} \cdot (1 - \beta_{12})) \right] \cdot \left[ \text{TPH}_{i,j,t=1} \left( \text{TPHBM} \cdot (1 - \beta_{12}) \right) \right] \cdot \left[ \text{PRI_ADJ}_{i,j,k} \cdot \left( \text{PROD_CAP_ADJ}_{i,j,k} \left( \beta_{4} \cdot \text{CU_BY_SC} \right) \right) \right] \cdot \left[ \text{CAPUTIL_HIST}_{i,j,k} \cdot \left( \beta_{4} \cdot \text{CU_BY_SC} \right) \right] \cdot \left[ \text{PROD_CAP} \right] \cdot \left[ \text{WAGE} \right] \cdot \left( \beta_{12} \cdot \beta_{10} \right) \cdot \left( \beta_{11} \right) \right] \cdot \left[ \beta_{4} \cdot \text{CU_BY_SC} \right] \cdot \left( \beta_{10} \right) \cdot \left( \beta_{12} \right)
\]

where \( \text{CU_BY_SC} = \left( \frac{\text{CAPUTIL}_{i,j,k,by}}{\text{CAPUTIL_HIST}_{i,j,k}} \right) \eta \)
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

\( \text{PROD\_CAP\_ADJ}_{i,j,k} \) - 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

\( \text{PRI\_ADJ}_{i,j,k} \) - 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

\( \text{PRODCAP}_{i,j,k,by} \) - annual productive capacity of coal mines for supply region \( i \), mine type \( j \), and coal type \( k \) for the base year

\( \text{CAPUTIL}_{i,j,k,by} \) - 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

\( \text{WAGE}_{by} \) - average annual wage for coal miners for the base year

\( \text{PCAP}_{j,by} \) - index for the annual user cost of capital for mine type \( j \), for the base year

\( \text{PFUEL}_{i,by} \) - weighted annual average of the electricity price and the diesel fuel price for supply region \( i \) 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

\( \text{CAPUTIL\_HIST}_{i,j,k} \) - 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 \( k \)

\( \text{CU\_BY\_SC} \) - 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

\( \eta \) - 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 AEO2008, 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 \( i \)

\( \beta_2 \) for the productive capacity term

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

\( \beta_4 \) for the capacity utilization term

\( \beta_5 \) 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 \( j \)

\( \beta_{10} \) for the user cost of capital 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.

$$CAL\_FACTOR_{i,j,k} = (BYP_{i,j,k} - P_{i,j,k,by})$$  \hspace{1cm} (1.B-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 production alone. This is accomplished by consolidating all of the non-production 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.

$$K_{i,j,k,t} = \{\exp \left[(A + \beta_{11}) \cdot (1-\beta_{12})\right]\} \cdot \left[TPH_{i,j,1}^{TPHBM \cdot (1-\beta_{12})}\right] \cdot \left[CAPUTIL\_HIST_{i,j,k}^{(\beta_{4} \cdot \beta_{12}) \cdot \left(1-\beta_{12}\right)}\right] \cdot \left[PROD\_CAP\_ADJ_{i,j,k}^{(\beta_{12} \cdot \beta_{2} + \beta_{3}) \cdot \beta_{12} \cdot \beta_{2} + \beta_{3}}\right] \cdot \left[PRI\_ADJ_{i,j,k}^{\left(\beta_{12}\right)}\right] \cdot \left[PRODCAP_{i,j,k,t}^{(\beta_{2} + \beta_{3}) \cdot \beta_{12} \cdot \beta_{2} + \beta_{3}}\right] \cdot \left[WAGE_{i,j,k,t}^{\beta_{12} \cdot \beta_{4} \cdot \beta_{9} \cdot \left(1-\beta_{12}\right)}\right] \cdot \left[PCAP_{i,j,k,t}^{\beta_{10} \cdot \beta_{12} \cdot \beta_{10} \cdot \beta_{12} \cdot \beta_{10}}\right] \cdot \left[PFUEL_{i,j,k,t}^{\beta_{11} \cdot \beta_{12} \cdot \beta_{11} \cdot \beta_{12}}\right]$$  \hspace{1cm} (1.B-3)
\[ PCAP_{j,t} = \left( \beta_{12} \cdot \beta_{10} \right) \cdot PFUEL_{i,t-1} \left( \beta_{12} \cdot \beta_{11} \right) \]

where:

\[ CU_{FY \_SC} = \left( \frac{CAPUTIL_{i,j,k,t} - 1}{CAPUTIL_{\text{HIST},i,j,k}} \right)^\eta \]

**Variables**

- \( K_{i,j,k,t} \) - 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 constant term 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
- \( PCAP_{i,j,t} \) - 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
- \( P_{i,j,k,t-1} \) - 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 and year t-1
- \( CAPUTIL\_\text{HIST}_{i,j,k} \) - 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
- \( \eta \) - 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 AEO2008, this term was set at 3.0)
Regression Coefficients (values provided in Table 1.D-1)

A overall constant for the model
βₙ for the intercept dummy variables for each supply region i
β₂ for the productive capacity term
β₃ for the productive capacity term by mine type j
β₄ for the capacity utilization term
β₅ for the labor productivity term
β₆ for the labor productivity term by supply region i
β₇ for the labor productivity term by mine type j
β₈ for the labor productivity term by supply region i and mine type j
β₉ for the labor cost term by mine type j
β₁₀ for the user cost of capital term
β₁₁ for the fuel price term
β₁₂ 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, and the PPI (producer price index) for mining machinery and equipment, are provided as user inputs.

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

\[
P_{i,j,k,t} = \text{CAL\_FACTOR}_{i,j,k} + [K_{i,j,k,t} \times \text{CAPUTIL}_{i,j,k,t}] \beta₄ \]

where

\( RMP_{i,j,k,t} \) - minemouth price of coal by supply region i, mine type j, and coal type k computed as a function of output (\( Q_{i,j,k,t} \))

\( \text{CAL\_FACTOR}_{i,j,k} \) - 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)

\( \text{CAPUTIL}_{i,j,k,t} \) - 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)

\( \beta₄ \) - 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 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.

\[
P_{i,j,k,z,t} = \text{CAL\_FACTOR}_{i,k} + [K_{i,j,k,t} \times \text{CAPUTIL\_HIST}_{i,j,k} \left( \beta_4 \times (\beta_4 \times \text{CU\_STEP\_SC}) \times \left( \frac{Q_{i,j,k,z,t}}{\text{PRODCAP}_{i,j,k,t}} \right) \right) \left( \beta_4 \times \text{CU\_STEP\_SC} \right)] 
\]

(1.B-5)

where

\[
\text{CU\_STEP\_SC} = \left( \frac{Q_{i,j,k,z,t}}{\text{PRODCAP}_{i,j,k,t}} \right) / \text{CAPUTIL\_HIST}_{i,j,k} \eta
\]

Variables
- \( P_{i,j,k,z,t} \) - 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.
- \( C_{i,j,k} \) - 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)
- \( \beta_4 \) - regression coefficient for the capacity utilization term
- \( K_{i,j,k,t} \) - multiplier for the non-production terms in the regression equation
- \( \text{PRODCAP}_{i,j,k,t} \) - annual productive capacity of coal mines for supply region \( i \), mine type \( j \), coal type \( k \), and year \( t \)
- \( \text{CAPUTIL\_HIST}_{i,j,k} \) - 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 \( k \)
- \( \text{CU\_STEP\_SC} \) - 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
- \( \eta \) - 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 AEO2008, 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 2006, 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 89.7 percent in 2001.

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

\[
\text{STEP}_Q_{i,j,k,z,t} = Q_{i,j,k,z,t} - Q_{i,j,k,z-1,t}
\]  

(1.B-6)

where

\( \text{STEP}_Q_{i,j,k,z,t} \) - 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 AEO2008, 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 FERC-423 and EIA-423 databases 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 for mining machinery and equipment; 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 AEO2008); 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:

\[i = \text{supply region}\]
\[j = \text{mine type (surface or underground)}\]
\[k = \text{coal type}\]
\[t = \text{year}\]
\[\text{by} = \text{base year}\]
\[z = \text{individual step on the step-function supply curves generated by the CPS for input to the Coal Distribution Submodule}\]
<table>
<thead>
<tr>
<th>CPS Variable Name</th>
<th>Description</th>
<th>Specification Level</th>
<th>Units</th>
<th>Variable Used in this Report</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAGE</td>
<td>Real labor cost escalator</td>
<td>National/year</td>
<td>--</td>
<td>--</td>
<td>EIA projection</td>
</tr>
<tr>
<td>L_PROD</td>
<td>Base year productivity</td>
<td>Supply region/mine type/coal type</td>
<td>Tons/miner hour</td>
<td>LP&lt;sub&gt;i,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>FR_PROD</td>
<td>Forecast year productivity (as a fraction of L_PROD)</td>
<td>Supply region/mine type/coal type/year</td>
<td>--</td>
<td>LP&lt;sub&gt;i,t&lt;/sub&gt;</td>
<td>EIA projection</td>
</tr>
<tr>
<td>ADJ_MMP_MULT</td>
<td>Price adjustment variable (multiplier)</td>
<td>Supply region/mine type/coal type/year</td>
<td>Scalar</td>
<td>--</td>
<td>EIA estimate</td>
</tr>
<tr>
<td>ADJ_MMP_ADD</td>
<td>Price adjustment variable (additive)</td>
<td>Supply region/mine type/coal type/year</td>
<td>1987</td>
<td>Dollars/Ton</td>
<td>EIA estimate</td>
</tr>
<tr>
<td>SBAS_REGION</td>
<td>Alphabetic supply region code</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>NBAS</td>
<td>Number of production records</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>File definition</td>
</tr>
<tr>
<td>CPROD_TYPE</td>
<td>Alphabetic coal type code</td>
<td>Supply region/coal type</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>B_PROD</td>
<td>Base year (2006) production (surface and deep)</td>
<td>Supply region/mine type/coal type</td>
<td>MMTons</td>
<td>P&lt;sub&gt;i,j,k,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>BTU</td>
<td>Average heat content (surface and deep)</td>
<td>Supply region/mine type/coal type</td>
<td>MMBtu/ton</td>
<td>--</td>
<td>FERC-423</td>
</tr>
<tr>
<td>SULFUR</td>
<td>Average sulfur content (surface and deep)</td>
<td>Supply region/mine type/coal type</td>
<td>Lbs/MMBtu</td>
<td>--</td>
<td>FERC-423</td>
</tr>
<tr>
<td>CAR</td>
<td>Average carbon dioxide emission factor (surface and deep)</td>
<td>Supply region/coal type</td>
<td>Lbs/MMBtu</td>
<td>--</td>
<td>EIA estimate</td>
</tr>
<tr>
<td>PRI</td>
<td>Base-Year (2006) coal price (surface and deep)</td>
<td>Supply region/coal type</td>
<td>1987</td>
<td>Dollars/Ton</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>MERCURY</td>
<td>Average mercury content (surface and deep)</td>
<td>Supply region/mine type/coal type</td>
<td>Lbs/trillion Btu</td>
<td>--</td>
<td>U.S. EPA</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------</td>
<td>---------------------</td>
<td>-------</td>
<td>------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>B_CAP_UTIL</td>
<td>Base-Year (2006) capacity utilization of coal mines (surface and deep)</td>
<td>Supply region/ mine type</td>
<td>Fraction</td>
<td>CAPUTIL&lt;sub&gt;i,j,k,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>B_PROD_CAP</td>
<td>Base-Year (2006) productive capacity (surface and deep)</td>
<td>Supply region/ mine type/coal type</td>
<td>MMTons</td>
<td>PRODCAP&lt;sub&gt;i,j,k,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>B_PROD_CAP_ADJ</td>
<td>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)</td>
<td>Supply region/ mine type/coal type</td>
<td>--</td>
<td>PROD_CAP_ADJ&lt;sub&gt;i,j,k,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>PRI_ADJ</td>
<td>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)</td>
<td>Supply region/ mine type/coal type</td>
<td>--</td>
<td>PRI_ADJ&lt;sub&gt;i,j,k,by&lt;/sub&gt;</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>UTIL_HIST</td>
<td>Representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated (surface and deep)</td>
<td>Supply region/ mine type/coal type</td>
<td>Percent</td>
<td>CAPUTIL_HIST&lt;sub&gt;i,j,k&lt;/sub&gt;</td>
<td>EIA specification</td>
</tr>
<tr>
<td>ELEC_SHARE</td>
<td>Share of total fuel costs at mines represented by electricity</td>
<td>Supply region/ mine type</td>
<td>Fraction</td>
<td>--</td>
<td>U.S. Census Bureau</td>
</tr>
<tr>
<td>DIST_SHARE</td>
<td>Share of total fuel costs at mines represented by diesel fuel</td>
<td>Supply region/ mine type</td>
<td>Fraction</td>
<td>--</td>
<td>U.S. Census Bureau</td>
</tr>
<tr>
<td>OCONT</td>
<td>Overall constant for CPS regression model</td>
<td>National</td>
<td>--</td>
<td>A</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>-------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>LUTIL</td>
<td>Pricing model coefficient (capacity utilization term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_4$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>LPCAP</td>
<td>Pricing model coefficient (cost of capital term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_{10}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>LPFUEL</td>
<td>Pricing model coefficient (electricity price term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_{11}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>TPH</td>
<td>Pricing model coefficient (overall productivity term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_5$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>TPH_DEEP</td>
<td>Pricing model coefficient (mine type productivity term)</td>
<td>Mine type</td>
<td>--</td>
<td>$\beta_{17}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>LPRODCAP</td>
<td>Pricing model coefficient (overall productive capacity term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_2$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>RHO</td>
<td>Pricing model coefficient (first-order autocorrelation term)</td>
<td>National</td>
<td>--</td>
<td>$\beta_{11}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>PDUMM</td>
<td>Pricing model adjustment factor applied to overall constant term to account for user-specified revisions of the coefficient for the labor productivity regression variable</td>
<td>National</td>
<td>--</td>
<td>TPHBM</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>DEEPRODCAP</td>
<td>Pricing model coefficient (mine type productive capacity term)</td>
<td>Mine type</td>
<td>--</td>
<td>$\beta_{13}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>DEEPWAGE</td>
<td>Pricing model coefficient (mine type labor cost term)</td>
<td>Mine Type</td>
<td>--</td>
<td>$\beta_{19}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>B_WAGE</td>
<td>Base-year hourly wage</td>
<td>National</td>
<td>1987 Dollars/Hour</td>
<td>WAGE</td>
<td>Bureau of Labor Statistics</td>
</tr>
<tr>
<td>F_INDEX</td>
<td>Base-year electricity price (industrial sector)</td>
<td>Supply region</td>
<td>1992 Dollars/MMBtu</td>
<td>--</td>
<td>EIA</td>
</tr>
<tr>
<td>SDS</td>
<td>Pricing model coefficients (intercept dummy variables)</td>
<td>Supply region</td>
<td>--</td>
<td>$\beta_{i1}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>SDD</td>
<td>Pricing model coefficients (used to adjust intercept terms for underground mines in CPS regions WM, WW and ZN)</td>
<td>Supply region</td>
<td>--</td>
<td>$\beta_{i1}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------</td>
<td>---------------------</td>
<td>-------</td>
<td>-----------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>SPROD</strong></td>
<td>Pricing model coefficients (regional productivity terms)</td>
<td>Supply region</td>
<td>--</td>
<td>$\beta_{i,6}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td><strong>DPROD</strong></td>
<td>Pricing model coefficients (regional and mine type productivity terms)</td>
<td>Supply region/mine type</td>
<td>--</td>
<td>$\beta_{i,j,7}$</td>
<td>Regression analysis</td>
</tr>
<tr>
<td><strong>P_EQUIP_SURF</strong></td>
<td>PPI for construction machinery</td>
<td>Mine type/year</td>
<td>Constant dollar index (1992 dollars)</td>
<td>--</td>
<td>Bureau of Labor Statistics</td>
</tr>
<tr>
<td><strong>P_EQUIP_UNDG</strong></td>
<td>PPI for mining machinery and equipment</td>
<td>Mine type/year</td>
<td>Constant dollar index (1992 dollars)</td>
<td>--</td>
<td>Bureau of Labor Statistics</td>
</tr>
<tr>
<td><strong>PCNT_REC</strong></td>
<td>Number of marginal cost curves</td>
<td>National</td>
<td>--</td>
<td>--</td>
<td>File definition</td>
</tr>
<tr>
<td><strong>PCNT_REGION</strong></td>
<td>Numerical supply region identifier</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td><strong>PCNT_CTYPE</strong></td>
<td>Numerical coal type identifier</td>
<td>Coal type</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td><strong>PCNT_PRICE</strong></td>
<td>Base-year minemouth coal price</td>
<td>Supply region/mine type/coal type</td>
<td>1987 Dollars/ton</td>
<td>--</td>
<td>EIA-7A</td>
</tr>
<tr>
<td><strong>PCNT_PROD</strong></td>
<td>Initial target production used to build step-function curves with 11 steps</td>
<td>Supply region/mine type/coal type</td>
<td>MMTons</td>
<td>--</td>
<td>EIA-7A</td>
</tr>
<tr>
<td><strong>MCNT_REC</strong></td>
<td>Number of marginal cost curves</td>
<td>National</td>
<td>--</td>
<td>--</td>
<td>File definition</td>
</tr>
<tr>
<td><strong>MCNT_REGION</strong></td>
<td>Numerical supply region identifier</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td><strong>MCNT_CTYPE</strong></td>
<td>Numerical coal type identifier</td>
<td>Coal type</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td><strong>MCNT_PRICE</strong></td>
<td>Initial target price used to build step-function curves with 11 steps</td>
<td>Supply region/mine type/coal type</td>
<td>1987 Dollars/ton</td>
<td>$P_{i,j,k,z=1,5}$</td>
<td>EIA-7A</td>
</tr>
<tr>
<td><strong>MCNT_PROD</strong></td>
<td>Base year production</td>
<td>Supply region/mine type/coal type</td>
<td>MMTons</td>
<td>--</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>----------</td>
<td>-------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>MCNT_STEP</td>
<td>Variations from the target price used to build step-function curves with 11 steps</td>
<td>National</td>
<td>Fraction</td>
<td>--</td>
<td>EIA estimate</td>
</tr>
<tr>
<td>SCLIMIT_CNT</td>
<td>Numerical supply curve code</td>
<td>Supply curve</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>SCLIMIT_REG</td>
<td>Numerical supply region code</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>SCLIMIT__REGNAME</td>
<td>Alphabetic supply region code</td>
<td>Supply region</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>SCLIMIT__CPSCT</td>
<td>Numerical coal type code</td>
<td>Coal type</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>SCLIMIT__CDSCT</td>
<td>Alphabetic coal type code</td>
<td>Coal type</td>
<td>--</td>
<td>--</td>
<td>Model definition</td>
</tr>
<tr>
<td>IYR</td>
<td>Supply curve limit</td>
<td>Supply curve</td>
<td>MMTons</td>
<td>--</td>
<td>EIA estim.</td>
</tr>
<tr>
<td>SCURVE__LIMIT_MAX</td>
<td>Maximum supply curve limit</td>
<td>National</td>
<td>MMTons</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_EXP</td>
<td>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 AEO2008) is used for the calculating prices for each of the last six steps of the eleven-step CPS supply curves.</td>
<td>National</td>
<td>--</td>
<td>η</td>
<td>EIA specification</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>-------</td>
<td>-------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>UTIL_EXP_BOT</td>
<td>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 AEO2008) is used for the calculating prices for each of the first five steps of the eleven-step CPS supply curves.</td>
<td>National</td>
<td>--</td>
<td>η</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MAX_SURF</td>
<td>Upper capacity utilization amount used to trigger additions to surface productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MAX_UNDG</td>
<td>Upper capacity utilization amount used to trigger additions to underground productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MID_SURF</td>
<td>Mid-level capacity utilization amount used to trigger additions to surface productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MID_UNDG</td>
<td>Mid-level capacity utilization amount used to trigger additions to underground productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MIN_SURF</td>
<td>Lower capacity utilization amount used to trigger retirements of surface productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MIN_UNDG</td>
<td>Lower capacity utilization amount used to trigger retirements of underground productive capacity</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MAX_SURF_ADJ</td>
<td>Factor used to increase surface productive capacity when capacity utilization UTIL_MAX_SURF</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>CPS Variable Name</td>
<td>Description</td>
<td>Specification Level</td>
<td>Units</td>
<td>Variable Used in this Report</td>
<td>Source(s)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>---------</td>
<td>------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>UTIL_MAX_UNDG_ADJ</td>
<td>Factor used to increase underground productive capacity when capacity utilization UTIL_MAX_UNDG</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MID_SURF_ADJ</td>
<td>Factor used to increase surface productive capacity when capacity utilization UTIL_MAX_SURF but UTIL_MID_SURF</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MID_UNDG_ADJ</td>
<td>Factor used to increase underground productive capacity when capacity utilization UTIL_MAX_UNDG but UTIL_MID_UNDG</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MIN_SURF_ADJ</td>
<td>Factor used to retire surface productive capacity when capacity utilization UTIL_MIN_SURF</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>UTIL_MIN_UNDG_ADJ</td>
<td>Factor used to retire underground productive capacity when capacity utilization UTIL_MIN_SURF</td>
<td>Supply region</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
<tr>
<td>MCNT_STEP</td>
<td>Variable use to establish production levels for each of the 11 steps represented on the CPS step-function supply curves</td>
<td>National</td>
<td>Fraction</td>
<td>--</td>
<td>EIA specification</td>
</tr>
</tbody>
</table>
**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

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

<table>
<thead>
<tr>
<th>CPS Variable Name</th>
<th>Description</th>
<th>Units</th>
<th>Variable Used in this Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCNT_P</td>
<td>Minemouth coal price associated with each CPS supply curve step provided to the CDS</td>
<td>1987 dollars/ton</td>
<td>$P_{i,j,k,z,t}$</td>
</tr>
<tr>
<td>MCNT_Q</td>
<td>Length of each CPS supply curve step provided to the CDS</td>
<td>Million tons</td>
<td>$Q_{i,j,k,z,t}$</td>
</tr>
<tr>
<td>MCNT_BTU</td>
<td>Average Btu content for each CPS supply curve step provided to the CDS</td>
<td>MMBtu per ton</td>
<td>--</td>
</tr>
<tr>
<td>MCNT_SULF</td>
<td>Average sulfur content for each CPS supply curve step provided to the CDS</td>
<td>lbs/MMBtu</td>
<td>--</td>
</tr>
<tr>
<td>MCNT_MERC</td>
<td>Average mercury content for each CPS supply curve step provided to the CDS</td>
<td>lbs/Trillion Btu</td>
<td>--</td>
</tr>
<tr>
<td>MCNT_CAR</td>
<td>Average carbon dioxide emission factor for each CPS supply curve step provided to the CDS</td>
<td>lbs/MMBtu</td>
<td>--</td>
</tr>
</tbody>
</table>
# 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>
<thead>
<tr>
<th>CPS Variable Name</th>
<th>Description</th>
<th>Units</th>
<th>Variable Used in this Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_PROD</td>
<td>Labor productivity for NEMS forecast year t</td>
<td>Tons/miner hour</td>
<td>TPH_{i,j,t}</td>
</tr>
<tr>
<td>E_FUEL</td>
<td>Hybrid fuel price (average of industrial electricity and distillate prices) for NEMS forecast year t</td>
<td>1992 dollars/MMBtu</td>
<td>PFUEL_{i,j,t}</td>
</tr>
<tr>
<td>D_FUEL</td>
<td>Diesel fuel prices for NEMS forecast year t</td>
<td>1992 dollars/MMBtu</td>
<td>--</td>
</tr>
<tr>
<td>R_WAGE</td>
<td>Average coal industry wage for NEMS forecast year t</td>
<td>1992 dollars/hour</td>
<td>WAGE_{t}</td>
</tr>
<tr>
<td>PK</td>
<td>User-cost of mining equipment for NEMS forecast years</td>
<td>Constant dollar index (1992 dollars)</td>
<td>PCAP_{t}</td>
</tr>
<tr>
<td>YINT</td>
<td>CPS calibration constant</td>
<td>--</td>
<td>C_{i,j,k}</td>
</tr>
<tr>
<td>FP</td>
<td>Multiplier for non-production terms in the CPS coal pricing equation</td>
<td>--</td>
<td>K_{i,j,k,t}</td>
</tr>
<tr>
<td>QTARG</td>
<td>Target quantities for years t &gt; 1, used to build step-function curves with 11 steps</td>
<td>Million tons</td>
<td>Q_{i,j,k,t}</td>
</tr>
<tr>
<td>SC_PRICE</td>
<td>Prices for each of the steps on the 11-step supply curves input to the CDS</td>
<td>1992 dollars/ton</td>
<td>P_{i,j,k,z,t}</td>
</tr>
<tr>
<td>SC_QUAN</td>
<td>Quantities for each of the steps on the 11-step supply curves input to the CDS</td>
<td>Million tons</td>
<td>Q_{i,j,k,z,t}</td>
</tr>
<tr>
<td>LAG_PRI</td>
<td>Minemouth price of coal by supply curve in year t-1</td>
<td>1992 dollars/ton</td>
<td>MMP_{i,j,k,t-1}</td>
</tr>
<tr>
<td>LAG_PROD</td>
<td>Coal production by supply curve in year t-1</td>
<td>Million tons</td>
<td>Q_{i,j,k,t-1}</td>
</tr>
<tr>
<td>PROD_CAP</td>
<td>Coal productive capacity by supply curve in year t</td>
<td>Million tons</td>
<td>PRODCAP_{i,j,k,t}</td>
</tr>
</tbody>
</table>
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, the costs of factor inputs (mine labor and fuel), 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 AEO2008. 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 and two mine types (surface and underground) for the years 1980 through 2005, excluding the years 1986-1992.10 In all, 342 observations are included (18 observations per year (13 surface and 5 underground) for each of the 19 years represented in the historical data series).

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 all regions except Central Appalachia. 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. 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.

---

10Data 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. Estimates of annual productive capacity for 1978 through 1985 were developed using reported daily productive capacity data and regional/mine type estimates for maximum average days worked.
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.

**Computation of $R^2$ with a constant term:**

\[
R^2 = 1 - \left[ \frac{\sum e_t^2}{\sum (y_t - \bar{y})^2} \right]
\]

(1.D-1)

where:

\[ e_t = y_t - \hat{y}_t \]

and

\[ \hat{y}_t = Xb \]

Or

\[
R^2 = 1 - \left[ \frac{SSR}{SST} \right]
\]

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:

\[
\bar{R}^2 = 1 - \left[ \frac{SSR}{(T - K)} \right] / \left[ SST / (T - 1) \right]
\]

(1.D-2)

In the above equations:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_t$</td>
<td>residuals</td>
</tr>
<tr>
<td>$y_t$</td>
<td>observed values of the independent variable</td>
</tr>
<tr>
<td>$\bar{y}$</td>
<td>mean of the observed values of $y_t$</td>
</tr>
<tr>
<td>$\hat{y}_t$</td>
<td>predicted values of the independent variable</td>
</tr>
<tr>
<td>$X_t$</td>
<td>vector of independent variables</td>
</tr>
<tr>
<td>$b$</td>
<td>estimated regression coefficients</td>
</tr>
<tr>
<td>SSR</td>
<td>sum of squared residuals</td>
</tr>
</tbody>
</table>
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 AEO2008 is:

$$
P_{i,j,k,t} = \text{CAL\_FACTOR}_{i,j,k,t} + [C_{i,j,k,t} \times \text{PROD\_CAP}_{i,j,k,t} (\beta_2 + \beta_{j,3}) \times \text{CAP\_UTIL}_{i,j,k,t} \beta_4] * (1.D-3)
$$

$$
\text{TPH}_{i,j,t} \times \text{PROD\_CAP}_{i,j,k,t-1} (\beta_{12} + (\beta_2 + \beta_{j,3})) * \text{CAP\_UTIL\_HIST}_{i,j,k} [\beta_4 - (\beta_4 \times \text{CU\_FY\_SC})] * (\beta_{12} \times \beta_{j,9}) * (\beta_{12} \times \beta_{j,10}) * \text{PCAP}_{j,t} * \text{PFUEL}_{i,t} (\beta_{11} * P_{i,j,k,t-1} - \beta_{12} \times \beta_{j,3} \times \beta_{12} \times \beta_{j,9} * \beta_{10} \times \beta_{12} \times \beta_{j,11})
$$

where:

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 AEO2008, prices were calibrated to the average annual minemouth coal prices for 2006.

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

$C_{i,j,k,t} = e^{(A + \beta_{i,1})} \times (1 - \beta_{12}) \times \text{TPH}_{i,j,t=1} (k \times \text{SE} \times (1 - \beta_{12})) \times \text{CAP\_UTIL\_HIST}_{i,j,k} [\beta_4 \times (\beta_4 \times \text{CU\_FY\_SC})] \times (\beta_{12}) * (1.D-4)

[\text{PROD\_CAP\_ADJ}_{i,j,k} (\beta_{i,2} + \beta_{j,3}) \times (1 - \beta_{12})] \times [\text{PRI\_ADJ}_{i,j,k} (\beta_{i,12})]

where:

The first term in equation 1.D-4 ($e^{(A + \beta_{i,1})} \times (1 - \beta_{12})$) 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 ($\text{TPH}_{i,j,t=1} (k \times \text{SE} \times (1 - \beta_{12}))$) represents a required adjustment to the intercept term for the coal-pricing equation to account for user-specified changes in the estimated coefficient for the overall productivity term. Specifically, the term $k$ represents the amount by which the overall parameter estimate ($\beta_5$) for the productivity term is to be revised. The SE term is the standard error of the parameter estimate ($\beta_5$) for the labor productivity term, and is a constant. For the AEO2008, $k$ was set equal to zero reflecting the assumption that the correlation between coal mining productivity and minemouth coal prices as estimated for the recent historical period will continue to hold over the AEO2008 forecast horizon.

The third term in equation 1.D-4 ($\text{CAP\_UTIL\_HIST}_{i,j,k} [\beta_4 \times (\beta_4 \times \text{CU\_FY\_SC})] \times (\beta_{12})$) represents a required adjustment to the intercept term for the coal-pricing equation to account for changes in the parameter estimate ($\beta_4$) for the capacity utilization term. In the AEO2008 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 $(\text{CAPUTIL}_{i,j,k,t-1} / \text{CAPUTIL}_{HIST,i,k})^{\eta}$. In this equation, $\text{CAPUTIL}_{i,j,k,t-1}$ is the projected level of capacity utilization for a specific supply curve in year $t-1$, $\text{CAPUTIL}_{HIST,i,k}$ is the representative historical rate of capacity utilization for this same CPS supply curve, and the term $\eta$ is a user-specified term. For the AEO2008, the user-specified term $\eta$ was set equal to 3.0.

The fourth term in equation 1.D-4 ($\text{PROD\_CAP\_ADJ}_{i,j,k}(\beta_2 + \beta_{j,3} \times (1-\beta_{12}))$) 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). $\text{PROD\_CAP\_ADJ}$ is a user-specified input calculated by dividing base-year (2006) productive capacity for supply region $i$ and mine type $j$ by the estimated base-year (2006) 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 ($\text{PRI\_ADJ}_{i,j,k}(\beta_{12})$) is 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). $\text{PRI\_ADJ}$ is a user-specified input calculated by dividing the average base-year (2006) minemouth coal price for supply region $i$ and mine type $j$ by the estimated average base-year (2006) 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
- $\text{PRODCAP}_{i,j,k,t}$: annual productive capacity of coal mines for supply region $i$, mine type $j$, coal type $k$ in year $t$
- $\text{CAPUTIL}_{i,j,k,t}$: 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)
- $\text{TPH}_{i,j,t}$: average annual coal mine labor productivity in tons per miner hour for supply region $i$, mine type $j$ in year $t$
- $\text{WAGE}_{j,t}$: average annual wage for coal miners for mine type $j$ in year $t$
- $\text{PCAP}_{j,t}$: index representing the annualized user cost of mining equipment for mine type $j$, in year $t$. The index is adjusted to constant 1992 dollars.
- $\text{PFUEL}_{i,t}$: 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

Regression Coefficients

A overall constant for the model
β_{i,1} for the intercept dummy variables for each supply region i
β_{2} for the productive capacity term
β_{i,3} for the productive capacity term by mine type j
β_{4} for the capacity utilization term
β_{5} for the labor productivity term
β_{i,6} for the labor productivity term by supply region i
β_{j,7} for the labor productivity term by mine type j
β_{i,j,8} for the labor productivity term by supply region i and mine type j
β_{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 first-order autocorrelation term
### Table 1.D-1. Regression Statistics for the Coal Pricing Model

<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta_0 )</td>
<td>Overall Constant</td>
<td>-0.428</td>
<td>0.331</td>
<td>-1.293</td>
</tr>
<tr>
<td>( \beta_{3,1} )</td>
<td>DUM_REG1 (Southern Appalachia (SA))</td>
<td>0.779</td>
<td>0.117</td>
<td>6.686*</td>
</tr>
<tr>
<td>( \beta_{5,1} )</td>
<td>DUM_REG2 (West Interior (WI))</td>
<td>1.056</td>
<td>0.102</td>
<td>10.388*</td>
</tr>
<tr>
<td>( \beta_{6,1} )</td>
<td>DUM_REG3 (Gulf Lignite (GL))</td>
<td>-0.292</td>
<td>0.056</td>
<td>-5.205*</td>
</tr>
<tr>
<td>( \beta_{7,1} )</td>
<td>DUM_REG4 (Dakota Lignite (DL))</td>
<td>1.317</td>
<td>0.165</td>
<td>7.968*</td>
</tr>
<tr>
<td>( \beta_{8,1} )</td>
<td>DUM_REG5 (Western Montana (WM))</td>
<td>3.005</td>
<td>0.461</td>
<td>6.520*</td>
</tr>
<tr>
<td>( \beta_{9,1} )</td>
<td>DUM_REG6 (Wyoming, Northern PRB (NW))</td>
<td>3.196</td>
<td>0.333</td>
<td>9.585*</td>
</tr>
<tr>
<td>( \beta_{10,1} )</td>
<td>DUM_REG7 (Wyoming, Southern PRB (SW))</td>
<td>3.611</td>
<td>0.286</td>
<td>12.621*</td>
</tr>
<tr>
<td>( \beta_{11,1} )</td>
<td>DUM_REG8 (Western Wyoming (WW))</td>
<td>1.183</td>
<td>0.300</td>
<td>3.938*</td>
</tr>
<tr>
<td>( \beta_{12,1} )</td>
<td>DUM_REG9 (Rocky Mountain (RM))</td>
<td>0.754</td>
<td>0.055</td>
<td>13.804*</td>
</tr>
<tr>
<td>( \beta_{13,1} )</td>
<td>DUM_REG10 (Arizona/New Mexico (ZN))</td>
<td>0.489</td>
<td>0.060</td>
<td>8.121*</td>
</tr>
<tr>
<td>( \beta_2 )</td>
<td>ln PRODCAP</td>
<td>0.450</td>
<td>NA*</td>
<td>NA*</td>
</tr>
<tr>
<td>( \beta_{4,3} )</td>
<td>DUM_MINE_TYPE (Underground) * ln PRODCAP</td>
<td>-0.074</td>
<td>0.047</td>
<td>-1.582</td>
</tr>
<tr>
<td>( \beta_4 )</td>
<td>ln CAPUTIL</td>
<td>0.395</td>
<td>0.063</td>
<td>6.256*</td>
</tr>
<tr>
<td>( \beta_5 )</td>
<td>ln TPH</td>
<td>-0.446</td>
<td>0.058</td>
<td>-7.753*</td>
</tr>
<tr>
<td>( \beta_{3,6} )</td>
<td>SA*ln TPH</td>
<td>0.370</td>
<td>0.114</td>
<td>3.240*</td>
</tr>
<tr>
<td>( \beta_{5,6} )</td>
<td>WI*ln TPH</td>
<td>0.335</td>
<td>0.086</td>
<td>3.910*</td>
</tr>
<tr>
<td>( \beta_{7,6} )</td>
<td>DL*ln TPH</td>
<td>-0.549</td>
<td>0.070</td>
<td>-7.880*</td>
</tr>
<tr>
<td>( \beta_{8,6} )</td>
<td>WM*ln TPH</td>
<td>-0.999</td>
<td>0.160</td>
<td>-6.258*</td>
</tr>
<tr>
<td>( \beta_{9,6} )</td>
<td>NW*ln TPH</td>
<td>-1.118</td>
<td>0.104</td>
<td>-10.702*</td>
</tr>
<tr>
<td>( \beta_{10,6} )</td>
<td>SW*ln TPH</td>
<td>-1.210</td>
<td>0.092</td>
<td>-13.107*</td>
</tr>
<tr>
<td>( \beta_{11,6} )</td>
<td>WW*ln TPH</td>
<td>-0.314</td>
<td>0.157</td>
<td>-1.995*</td>
</tr>
<tr>
<td>( \beta_{1,7} )</td>
<td>DUM_MINE_TYPE (Underground) * ln TPH</td>
<td>-0.435</td>
<td>0.051</td>
<td>-8.608*</td>
</tr>
<tr>
<td>( \beta_{1,7,1,8} )</td>
<td>NA * DUM_MINE_TYPE (Underground) * ln TPH</td>
<td>0.218</td>
<td>0.037</td>
<td>5.936*</td>
</tr>
<tr>
<td>( \beta_{3,1,7,1,8} )</td>
<td>SA * DUM_MINE_TYPE (Underground) * ln TPH</td>
<td>-0.271</td>
<td>0.102</td>
<td>-2.667*</td>
</tr>
<tr>
<td>( \beta_{4,1,7,1,8} )</td>
<td>EI * DUM_MINE_TYPE (Underground) * ln TPH</td>
<td>0.261</td>
<td>0.043</td>
<td>6.054*</td>
</tr>
<tr>
<td>( \beta_{1,9} )</td>
<td>DUM_MINE_TYPE (Underground) * ln WAGE</td>
<td>0.119</td>
<td>0.076</td>
<td>1.563</td>
</tr>
<tr>
<td>( \beta_{10} )</td>
<td>ln PCAP</td>
<td>0.103</td>
<td>0.034</td>
<td>2.991*</td>
</tr>
<tr>
<td>( \beta_{11} )</td>
<td>ln PFUEL</td>
<td>0.137</td>
<td>0.029</td>
<td>4.683*</td>
</tr>
<tr>
<td>( \beta_{12} )</td>
<td>Autocorrelation Parameter (Rho)</td>
<td>0.514</td>
<td>0.052</td>
<td>9.796*</td>
</tr>
<tr>
<td>Adjusted R squared</td>
<td></td>
<td>0.997</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durbin-Watson Statistic</td>
<td></td>
<td>2.114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Observations</td>
<td></td>
<td>342b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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 0.214.

The use of a weighted regression technique using the TSP 4.5 statistical package resulted 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 ten CPS supply regions and two mine types (surface and underground) for the years 1980 through 2005, excluding the years 1986-1992.  In all, 342 observations are included (18 observations per year (13 surface and 5 underground) for each of the 19 years represented in the historical data series).

Notes: The endogenous explanatory variables in the regression are PRODCAP, CAPUTIL, TPH, WAGE, PCAP, and PFUEL.  Instruments excluded from the supply equation are lagged fossil electricity generation, lagged coal share of total electricity generation, lagged days of supply at electricity sector power plants, lagged industrial coal consumption, lagged exports, coal inventories at electricity sector plants, lagged mine price of coal, lagged productive capacity, lagged capacity utilization, lagged mine productivity, lagged fuel price, lagged coal industry wage, the world oil price, the price of natural gas to the electric sector, and the average heat, sulfur and ash content for coal received at electricity sector plants.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{i,j,t}$</td>
<td>Average annual minemouth price of coal by CPS supply region and mine type</td>
<td>1992 Dollars per short ton</td>
<td>Energy Information Administration, Form EIA-7A, &quot;Coal Production Report&quot;</td>
</tr>
<tr>
<td>PRODCAP$_{i,j,t}$</td>
<td>Annual coal productive capacity by region and mine type</td>
<td>Million short tons</td>
<td>Energy Information Administration, Form EIA-7A, &quot;Coal Production Report&quot;</td>
</tr>
<tr>
<td>CAPUTIL$_{i,j,t}$</td>
<td>Average annual capacity utilization at coal mines by region and mine type</td>
<td>Percent</td>
<td>Energy Information Administration, Form EIA-7A, &quot;Coal Production Report&quot;</td>
</tr>
<tr>
<td>TPH$_{i,j,t}$</td>
<td>Average annual labor productivity by region and mine type</td>
<td>Short tons per miner hour</td>
<td>Energy Information Administration, Form EIA-7A, &quot;Coal Production Report&quot;</td>
</tr>
<tr>
<td>WAGE$_t$</td>
<td>Average hourly coal industry wage (national level)</td>
<td>1992 Dollars per miner hour</td>
<td>U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID’s: EEU10120006 and CEU1021210006</td>
</tr>
</tbody>
</table>

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 $t$;
- $\delta$ 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 $t$;
- $\delta p_t$ 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>
<thead>
<tr>
<th>Data Item</th>
<th>Description</th>
<th>Units</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content of coal</td>
<td>Average annual ash content of coal for receipts at electric utility plants by CPS supply region and mine type</td>
<td>Percent by weight</td>
<td>Federal Energy Regulatory Commission, FERC Form 423, “Monthly Report of Cost and Quality of Fuels for Electric Plants” and Energy Information Administration, Form EIA-423, &quot;Monthly Cost and Quality of Fuels for Electric Plants Report&quot;</td>
</tr>
</tbody>
</table>
## Table 1.D-3. Data Sources for Instruments Excluded from the Supply Equation

<table>
<thead>
<tr>
<th>Data Item</th>
<th>Description</th>
<th>Units</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Production</td>
<td>Total U.S. production minus production for the current observation</td>
<td>Million tons</td>
<td>Energy Information Administration, Form EIA-7A, “Coal Production Report”</td>
</tr>
</tbody>
</table>
Appendix 1.E

Bibliography


Energy Information Administration, Coal Data: A Reference, DOE/EIA-0064(93) (Washington, DC, February 1995) and prior issues.


Fiscor, S., “U.S. Longwall Census 2007,” Coal Age (February 2008) and prior issues.


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 Integrated Analysis and Forecasting
Energy Information Administration
EI-80
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 14 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 2008.

Name: Coal Distribution Submodule
Acronym: CDS
Model Contact: Diane Kearney, Department of Energy, EI-82, Washington, DC 20585
(202) 586-2415; (diane.kearney@eia.doe.gov)
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

Six appendices to the text of this section contain:

- 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 2030) 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 14 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, 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
- 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 40 coal supply sources used in the AEO2008 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 14 demand regions. There are four supply regions east of the Mississippi River that contain 23 of the 40 coal supply sources used for the Annual Energy Outlook 2008 (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 AEO2008 is shown in Table 2.1.

The 14 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 North American Electricity Reliability Council (NERC) regions by the NEMS Electricity Market Module.
<table>
<thead>
<tr>
<th>CMM Supply Region</th>
<th>Coal Type</th>
<th>Production (million tons)</th>
<th>Average MMBtu/Ton</th>
<th>Average lbs Sulfur/MMBtu</th>
<th>Average Ash % by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &quot;NA&quot; (North Appalachia = PA, OH, MD, No. WV)</td>
<td>MDP</td>
<td>3.4</td>
<td>26.271</td>
<td>0.68</td>
<td>6.34</td>
</tr>
<tr>
<td></td>
<td>MDB/MSB</td>
<td>66.8</td>
<td>25.24</td>
<td>1.28</td>
<td>10.35</td>
</tr>
<tr>
<td></td>
<td>HDB/HSB</td>
<td>66.2</td>
<td>24.84</td>
<td>2.49</td>
<td>10.63</td>
</tr>
<tr>
<td></td>
<td>HSL</td>
<td>13.6</td>
<td>12.70</td>
<td>2.82</td>
<td>44.24</td>
</tr>
<tr>
<td>2. &quot;CA&quot; (Central Appalachia = So. WV, VA, East KY, No. TN)</td>
<td>MDP</td>
<td>38.3</td>
<td>26.271</td>
<td>0.62</td>
<td>6.09</td>
</tr>
<tr>
<td></td>
<td>CDB/CSB</td>
<td>44.9</td>
<td>24.84</td>
<td>0.55</td>
<td>11.08</td>
</tr>
<tr>
<td></td>
<td>MDB/MSB</td>
<td>153.4</td>
<td>24.74</td>
<td>0.86</td>
<td>11.05</td>
</tr>
<tr>
<td>3. &quot;SA&quot; (South Appalachia = AL, So. TN)</td>
<td>CDP</td>
<td>7.4</td>
<td>26.271</td>
<td>0.51</td>
<td>8.05</td>
</tr>
<tr>
<td></td>
<td>CDB/CSB</td>
<td>0.2</td>
<td>24.84</td>
<td>0.50</td>
<td>10.28</td>
</tr>
<tr>
<td></td>
<td>MDB/MSB</td>
<td>11.4</td>
<td>24.85</td>
<td>1.21</td>
<td>13.17</td>
</tr>
<tr>
<td>4. &quot;EI&quot; (East Interior = IL, IN, West KY, MS)</td>
<td>MDB/MSB</td>
<td>26.4</td>
<td>22.26</td>
<td>1.06</td>
<td>8.37</td>
</tr>
<tr>
<td></td>
<td>HDB/HSB</td>
<td>68.7</td>
<td>22.85</td>
<td>2.67</td>
<td>9.79</td>
</tr>
<tr>
<td></td>
<td>MSL</td>
<td>3.8</td>
<td>10.23</td>
<td>0.94</td>
<td>15.80</td>
</tr>
<tr>
<td>5. &quot;WI&quot; (West Interior = KS, MO, AR, OK, TX, bituminous only)</td>
<td>HSB</td>
<td>2.8</td>
<td>22.66</td>
<td>2.42</td>
<td>17.09</td>
</tr>
<tr>
<td>6. &quot;GL&quot; (Gulf Lignite = TX, LA, lignite only)</td>
<td>MSL</td>
<td>33.4</td>
<td>13.38</td>
<td>1.29</td>
<td>14.71</td>
</tr>
<tr>
<td></td>
<td>HSL</td>
<td>16.3</td>
<td>12.57</td>
<td>2.40</td>
<td>18.75</td>
</tr>
<tr>
<td>7. &quot;DL&quot; (Dakota Lignite = ND, MT, lignite only)</td>
<td>MSL</td>
<td>30.8</td>
<td>13.26</td>
<td>1.07</td>
<td>9.26</td>
</tr>
<tr>
<td>8. &quot;WM&quot; (Western Montana)</td>
<td>CSS</td>
<td>0.3</td>
<td>20.03</td>
<td>0.58</td>
<td>7.44</td>
</tr>
<tr>
<td></td>
<td>CSS</td>
<td>22.5</td>
<td>18.72</td>
<td>0.37</td>
<td>4.50</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>18.7</td>
<td>17.19</td>
<td>0.79</td>
<td>9.47</td>
</tr>
<tr>
<td>9. &quot;NW&quot; (Northern Wyoming = WY, Northern Powder River Basin)</td>
<td>CSS</td>
<td>172.0</td>
<td>16.88</td>
<td>0.39</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>4.0</td>
<td>16.27</td>
<td>0.83</td>
<td>6.86</td>
</tr>
<tr>
<td>10. &quot;SW&quot; (Southern Wyoming = WY, Southern Powder River Basin)</td>
<td>CSS</td>
<td>255.1</td>
<td>17.66</td>
<td>0.31</td>
<td>5.03</td>
</tr>
<tr>
<td>11. &quot;WW&quot; (Western WY)</td>
<td>CSS</td>
<td>0.5</td>
<td>18.53</td>
<td>0.63</td>
<td>11.32</td>
</tr>
<tr>
<td></td>
<td>CSS</td>
<td>3.2</td>
<td>18.88</td>
<td>0.50</td>
<td>8.92</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>11.9</td>
<td>19.00</td>
<td>0.77</td>
<td>8.86</td>
</tr>
<tr>
<td>12. &quot;RM&quot; (Rocky Mountain - CO, UT)</td>
<td>CDB</td>
<td>52.7</td>
<td>22.95</td>
<td>0.51</td>
<td>11.02</td>
</tr>
<tr>
<td></td>
<td>CSS</td>
<td>9.7</td>
<td>20.70</td>
<td>0.41</td>
<td>7.53</td>
</tr>
<tr>
<td>13. &quot;ZN&quot; (Southwest = AZ, NM)</td>
<td>CSB</td>
<td>13.0</td>
<td>20.89</td>
<td>0.47</td>
<td>11.15</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>14.1</td>
<td>18.09</td>
<td>0.95</td>
<td>20.59</td>
</tr>
<tr>
<td></td>
<td>MDB</td>
<td>7.0</td>
<td>19.52</td>
<td>0.70</td>
<td>20.18</td>
</tr>
<tr>
<td>14. &quot;AW&quot; (Northwest = WA, AK)</td>
<td>MSS</td>
<td>4.0</td>
<td>15.61</td>
<td>0.95</td>
<td>13.88</td>
</tr>
</tbody>
</table>
Figure 2.2. CMM – Domestic Coal Demand Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Region Content</th>
<th>Region</th>
<th>Region Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NE</td>
<td>CT,MA,ME,NH,RI,VT</td>
<td>8. AM</td>
<td>AL,MS</td>
</tr>
<tr>
<td>2. YP</td>
<td>NY,PA,NJ</td>
<td>9. CW</td>
<td>MN,IA,ND,SD,NE,MO,KS</td>
</tr>
<tr>
<td>3. SA</td>
<td>WV,MD,DC,DE,VA,NC,SC</td>
<td>10. WS</td>
<td>TX,LA,OK,AR</td>
</tr>
<tr>
<td>4. GF</td>
<td>GA,FL</td>
<td>11. MT</td>
<td>MT,WY,ID</td>
</tr>
<tr>
<td>5. OH</td>
<td>OH</td>
<td>12. CU</td>
<td>CO,UT,NV</td>
</tr>
<tr>
<td>6. EN</td>
<td>IN,IL,MI,WI</td>
<td>13. ZN</td>
<td>AZ,NM</td>
</tr>
<tr>
<td>7. KT</td>
<td>KY,TN</td>
<td>14. PC</td>
<td>AK,HI,WA,OR,CA</td>
</tr>
</tbody>
</table>
**Table 2.2. CMM -- Domestic Coal Demand Regions**

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

**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 certain sectoral demands, 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 2008 is shown in Table 2.3.
Table 2.3. Domestic CMM Demand Structure -
Sectors and Subsectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of Demand Subsectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Residential/Commercial</td>
<td>2</td>
</tr>
<tr>
<td>2. Industrial Steam</td>
<td>3</td>
</tr>
<tr>
<td>3. Industrial Metallurgical</td>
<td>2</td>
</tr>
<tr>
<td>4. Industrial Coal-to-liquids</td>
<td>1</td>
</tr>
<tr>
<td>5. Export</td>
<td>6</td>
</tr>
<tr>
<td>6. Electricity</td>
<td>35</td>
</tr>
<tr>
<td><strong>Total Number of Subsectors</strong></td>
<td><strong>49</strong></td>
</tr>
</tbody>
</table>

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. For AEO2008, the Electricity sector is allowed to use coal from any of the 40 supply curves modeled. (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”.) 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 not any 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 options in the AEO2008 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 are generally exempt from seriously constraining emissions regulation, but 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, but are on average newer and larger than “stoker” boilers and are thus often subject to restrictions on sulfur dioxide emissions. 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. 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 not any 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. For the AEO2008, biomass-to-liquids (BTL) facilities were introduced in the PMM modeling structure. These facilities compete with CTL.

CTL facilities are modeled in the PMM as indirect liquefaction “co-co” facilities, meaning they produce both liquid fuels (of which 37 percent is assumed to be diesel, 25 percent is kerosene,
### Table 2.4. Electricity Subsectors

<table>
<thead>
<tr>
<th>Sector Code</th>
<th>SECTOR CHARACTERISTICS</th>
<th>Flue Gas Desulfurization Equipment</th>
<th>NO\textsubscript{x} Control Equipment</th>
<th>Additional Mercury Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.B1</td>
<td>Bag house</td>
<td>NA</td>
<td>Any</td>
<td>NA</td>
</tr>
<tr>
<td>2.B2</td>
<td>Bag house</td>
<td>NA</td>
<td>Any</td>
<td>SC</td>
</tr>
<tr>
<td>3.B3</td>
<td>Bag house</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4.B4</td>
<td>Bag house</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>SC</td>
</tr>
<tr>
<td>5.B5</td>
<td>Bag house</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>NA</td>
</tr>
<tr>
<td>6.B6</td>
<td>Bag house</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>SC</td>
</tr>
<tr>
<td>7.B7</td>
<td>Bag house</td>
<td>Dry Scrubber</td>
<td>Any</td>
<td>NA</td>
</tr>
<tr>
<td>8.B8</td>
<td>Bag house</td>
<td>Dry Scrubber</td>
<td>Any</td>
<td>SC</td>
</tr>
<tr>
<td>9.C1</td>
<td>Cold side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>NA</td>
</tr>
<tr>
<td>10.C2</td>
<td>Cold side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>FF</td>
</tr>
<tr>
<td>11.C3</td>
<td>Cold side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>SC/FF</td>
</tr>
<tr>
<td>12.C4</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>13.C5</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>FF</td>
</tr>
<tr>
<td>14.C6</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>SC/FF</td>
</tr>
<tr>
<td>15.C7</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>NA</td>
</tr>
<tr>
<td>16.C8</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>FF</td>
</tr>
<tr>
<td>17.C9</td>
<td>Cold side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>SC/FF</td>
</tr>
<tr>
<td>18.CX</td>
<td>Cold side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>19.CY</td>
<td>Cold side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>NA</td>
<td>FF</td>
</tr>
<tr>
<td>20.CZ</td>
<td>Cold side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>SC/FF</td>
</tr>
<tr>
<td>21.H1</td>
<td>Hot side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>NA</td>
</tr>
<tr>
<td>22.H2</td>
<td>Hot side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>FF</td>
</tr>
<tr>
<td>23.H3</td>
<td>Hot side electrostatic precipitator</td>
<td>NA</td>
<td>Any</td>
<td>SC/FF</td>
</tr>
<tr>
<td>24.H4</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>25.H5</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>FF</td>
</tr>
<tr>
<td>26.H6</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>NA</td>
<td>SCFF</td>
</tr>
<tr>
<td>27.H7</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>NA</td>
</tr>
<tr>
<td>28.H8</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>FF</td>
</tr>
<tr>
<td>29.H9</td>
<td>Hot side electrostatic precipitator</td>
<td>Wet scrubber</td>
<td>Selective Catalytic Reduction</td>
<td>SC/FF</td>
</tr>
<tr>
<td>30.HA</td>
<td>Hot side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>Any</td>
<td>NA</td>
</tr>
<tr>
<td>31.HB</td>
<td>Hot side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>Any</td>
<td>FF</td>
</tr>
<tr>
<td>32.HC</td>
<td>Hot side electrostatic precipitator</td>
<td>Dry Scrubber</td>
<td>Any</td>
<td>SC/FF</td>
</tr>
<tr>
<td>33.PC</td>
<td>New Pulverized Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34.IG</td>
<td>New Integrated Gasification Combined Cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.IS</td>
<td>Integrated Gasification Combined Cycle with Sequestration</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

No longer considered mercury control option in NEMS although still present in modeling structure.
and 38 percent is naphtha) and electricity. Each modeled plant is assumed to produce 758 MW of electricity. Seventeen percent is available to the grid, 38 percent supports the conversion process, while the remaining energy is retained in the liquid product.

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 14 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 14 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., 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 sector represents a potential technology that could become economic when low-sulfur distillate prices are high. Demands for CTL 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 CTL is simplified by only allowing certain coal demand regions to participate in the CTL 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 region set by 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 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, 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.13

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. Allowance prices for SO₂, NOₓ, and mercury are sent to the PMM and are considered in the

---

13 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.
overall cost of the coal fuel supplied. (Emissions from CTL facilities are 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

Coal production occurs in over 200 counties in 26 States. Coal deposits are widespread, with reserves occurring in 33 of the 50 States; it is the Nation's most abundant nonrenewable fuel resource. The coal supply industry, while currently undergoing consolidation, still has over 1,500 mines controlled by several hundred firms.

Coal demand occurs in over 600 counties in 50 States; domestic coal consumption takes place at over 1,500 identifiable locations, and is dominated by the coal consumption of electric power generators at over 400 different locations - over 90 percent of U.S. coal demand in 2005. 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 40 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), Clean Air Interstate Rule (CAIR), and the Clean Air Mercury Rule (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.

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 SO₂ 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 SO₂ emissions of 8.95 million tons of SO₂ 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 SO₂ per million Btu of heat input. The first phase of CAIR will begin in 2010 and will supersede the provisions of CAAA90, initially capping the emissions of affected states to 3.6 million tons. The second phase of CAIR restricts affected states to 2.5 million tons beginning in 2015. (The NOₓ provisions of CAIR are modeled only in the EMM.)

In addition to sulfur content, the CMM has also been updated with 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. The first phase of mercury the nation-wide emissions limits (38 tons per year), as mandated through CAMR, will become effective in 2010. The second phase limit of 15 tons per year will become effective in 2018.

A sulfur penalty and mercury penalty calculation 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, 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 SO₂ 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. 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 make capital decision 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, removing 99 percent of sulfur dioxide and 95 percent of mercury potential 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 mix of coals and calculates allowance price calculations. While the ECP also calculates allowances prices, it is responsible for the SO₂ 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 boilers 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 AEO2008, 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.\(^{14}\) 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.\textsuperscript{15} 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.\textsuperscript{16}

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 nor distance, estimation of route-specific transport rates (i.e., when required for topical analyses) will be 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 14 demand regions with each of the 40 supply curves. In principle, there are thus 14*40*49=27,440 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 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 in 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 is easily modified 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 provide 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

\textsuperscript{15} 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.

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 (2000 dollars) to the transportation rate for incremental volumes of subbituminous coal.\footnote{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 \textit{Annual Energy Outlook 2002}'s Powder River Basin production and transportation rates.}

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 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". 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, transport activities and lower bounds (provided by contracts). "CREMTX", in turn calls the linear program solver, Optimization and Modeling Library (OML), for the initial iteration in each forecast year.
- "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".
- "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

---

18 To avoid confusion in the following discussion, subroutine and file names are always written in quotation marks, e.g., "CDS", "EMMOUT".
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 14 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".

- "CEXPR" 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" 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 read input data from four physical files. These input units are:

- "CLPARAM" which contains parameters that order the assignment of demands, assign coal type labels and sectoral names, and provide 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, 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. For 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”

CREMTX
Creates LP Matrix

RDCDSIN

RDCEXIN
Reads input files

RCMMDB
Reads in the coal database

COALDEFS
Writes definition tables to database

WRCINDB
Writes input data to database

CMAPSR
Reads input file and Maps Demands

CDSINT
Reads input files

CBFOUT
Calculates Btu Conversion

CLPARAM
Parameter Data

CLRATES
Transportation Rates

CLSHARE
Demand Shares

CLNODES
Supply and Demand Region Names

CLCONT
Utility contracts

See Appendix 3.C for input files

CMMDBDEF
Coal definition tables

::represents exogeneously produced input files
: represents Subroutines
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 area 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, 14 demand regions and 40 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 multimode 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, average contract duration, and average distance (west only). Although the indices are derived from railroad information, they are universally applied to all coal transportation rates within the CMM. In the AEO2008 reference case, eastern coal transportation rates are projected to rise by 1 percent between 2005 and 2030, and western rates are projected to rise by 2 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 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. 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.

---

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:** February 2008

**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:**

*Office:* Integrated Analysis and Forecasting  
*Division:* Coal and Electric Power  
*Model Contact:* Diane Kearney  
*Telephone:* (202) 586-2415  
*E-mail:* Diane Kearney (diane.kearney@eia.doe.gov)

**Documentation:**

**Archive Media and Installation Manual:** NEMS08 - *Annual Energy Outlook 2008*.

**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 2030

- **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 14 domestic demand regions.

**Special Features:**
- All demands are exogenous to the CDS.
- Supply curves (there are 40 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 40 coal supply sources representing 12 types of coal produced in 14 supply regions. Coal shipments 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 27,440 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 14 demand regions. A single model run represents a single year, but up to 41 consecutive years (1990-2030) may be run in an iterative fashion. Currently, the NEMS system provides demand input for the 1990-2030 period.
- **Modeling Technique:** The model utilizes a linear programming that minimizes delivered cost to all demand sectors.
- **Model Interfaces:**
  - The NEMS residential, commercial, and industrial models provide demands 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 coal production, Btu conversion factors, minemouth, transportation and delivered costs for coal supplies to meet these demands to the NEMS system.
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 AEO2008): (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 Report - Manufacturing Plants"
— Form EIA-5, "Quarterly Coal Consumption and Quality Report, Coke Plants"
— Form EIA-6, "Coal Distribution Report - Annual"
— Form EIA-7A, "Coal Production Report"
— FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
— 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)

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 which 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, a 14th 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. Transportation costs are added to the cost of production in order to move coal from supply regions to demand regions. The costs of limiting sulfur dioxide emissions and other pollutants for certain scenarios (i.e. mercury and carbon dioxide) are also considered 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 the effects of emissions limits on mercury are of interest and are used in the reference case of the Annual Energy Outlook 2008 to model the Clean Air Mercury Rule. 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. 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 5,800 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

<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>TRANSPORTATION VECTORS</th>
<th>CONTRACT ESCAPE VECTORS</th>
<th>DIVERSITY ESCAPE VECTORS</th>
<th>MERC. PRICE CAP</th>
<th>MERC. ESCAPE VECTOR</th>
<th>ACTHY CARBON VECTOR</th>
<th>CARBON EMISSION VECTOR</th>
<th>Row Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MASK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1ST TIER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1ST TIER W/ ACTIV CARBON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTRACT ESCAPE VECTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2ND TIER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2ND TIER W/ ACTIV CARBON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTRACT ESCAPE VECTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTRACT ESCAPE VECTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBJECTIVE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRODUCTION ROW:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTRACT ROWS:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIVERSITY ROWS:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSPORTATION ROW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNSCRUBBED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SULPHUR DIOXIDE CONSTRAINT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MERCURY CONSTRAINT:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACTIVATED CARBON ROW:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARBON CONSTRAINT:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>a</th>
<th>D</th>
<th>EMETAX</th>
<th>m</th>
<th>M</th>
<th>PCAP</th>
<th>t0</th>
<th>t1</th>
<th>t2</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>= tons of activated carbon required per trillion Btu (mercury scenarios only)</td>
<td>= coal demand</td>
<td>= carbon allowance price (only carbon scenarios)</td>
<td>= mercury content</td>
<td>= mercury emissions limit (only mercury scenarios)</td>
<td>= productive capacity limit for supply curve</td>
<td>= 1st tier transportation rate bound</td>
<td>= 1st tier transportation cost</td>
<td>= incremental cost of 2nd tier transportation cost above 1st tier transportation cost</td>
<td>= dollars per lb of activated carbon (mercury scenarios only)</td>
</tr>
</tbody>
</table>
Objective Function

The objective of the LP is to minimize delivered 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:

$$\sum_{i,r,u,s} [Q_{p,i,r,s,t,u} \times P_{i,r,t,u}] + \sum_{i,j,p,r,t,u,v} [Q_{t,i,j,p,r,t,u,v} \times T_{i,j,p,r,t,u,v}] + \sum_{i,j,k,r,t,u} [Q_{2t, t,j,k,r,t,u} \times T_{i,j,k,r,t,u}] + \sum_{v} [A_v \times x_v] + [H \times y] + [C \times z] + \text{escape vector costs}\quad (2.B-1)$$

where the indexes are defined as:

**Index Definitions**

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

where the columns are defined as:

**Column Definitions**

<table>
<thead>
<tr>
<th>Column Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{p,i,r,s,t,u}$</td>
<td>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).</td>
</tr>
<tr>
<td>$Q_{t,i,j,p,r,t,u,v}$</td>
<td>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</td>
</tr>
</tbody>
</table>
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

\[ Q_{it,j,k,r,t,u} = \] 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 2\textsuperscript{nd} 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:

\[ A_v = \] 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:  
\[ \Sigma_v Q_{it,j,k,r,t,u} - \Sigma_v Q_{it,j,k,r,t,v} = 0 \]  (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**

**EQUATIONS:** For specific \(i, r, t, u\) and \(u\):
\[
\sum_{s} Q_{p,i,r,s,t,u} \leq PCAP_{i,r,t,u} \tag{2.B-3}
\]

**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 \(k\):
\[
\sum_{i,r,t,u,v} Q_{t,i,j,k,r,t,u,v} = D_{j,k} \tag{2.B-4}
\]

**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**

**EQUATIONS:** For specific \(i, j, r, t, u\):
\[
\sum_{p,v,w} Q_{t,i,j,p,r,t,u,v} - \text{escape vector quantity} \geq B_{i,j,p,r,t,u,w} \tag{2.B-5}
\]

**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**

**EQUATIONS:** For a specific \(j, p, r\) (subbituminous or lignite only), where “B” equals subbituminous or lignite coal limit:
\[
\sum_{t,u} Q_{t,i,j,p,r,t,u} \leq B_{i,j,p,r} \tag{2.B-6}
\]

**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**

**EQUATIONS:**
\[
\sum_{p} (Q_{t,i,j,p,r,t,u} - Q_{t2,i,j,p,r,t,u}) \leq T_{i,j,r,t,u} \tag{2.B-7}
\]

**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**

**EQUATIONS:**
\[
sulfur dioxide emissions from imports + \sum_{i,j,p,r,t,u} [s_{i,j,r,t,u} * Q_{t,i,j,p,r,t,u}] \leq S \tag{2.B-8}
\]

**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
EQUATIONS: \[ \sum_{i,j,k,r,t,u} [m_{i,r,t,u}* Q_{i,j,k,r,t,u}] - H - \text{escape vector quantity} \leq M \] (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”. 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
EQUATIONS: \[ \sum_{i,j,p,t,u,v} [a_{p,v}* Q_{i,j,p,t,u,v}] - 10 * \sum_{v} A_v \leq 0 \] (2.B-10)
DEFINITION: Balances the activated carbon used in association with the electricity sector transportation vectors with the activated carbon supply curves.
CORRESPONDING ROW IN BLOCK DIAGRAM: ACIXXY

CARBON TAX
EQUATIONS: \[ \sum_{i,j,p,t,u} [c_{i,j,p,t,u}* Q_{i,j,p,t,u}] - C \leq 0 \] (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.
CORRESPONDING ROW IN BLOCK DIAGRAM: CARBONXX

Output Variables

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

\[ U_{i,k,t} = \text{Finalized (solution) delivered price (minemouth plus transportation cost) to a specific sector in demand region i. This variable is the final optimized value from the CDS.} \]
### 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).

<table>
<thead>
<tr>
<th>MASK</th>
<th>ROW OR COLUMN</th>
<th>ACTIVITY REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIXSS(ACSTEP)Y</td>
<td>Column</td>
<td>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</td>
</tr>
<tr>
<td>ACIXXXXXY</td>
<td>Row</td>
<td>Assigns activated carbon requirement (lbs of activated carbon per trillion Btu) for each activated carbon step in transportation column</td>
</tr>
<tr>
<td>(ACSTEP)(SR)(U)(M)(DR)(PT)(C)</td>
<td>Column</td>
<td>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)</td>
</tr>
<tr>
<td>I(SR)(U)(M)(R)(DR)(PT)(C)</td>
<td>Column</td>
<td>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)</td>
</tr>
<tr>
<td>C(SR)(DR)X(C)</td>
<td>Column</td>
<td>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.</td>
</tr>
<tr>
<td>C(SR)(DR)X(C)</td>
<td>Row</td>
<td>Contract constraint from supply region (SR) to demand region (DR) of coal type (C) for the unscrubbed electricity subsectors.</td>
</tr>
<tr>
<td>CARBONXX</td>
<td>Column</td>
<td>Assigns carbon tax to coal in carbon scenario and influences patterns of coal use in electricity sector</td>
</tr>
<tr>
<td>CARBONXX</td>
<td>Row</td>
<td>Assigns carbon content to electricity sector transportation rates</td>
</tr>
<tr>
<td>D.(DR)(SEC)</td>
<td>Row</td>
<td>Coal demand from demand region (DR) for demand subsector (SEC)</td>
</tr>
<tr>
<td>DSL(DR)(PT)</td>
<td>Column</td>
<td>Escape column vector for lignite diversity constraint for demand region (DR) and electricity plant type (PT). Not active in final</td>
</tr>
<tr>
<td>MASK</td>
<td>ROW OR COLUMN</td>
<td>ACTIVITY REPRESENTED</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>DSS(DR)(PT)</td>
<td>Column</td>
<td>Escape column vector for subbituminous diversity constraint for demand region (DR) and electricity plant type (PT). Not active in final solution.</td>
</tr>
<tr>
<td>DVL(DR)(PT)</td>
<td>Row</td>
<td>Coal diversity constraint for lignite coal, demand region (DR), electricity subsector (PT).</td>
</tr>
<tr>
<td>DVS(DR)(PT)</td>
<td>Row</td>
<td>Coal diversity constraint for subbituminous coal, demand region (DR), electricity subsector (PT).</td>
</tr>
<tr>
<td>F(SR)(DR)X(C)</td>
<td>Column</td>
<td>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.</td>
</tr>
<tr>
<td>F(SR)(DR)X(C)</td>
<td>Row</td>
<td>Contract constraint from supply region (SR) to demand region (DR) of coal type (C) for the scrubbed electricity subsectors</td>
</tr>
<tr>
<td>FAB(DR)(C)</td>
<td>Row (free)</td>
<td>Used to calculate average heat content of coal used in electricity sector by demand region (DR) and coal type (C)</td>
</tr>
<tr>
<td>FAC(DR)(C)</td>
<td>Row (free)</td>
<td>Used to calculate total carbon (million metric tonnes of carbon equivalent) of coal by demand region (DR) and coaltype (C) for electricity sector</td>
</tr>
<tr>
<td>FAM(DR)(C)</td>
<td>Row (free)</td>
<td>Calculates uncontrolled total mercury in coal (in lbs) by demand region (DR) and coal type (C) for the electricity sector</td>
</tr>
<tr>
<td>FHG(DR)(PT)</td>
<td>Row (free)</td>
<td>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)</td>
</tr>
<tr>
<td>FP(SR)(U)(R)</td>
<td>Row (free)</td>
<td>Calculates coal production from supply region (SR), sulfur level (U), and coal rank (R)</td>
</tr>
<tr>
<td>HOURS</td>
<td>Row (free)</td>
<td>Estimates number of miner hours required to produce coal from a supply region (SR)</td>
</tr>
<tr>
<td>LB(CR)L1</td>
<td>Row (free)</td>
<td>Calculates millions of tons of coal used for CTL by census region (CR)</td>
</tr>
<tr>
<td>LC(CR)L1</td>
<td>Row (free)</td>
<td>Determines total carbon present in coal used for CTL by census region (CR)</td>
</tr>
<tr>
<td>LCEN(CR)L1</td>
<td>Row (free)</td>
<td>Calculates total trillion Btu of coal used in CTL by census region (CR)</td>
</tr>
<tr>
<td>LIQUPMM(PMM)</td>
<td>Row (free)</td>
<td>Determines coal used for CTL by PMM region (PMM)</td>
</tr>
<tr>
<td>LP(M)(DR)(PMM)L</td>
<td>Row (free)</td>
<td>Sums CTL coal distribution by minetype (M), demand region (DR), and PMM region (PMM)</td>
</tr>
<tr>
<td>LP(SR)(U)(M)(R)(PMM)</td>
<td>Row (free)</td>
<td>Sums CTL coal distribution by supply region (SR), sulfur level (U), minetype (M), coal rank (R)</td>
</tr>
<tr>
<td>MASK</td>
<td>ROW OR COLUMN</td>
<td>ACTIVITY REPRESENTED</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>MERCAC01</td>
<td>Row (free)</td>
<td>Calculates total amount of mercury tons removed using activated carbon injection</td>
</tr>
<tr>
<td>MERCEV</td>
<td>Column</td>
<td>Provides upper bound for mercury allowance price</td>
</tr>
<tr>
<td>MERCP01</td>
<td>Row</td>
<td>Mercury penalty constraint for electricity sector (mercury scenarios only)</td>
</tr>
<tr>
<td>MOREHGXX</td>
<td>Column</td>
<td>Escape vector allowing more mercury to be emitted if tight mercury constraint causes infeasibility. Not active in final solution.</td>
</tr>
<tr>
<td>P(SR)(U)(M)(S)</td>
<td>Column</td>
<td>Coal production in supply region (SR), sulfur level (U), mine type (M), and step (S)</td>
</tr>
<tr>
<td>S@(SR)(U)(M)(C)</td>
<td>Row</td>
<td>Coal production in supply region (SR) of sulfur level (U), mine type (M), and coal type (C)</td>
</tr>
<tr>
<td>SULFPEN</td>
<td>Row</td>
<td>Sulfur penalty constraint for electricity sector</td>
</tr>
<tr>
<td>T(SR)(U)(M)(R)(DR)(SEC)(C)</td>
<td>Column</td>
<td>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)</td>
</tr>
<tr>
<td>WAGES</td>
<td>Row (free)</td>
<td>Estimates total wages required to produce coal</td>
</tr>
<tr>
<td>X@(SR)(U)(M)(C)</td>
<td>Row</td>
<td>Coal production capacity limit for supply region (SR) of sulfur level (U), mine type (M), and coal type (C)</td>
</tr>
</tbody>
</table>

where,

**U.S. DEMAND 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
SR  SUPPLY REGIONS
NA  PENNSYLVANIA, OHIO, MARYLAND, WEST VIRGINIA (NORTH)
CA  WEST VIRGINIA (SOUTH), KENTUCKY (EAST), VIRGINIA, TENNESSEE (NORTH)
SA  ALABAMA, TENNESSEE (SOUTH)
EI  IOWA, MISSOURI, KANSAS, OKLAHOMA, ARKANSAS, TEXAS (BITUMINOUS)
GL  WEST VIRGINIA (SOUTH), KENTUCKY (EAST), VIRGINIA, TENNESSEE (NORTH)
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  SOUTH ATLANTIC
  4  EAST NORTH CENTRAL
  5  EAST SOUTH CENTRAL
  6  WEST NORTH 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 SO₂ per million Btu
  M  Medium:  > 1.2 but ≤ 3.33 lbs SO₂ per million Btu
  H  High:  > 3.33 lbs SO₂ per million Btu

M  MINE TYPE
  D  Underground Mining
  S  Surface Mining
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

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
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 (2006). 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 AEO2008, 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 14 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 14 rows contain rational numbers used to disaggregate industrial demands. The second set of 14 rows contains the shares for residential/commercial demands. The third set of 14 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 2030. Beginning with AEO2006, imports are endogenous so this structure is no longer being used.

The next matrix has a 14 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 2008. 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. The model calculates the stocks based on differences between successive years.

The next data entry designates the base year of the model. For AEO2008, this is 2006.

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

**CLEXEWS.** 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 (1990-2008) 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. 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 effect 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 AEO2008, 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, 3834 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 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.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Source of data, if applicable</th>
<th>Scrubbed Plant Unit 1</th>
<th>Scrubbed Plant Unit 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculation of supply curve historical share</td>
<td>clcont</td>
<td>100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Historical consumption of supply curve “X” @ unit (trillion Btu):</td>
<td>clcont</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Calculate share</td>
<td></td>
<td>100/150=0.67</td>
<td>80/200=0.40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Apply profile percentage</td>
<td>clcont</td>
<td>0.80</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity demand for plant unit for forecast year, T (trillion Btu):</td>
<td>electricity model</td>
<td>170</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Calculation of minimum flow for each unit</td>
<td></td>
<td>170*0.53=90</td>
<td>210*0.20=42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum flow by plant unit for forecast year, T (trillion Btu):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total contract value, specified by scrubbed/unscrubbed categorization, demand region, and supply curve (trillion Btu)</td>
<td></td>
<td></td>
<td></td>
<td>90+42=132</td>
</tr>
</tbody>
</table>

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 14 demand regions. For AEO2008, "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 2030.

“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 14 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 14 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 transportation index coefficients are located after “KCNUR.” “RAIL WAGE INDEX” projections are forecasted values for average wages for railroad workers. They are not currently used in the AEO2008. Inputs for the transportation including productivity, average distance for western sourced coal, contract duration, and the PPI for railroad equipment follow the transportation index coefficients. "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 AEO2008.

"BTR" previously defined rail transportation cost escalators. (“BTR” is not used in the AEO2008.)

"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 41 years (1990-2030).

"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 1998-2006.

**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 2.C-1. Parameter and Variable List for CDS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSULF(4, MNUMYR)</td>
<td>coalrep</td>
<td>Appalachia bituminous coal (million tons)</td>
</tr>
<tr>
<td>ALLCOALs(40)</td>
<td>cdscom2l</td>
<td>Supply coal type combinations (e.g. NACDB, NAMDB, etc.)</td>
</tr>
<tr>
<td>APPCDs=3</td>
<td>cdsparms</td>
<td>Number of CMM supply regions in Appalachia</td>
</tr>
<tr>
<td>APSULF(4, MNUMYR)</td>
<td>coalrep</td>
<td>Appalachian premium coal (million tons)</td>
</tr>
<tr>
<td>ASTN(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Assigned tons</td>
</tr>
<tr>
<td>ASTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Assigned trillion Btu</td>
</tr>
<tr>
<td>BASEYR</td>
<td>parametr</td>
<td>Base calendar year corresponding to CURIYR = 1</td>
</tr>
<tr>
<td>BSRZR(NTOTSECT, NDREG)</td>
<td>cdscom2l</td>
<td>Rail route multipliers by demand region; read in from clparam.txt; currently set to 1.0</td>
</tr>
<tr>
<td>BSRZR_UTIL(NFYRS)</td>
<td>cdscom2l</td>
<td>Input from clparam.txt; used to calibrate delivered utility coal prices</td>
</tr>
<tr>
<td>BTR(NSREG+1, NFYRS)</td>
<td>cdscom2l</td>
<td>Network rail rate multiplier; currently not used in the model</td>
</tr>
<tr>
<td>BTUTZR(NUTSEC, NDREG)</td>
<td>cdscom1l</td>
<td>Btu conversion factor for utility sectors (million Btu/ton)</td>
</tr>
<tr>
<td>BTW(NFYRS)</td>
<td>cdscom2l</td>
<td>Network water rate multiplier; currently not used in the model</td>
</tr>
<tr>
<td>C_ECP_BTU(MX_SO2T, NUTSEC+1, NDREG)</td>
<td>uso2grp</td>
<td>Trillion Btus by sulfur category, utility sector, and coal demand region</td>
</tr>
<tr>
<td>C_ECP_PRC(MX_SO2T, NDREG)</td>
<td>uso2grp</td>
<td>Coal price by sulfur category and by coal demand region ($/mmBtu)</td>
</tr>
<tr>
<td>C_ECP_SO2(MX_SO2T, NDREG)</td>
<td>uso2grp</td>
<td>SO2 content by sulfur category and coal demand region (lbs/mmBtu)</td>
</tr>
<tr>
<td>CBTU(NSREG, NCOALTYP)</td>
<td>cdscom2l</td>
<td>Carbon factor by supply region and coal type</td>
</tr>
<tr>
<td>CDSIN(NDREG, MNUMCR)</td>
<td>cdsshr</td>
<td>Industrial sector share factors (read in from clshare.txt)</td>
</tr>
<tr>
<td>CDSMC(NDREG, MNUMCR)</td>
<td>cdsshr</td>
<td>Metallurgical coal sector share factors (read in from clshare.txt)</td>
</tr>
<tr>
<td>CDSRC(NDREG, MNUMCR)</td>
<td>cdsshr</td>
<td>Residential/commercial sector share factors (read in from clshare.txt)</td>
</tr>
<tr>
<td>CDTN(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Calculated delivered price/ton</td>
</tr>
<tr>
<td>CDTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Calculated delivered price/MMBtu</td>
</tr>
<tr>
<td>CDYRS(NMAXCTRK, NFYRS)</td>
<td>cdscom2l</td>
<td>Utility contract demand (trillion Btu)</td>
</tr>
<tr>
<td>CESIO</td>
<td>omibuf</td>
<td>Memory required by coal LP model</td>
</tr>
<tr>
<td>CLITR</td>
<td>cdscpsp</td>
<td>Coal iteration</td>
</tr>
<tr>
<td>CMAXITR</td>
<td>cdscpsp</td>
<td>Maximum number of coal iterations allowed</td>
</tr>
<tr>
<td>CLSULF(NSREG, 4, MNUMYR)</td>
<td>coalrep</td>
<td>Coal production by supply region (million tons)</td>
</tr>
<tr>
<td>CLSYNGQn(17, MNUMYR)</td>
<td>coalout</td>
<td>Coal synthetic natural gas quantity</td>
</tr>
<tr>
<td>CNSCTE=10</td>
<td>cdsparms</td>
<td>Number of coals available within a set</td>
</tr>
<tr>
<td>CNTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Contract trillion Btu (lower bounds)</td>
</tr>
<tr>
<td>COAL(NSREG, NCOALTYP)</td>
<td>cdscom2l</td>
<td>Coal type code (e.g. CSS (low sulfur/surface/subbituminous))</td>
</tr>
<tr>
<td>COALIYR</td>
<td>cdscom1l</td>
<td>Internal year index</td>
</tr>
<tr>
<td>COALPRICE(MNUMLR, MNUMYR)</td>
<td>coalrep</td>
<td>Coal price ($/short ton)</td>
</tr>
</tbody>
</table>
## Table 2.C-1. Parameter and Variable List for CDS (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COF(6)</td>
<td>cdscom2l</td>
<td>Coefficients for transportation equation</td>
</tr>
<tr>
<td>CPSB(3,MNUMYR)</td>
<td>coalout</td>
<td>Coal minemouth price in ($/ton)</td>
</tr>
<tr>
<td>CPSBF(NSREG,NFYRS)</td>
<td>cdscom1l</td>
<td>Total minemouth price ($/ton)</td>
</tr>
<tr>
<td>CPSFLG</td>
<td>cdscpssp</td>
<td>=0 before the CPS submodule is called and 1 afterwards</td>
</tr>
<tr>
<td>CQDBFB(MNUMCR,NEMSEC,MNUMYR)</td>
<td>coalout</td>
<td>Coal consumption (trillion Btu)</td>
</tr>
<tr>
<td>CQDBFT(MNUMCR,NEMSEC,MNUMYR)</td>
<td>cdscom1l</td>
<td>Coal conversion factor for consumption (million Btu/ton)</td>
</tr>
<tr>
<td>CQEXP</td>
<td>cdcom1l</td>
<td>Total export demand (trillion Btu)</td>
</tr>
<tr>
<td>CWSBB(3,MNUMYR)</td>
<td>coalout</td>
<td>Coal production (East, West Miss, U.S.) (trillion Btu)</td>
</tr>
<tr>
<td>CWSBF(NSREG,NFYRS)</td>
<td>cdscom1l</td>
<td>Coal production by CDS supply regions (million Btu)</td>
</tr>
<tr>
<td>CWSBT(NSREG,NFYRS)</td>
<td>cdscom1l</td>
<td>Conversion factor for coal production (million Btu/ton)</td>
</tr>
<tr>
<td>CWSBT(3,MNUMYR)</td>
<td>coalout</td>
<td>Coal Btu conversion factor for production (million Btu/ton)</td>
</tr>
<tr>
<td>CTRK_INDEX(2,NCOALTYP,NSREG,NTOTDREG)</td>
<td>cdscom2l</td>
<td>Index for contracts (e.g. =1 for 1st contract, 2 for 2nd contract, etc.)</td>
</tr>
<tr>
<td>CURIYR</td>
<td>ncctrl</td>
<td>Current iteration year index</td>
</tr>
<tr>
<td>DEMDEX(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Index needed for sorting</td>
</tr>
<tr>
<td>DEMKEY(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Key (8 digits demand, supply, sector, and coal type)</td>
</tr>
<tr>
<td>DEMRGN(NTOTDREG)</td>
<td>cdscom2l</td>
<td>Demand region (e.g. NE, YP, etc.)</td>
</tr>
<tr>
<td>DFCLOSE(DBFILE)</td>
<td>dfinc2</td>
<td>Function which terminates processing of a database file</td>
</tr>
<tr>
<td>DFMCBND(BNDNAME,CNAME,LVALUE,VALUE)</td>
<td>dfinc2</td>
<td>Creates or changes a bound value</td>
</tr>
<tr>
<td>DFMCRTF(RNAME,TYPE)</td>
<td>dfinc2</td>
<td>Declares or changes the row type</td>
</tr>
<tr>
<td>DFMCVAL(CNAME,RNAME,VALUE)</td>
<td>dfinc2</td>
<td>Creates or changes a value for a row/column intersection</td>
</tr>
<tr>
<td>DFEND()</td>
<td>dfinc2</td>
<td>Function which terminates matrix processing</td>
</tr>
<tr>
<td>DFMINIT(DB,MODE)</td>
<td>dfinc2</td>
<td>Initializes a database for matrix processing</td>
</tr>
<tr>
<td>DFOPEN(DBFILE,ACTFILE)</td>
<td>dfinc2</td>
<td>Opens the datafile for the LP problem</td>
</tr>
<tr>
<td>DFPINIT(DB,DF,DFPROB)</td>
<td>dfinc2</td>
<td>Initializes processing of the LP problem in the current database</td>
</tr>
<tr>
<td>DPTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Decision price</td>
</tr>
<tr>
<td>DTJL(NMAXPART,NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Coal demand requirement by coal type for the nonutility sector (million tons)</td>
</tr>
<tr>
<td>DVCONT(90, NFYRS)</td>
<td>cdscom2l</td>
<td>Contract constraint</td>
</tr>
<tr>
<td>DVLBND</td>
<td>cdscom2l</td>
<td>Upper bound for lignite</td>
</tr>
<tr>
<td>DVSBND</td>
<td>cdscom2l</td>
<td>Upper bound for subbituminous coal</td>
</tr>
<tr>
<td>EDYRS(MAXEXPT,NFYRS)</td>
<td>cdscom1l</td>
<td>Export demand (trillion Btu)</td>
</tr>
<tr>
<td>EMCOALPROD(numcoalch4regs+1,2,MNUMYR)</td>
<td>emission</td>
<td>Coal production by emission regions plus US</td>
</tr>
</tbody>
</table>

Energy Information Administration/ Model Documentation: Coal Market Module
<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMELBNK(MNUMYR)</td>
<td>emission</td>
<td>Available banked sulfur dioxide allowances</td>
</tr>
<tr>
<td>EMELPSO2(MNUMYR)</td>
<td>emission</td>
<td>CMM sulfur dioxide emission allowance price</td>
</tr>
<tr>
<td>EMETAX(1,MNUMYR)</td>
<td>emission</td>
<td>Carbon tax for coal</td>
</tr>
<tr>
<td>EMISS=4</td>
<td>cdsparms</td>
<td>Number of supply regions East of the Mississippi River</td>
</tr>
<tr>
<td>EMLIM(4,MNUMYR)</td>
<td>emission</td>
<td>Emission constraints for CO2, SOX, NOX, and Hg</td>
</tr>
<tr>
<td>EMRFSA(MNUMYR)</td>
<td>emission</td>
<td>SO2 emissions limit</td>
</tr>
<tr>
<td>ESCAL</td>
<td>cdscom2l</td>
<td>Transportation rate escalator</td>
</tr>
<tr>
<td>ESCAL97</td>
<td>cdscom2l</td>
<td>Used as an escalator for transportation rates</td>
</tr>
<tr>
<td>FCNTR(MAXTNAM)</td>
<td>cdscom2l</td>
<td>Number of supply regions East of the Mississippi River</td>
</tr>
<tr>
<td>FCRL</td>
<td>ncntrl</td>
<td>Final convergence and reporting loop switch (1=converged, 0 = unconverged)</td>
</tr>
<tr>
<td>FILE_MGR</td>
<td>cdsfmgr</td>
<td>File manager</td>
</tr>
<tr>
<td>FIRSTFLG</td>
<td>cdscspsp</td>
<td>Flag which is always set equal to 1</td>
</tr>
<tr>
<td>FIRSYR</td>
<td>ncntrl</td>
<td>First forecast year index (e.g. 2)</td>
</tr>
<tr>
<td>FRADI(NOTSEC,NDREG)</td>
<td>cdscom2l</td>
<td>Fraction for allocating demands to resid/comm, industrial, metallurgical and coal to liquids sectors</td>
</tr>
<tr>
<td>FRCSTYR=2</td>
<td>cdsparms</td>
<td>Number of look-ahead years for production capacity expansion (not currently in use in the model)</td>
</tr>
<tr>
<td>IBSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Interior bituminous coal (million tons)</td>
</tr>
<tr>
<td>ICC(NMAXCTRK)</td>
<td>cdscom2l</td>
<td>Coal set index number for contracts</td>
</tr>
<tr>
<td>IC(NMAXCTRK)</td>
<td>cdscom2l</td>
<td>Contracted demand region</td>
</tr>
<tr>
<td>ICSETC(NCSET,CNCSET)</td>
<td>cdscom2l</td>
<td>The coaltype component of the member of a coal set (e.g. coaltype =1); paired with ICSETS</td>
</tr>
<tr>
<td>ICSETS(NCSET,CNCSET)</td>
<td>cdscom2l</td>
<td>The supply region component of the member of a coal set (e.g. 11); paired with ICSETC</td>
</tr>
<tr>
<td>ICTY(NMAXCTRK)</td>
<td>cdscom2l</td>
<td>Part of contract file; 4th column; indicates coaltype (values 1-8)</td>
</tr>
<tr>
<td>IDC(90)</td>
<td>cdscom2l</td>
<td>=L for lignite or S for subbituminous; part of constraint input file in clparam.txt</td>
</tr>
<tr>
<td>IDD(90)</td>
<td>cdscom2l</td>
<td>Demand region (values 1-14); part of lignite and subbituminous constraint input file in clparam.txt</td>
</tr>
<tr>
<td>IDLCNT(NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Contract line number</td>
</tr>
<tr>
<td>IDLR(NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Index of demand region for nonutility sectors</td>
</tr>
<tr>
<td>IDLZ(NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Index of demand sector for nonutility sectors</td>
</tr>
<tr>
<td>IDS(90)</td>
<td>cdscom2l</td>
<td>= electricity sector; part of lignite and subbituminous constraint input file in clparam.txt</td>
</tr>
<tr>
<td>IFED(NTOTDREG)</td>
<td>cdscom2l</td>
<td>Converts CDS demand region index to census division index</td>
</tr>
<tr>
<td>ILSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Interior lignite coal (million tons)</td>
</tr>
<tr>
<td>IMPBTU(10,3,NFYRS)</td>
<td>cdscom1l</td>
<td>Import total by census divisions (trillion Btu)</td>
</tr>
<tr>
<td>IMPBTUC(NREG,3,NFYRS)</td>
<td>cdscom1l</td>
<td>Import total by CDS demand regions (trillion Btu)</td>
</tr>
<tr>
<td>IMPSEC=3</td>
<td>cdsparms</td>
<td>Number of import sectors (utility, metallurgical, industrial)</td>
</tr>
<tr>
<td>IMPTON(10,3,NFYRS)</td>
<td>cdscom1l</td>
<td>Import total by census divisions (million tons)</td>
</tr>
</tbody>
</table>
### Table 2.C-1. Parameter and Variable List for CDS (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPTONC(NDREG,3,NFYRS)</td>
<td>cdscom1i</td>
<td>Import total in by CDS demand regions (million tons)</td>
</tr>
<tr>
<td>INTCDS=6</td>
<td>cdparms</td>
<td>CMM supply regions belonging to Appalachia (1-3) and the Interior (4-6)</td>
</tr>
<tr>
<td>IRETOPT</td>
<td>cdsntrms</td>
<td>Optimal solution flag returned from the LP (0 indicates feasibility; 1 indicates infeasibility)</td>
</tr>
<tr>
<td>ISCRUB=7</td>
<td>cdsntrms</td>
<td>Integer representing number of scrubbed sectors</td>
</tr>
<tr>
<td>[SEC(NTOTSECT)]</td>
<td>cdsntrms</td>
<td>Converts detailed 21 demand sectors to 6 sectors (resid/comm, industrial, metallurgical, coal-to-liquids, exports, and electricity)</td>
</tr>
<tr>
<td>[STJ(NMAXPART,NMAXDJOB)]</td>
<td>cdsntrms</td>
<td>Index of supply region by route and demand job</td>
</tr>
<tr>
<td>[SUL(NCOALTYTYP)]</td>
<td>cdsntrms</td>
<td>Coal type sulfur</td>
</tr>
<tr>
<td>[SVC(NMAXCURV)]</td>
<td>cdsntrms</td>
<td>Coal type index</td>
</tr>
<tr>
<td>[SVR(NMAXCURV)]</td>
<td>cdsntrms</td>
<td>Supply region index</td>
</tr>
<tr>
<td>[UNIT]</td>
<td>cdağmgr</td>
<td>Unit for WRITE statement</td>
</tr>
<tr>
<td>[UNITDB]</td>
<td>cdağmgr</td>
<td>Unit to WRITE to the debug file</td>
</tr>
<tr>
<td>[UNITDS]</td>
<td>cdağmgr</td>
<td>Unit to WRITE to the CDS file</td>
</tr>
<tr>
<td>[KCUR(NUTSEC,NDREG)]</td>
<td>cdsntrms</td>
<td>Indices of coal sets for utility demands</td>
</tr>
<tr>
<td>[KCUR(NUTSEC,NDREG)]</td>
<td>cdsntrms</td>
<td>Labor productivity (tons/hour) assumptions; read in from cluster.txt</td>
</tr>
<tr>
<td>[L_PROD(NSREG,2,MNUMYR)]</td>
<td>cdsntrms</td>
<td>Index of supply region by route and demand job</td>
</tr>
<tr>
<td>[LCVBU(T(MNUMPR,MNUMYR)]</td>
<td>coalout</td>
<td>Coal supply curve heat content (mmBtu/ton)</td>
</tr>
<tr>
<td>[LCVELAS(MNUMPR,MNUMYR)]</td>
<td>coalout</td>
<td>Elasticity of coal supply curve for coal-to-liquids</td>
</tr>
<tr>
<td>[LCVTONP(MNUMPR,MNUMYR)]</td>
<td>coalout</td>
<td>Coal supply curve delivered price ($/ton)</td>
</tr>
<tr>
<td>[LCVTONQ(MNUMPR,MNUMYR)]</td>
<td>coalout</td>
<td>Coal supply curve production (million tons)</td>
</tr>
<tr>
<td>[LIGCONST]</td>
<td>cdsntrms</td>
<td>Lignite constraint in clparam.txt</td>
</tr>
<tr>
<td>[LIQUCARB(MNUMCR,MNUMYR)]</td>
<td>coalout</td>
<td>Carbon content of coal to coal-to-liquids (kilograms/mmBtu)</td>
</tr>
<tr>
<td>[LIQUSULF(MNUMCR,MNUMYR)]</td>
<td>coalout</td>
<td>Sulfur content of coal to coal-to-liquids (lbs/mmBtu)</td>
</tr>
<tr>
<td>[LTRANETN(MNUMPR,MNUMYR)]</td>
<td>coalout</td>
<td>Transportation rate ($/ton)</td>
</tr>
<tr>
<td>[MAPCDS(NDREG)]</td>
<td>cdsshr</td>
<td>Maps census regions to coal demand regions</td>
</tr>
<tr>
<td>[MAPCEN(NDREG+1)]</td>
<td>cdsshr</td>
<td>Maps coal demand regions to census regions</td>
</tr>
<tr>
<td>[MAXDNAM]=550</td>
<td>cdsntrms</td>
<td>Names of demand rows</td>
</tr>
<tr>
<td>[MAXPNAM]=250</td>
<td>cdsntrms</td>
<td>Names of production activities</td>
</tr>
<tr>
<td>[MAXTNAM]=3500</td>
<td>cdsntrms</td>
<td>Names of transportation activities</td>
</tr>
<tr>
<td>[MC_ECIWSP(MNUMYR)]</td>
<td>macout</td>
<td>Empl Cost Index, private wages &amp; manufacturing salary; 1989 = 1.00</td>
</tr>
<tr>
<td>[MC_PWGD(M)-2:MNUMYR]</td>
<td>macout</td>
<td>Implicit GDP deflator; 1987 = 1.00</td>
</tr>
<tr>
<td>[MC_WPI14(MNUMYR)]</td>
<td>macout</td>
<td>Producer price index for transportation equipment</td>
</tr>
<tr>
<td>[MCNT_BTU(600)]</td>
<td>cdspsp</td>
<td>BTU conversion (marginal cost curve)</td>
</tr>
<tr>
<td>[MCNT_CAR(600)]</td>
<td>cdspsp</td>
<td>Carbon factor (marginal cost curve)</td>
</tr>
<tr>
<td>[MCNT_CTYPE]</td>
<td>cdspsp</td>
<td>Coal type (marginal cost curve)</td>
</tr>
<tr>
<td>[MCNT_FRAC(600)]</td>
<td>cdspsp</td>
<td>Mine type (marginal cost curve)</td>
</tr>
<tr>
<td>Variable</td>
<td>Include File</td>
<td>Definition</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>MCNT_P(600,8)</td>
<td>cdscpsp</td>
<td>Coal price for each step (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_PRICE(600)</td>
<td>cdscpsp</td>
<td>Minemouth price (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_PROD(600)</td>
<td>cdscpsp</td>
<td>Production (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_Q(600,8)</td>
<td>cdscpsp</td>
<td>Coal quantity for each step (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_REC</td>
<td>cdscpsp</td>
<td>Number of record (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_REGION</td>
<td>cdscpsp</td>
<td>Supply region (marginal cost curve)</td>
</tr>
<tr>
<td>MCNT_STEP(8)</td>
<td>cdscpsp</td>
<td>Step size</td>
</tr>
<tr>
<td>MCNT_SULF(600)</td>
<td>cdscpsp</td>
<td>Sulfur level (marginal cost curve)</td>
</tr>
<tr>
<td>MDLZ(NMAXCTRK)</td>
<td>cdscom2l</td>
<td>Index of contract sector</td>
</tr>
<tr>
<td>MNUMCR=11</td>
<td>parametr</td>
<td>Census regions (9 + CA + US)</td>
</tr>
<tr>
<td>NNUMLR=17</td>
<td>parametr</td>
<td>Coal supply regions (16 + US)</td>
</tr>
<tr>
<td>NNUMYR=36</td>
<td>parametr</td>
<td>Maximum number of forecast years</td>
</tr>
<tr>
<td>MPTN(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Minemouth price/ton</td>
</tr>
<tr>
<td>MPTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Minemouth price/trillion Btu</td>
</tr>
<tr>
<td>MTJ(NMABDJOB)</td>
<td>cdscom2l</td>
<td>Number of routes for job</td>
</tr>
<tr>
<td>NCESIO=200000</td>
<td>omlbuf</td>
<td>Size of workspace for coal matrix</td>
</tr>
<tr>
<td>NCOALS</td>
<td>cdscom2l</td>
<td>Number of supply region/coaltype combinations; currently 36</td>
</tr>
<tr>
<td>NCOALTYP=8</td>
<td>cdsparms</td>
<td>Number of coal types per supply region</td>
</tr>
<tr>
<td>NCSET=36</td>
<td>cdsparms</td>
<td>Number of coal sets available</td>
</tr>
<tr>
<td>NCUTSET=12</td>
<td>cdsparms</td>
<td>Number of utility coal sets</td>
</tr>
<tr>
<td>NDREG=14</td>
<td>parametr</td>
<td>Coal demand regions</td>
</tr>
<tr>
<td>NDV</td>
<td>cdscom2l</td>
<td>Number of lignite and subbituminous constraints in clparam.txt</td>
</tr>
<tr>
<td>NEMSEC=7</td>
<td>cdsparms</td>
<td>Number of NEMS sectors (NTOTSECT + imports)</td>
</tr>
<tr>
<td>NFYRS=36</td>
<td>cdsparms</td>
<td>Number of forecasted years</td>
</tr>
<tr>
<td>NMAXCTRK=350</td>
<td>cdsparms</td>
<td>Maximum number of contracts</td>
</tr>
<tr>
<td>NMAXCURV=300</td>
<td>cdsparms</td>
<td>Maximum number of supply curves</td>
</tr>
<tr>
<td>NMAXDJOB</td>
<td>cdsparms</td>
<td>Coal demand requirement by coal type (million tons)</td>
</tr>
<tr>
<td>NMAXDJOB=900</td>
<td>cdsparms</td>
<td>Maximum number of demand jobs</td>
</tr>
<tr>
<td>NMAXEXPT=50</td>
<td>cdsparms</td>
<td>Maximum number of export demands</td>
</tr>
<tr>
<td>NMAXPART=20</td>
<td>cdsparms</td>
<td>Maximum number of participants per demand job</td>
</tr>
<tr>
<td>NMAXSTEP=4000</td>
<td>cdsparms</td>
<td>Maximum number of curve steps</td>
</tr>
<tr>
<td>NOCONTR</td>
<td>cdscom2l</td>
<td>Number of contracts in contract file</td>
</tr>
<tr>
<td>NODES(5,60)</td>
<td>cdscom2l</td>
<td>Supply and demand region abbreviations; NODES(1,1-14)= supply regions; NODES(1,12-24)= demand regions</td>
</tr>
<tr>
<td>NONUTIL=14</td>
<td>cdsparms</td>
<td>Number of detailed nonutility sectors (R1,R2,IP,IS,IO,M1,M2,L1,and X1-X6)</td>
</tr>
<tr>
<td>NOTSEC=8</td>
<td>cdsparms</td>
<td>Number of residential/commercial, industrial, metallurgical, and coal-to-liquids sectors</td>
</tr>
<tr>
<td>NSREG=14</td>
<td>cdsparms</td>
<td>Number of coal supply regions</td>
</tr>
<tr>
<td>NTOTDREG=14</td>
<td>cdsparms</td>
<td>Total number of demand regions</td>
</tr>
<tr>
<td>Variable</td>
<td>Include File</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>NTOTSECT=21</td>
<td>cdsparms</td>
<td>Total number of demand sectors (R1,R2,IP,IS,IO,M1,M2,L1,X1-X6, and U1-U7)</td>
</tr>
<tr>
<td>NUMSTYP=3</td>
<td>cdsparms</td>
<td>Number of coal types (low-, medium-, and high-sulfur)</td>
</tr>
<tr>
<td>NUMSULFLVL=3</td>
<td>cdsparms</td>
<td>Number of sulfur categories (low, medium, and high)</td>
</tr>
<tr>
<td>NUTSEC=7</td>
<td>cdsparms</td>
<td>Number of utility sectors</td>
</tr>
<tr>
<td>NXPSEC=6</td>
<td>cdsparms</td>
<td>Number of export sectors</td>
</tr>
<tr>
<td>ODTRATE(NSREG,NCOAL,NTOTDREG,NTOTSECT)</td>
<td>cdscom1l</td>
<td>Transportation rates from clrates.txt</td>
</tr>
<tr>
<td>PABSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of Appalachian bituminous coal ($/ton)</td>
</tr>
<tr>
<td>PALSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of Appalachian lignite coal ($/ton)</td>
</tr>
<tr>
<td>PAPSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of Appalachian premium coal ($/ton)</td>
</tr>
<tr>
<td>PCLCM(MNUMCR,MNUMYR)</td>
<td>mdblk</td>
<td>Price of coal for the commercial sector ($/mmBtu)</td>
</tr>
<tr>
<td>PCLEL(MNUMCR,MNUMYR)</td>
<td>mdblk</td>
<td>Price of coal for the electricity sector ($/mmBtu)</td>
</tr>
<tr>
<td>PCLIN(MNUMCR,MNUMYR)</td>
<td>coalrep</td>
<td>Price of coal for the industrial sector ($/mmBtu)</td>
</tr>
<tr>
<td>PCLRFPD(MNUMPR,MNUMYR)</td>
<td>coalout</td>
<td>Price of coal for coal-to-liquids ($/mmBtu)</td>
</tr>
<tr>
<td>PCLRS(MNUMCR,MNUMYR)</td>
<td>mdblk</td>
<td>Price of coal for the residential sector ($/mmBtu)</td>
</tr>
<tr>
<td>PCLSULF(NSREG,4,3,MNUMYR)</td>
<td>coalrep</td>
<td>Coal price by supply region ($/ton)</td>
</tr>
<tr>
<td>PCNT_BTU(600)</td>
<td>cdscpsp</td>
<td>BTU conversion (capacity curve)</td>
</tr>
<tr>
<td>PCNT_CAR(600)</td>
<td>cdscpsp</td>
<td>Carbon factor (capacity curve)</td>
</tr>
<tr>
<td>PCNT_CTYPE</td>
<td>cdscpsp</td>
<td>Coal type (capacity curve)</td>
</tr>
<tr>
<td>PCNT_FRAC(600)</td>
<td>cdscpsp</td>
<td>Mine type (capacity curve)</td>
</tr>
<tr>
<td>PCNT_P(600,8)</td>
<td>cdscpsp</td>
<td>Coal price for each step (capacity curve)</td>
</tr>
<tr>
<td>PCNT_PRICE(600)</td>
<td>cdscpsp</td>
<td>Minemouth price (capacity curve)</td>
</tr>
<tr>
<td>PCNT_PROD(600)</td>
<td>cdscpsp</td>
<td>Production (capacity curve)</td>
</tr>
<tr>
<td>PCNT_Q(600,8)</td>
<td>cdscpsp</td>
<td>Coal quantity for each step (capacity curve)</td>
</tr>
<tr>
<td>PCNT_REC</td>
<td>cdscpsp</td>
<td>Number of record (capacity curve)</td>
</tr>
<tr>
<td>PCNT_REGION</td>
<td>cdscpsp</td>
<td>Supply region (capacity curve)</td>
</tr>
<tr>
<td>PCNT_SULF(600)</td>
<td>cdscpsp</td>
<td>Sulfur level (capacity curve)</td>
</tr>
<tr>
<td>PD(NSREG)</td>
<td>cdscsp</td>
<td>Production for deep mines (million tons)</td>
</tr>
<tr>
<td>PUTZM(NUTSEC,NDREG)</td>
<td>cdscm1l</td>
<td>Utility delivered price by utility sector ($/million Btu)</td>
</tr>
<tr>
<td>PIBSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of Interior bituminous coal ($/ton)</td>
</tr>
<tr>
<td>PILSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of Interior lignite coal ($/ton)</td>
</tr>
<tr>
<td>PMCIN(MNUMCR,MNUMYR)</td>
<td>mdblk</td>
<td>Metallurgical coal price for industrial sector ($/mmBtu)</td>
</tr>
<tr>
<td>PMN(NSREG,NCOAL)</td>
<td>cdscm2l</td>
<td>Value of coal from a region ($/ton)</td>
</tr>
<tr>
<td>PMPROD(NSREG,NCOAL)</td>
<td>cdscm1l</td>
<td>Value of coal from a supply region (including adjustment for premium coal)</td>
</tr>
<tr>
<td>Variable</td>
<td>Include File</td>
<td>Definition</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>PMPRODR(NSREG,NCOALTYP,NFYRS)</td>
<td>cdscom1l</td>
<td>Value of coal from a supply region (including adjustment for premium coal) for a given year</td>
</tr>
<tr>
<td>PREMBTU=27.43</td>
<td>cdsparms</td>
<td>Btu conversion factor for premium coal</td>
</tr>
<tr>
<td>PRTDBG</td>
<td>ncntrl</td>
<td>Print debug</td>
</tr>
<tr>
<td>PS(NSREG)</td>
<td>cdscom2l</td>
<td>Production for surface mines (million tons)</td>
</tr>
<tr>
<td>PSRMT(NSREG,2)</td>
<td>cdscom2l</td>
<td>Production by supply region and minetype</td>
</tr>
<tr>
<td>PSRMTYR(NSREG,2,NFYRS)</td>
<td>cdscom2l</td>
<td>Production by supply region, minetype, and forecast year (extra variable not in use)</td>
</tr>
<tr>
<td>PSRNG(NMAXCURV)</td>
<td>cdscom2l</td>
<td>Minemouth price in 1987 $/ton</td>
</tr>
<tr>
<td>PTARG(16,2,16)</td>
<td>cdscpsp</td>
<td>Target price</td>
</tr>
<tr>
<td>PWBSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of western bituminous coal ($/ton)</td>
</tr>
<tr>
<td>PWLSSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of western lignite coal ($/ton)</td>
</tr>
<tr>
<td>PWSSSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Price of western subbituminous coal ($/ton)</td>
</tr>
<tr>
<td>QCLCM(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of coal for commercial sector (trillion Btu)</td>
</tr>
<tr>
<td>QCLCML(MNUMCR)</td>
<td>cdscses</td>
<td>Lagged commercial production (trillion Btu)</td>
</tr>
<tr>
<td>QCLEL(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of coal for electricity sector (trillion Btu)</td>
</tr>
<tr>
<td>QCLIN(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of coal for industrial sector (trillion Btu)</td>
</tr>
<tr>
<td>QCLINL(MNUMCR)</td>
<td>cdscses</td>
<td>Lagged industrial production (trillion Btu)</td>
</tr>
<tr>
<td>QCLNHNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at new units with high emission standards (can burn any type of coal)</td>
</tr>
<tr>
<td>QCLNLNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at new units with low emission standards (can only burn low sulfur coal)</td>
</tr>
<tr>
<td>QCLNMNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at new units with medium emission standards (can burn low sulfur or medium sulfur coal)</td>
</tr>
<tr>
<td>QCLOHNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at old units with high emission standards (can burn any type of coal)</td>
</tr>
<tr>
<td>QCLOLNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at old units with low emission standards (can only burn low sulfur coal)</td>
</tr>
<tr>
<td>QCLOMNMR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal (trillion Btu) at old units with medium emission standards (can burn low or medium sulfur coal)</td>
</tr>
<tr>
<td>QCLRS(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of coal for residential sector (trillion Btu)</td>
</tr>
<tr>
<td>QCLRSRL(MNUMCR)</td>
<td>cdscses</td>
<td>Lagged residential production (trillion Btu)</td>
</tr>
<tr>
<td>QCLSBNR(NDRGG,MNUMYR)</td>
<td>coalemm</td>
<td>Demand for coal at scrubbed units (trillion Btu)</td>
</tr>
<tr>
<td>QCLSNN(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of coal synthetics (trillion Btu)</td>
</tr>
<tr>
<td>QDIN1R(NDREG)</td>
<td>cdscom1l</td>
<td>Industrial demand (trillion Btu)</td>
</tr>
<tr>
<td>QDL(NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Coal demand per demand job in trillion Btu</td>
</tr>
<tr>
<td>QDL11R(NDREG)</td>
<td>cdscom1l</td>
<td>Coal-to-liquid coal demand (trillion Btu)</td>
</tr>
<tr>
<td>QDMT1R(NDREG)</td>
<td>cdscenl</td>
<td>Metallurgical coal demand (trillion Btu)</td>
</tr>
<tr>
<td>QDRC1R(NDREG)</td>
<td>cdscenl</td>
<td>Residential/commercial demand (trillion Btu)</td>
</tr>
<tr>
<td>QDUTZR(NUTSEC,NDREG)</td>
<td>cdscenl</td>
<td>Utility demand by utility sector (trillion Btu)</td>
</tr>
<tr>
<td>QMCIN(MNUMCR,MNUMYR)</td>
<td>qblk</td>
<td>Quantity of metallurgical coal (trillion Btu)</td>
</tr>
</tbody>
</table>
Table 2.C-1. Parameter and Variable List for CDS (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>QMCINL(MNUMCR)</td>
<td>cdsces</td>
<td>Lagged metallurgical coal production (trillion Btu)</td>
</tr>
<tr>
<td>QPROD(NSREG, NCOALTYP)</td>
<td>cdscom1l</td>
<td>Coal production (including adjustment for premium coal)</td>
</tr>
<tr>
<td>QPRODR(NSREG, NCOALTYP,NFYRS)</td>
<td>coalcds</td>
<td>Coal production (including adjustment for premium coal) by year</td>
</tr>
<tr>
<td>QPRODS(NSREG, NCOALTYP)</td>
<td>coalcds</td>
<td>Straight 35-curve production (excluding adjustment for premium coal)</td>
</tr>
<tr>
<td>R_WAGE(NSREG,MNUMYR)</td>
<td>cdscom2l</td>
<td>Real wage by supply region and forecast year</td>
</tr>
<tr>
<td>RPTN(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Transportation rate/ton</td>
</tr>
<tr>
<td>RPTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Transportation rate/trillion Btu</td>
</tr>
<tr>
<td>RQTN(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Required tons</td>
</tr>
<tr>
<td>RQTR(MAXTNAM)</td>
<td>cdsrevise</td>
<td>Required trillion Btu</td>
</tr>
<tr>
<td>RSBTU(NMAXCURV)</td>
<td>cdscom2l</td>
<td>Btu content (million Btu/ton)</td>
</tr>
<tr>
<td>SBTU(NSREG, NCOALTYP)</td>
<td>cdscom2l</td>
<td>Btu conversion factor by supply region and coal type (million Btu/ton)</td>
</tr>
<tr>
<td>SECNAM(NTOTSECT)</td>
<td>cdscom2l</td>
<td>Demand sector name (e.g. R1,R2,IP,IS,etc); input from clparam.txt</td>
</tr>
<tr>
<td>SECTOR(3,NTOTSECT)</td>
<td>cdscom2l</td>
<td>Sector name (e.g. RESID/COMM1, IND. PREM, etc.)</td>
</tr>
<tr>
<td>SO2_PCB=0.980</td>
<td>cdsparms</td>
<td>1.0 minus fraction of sulfur left in ash, bituminous coal</td>
</tr>
<tr>
<td>SO2_PCL=0.960</td>
<td>cdsparms</td>
<td>1.0 minus fraction of sulfur left in ash, lignite coal</td>
</tr>
<tr>
<td>SO2_PCS=0.940</td>
<td>cdsparms</td>
<td>1.0 minus fraction of sulfur left in ash, subbituminous coal</td>
</tr>
<tr>
<td>SO2TX(MAXTNAM)</td>
<td>cdsrevise</td>
<td>SO2 penalty ($/mmBtu)</td>
</tr>
<tr>
<td>SOUTZR(NUTSEC,NDREG)</td>
<td>cdscom1l</td>
<td>SO2 content for utility sectors (lb/million Btu)</td>
</tr>
<tr>
<td>SSUL(NSREG, NCOALTYP)</td>
<td>cdscom2l</td>
<td>Sulfur level by supply region and coal type</td>
</tr>
<tr>
<td>STARTYR=6</td>
<td>cdsparms</td>
<td>First year the coal model LP should solve; set to 1995</td>
</tr>
<tr>
<td>SUBCONST</td>
<td>cdscom2l</td>
<td>Subbituminous constraint in clparam.txt</td>
</tr>
<tr>
<td>SULFCONT</td>
<td>cdscom2l</td>
<td>Sulfur content (considers the sulfur removed at plant) (lbs/mmBtu)</td>
</tr>
<tr>
<td>SULFPEN</td>
<td>cdscom2l</td>
<td>Row name for sulfur constraint</td>
</tr>
<tr>
<td>SUPNO(16,32)</td>
<td>cdscom2l</td>
<td>Supply curve number</td>
</tr>
<tr>
<td>SUPRGN(NSREG)</td>
<td>cdscom2l</td>
<td>Supply region</td>
</tr>
<tr>
<td>TJL(NMAXPART,NMAXDJOB)</td>
<td>cdscom2l</td>
<td>Coal assigned by coal type (million tons)</td>
</tr>
<tr>
<td>TONN(10,25,3,NFYRS)</td>
<td>cdscom1l</td>
<td>Import tonnage (million tons)</td>
</tr>
<tr>
<td>TOTALHOURS(NFYRS)</td>
<td>cdscom2l</td>
<td>Total labor hours by forecast year</td>
</tr>
<tr>
<td>TOTALWAGES(NFYRS)</td>
<td>cdscom2l</td>
<td>Total wages by forecast year</td>
</tr>
<tr>
<td>TOTLABPROD(MNUMYR)</td>
<td>coalrep</td>
<td>Total labor productivity in a given forecast year (tons/hour)</td>
</tr>
<tr>
<td>TOTPROD(NFYRS)</td>
<td>cdscom2l</td>
<td>Total production by forecast year</td>
</tr>
<tr>
<td>TRN_INDEX(NUTSEC,NCOALTYP,NSREG, NTOTDREG)</td>
<td>cdscom2l</td>
<td>Index indicating whether transportation vector is required (0=Not required; 1=Required)</td>
</tr>
<tr>
<td>UPEBYR</td>
<td>uso2grp</td>
<td>End banking year (year banked allowance cannot be used)</td>
</tr>
<tr>
<td>UPSLWFCTR</td>
<td>uso2grp</td>
<td>SO2 penalty price lower bound factor (currently 0.00)</td>
</tr>
</tbody>
</table>
### Table 2.C-1. Parameter and Variable List for CDS (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Include File</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPSYEAR</td>
<td>uso2grp</td>
<td>Year to start creating SO2 penalty price bounds (currently 1999)</td>
</tr>
<tr>
<td>UPTPSO2(MNUMYR+1)</td>
<td>uso2grp</td>
<td>Target SO2 penalty price</td>
</tr>
<tr>
<td>USPLIT=6</td>
<td>cdsparms</td>
<td>Utility coal types for reporting (old, new, scrubbed, and low-, medium-, and high-sulfur)</td>
</tr>
<tr>
<td>UTCONS</td>
<td>coalrep</td>
<td>Utility coal consumption (trillion Btu)</td>
</tr>
<tr>
<td>UTPSO2</td>
<td>coalrep</td>
<td>Utility potential SO2 emissions (million tons)</td>
</tr>
<tr>
<td>WAGEGROWTH(MNUMYR)</td>
<td>coalrep</td>
<td>Growth in wages from 2001</td>
</tr>
<tr>
<td>WAGEPHOUR(MNUMYR)</td>
<td>coalrep</td>
<td>Total wage per hour by year</td>
</tr>
<tr>
<td>WBSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>West bituminous coal (million tons)</td>
</tr>
<tr>
<td>WFCBND(COLNAME,LOBOUND,UPBOUND)</td>
<td>wfinc2</td>
<td>Change column bounds</td>
</tr>
<tr>
<td>WFCNAME(MODEL,LEN,MODLNAME)</td>
<td>wfinc2</td>
<td>Defines the model space for the LP problem</td>
</tr>
<tr>
<td>WFINSRT(FILENAME,DECKNAME)</td>
<td>wfinc2</td>
<td>Loads the starting basis for the LP problem</td>
</tr>
<tr>
<td>WFOPT()</td>
<td>wfinc2</td>
<td>Optimizes the model</td>
</tr>
<tr>
<td>WFPUNCH(FILENAME,DECKNAME)</td>
<td>wfinc2</td>
<td>Saves the current basis into a standard format file</td>
</tr>
<tr>
<td>WFRNAME(INDEX,NAME)</td>
<td>wfinc2</td>
<td>Retrieves a row name</td>
</tr>
<tr>
<td>WFSCOL(NAME,SELECT,STAT,SOLVAL)</td>
<td>wfinc2</td>
<td>Retrieves solution values for a column vector</td>
</tr>
<tr>
<td>WFSET(MODEL)</td>
<td>wfinc2</td>
<td>Sets matrix</td>
</tr>
<tr>
<td>WFSCOL(NAME,SELECT,STAT,SOLVAL)</td>
<td>wfinc2</td>
<td>Retrieves solution values for a row</td>
</tr>
<tr>
<td>WLSUF(4,MNUMYR)</td>
<td>coalrep</td>
<td>West lignite coal (million tons)</td>
</tr>
<tr>
<td>WMCF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Metallurgical coal world flows (million tons)</td>
</tr>
<tr>
<td>WSCF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Steam coal world flows (million tons)</td>
</tr>
<tr>
<td>WSSULF(4,MNUMYR)</td>
<td>coalrep</td>
<td>West subbituminous coal (million tons)</td>
</tr>
<tr>
<td>WTCF(4,MNUMYR)</td>
<td>coalrep</td>
<td>Total coal world flows (million tons)</td>
</tr>
<tr>
<td>XC(NCSET)</td>
<td>cdscom2l</td>
<td>Contract demand (trillion Btu)</td>
</tr>
<tr>
<td>XT(NCSET)</td>
<td>cdscom2l</td>
<td>Utility demand (trillion Btu)</td>
</tr>
<tr>
<td>YEARPR</td>
<td>ncntrl</td>
<td>For reporting, year dollars (e.g. 2001)</td>
</tr>
</tbody>
</table>

### 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,
109, 110, 111, 112, 113 and 114. 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 109, "Coal Production and Minemouth Prices By Region," provides annual summaries of
national distribution from the same aggregated supply regions used in Table 87, 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 110, "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 111, "Coal Prices by Region and Type" lists minemouth prices for each forecast year by
supply region by coal rank and sulfur level.
Tables 112, 113 and 114 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, 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 Utility 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 20 in the Supplement to the Annual Energy Outlook 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 AEO2008, 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 measure the change in real average transportation rates (dollars per ton) occurring 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, average contract duration, and average distance (west only). Although the indices are derived from railroad information, they are universally applied to all coal transportation rates over six economic demand sectors (electric power generation, industrial steam generation, coal-to-liquids production, coal coke manufacturing, residential/commercial consumption, and coal exports) within the CMM. By 2030 in the AEO2008 reference case, the transportation rates for eastern coal are expected to rise in real terms from the base year (2006) rates by 1 percent and for western coal by 2 percent over the next 25 years.

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 AEO2008 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.

**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. By 1999, this percentage increased to 76 percent. 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 for AEO2005 was formulated with a railroad focus.

The last 20 or so years have been characterized by rapid change in the railroad transportation industry. The Staggers Act of 1980 partially deregulated the railroad industry allowing greater flexibility in the prices charged to rail customers. 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, in two phases, on the electric power industry. Long coal contracts, although typical in the past, no longer seemed appropriate with the possibility of further emissions regulations in the future. In 1980, 55 percent of the validated contracts (reporting both a start and end date on the FERC 580 and subsequently in the Coal Transportation Rate Database) were of a duration of 11 years or more; by 1980, the percentage dropped (28 percent). Also, longer contracts, even those with escalation clauses, had the tendency to be financially unsatisfactory to at least one party involved. Eventually, as longer contracts expired, shorter contracts became more prevalent. In 1980, only 8.6 percent of the validated contracts in the CTRDB were 5 years or less in duration. By 1999, 36 percent were 5 years or less in duration. Shorter contracts allowed more flexibility for generators to experiment with alternative sources of coal. 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.

---

20 Source: Energy Information Administration, Coal Transportation Rate Database. The Coal Transportation Database represents only a sample of coal transportation shipments.
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.

In reviewing the historical influential factors contributing to the decline in transportation rates and the data, four variables, productivity, the user cost of capital for railroad equipment, contract duration, and distance, were ultimately used to derive the transportation rate indices first introduced in AEO2005. Productivity, as in previous formulations, was determined to be an important and necessary component of any transportation index regression; while productivity improvements are significant, they would not have been feasible without investments in capital structure. For that reason, a measure of the user cost of capital for rail equipment is included in the formulation. Shorter contracts presented an opportunity for western coal to make inroads in eastern markets and western railroads facilitated the effort by lowering prices. Also, as more western coal entered the market, the average distance for a haul increased, and with all else held constant, this had a tendency to increase the average transportation rate (on a tonnage basis).

In the previous methodology, time trend provided a reasonable, statistically significant proxy for an actual measure of productivity. Time trend is limited in that it does not allow for an assumption of declining or slower growth in future productivity. (For example, it is illogical to show an assumption of declining productivity by assuming a sequence of 2003, 2002, 2001, 2000, etc., where the series is going back in time.) Therefore, an improved measure of rail productivity, was a goal of the formulation for AEO2005. The AEO2005 version of productivity, billion freight ton-miles per employee, affords the opportunity to run sensitivity tests to alter productivity growth and evaluate its effect on projections. In AEO2008, a two standard deviation adjustment for the productivity coefficient is assumed. The standard deviation adjustment, implies that changes in productivity, will have less of an impact on the change in future transportation rates than they had in the past.

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 element of investment was deemed to be a necessity in the regression. For the 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.

Diesel fuel (price and/or gallons consumed) and labor (wages and/or number of employees) represent data that were excluded from the regression that were initially regarded to be important. Diesel fuel prices and labor wages were both used in previous formulations of the index. Diesel fuel costs and labor wages are important costs for railroads to determine prices. In fact, wages and wage supplements (including health and welfare benefits) according to the Association of American Railroad’s RCAF weighting factors for 2002, represent 47 percent of the railroad operating costs and fixed charges. Fuel is less significant but represents 9 percent of the railroad operating costs and fixed charges.21 Despite the significance of these variables in the total transportation costs, they did not demonstrate strong explanatory power for historical variations in prices. In addition, there is a degree of correlation between productivity and use of labor and fuel. A reduction in the labor force and improvements in fuel efficiency are partially accounted for in improvements in railroad productivity in the historical period.

Shorter contracts between coal producers and suppliers allowed western coal to vie for market share and western rail companies supported the effort by lowering prices. Without shorter contracts, there would have been less of an opportunity for western railroads to gain market share and since western coal must

travel large distances, the need to lower rail rates was also required for western coal to be economically attractive. On the other hand, for the east, longer contracts represent a period when eastern railroads were able to charge higher rates without fear of competition from the west. As western transportation rates declined in an effort to gain market share, eastern railroads were forced to compete with the expanding market share of the west. Shorter contracts between coal consumers and producers were accompanied by more competitively priced coal shipments from the railroads.

Distance also is an important factor for western transportation rates. Western coal increased in use over the historical time frame and was transported greater distances in order to do so. The longer distances involved in delivering a shipment, the larger the fuel and labor costs. Therefore, increases in average distance are also associated with inroads by western coal and tend to have an additive cost on the transportation rate (measured in dollars per ton) when all other factors are held constant.

For the dependent variable, the PPI for rail transportation could no longer be used for the revised formulation since a regional, East and West PPI, is not available. For the regression, calculated prices from the Coal Transportation Rate Database (CTRDB), were used to develop the index for the historical period. Multi-mode shipments were included with rail since rail travel is frequently a component of multi-mode shipments.

Deregulation, productivity improvements, shorter contracts, reduction in work force, fuel efficiency, and increased use of western coal are all contributing factors to declining national transportation rates. The variables: productivity, user cost of capital of railroad equipment, contract duration, and distance, 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**

\[
\text{EAST INDEX} = f(\text{PRODUCTIVITY, USER COST OF CAPITAL OF RAILROAD EQUIPMENT, CONTRACT DURATION})
\]

and

\[
\text{WEST INDEX} = f(\text{PRODUCTIVITY, USER COST OF CAPITAL OF RAILROAD EQUIPMENT, CONTRACT DURATION, DISTANCE})
\]

where:

**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 Coal Transportation Rate Database (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 data years 2000 and 2001, although present in the CTRDB, were still considered incomplete data years and therefore excluded at the time of the formulation of the index. Other shipment modes, such as conveyor, truck, and barge, were not included since most coal transportation occurs via railroad and the majority of the available data is for railroads. Multi-mode shipments were included since rail typically
makes up a component of the route. However, for the single year 1998, multi-mode shipments were not included because the corresponding transportation rates were not reported in the CTRDB. Similarly, if any coal shipment did not have a corresponding transportation rate in the CTRDB, it was omitted from the historical data series.

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 waybill sample.

**PRODUCTIVITY** is defined as ton-miles per employee per year for Class I railroads classified as Western carriers for 1980 through 1999. This variable is not indexed. The ton-miles and employee information is derived from data collected by the Association of American Railroads (AAR) and represents productivity for all 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 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. 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:

\[
UCC_t = (r_t + \delta - (p_t - p_{t-1})/p_{t-1}) \times p_t
\]

where

\[ r_t \] is a proxy for the real rate of interest, where \[ r_t = (\text{AA Utility Bond Rate}_t/100) - [\text{GDP Deflator}_t - \text{GDP Deflator}_{t-1}]/\text{GDP Deflator}_{t-1}; \]

---

\( \delta \) is the rate of depreciation on railroad equipment, assumed to equal 10 percent; 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:

\( r_p \) is the opportunity cost of having funds tied up in railroad equipment in year \( t \);

\( \delta p \) is the compensation to the railroad company for depreciation in year \( t \); and

\( ((p_t - p_{t-1})/ p_{t-1}) \) 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 \( t \)).

**CONTRACT DURATION** is the percentage of validated tonnage (tonnage that is greater than zero and has corresponding contract duration information) from the EIA report, "Coal Transportation Rates and Trends in the United States, 1979-2001," (based on the CTRDB) that is five years or less (for the West index) or ten years or less (for the East index).

**DISTANCE** is the average distance in miles traveled per year for rail and multi-mode coal shipments originating from western coal mines as reported in the CTRDB. This variable is only used for the West index.

**RHO**: In conducting the regression for the 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 equation.

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

**EAST INDEX** = \[ \exp(A_E + k \times (-SE_E)) \times \text{productivity}^{B1+k\times SE_E} \times uccrequ^{B2} \times \text{contractdur}^{B3} \] / EAST INDEX\_O

**WEST INDEX** = \[ \exp((A_W + k \times (-SE_W)) \times (1 - \text{rho})) \times \text{productivity}^{B4+k\times SE_W} \times uccrequ^{B5} \times \text{contractdur}^{B6} \times \text{distance}^{B7} \times \text{WEST INDEX}_{t-1} \times \rho_{a-g} \times \text{productivity}_{t-1}^{(B4+k\times SE_W)} \times uccrequ_{t-1}^{B5} \times \text{contractdur}_{t-1}^{B6} \times \text{distance}_{t-1}^{(B7 - \text{rho})} \] / WEST INDEX\_O

where:

\( A_E = 0.506 \)

\( k = 2 \) (number of standard deviation adjustments on productivity term)

\( SE_E = 0.041 \) (standard error of productivity term)

\( B1 = -0.161 \)

\( B2 = 0.170 \)

\( B3 = -0.158 \)

EAST INDEX\_O = the value of EAST INDEX in the base year of the forecast (2003)

\( A_W = -4.308 \)

\( SE_W = 0.100 \) (standard error of productivity term)

\( \text{Rho} = 0.644 \) (correction for autocorrelation)

\( B4 = -0.263 \)
B5 = 0.126  
B6 = -0.293  
B7 = 0.801

WEST INDEX\textsubscript{0} = the value of WEST INDEX in the base year of the forecast (2003)

uccrequ = user cost of capital for railroad equipment
contractdur = contract duration

**Table 2.D-1. Statistical Regression Results**

<table>
<thead>
<tr>
<th></th>
<th>EAST INDEX</th>
<th>WEST INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of estimation</td>
<td>Ordinary Least Squares</td>
<td>Ordinary Least Squares</td>
</tr>
<tr>
<td>Number of observations</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Mean of dependent variable</td>
<td>0.282657</td>
<td>0.416546</td>
</tr>
<tr>
<td>Standard deviation of dep. var.:</td>
<td>0.151960</td>
<td>0.268356</td>
</tr>
<tr>
<td>Sum of squared residuals:</td>
<td>0.030131</td>
<td>0.034194</td>
</tr>
<tr>
<td>Variance of residuals:</td>
<td>0.188319\textsuperscript{\text{02}}</td>
<td>0.244243\textsuperscript{\text{02}}</td>
</tr>
<tr>
<td>Standard error of regression:</td>
<td>0.931325</td>
<td>0.975233</td>
</tr>
<tr>
<td>R\textsuperscript{2}</td>
<td>0.931325</td>
<td>0.975233</td>
</tr>
<tr>
<td>Adjusted R\textsuperscript{2}</td>
<td>0.918448</td>
<td>0.966387</td>
</tr>
<tr>
<td>LM heteroscedasticity test:</td>
<td>2.59668</td>
<td>1.58762</td>
</tr>
<tr>
<td>Durbin-Watson:</td>
<td>2.06402</td>
<td>1.58762</td>
</tr>
<tr>
<td>Jarque-Bera test:</td>
<td>0.668757</td>
<td></td>
</tr>
<tr>
<td>Ramsey's RESET2:</td>
<td>3.78544</td>
<td></td>
</tr>
<tr>
<td>F (zero slopes):</td>
<td>72.3270</td>
<td></td>
</tr>
<tr>
<td>Log likelihood:</td>
<td>36.6005</td>
<td>35.0782</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimated Coefficient</th>
<th>Standard Error</th>
<th>t-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.506285</td>
<td>0.200645</td>
<td>2.52328</td>
<td>[0.023]</td>
</tr>
<tr>
<td>Log(Productivity)</td>
<td>-0.161279</td>
<td>0.041411</td>
<td>-3.89459</td>
<td>[0.001]</td>
</tr>
<tr>
<td>Log(User cost of capital for rail equipment)</td>
<td>0.170339</td>
<td>0.058421</td>
<td>2.91571</td>
<td>[0.010]</td>
</tr>
<tr>
<td>Log(Contract Duration (\text{&lt;=}10 years))</td>
<td>-.158628</td>
<td>0.038933</td>
<td>-4.07436</td>
<td>[0.001]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimated Coefficient</th>
<th>Standard Error</th>
<th>t-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-4.30811</td>
<td>2.25747</td>
<td>-1.90838</td>
<td>[0.056]</td>
</tr>
<tr>
<td>Log(Productivity)</td>
<td>-0.262807</td>
<td>0.099711</td>
<td>-2.63570</td>
<td>[0.008]</td>
</tr>
<tr>
<td>Log(User cost of capital for rail equipment)</td>
<td>0.126217</td>
<td>0.065434</td>
<td>1.92894</td>
<td>[0.054]</td>
</tr>
<tr>
<td>Log(Average distance)</td>
<td>0.801378</td>
<td>0.332820</td>
<td>2.40784</td>
<td>[0.016]</td>
</tr>
<tr>
<td>Log(Contract Duration (5 years or less))</td>
<td>-0.293022</td>
<td>0.073552</td>
<td>-3.98387</td>
<td>[0.000]</td>
</tr>
<tr>
<td>Rho</td>
<td>0.643669</td>
<td>0.184372</td>
<td>3.49114</td>
<td>[0.000]</td>
</tr>
</tbody>
</table>
Table 2.D-2. Data Sources for Transportation Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Historical Data</th>
<th>Forecasted Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation Rate</td>
<td>No units (index)</td>
<td>Derived from Energy Information Administration, Coal Transportation Rate Database</td>
<td>Forecasted endogenously from econometric equation.</td>
</tr>
<tr>
<td>Productivity</td>
<td>Billion Freight Ton-Miles/Employee</td>
<td>Derived from data from the Association of American Railroads</td>
<td>East and West: average annual increase of 2.9 percent from 2006 for the east and 1.8 percent for the west for AEO2008</td>
</tr>
<tr>
<td>User Cost of Capital for Rail Equipment</td>
<td>No units (index)</td>
<td>PPI for rail equipment was forecasted exogenously (0.04 percent real average annual decline from 2006 levels in AEO2008)</td>
<td>Exogenously forecasted. Held constant at 2001 levels.</td>
</tr>
<tr>
<td>Average Distance</td>
<td>Miles</td>
<td>Energy Information Administration, Coal Transportation Rate Database</td>
<td>Exogenously forecasted. Held constant at 1998 level.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Productivity (East ton-miles/East employees)</th>
<th>UCC Rail Equip</th>
<th>Contract Duration (%)</th>
<th>Transportation Rate (1987 dollars, 1999=1.00)</th>
<th>GDP Deflator</th>
<th>AA Utility Bond Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1.75</td>
<td>12.63</td>
<td>20.2</td>
<td>1.43</td>
<td>0.74</td>
<td>12.99</td>
</tr>
<tr>
<td>1981</td>
<td>1.82</td>
<td>21.39</td>
<td>20.4</td>
<td>1.58</td>
<td>0.81</td>
<td>15.29</td>
</tr>
<tr>
<td>1982</td>
<td>1.82</td>
<td>25.11</td>
<td>18.4</td>
<td>1.58</td>
<td>0.86</td>
<td>14.78</td>
</tr>
<tr>
<td>1983</td>
<td>2.24</td>
<td>24.54</td>
<td>18.2</td>
<td>1.61</td>
<td>0.89</td>
<td>12.83</td>
</tr>
<tr>
<td>1984</td>
<td>2.48</td>
<td>24.53</td>
<td>15.2</td>
<td>1.62</td>
<td>0.92</td>
<td>13.67</td>
</tr>
<tr>
<td>1985</td>
<td>2.52</td>
<td>21.81</td>
<td>17.2</td>
<td>1.48</td>
<td>0.95</td>
<td>12.07</td>
</tr>
<tr>
<td>1986</td>
<td>2.63</td>
<td>20.35</td>
<td>21.2</td>
<td>1.49</td>
<td>0.97</td>
<td>9.31</td>
</tr>
<tr>
<td>1987</td>
<td>3.11</td>
<td>21.30</td>
<td>21.2</td>
<td>1.45</td>
<td>1.00</td>
<td>9.77</td>
</tr>
<tr>
<td>1988</td>
<td>3.40</td>
<td>18.26</td>
<td>19.5</td>
<td>1.47</td>
<td>1.03</td>
<td>10.26</td>
</tr>
<tr>
<td>1989</td>
<td>3.54</td>
<td>14.44</td>
<td>11.4</td>
<td>1.39</td>
<td>1.07</td>
<td>9.55</td>
</tr>
<tr>
<td>1990</td>
<td>3.94</td>
<td>16.63</td>
<td>26.1</td>
<td>1.37</td>
<td>1.11</td>
<td>9.66</td>
</tr>
<tr>
<td>1991</td>
<td>4.09</td>
<td>17.00</td>
<td>28.1</td>
<td>1.34</td>
<td>1.15</td>
<td>9.10</td>
</tr>
<tr>
<td>1992</td>
<td>4.32</td>
<td>18.13</td>
<td>28.5</td>
<td>1.20</td>
<td>1.18</td>
<td>8.55</td>
</tr>
<tr>
<td>1993</td>
<td>4.66</td>
<td>16.79</td>
<td>31.1</td>
<td>1.24</td>
<td>1.21</td>
<td>7.43</td>
</tr>
<tr>
<td>1994</td>
<td>5.07</td>
<td>15.75</td>
<td>36.1</td>
<td>1.12</td>
<td>1.23</td>
<td>8.21</td>
</tr>
<tr>
<td>1995</td>
<td>5.35</td>
<td>14.44</td>
<td>39.6</td>
<td>1.14</td>
<td>1.26</td>
<td>7.76</td>
</tr>
<tr>
<td>1996</td>
<td>5.68</td>
<td>16.89</td>
<td>46.6</td>
<td>1.14</td>
<td>1.28</td>
<td>7.57</td>
</tr>
<tr>
<td>1997</td>
<td>6.07</td>
<td>19.95</td>
<td>48.6</td>
<td>1.14</td>
<td>1.30</td>
<td>7.54</td>
</tr>
<tr>
<td>1998</td>
<td>6.20</td>
<td>17.08</td>
<td>49.4</td>
<td>1.05</td>
<td>1.32</td>
<td>6.91</td>
</tr>
<tr>
<td>1999</td>
<td>6.04</td>
<td>17.53</td>
<td>50.2</td>
<td>1.00</td>
<td>1.34</td>
<td>7.51</td>
</tr>
</tbody>
</table>
Table 2.D-4: Historical Data Used to Calculate West Index

<table>
<thead>
<tr>
<th>Year</th>
<th>Productivity (West ton-miles/West employees)</th>
<th>UCC Rail Equip</th>
<th>Contract Duration (%)</th>
<th>Average Distance (Miles)</th>
<th>Transportation Rate (1987 dollars, 1999=1.00)</th>
<th>GDP Deflator</th>
<th>AA Utility Bond Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>2.42</td>
<td>12.63</td>
<td>8.6</td>
<td>922</td>
<td>1.84</td>
<td>0.74</td>
<td>12.99</td>
</tr>
<tr>
<td>1981</td>
<td>2.50</td>
<td>21.39</td>
<td>8.5</td>
<td>921</td>
<td>1.89</td>
<td>0.81</td>
<td>15.29</td>
</tr>
<tr>
<td>1982</td>
<td>2.57</td>
<td>25.11</td>
<td>6.9</td>
<td>887</td>
<td>1.96</td>
<td>0.86</td>
<td>14.78</td>
</tr>
<tr>
<td>1983</td>
<td>2.98</td>
<td>24.54</td>
<td>7.2</td>
<td>886</td>
<td>1.96</td>
<td>0.89</td>
<td>12.83</td>
</tr>
<tr>
<td>1984</td>
<td>3.31</td>
<td>24.53</td>
<td>7.5</td>
<td>934</td>
<td>2.15</td>
<td>0.92</td>
<td>13.67</td>
</tr>
<tr>
<td>1985</td>
<td>3.32</td>
<td>21.81</td>
<td>8.5</td>
<td>943</td>
<td>2.04</td>
<td>0.95</td>
<td>12.07</td>
</tr>
<tr>
<td>1986</td>
<td>3.64</td>
<td>20.35</td>
<td>8.2</td>
<td>1031</td>
<td>2.13</td>
<td>0.97</td>
<td>9.31</td>
</tr>
<tr>
<td>1987</td>
<td>4.41</td>
<td>21.30</td>
<td>9.6</td>
<td>1013</td>
<td>1.94</td>
<td>1.00</td>
<td>9.77</td>
</tr>
<tr>
<td>1988</td>
<td>4.88</td>
<td>18.26</td>
<td>9.4</td>
<td>1029</td>
<td>1.73</td>
<td>1.03</td>
<td>10.26</td>
</tr>
<tr>
<td>1989</td>
<td>5.18</td>
<td>14.44</td>
<td>9.8</td>
<td>1047</td>
<td>1.65</td>
<td>1.07</td>
<td>9.55</td>
</tr>
<tr>
<td>1990</td>
<td>5.47</td>
<td>16.63</td>
<td>13.3</td>
<td>1061</td>
<td>1.57</td>
<td>1.11</td>
<td>9.66</td>
</tr>
<tr>
<td>1991</td>
<td>5.78</td>
<td>17.00</td>
<td>14.9</td>
<td>1061</td>
<td>1.34</td>
<td>1.15</td>
<td>9.10</td>
</tr>
<tr>
<td>1992</td>
<td>6.21</td>
<td>18.13</td>
<td>15.0</td>
<td>1063</td>
<td>1.33</td>
<td>1.18</td>
<td>8.55</td>
</tr>
<tr>
<td>1993</td>
<td>6.54</td>
<td>16.79</td>
<td>17.6</td>
<td>1071</td>
<td>1.25</td>
<td>1.21</td>
<td>7.43</td>
</tr>
<tr>
<td>1994</td>
<td>7.20</td>
<td>15.75</td>
<td>19.3</td>
<td>1049</td>
<td>1.19</td>
<td>1.23</td>
<td>8.21</td>
</tr>
<tr>
<td>1995</td>
<td>8.03</td>
<td>14.44</td>
<td>24.0</td>
<td>1080</td>
<td>1.17</td>
<td>1.26</td>
<td>7.76</td>
</tr>
<tr>
<td>1996</td>
<td>8.64</td>
<td>16.89</td>
<td>32.4</td>
<td>1089</td>
<td>1.10</td>
<td>1.28</td>
<td>7.57</td>
</tr>
<tr>
<td>1997</td>
<td>8.58</td>
<td>19.95</td>
<td>35.5</td>
<td>1135</td>
<td>1.09</td>
<td>1.30</td>
<td>7.54</td>
</tr>
<tr>
<td>1998</td>
<td>8.71</td>
<td>17.08</td>
<td>35.0</td>
<td>1063</td>
<td>1.02</td>
<td>1.32</td>
<td>6.91</td>
</tr>
<tr>
<td>1999</td>
<td>9.43</td>
<td>17.53</td>
<td>35.8</td>
<td>1059</td>
<td>1.00</td>
<td>1.34</td>
<td>7.51</td>
</tr>
</tbody>
</table>

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 AEO2008, 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 AEO2007, it was assumed that the fuel surcharge was not already present in the base year (2005) transportation rates. For AEO2008, it was assumed that the base year (2006) transportation rates already included an assessed fuel surcharge. For AEO2008, the model calculates the fuel surcharges for 2006 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 Mine Safety and Health Administration, and State agency reports of mining activity supplement these sources.

- **Form EIA-3, "Quarterly Coal Consumption Report—Manufacturing Plants"**, surveys heat, sulfur and ash content of coal receipts delivered to industrial steam 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-6A, "Coal Distribution Report - Annual"** covers distribution from mine to consumer by economic sector, transport mode, and tonnage.
- **Form EIA-7A,"Coal Production Report"** covers 5,000 coal producers and reports production, minemouth prices, coal seams mined, labor productivity, employment, stocks, and recoverable reserves at mines. A supplement in 1983 covered prices, Btu, ash, and sulfur content as sold to individual economic sectors; but these data were collected on a "Dry" basis.(Energy Information Administration, *Coal Production 1984*, DOE/EIA-0118(84) (Washington, DC, November 1985).
- **Form EIA-759, "Monthly Power Plant Report,"** covers 100 percent of electricity generating plants with 50 megawatts (MW) or more of capacity, reporting consumption and stocks.
- **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.
- **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.
- **FERC Form 580, "Interrogatory on Fuel and Energy Purchase Practices",** is 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 Census Bureau records coal exports by rank, value and tonnage from each port district. The Form IM 145 reports imports by rank, value, tonnage, and port district.

Data Gaps

The resources that are available to support the NEMS CPS and CDS include a series of databases that are valuable for their national scope and Census-like coverage. However, as shown in Table 2.D-5, no data are routinely collected on the quality of coal produced at the mine or the minemouth price for coals of different quality levels. 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 data to identifying the tonnage from each mining State that is exported at each port of exit. Also, there are currently no data describing the minemouth price for coal delivered to any of the economic sectors modeled. The FERC Form 423 and EIA-423 together with the forms EIA-3A and EIA-5Q now provide the only coal quality data available, and is restricted to the electricity, industrial steam and coking coal sectors. In order to address the ongoing problem of respondents who are missing from both EIA-423 and FERC Form 423 (due to non-response), EIA-906 and data from previous years’ surveys were used to estimate coal deliveries at various electric generators. Coals consumed by these surveyed sectors (electricity, industrial steam, and coking coal) are known to differ in quality from coals delivered to sectors currently unsurveyed (the Residential, Commercial, Export Metallurgical and Export Steam sectors). However, consumption in the unsurveyed sectors accounted for a small percentage of production.

Available data on coal transportation rates are restricted to the nonproprietary data collected on FERC Form 580. In addition to the withholding of proprietary data on the survey, its coverage is restricted to a portion of the electric utility sector that excludes both some of the largest and many of the smaller electricity generation utilities in the Nation. The difference between delivered costs as shown on the FERC Form 423 and EIA-423, Forms 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. 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 2008 is summarized in Table 2.D-5.
Table 2.D-5. Survey Sources for CMM Inputs by Demand Sector

<table>
<thead>
<tr>
<th>ITEM</th>
<th>NON-UTILITY AND</th>
<th>IPP</th>
<th>INDUSTRIAL</th>
<th>COKING</th>
<th>RES/COM</th>
<th>EXPORT</th>
<th>IMPORT</th>
<th>MINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prices:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minemouth</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>Delivered</td>
<td>EIA/F423</td>
<td>NA</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>EIA-3/</td>
<td>EM522</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EIA/F423</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FERC 580</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Transport:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td>FERC 580</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Miles</td>
<td>FERC 580</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Origin</td>
<td>EIA/F423</td>
<td>NA</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>EIA-6A</td>
<td>EIA-6A</td>
<td>NA</td>
<td>IM545</td>
</tr>
<tr>
<td>Destination</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>EIA-6A</td>
<td>EM522/</td>
<td>EIA-6A</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EIA/F423</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonnage:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>NA</td>
<td>NA</td>
<td>EIA-6A</td>
<td>EIA-6A</td>
<td>NA</td>
<td>EIA-6A</td>
<td>NA</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>Distribution</td>
<td>EIA/F423</td>
<td>NA</td>
<td>NA</td>
<td>EIA-6A</td>
<td>EIA-6A</td>
<td>EIA-6A</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Receipts</td>
<td>EIA/F423</td>
<td>NA</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Consumption</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>EM522</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Stocks</td>
<td>EIA-759</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>EIA-7A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank/Grade</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>EM522</td>
<td>IM545</td>
<td>EIA-7A</td>
</tr>
<tr>
<td>Volatiles%</td>
<td>NA</td>
<td>EIA-860B</td>
<td>NA</td>
<td>NA</td>
<td>EIA-5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Btu Content</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>NA</td>
<td>NA</td>
<td>EIA-3</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sulfur %</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>EIA-5</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Ash %</td>
<td>EIA/F423</td>
<td>EIA-860B</td>
<td>EIA-3</td>
<td>EIA-5</td>
<td>NA</td>
<td>EIA-5</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Particulates</td>
<td>EIA-767</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SO2</td>
<td>EIA-767</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>NOX</td>
<td>EIA-767</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>COX</td>
<td>EIA-767</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>EIA/F423= EIA-423 &amp; FERC 423</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NA=Not available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EIA/F423= EIA-423 & FERC 423
Appendix 2.E

Bibliography


*Coal Age*, vol.87, No.5, (May 1982).


Appendix 2.F

Coal Distribution Submodule Program Availability

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

Office of Integrated Analysis and Forecasting
EI-82
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 in 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 2008.
Name: Coal Distribution Submodule-International Component
Acronym: CDS
Archive Package: NEMS08 (Available from the Energy Information Administration, Office of Integrated Analysis and Forecasting)
Model Contact: Diane Kearney, Department of Energy, EI-82, Washington DC 20585
(202) 586-2415 or (Diane.Kearney@eia.doe.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 model objective, 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 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 2030) 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 3.1) 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 3.2). 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>
<thead>
<tr>
<th>Table 3.1. CDS International Coal Export Types and Demand Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Export Type</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Premium</td>
</tr>
<tr>
<td>Low-Sulfur Bituminous</td>
</tr>
<tr>
<td>Subbituminous</td>
</tr>
</tbody>
</table>

Note: For definitions of NEMS CPS/CDS coal types see Table 1.1 of this report
Figure 3.1. U.S. Export and Import Regions Used in the CDS

Figure 3.2. International Component Inputs/Outputs

Import Demands
Coal Export Supply Curves (Price and Capacity by International Coal Supply Regions)
Ocean Freight Rates for International Supply and Demand Region Pairs
Inland Transportation Rates for U.S. Imports
Coal Import Diversity Constraints
Coal Export Diversity Constraints
U.S. Import Contracts to Represent Minimum Historical Flows

Projected Quantities of World Coal Trade Specified by International Coal Supply and Demand Region Pairs and Sector (Steam and Coking)
### Table 3.2. CDS Coal Export Regions

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

**NA** = Not applicable.

### Table 3.3. CDS Coal Import Regions

<table>
<thead>
<tr>
<th>Import Regions</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 U.S. East Coast (E)</td>
<td>NA</td>
</tr>
<tr>
<td>2 U.S. South Coast (S)</td>
<td>NA</td>
</tr>
<tr>
<td>3 U.S. Northern Interior (I)</td>
<td>NA</td>
</tr>
<tr>
<td>4 U.S. Non-Contiguous (N)</td>
<td>NA</td>
</tr>
<tr>
<td>5 Canada, Eastern</td>
<td>NA</td>
</tr>
<tr>
<td>6 Canada, Interior</td>
<td>NA</td>
</tr>
<tr>
<td>7 Scandinavia</td>
<td>Denmark, Finland, Norway, Sweden</td>
</tr>
<tr>
<td>8 United Kingdom/Ireland</td>
<td>NA</td>
</tr>
<tr>
<td>9 Germany/Austria</td>
<td>NA</td>
</tr>
</tbody>
</table>
| 10 Other NW Europe      | Belgium, France, Luxembourg, 
|                         | Netherlands                         |
| 11 Iberia              | Portugal, Spain                   |
| 12 Italy               | NA                                |
| 13 Med./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                           |
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 SO₂ 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. U.S. imports are subject to U.S. mercury emission regulations as set forth under CAMR. 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.
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 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 (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. For the U.S., imports to the electricity sector are subject to the emission limits for SO₂ and mercury as specified in CAAA90, CAIR, and CAMR. 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: February 2008

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: Integrated Analysis and Forecasting

Division: Coal and Electric Power

Model Contact: Diane Kearney

Telephone: (202) 586-2415

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

Documentation:


Archive Media and Installation Manual:

NEMS08 - Annual Energy Outlook 2008

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 over all "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\textsubscript{2} emissions.
- **Input Data:**


  — 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:

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 2008. 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 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 AEO2008. 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 AEO2008, 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 limits.
Table 3.B-1. CDS Linear Program Structure – International Component

<table>
<thead>
<tr>
<th>Module</th>
<th>Reference for Mask Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CT)</td>
<td>U.S. coal type number, e.g., 1-8</td>
</tr>
<tr>
<td>(DR)</td>
<td>U.S. domestic coal demand regions; e.g., NE, NY, PA, GA, OH, EN, HT, AM, CW, WS, MT, CU, ZN, PR</td>
</tr>
<tr>
<td>(IP)</td>
<td>International demand regions; e.g., NE, MC, SC, BT, GY, QW, PS, IT, RM, MK, LA, JA, EA, CH, AS, IN, UE, LI, ULI, LIN</td>
</tr>
<tr>
<td>(IS)</td>
<td>International sector; T = C</td>
</tr>
<tr>
<td>(ISR)</td>
<td>International supply regions; e.g., NW, ML, QL, QZ, PG, FE, QA, SF, JN, HL, AU</td>
</tr>
<tr>
<td>(IP)</td>
<td>U.S. electricity plants types; e.g., BY, BK, CT, CS, CV, CH, HY, NW, HA, HC, PC, IC, IS</td>
</tr>
<tr>
<td>(ISN)</td>
<td>Sector number; e.g., 1-4</td>
</tr>
<tr>
<td>(CSTP)</td>
<td>Supply curve step numbers; e.g., 1-6</td>
</tr>
<tr>
<td>(UP)</td>
<td>U.S. ports; e.g., E, I, G, N</td>
</tr>
<tr>
<td>(USP)</td>
<td>U.S. domestic supply regions; e.g., NA, CA, EA, EI, WI, GL, DL, WM, NW, SW, WW, PM, ZN, AW</td>
</tr>
<tr>
<td>(USR)</td>
<td>U.S. export subsector number; e.g., 1-8</td>
</tr>
<tr>
<td>(USR)</td>
<td>U.S. international coal supply regions (DR)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module</th>
<th>Reference for Coefficients (per trillion Btu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>tons of activated carbon required of coal (mercury scenarios only)</td>
</tr>
<tr>
<td>(b)</td>
<td>carbon content</td>
</tr>
<tr>
<td>(c)</td>
<td>CAP: mercury allowance price limit (only certain mercury scenarios)</td>
</tr>
<tr>
<td>(d)</td>
<td>export share</td>
</tr>
<tr>
<td>(e)</td>
<td>EMETAC: carbon allowance price (only carbon scenarios)</td>
</tr>
<tr>
<td>(f)</td>
<td>height cost</td>
</tr>
<tr>
<td>(g)</td>
<td>IC: import share</td>
</tr>
<tr>
<td>(h)</td>
<td>mercury content</td>
</tr>
<tr>
<td>(i)</td>
<td>production costs</td>
</tr>
<tr>
<td>(j)</td>
<td>sulfur dioxide content</td>
</tr>
<tr>
<td>(k)</td>
<td>transportation costs</td>
</tr>
<tr>
<td>(l)</td>
<td>dollars per pound of activated carbon (mercury scenarios only)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module</th>
<th>Reference for Right-Hand Side (RHS) Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D)</td>
<td>coal demand</td>
</tr>
<tr>
<td>(M)</td>
<td>mercury emissions limit</td>
</tr>
<tr>
<td>(S)</td>
<td>sulfur dioxide emissions limit</td>
</tr>
<tr>
<td>TP</td>
<td>minimum for total U.S. imports (million short tons)</td>
</tr>
<tr>
<td>Tpp</td>
<td>maximum for total U.S. imports (million short tons)</td>
</tr>
<tr>
<td>Tppp</td>
<td>minimum for total U.S. metallurgical imports (million short tons)</td>
</tr>
<tr>
<td>Tpppp</td>
<td>minimum for total U.S. industrial imports (million short tons)</td>
</tr>
<tr>
<td>Tppppp</td>
<td>minimum for U.S. electricity imports for unscrubbed plants</td>
</tr>
<tr>
<td>Tpppppp</td>
<td>minimum for U.S. electricity imports for scrubbed plants</td>
</tr>
</tbody>
</table>

### Note
- **Section 3.3.** Energy Information Administration: Model Documentation - Coal Market Module
- **Module:** Coal Distribution Submodule Block Diagram

### Table 3.B-1: Coal Distribution Submodule Block Diagram

#### International Component

### Objective

Objective: Max

#### U.S. Exports Only

- **Export Diversity Constraint:**
  - for electricity vectors
  - for metallurgical vectors

- **U.S. Export Supply Balance:**
  - for electricity vectors
  - for metallurgical vectors

- **Export Demand Balance:**
  - for electricity vectors
  - for metallurgical vectors

#### Export Shares

- **Import Share (IS):**
  - T or C

#### Sector

- **Thermal:**
  - for electricity vectors
  - for metallurgical vectors

#### Activation Carbon Flow Constraints

- for electricity vectors

#### Carbon Flow Constraints

- for electricity vectors

### World Trade Structure

- **Non-U.S. Production-Gasification Balance:**
  - for electricity vectors
  - for metallurgical vectors

- **Non-U.S. Export Demand Balance:**
  - for electricity vectors
  - for metallurgical vectors

### Transportation Vectors

- **U.S. Imports Only:**
  - for electricity vectors
  - for metallurgical vectors

- **Export Vectors Only:**
  - for electricity vectors
  - for metallurgical vectors

### Reference for Coefficients

- **Export Demand Shares:**
  - for electricity vectors
  - for metallurgical vectors

- **Export Share:**
  - for electricity vectors
  - for metallurgical vectors

### Reference for Mask Components

- **Coal Distribution Submodule Block Diagram:**
  - for electricity vectors
  - for metallurgical vectors

### Note

- **International Component:**
  - for electricity vectors
  - for metallurgical vectors
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:

\[
\sum_{i,s,t} PX_{i,s,t} * P_{i,s,t} + \sum_{i,j,t} TX_{i,j,t} * F_{i,j,t} + \sum_{i,j,m,t,v,z} UI_{i,j,m,t,v,z} * T_{i,j,m,t,v,z}
\]  

(3.B-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 as:

Index Definitions

<table>
<thead>
<tr>
<th>Index Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>International supply regions for coal exports</td>
</tr>
<tr>
<td>(j)</td>
<td>International import regions</td>
</tr>
<tr>
<td>(k)</td>
<td>U.S. coal export sub-sectors (correspond to U.S. export sectors in domestic component of CDS)</td>
</tr>
<tr>
<td>(m)</td>
<td>U.S. domestic subsector, either plant type for the electricity sector or sector number for the industrial and metallurgical sectors</td>
</tr>
<tr>
<td>(s)</td>
<td>Step on curve for coal export supply curve for non-U.S. international export regions</td>
</tr>
<tr>
<td>(t)</td>
<td>International coal sector (thermal or coking)</td>
</tr>
<tr>
<td>(u)</td>
<td>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 14 possible export regions</td>
</tr>
<tr>
<td>(v)</td>
<td>Activated carbon supply curve step</td>
</tr>
<tr>
<td>(z)</td>
<td>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.</td>
</tr>
</tbody>
</table>

Column Definitions

<table>
<thead>
<tr>
<th>Column Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP_i</td>
<td>Sum of coal exported from U.S. or non-U.S. international export region i.</td>
</tr>
</tbody>
</table>
\( F_{i,s,t} \) \hspace{1cm} 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.

\( \text{IMP}_{i,t} \) \hspace{1cm} Sum of coal imported for international coal sector \( t \) to international import region \( j \) (U.S. or non-U.S.).

\( P_{i,s,t} \) \hspace{1cm} 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.

\( \text{PX}_{i,s,t} \) \hspace{1cm} Quantity of coal from step \( s \) of export supply curve in non-U.S. export region \( i \) for international sector \( t \).

\( T_{i,j,m,t,v,z} \) \hspace{1cm} 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 \( s \), for international coal sector \( t \), and U.S. domestic coal import region \( z \).

\( \text{TX}_{i,j,t} \) \hspace{1cm} Quantity of coal transported from U.S. or non-U.S. export region \( i \) to import region \( j \) for international sector \( t \).

\( \text{UI}_{i,j,m,t,v,z} \) \hspace{1cm} 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 \( s \), for international coal sector \( t \), and U.S. domestic coal import region \( z \).

\( \text{UX}_{k,z} \) \hspace{1cm} Quantity of coal exported for U.S. export sub-sector \( k \) from U.S. coal export sub-region \( z \).

\( \text{QI}_{k,u,z} \) \hspace{1cm} 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 + \( \sum_{v} \text{UI}_{i,j,m,t,v,z} = \text{D}_{j,m,t,z} \) (3.B-2)

where,

\( \text{D}_{j,m,t,z} \) \hspace{1cm} 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: \( \text{D} \cdot \text{(DR)} \cdot \text{(PT)}, \text{D} \cdot \text{(DR)} \cdot \text{(SN)} \) and \( \text{D} \cdot \text{(DR)} \cdot \text{M(SN)} \)

**BALANCE OF U.S. INLAND TRANSPORTATION AND INTERNATIONAL FREIGHT TO U.S. EQUATIONS:** \( \text{TX}_{i,j,t} - \sum_{m,v,z} \text{UI}_{i,j,m,t,v,z} = 0 \) (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 EQUATIONS:** \( \text{SO}_2 \) emissions from non-imported coal + \( \sum_{i,j,m,t,v,z} \left[ s_{i,j} \times U_{i,j,m,t,v,z} \right] \leq S \) \hspace{1cm} (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 “\( s \)” equals the sulfur dioxide content of the coal. 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 EQUATIONS:**

mercury emissions from non-imported coal + \( \sum_{i,j,m,t,v,z} \left[ m_{i,j} \times U_{i,j,m,t,v,z} \right] - H \) – escape vector quantity \( \leq M \) \hspace{1cm} (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, “\( M \)”.

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 EQUATIONS**

activated carbon used with non-imported coal + \( \sum_{i,j,m,t,v,z} \left[ a_{p,v} \times U_{i,j,m,t,v,z} \right] - 10 \times \sum v A_v \leq 0 \hspace{1cm} (3.B-6)

Definition: Balances the activated carbon used in association with the electricity sector transportation vectors with the activated carbon supply curves. For more detail on activated carbon use from non-imported coal, see “2. Coal Distribution Submodule – Domestic Component.”

CORRESPONDING ROWS IN BLOCK DIAGRAM: ACIXXXX

**CARBON TAX EQUATIONS:**

carbon emissions from non-imported coal + \( \sum_{i,j,m,t,v,z} \left[ c_{i,m} \times U_{i,j,m,t,v,z} \right] - C \leq 0 \hspace{1cm} (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. 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

WORLD COAL TRADE ROWS

NON-U.S. PRODUCTION/SHIPPING BALANCE  (3.B-13)
EQUATIONS: \( \Sigma_i PX_{i,s,t} - \Sigma_j TX_{i,j,t} = 0 \)
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  (3.B-14)
EQUATIONS: \( \Sigma_j TX_{i,j,t} = D_{j,t} \)
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

EQUATIONS: \( \Sigma_j TX_{i,j,t} - IMP_{j,t} = 0 \)
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  (3.B-16)
EQUATIONS: \( TX_{i,j,t} - IC_{i,j,t} * IMP_{j,t} < 0 \)
Definition: Import constraint specifying that only a certain share of imports for an import region \( j \) can come from export region \( i \).
U.S. AND NON-U.S. PRODUCTION/EXPORT BALANCE

EQUATIONS: \[ a \sum_{i} PX_{i,s,t} + b \sum_{k,z} UX_{k,z} \times EXP_{i,t} = 0, \] (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: VI(IDR)(IS)(ISR)

U.S. EXPORT BALANCE

EQUATIONS: \[ \sum_{k,z} UX_{k,z} - \sum_{j} TX_{i,j,t} = 0, \] (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: BSXUS and BSX(ISR)

U.S. EXPORT BALANCE

EQUATIONS: \[ \sum_{u} QT_{k,u,z} - UX_{k,z} = 0 \] (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: SDX(UXSR)(UXS)

U.S. AND NON-U.S. EXPORT CONSTRAINT

EQUATIONS: \[ TX_{i,j,t} \times EC_{i,j,t} \times EXP_{i,t} < 0 \] (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 \( j \).

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).

<table>
<thead>
<tr>
<th>MASK</th>
<th>ROW OR COLUMN</th>
<th>ACTIVITY REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIXSS(STEPS)Y</td>
<td>Column</td>
<td>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</td>
</tr>
<tr>
<td>ACIXXXXY</td>
<td>Column</td>
<td>Assigns activated carbon requirement (pounds of activated carbon per trillion Btu) for each activated carbon step in transportation column</td>
</tr>
<tr>
<td>BDX(IDR)(IS)</td>
<td>Row</td>
<td>Imports balance row for international import region (IDR) for international coal sector (IS)</td>
</tr>
<tr>
<td>BSX(ISR)</td>
<td>Row</td>
<td>Export balance row for export region (ISR)</td>
</tr>
<tr>
<td>BSXUS</td>
<td>Row</td>
<td>Balance row for U.S. exports</td>
</tr>
<tr>
<td>CARBONXX</td>
<td>Column</td>
<td>Assigns carbon tax to coal in carbon scenario and influences patterns of coal use in electricity sector</td>
</tr>
<tr>
<td>CARBONXX</td>
<td>Row</td>
<td>Assigns carbon content to electricity sector transportation columns</td>
</tr>
<tr>
<td>C(ISR)(DR)I1</td>
<td>Row</td>
<td>Sets minimum level for U.S. electricity imports for unscrubbed plants by export region (ISR) to U.S. demand region (DR)</td>
</tr>
<tr>
<td>D.(DR)I(SN)</td>
<td>Row</td>
<td>Coal demand from demand region (DR) for industrial sector, I, and sector number (SN)</td>
</tr>
<tr>
<td>D.(DR)M(SN)</td>
<td>Row</td>
<td>Coal demand from demand region (DR) for metallurgical sector, M, and sector number (SN)</td>
</tr>
<tr>
<td>D.(DR)(PT)</td>
<td>Row</td>
<td>Coal demand from demand region (DR) for electricity plant types (PT)</td>
</tr>
<tr>
<td>D.(UXSR)X(UXS)</td>
<td>Row</td>
<td>Export balance row for U.S. export sub-region (UXSR) of U.S. export sub-sector (UXS)</td>
</tr>
<tr>
<td>DX.(IDR)C</td>
<td>Row</td>
<td>Import row for import region (IDR) and international coking coal sector</td>
</tr>
<tr>
<td>DX.(IDR)T</td>
<td>Row</td>
<td>Import row for import region (IDR) and international thermal coal sector</td>
</tr>
<tr>
<td>EXP(ISR)</td>
<td>Column</td>
<td>Sum of exports from export region (ISR)</td>
</tr>
<tr>
<td>F(ISR)(DR)I1</td>
<td>Row</td>
<td>Sets minimum level for U.S. electricity imports for scrubbed plants by export region (ISR) to U.S. demand region (DR)</td>
</tr>
<tr>
<td>IMP(IDR)(IS)</td>
<td>Column</td>
<td>Sum of imports from import region (IDR) for international coal sector (IS)</td>
</tr>
<tr>
<td>MASK</td>
<td>ROW OR COLUMN</td>
<td>ACTIVITY REPRESENTED</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IMPINDSW</td>
<td>Row</td>
<td>Sets minimum level for industrial imports for a given year</td>
</tr>
<tr>
<td>IMPMETSW</td>
<td>Row</td>
<td>Sets minimum level for metallurgical imports for a given year</td>
</tr>
<tr>
<td>IMPSTMAX</td>
<td>Row</td>
<td>Sets maximum level for total imports for a given year</td>
</tr>
<tr>
<td>IMPSTMIN</td>
<td>Row</td>
<td>Sets minimum level for total imports for a given year</td>
</tr>
<tr>
<td>MERCEV</td>
<td>Column</td>
<td>Provides upper bound for mercury allowance price</td>
</tr>
<tr>
<td>MERCP01</td>
<td>Row</td>
<td>Mercury penalty constraint for electricity sector</td>
</tr>
<tr>
<td>MOREHGXX</td>
<td>Column</td>
<td>Escape vector allowing more mercury to be emitted if tight mercury constraint causes infeasibility. Not active in final solution.</td>
</tr>
<tr>
<td>OII(SN)(ISR)T(DR)</td>
<td>Column</td>
<td>U.S. import volume transported within the U.S. for use in the industrial steam sector</td>
</tr>
<tr>
<td>OIM(SN)(ISR)C(DR)</td>
<td>Column</td>
<td>U.S. import volume transported within the U.S. for in the metallurgical sector</td>
</tr>
<tr>
<td>PX.(ISR)(IS)(STEPS)</td>
<td>Column</td>
<td>Supply of exports for non-U.S. international export region (ISR) for international coal sector (IS) and supply curve step (STEPS)</td>
</tr>
<tr>
<td>SDX(UXSR)(UXS)</td>
<td>Row</td>
<td>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)</td>
</tr>
<tr>
<td>SULFPEN1</td>
<td>Row</td>
<td>Sulfur penalty constraint for the east for electricity sector</td>
</tr>
<tr>
<td>SULFPEN2</td>
<td>Row</td>
<td>Sulfur penalty constraint for the west for electricity sector</td>
</tr>
<tr>
<td>SXX(ISR)(IDR)C</td>
<td>Row</td>
<td>Row balancing the supply of coal exports from international export region (ISR) to international import region (IDR) for coking coal</td>
</tr>
<tr>
<td>SXX(ISR)(IDR)T</td>
<td>Row</td>
<td>Row balancing the supply of coal exports from international export region (ISR) to international import region (IDR) for thermal coal</td>
</tr>
<tr>
<td>TCU(UP)(ISR)XX</td>
<td>Row</td>
<td>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)</td>
</tr>
<tr>
<td>TTU(UP)(ISR)XX</td>
<td>Row</td>
<td>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)</td>
</tr>
<tr>
<td>MASK</td>
<td>ROW OR COLUMN</td>
<td>ACTIVITY REPRESENTED</td>
</tr>
<tr>
<td>------</td>
<td>---------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>T(USR)(UXSR)X(UXS)(CT)</td>
<td>Column</td>
<td>U.S. export volume transported internally from U.S. export regions - where coal is produced - (USR) to U.S. export export sub-regions (UXSR) for U.S. export sub-sectors for coal type (CT)</td>
</tr>
<tr>
<td>TX(DR)X(UXS)(IDR)(IS)</td>
<td>Column</td>
<td>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)</td>
</tr>
<tr>
<td>TX(ISR)-(IDR)(IS)</td>
<td>Column</td>
<td>Export volume transported from non-U.S. export export region (ISR) to international import region (IDR) for international export sector (IS)</td>
</tr>
<tr>
<td>UX(UXSR)-X(UXS)</td>
<td>Column</td>
<td>Export volume for U.S. export 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.</td>
</tr>
<tr>
<td>VE(ISR)(IDR)(IS)</td>
<td>Row</td>
<td>Diversity export constraint on international export export region (ISR) to import region (IDR) for international export sector (IS)</td>
</tr>
<tr>
<td>VI(IDR)(IS)(ISR)</td>
<td>Row</td>
<td>Diversity import constraint on import region (IDR) for international export sector (IS) from export region (ISR)</td>
</tr>
</tbody>
</table>

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 UXR** 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
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>MINNESOTA, IOWA, NORTH DAKOTA, SOUTH DAKOTA, NEBRASKA, KANSAS, MISSOURI</td>
</tr>
<tr>
<td>WS</td>
<td>TEXAS, OKLAHOMA, ARKANSAS, LOUISIANA</td>
</tr>
<tr>
<td>MT</td>
<td>MONTANA, WYOMING, IDAHO</td>
</tr>
<tr>
<td>CU</td>
<td>COLORADO, UTAH, NEVADA</td>
</tr>
<tr>
<td>ZN</td>
<td>ARIZONA, NEW MEXICO</td>
</tr>
<tr>
<td>PC</td>
<td>ALASKA, HAWAII, WASHINGTON, OREGON, CALIFORNIA</td>
</tr>
</tbody>
</table>

**International Import Regions**

<table>
<thead>
<tr>
<th>Code</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE</td>
<td>East Coast Canada</td>
</tr>
<tr>
<td>NI</td>
<td>Interior Canada</td>
</tr>
<tr>
<td>SC</td>
<td>Scandinavia</td>
</tr>
<tr>
<td>BT</td>
<td>United Kingdom, Ireland</td>
</tr>
<tr>
<td>GY</td>
<td>Germany, Austria</td>
</tr>
<tr>
<td>OW</td>
<td>Other Northern Europe</td>
</tr>
<tr>
<td>PS</td>
<td>Iberian Peninsula</td>
</tr>
<tr>
<td>IT</td>
<td>Italy (thermal and coking)</td>
</tr>
<tr>
<td>RM</td>
<td>E. Europe and Mediterranean</td>
</tr>
<tr>
<td>MX</td>
<td>Mexico</td>
</tr>
<tr>
<td>LA</td>
<td>South America</td>
</tr>
<tr>
<td>JA</td>
<td>Japan</td>
</tr>
<tr>
<td>EA</td>
<td>East Asia</td>
</tr>
<tr>
<td>CH</td>
<td>China, Hong Kong</td>
</tr>
<tr>
<td>AS</td>
<td>ASEAN</td>
</tr>
<tr>
<td>IN</td>
<td>Indian Subcontinent, S. Asia</td>
</tr>
<tr>
<td>UE</td>
<td>US Eastern</td>
</tr>
<tr>
<td>UG</td>
<td>US Gulf</td>
</tr>
<tr>
<td>UI</td>
<td>US Interior</td>
</tr>
<tr>
<td>UN</td>
<td>US Noncontiguous</td>
</tr>
</tbody>
</table>

**International Coal Sectors**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Coking</td>
</tr>
<tr>
<td>T</td>
<td>Thermal</td>
</tr>
</tbody>
</table>

**International Export Regions**

<table>
<thead>
<tr>
<th>Code</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>Canada (alternate for Canada)</td>
</tr>
<tr>
<td>NW</td>
<td>West Coast Canada</td>
</tr>
<tr>
<td>NI</td>
<td>Interior Canada (thermal only)</td>
</tr>
<tr>
<td>CL</td>
<td>Colombia (thermal only)</td>
</tr>
<tr>
<td>VZ</td>
<td>Venezuela (thermal only)</td>
</tr>
<tr>
<td>PO</td>
<td>Poland</td>
</tr>
<tr>
<td>RE</td>
<td>Former Soviet Union (exports to Europe)</td>
</tr>
<tr>
<td>RA</td>
<td>Former Soviet Union (exports to Asia)</td>
</tr>
<tr>
<td>SF</td>
<td>South Africa</td>
</tr>
<tr>
<td>IN</td>
<td>Indonesia</td>
</tr>
<tr>
<td>HI</td>
<td>China</td>
</tr>
<tr>
<td>AU</td>
<td>Australia</td>
</tr>
<tr>
<td>VT</td>
<td>Vietnam</td>
</tr>
<tr>
<td>US</td>
<td>US</td>
</tr>
<tr>
<td>UA</td>
<td>US All</td>
</tr>
<tr>
<td>UG</td>
<td>US Gulf</td>
</tr>
</tbody>
</table>
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 (minememouth 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 Btu’s 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:
  \[\text{FOBYR} \times \frac{12.6 \text{ thousand Btu per pound of coal equivalent}}{\text{CV}} \times \frac{1987 \text{ GDP deflator}}{1992 \text{ GDP deflator}} \times \frac{27.78 \text{ mmBtu per metric ton of coal equivalent}}{\text{CV}}\]

  or equivalently,

  \[\text{FOBYR} \times \frac{1987 \text{ GDP deflator}}{1992 \text{ GDP deflator}} \times \frac{2204.623 \text{ pounds per metric ton}}{\text{CV}} \times \text{10}^3\]

- Conversion of CAPYR, coal export capacity, to trillion Btu using the following calculation:
  \[\text{CAPYR} \times \frac{\text{CV}}{12.6 \text{ thousand Btu per pound of coal equivalent}} \times \frac{27.78 \text{ mmBtu per metric ton of coal equivalent}}{\text{CV}}\]
or equivalently,

CAPYR * 2204.623 pounds per metric ton * CV / 10^3.

- Conversion of SULCON to thousand tons of SO₂ 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 2030 (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.

CLESEXS. This file contains international requirements for U.S. coal export levels for the historical and Short-Term Energy Outlook years of the forecast. 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 2008. From left to right these indices are (1) the domestic CDS demand 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.

23 In general, the Energy Information Administrations 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.
**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 AEO2008 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

<table>
<thead>
<tr>
<th>CDS Variable</th>
<th>Input</th>
<th>Specification Level&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Input Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPYR</td>
<td>Coal export capacity</td>
<td>Coal export region/coal sector/export supply curve step/forecast year</td>
<td>Million metric tons</td>
</tr>
<tr>
<td>CV</td>
<td>Btu conversion assignment for coal export supply curve</td>
<td>Coal export region/coal sector/export supply curve step</td>
<td>Thousand Btu per pound of coal</td>
</tr>
<tr>
<td>DEMAND</td>
<td>Coal import requirement (Non-U.S.)</td>
<td>Coal import region/coal demand sector/forecast year</td>
<td>Million metric tons of coal equivalent</td>
</tr>
<tr>
<td>EXPSHARE</td>
<td>Exporter diversity constraints</td>
<td>Coal export region/coal import region</td>
<td>Percentage</td>
</tr>
<tr>
<td>FOBYR</td>
<td>Coal export prices (FOB port of exit)</td>
<td>Coal export region/coal sector/export supply curve step/forecast year</td>
<td>1992 dollars per metric ton</td>
</tr>
<tr>
<td>FREIGHT</td>
<td>Ocean freight rates</td>
<td>Coal export region/coal import region/coal sector/coal demand sector</td>
<td>1992 dollars per metric ton</td>
</tr>
<tr>
<td>HSMAX&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Maximum share of high-sulfur coal imports</td>
<td>Coal import region/forecast year</td>
<td>Fraction</td>
</tr>
<tr>
<td>HSPCT&lt;sup&gt;b&lt;/sup&gt;</td>
<td>SO₂ emissions &quot;pass-through&quot; rate</td>
<td>Coal import region/coal demand sector/forecast year</td>
<td>Fraction</td>
</tr>
<tr>
<td>IMPMERC&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Mercury content assignment for coal export supply curve</td>
<td>Coal export region/coal type</td>
<td>Pounds of mercury per trillion Btu</td>
</tr>
<tr>
<td>IMPSHARE</td>
<td>Importer diversity constraints</td>
<td>Coal export region/coal import region</td>
<td>Percentage</td>
</tr>
<tr>
<td>IMPCO₂&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Carbon dioxide content assignment for coal export supply curve</td>
<td>Coal export region/coal type</td>
<td>Pounds of CO₂ per million Btu</td>
</tr>
<tr>
<td>LSPCT&lt;sup&gt;b&lt;/sup&gt;</td>
<td>SO₂ emissions &quot;pass-through&quot; rate</td>
<td>Coal import region/coal demand sector/forecast year</td>
<td>Fraction</td>
</tr>
<tr>
<td>MAXSUL&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Limit on total SO₂ emissions for international trade</td>
<td>Coal import region/forecast region</td>
<td>Thousand metric tons</td>
</tr>
<tr>
<td>SCALINT</td>
<td>Price adjustment factor for non-U.S. export supply curves</td>
<td>Coal export region/coal type/export supply curve step/forecast year</td>
<td>Scalar</td>
</tr>
<tr>
<td>SUBMAX&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Maximum share of subbituminous coal imports</td>
<td>Coal import region/forecast year</td>
<td>Fraction</td>
</tr>
<tr>
<td>SULCON&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Sulfur content assignment for coal export supply curve</td>
<td>Coal export region/coal type</td>
<td>Thousand metric tons of SO₂ emissions per metric ton of coal equivalent</td>
</tr>
</tbody>
</table>

<sup>a</sup>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.

<sup>b</sup>These variables are not currently used.

<sup>c</sup>Used for U.S. imports.

### Table 3.C-2. Outputs

<table>
<thead>
<tr>
<th>Input</th>
<th>CDS Variable</th>
<th>Specification Level&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>World coal trade flows</td>
<td>SOLVAL</td>
<td>Coal export region/coal import region/coal sector/coal demand sector/forecast year</td>
<td>Trillion Btu</td>
</tr>
</tbody>
</table>
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 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.

Published information regarding the outlook for the existing stock of coal export capacity along with information and data on planned expansions to coal export productive capacity and port capacity are used to adjust country-level coal export capacity for NEMS forecast years. 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:

**Handysize** (vessel size $< 55,000$ dwt)

Rate (1992 dollars/tonne) = $(2.5 + 1.5D) * (1992 \ GDP \ deflator/1997 \ GDP \ deflator)$

**Panamax** (vessel size $> 55,000$ but $< 80,000$ dwt)

Rate (1992 dollars/tonne) = $(1.2 + 1.3D) * (1992 \ GDP \ deflator/1997 \ GDP \ deflator)$

**Capesize** (vessel size $> 80,000$ dwt)

Rate (1992 dollars/tonne) = $(1.3 + 0.9D) * (1992 \ GDP \ deflator/1997 \ GDP \ deflator)$
where,

\[ D = \text{distance in thousand nautical miles (1 nautical mile = 6076.115 feet)} \]
\[ \text{tonne} = \text{metric ton (2204.623 pounds)} \]
\[ \text{dwt} = \text{deadweight ton (2240 pounds)} \]

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

Bibliography


