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Model Documentation

Coal Market Module

of the National Energy Modeling System

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Prepared by:

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

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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 2004 (AEO2004)*. 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 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 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 D, Part I) 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 base year (e.g. 2002) as required by the CMM's Coal Distribution Submodule.

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 allowance cost) 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 16 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 constrained 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 next three Parts of this report give the specifics of the CPS, the domestic component of the CDS, and the international component of the CDS, respectively. Each section provides details regarding the objectives, assumptions, mathematical structure, and primary input and output variables for each modeling area. 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 Part provide supporting documentation for the CMM files currently residing on a computer workstation at EIA. 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 Part 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 (annual publication of forecasted supply and demand for the U.S.)
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 (composed of the CDS and CPS)
CPS:	Coal Production Submodule
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; the cost of coal at the point where it is ready to be shipped, at the point of origin
ICR:	Information Collection Request
ICTM:	Internatinal Coal Trade Model
IFFS:	Intermediate Future Forecasting System (predecessor to NEMS)
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
PMM:	Petroleum Market Module
PRB:	Powder and Green River Basin
RAMC:	Resource Allocation and Mine Costing Model (predecessor to the CMM)
RHS:	Right-hand side of linear programming constraints
SO_2:	Sulfur Dioxide
WOCTES:	World Coal Trade Expert System

Part I—Coal Production Submodule

1. Introduction

Statement of Purpose

Part I of the Coal Market Module documentation report addresses the objectives and the conceptual and methodological approach for the Coal Production Submodule (CPS). This part 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 in Part I of the report 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.[1] 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 2001. The regression equation, together with projected levels of productive capacity, labor productivity, miner wages, fuel prices, and the cost of capital, produce minemouth price estimates for coal by region, mine type, and coal type for different levels of capacity utilization.

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 CDS, which finds the least cost solution (minemouth price plus transportation cost) of satisfying the projected annual levels of domestic and international coal demand.

[1]The measure used for the price of fuel in the *AEO2004* coal pricing model was 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 87 percent of the fuel costs at U.S. underground mines in 1997 and an estimated 33 percent of the fuel costs at surface mines. The second most important fuel at U.S. coal mines is fuel oil (distillate and residual), which accounted for 7 percent of the fuel costs at underground mines in 1997 and 44 percent of the fuel costs at surface. U.S. Census Bureau, *1997 Census of Mineral Industries*, *Bituminous Coal and Lignite Surface Mining1997*, EC97N-2121A (Washington, DC, October 1999); *Bituminous Coal Underground Mining 1997*, EC97N-2121B (Washington, DC, October 1999); *Anthracite Mining 1997*, EC97N-2121C (Washington, DC, July 1999).

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 2004*.

Name: Coal Production Submodule
Acronym: CPS
Archive Package: NEMS2004 (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)

Part I Organization

Part I of this report describes the modeling approach used in the Coal Production Submodule. Subsequent sections of Part I describe:

- The model objectives, input and output, and relationship to other models (Chapter 2)
- The theoretical approach, assumptions, and other approaches (Chapter 3)
- The model structure, including key computations and equations (Chapter 4).

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

2. Model Purpose and Scope

Model Objectives

The objective of the CPS is to develop mid-term (to 2025) annual domestic coal supply curves for the Coal Distribution Submodule (CDS) of the Coal Market Module (CMM) of the National Energy Modeling System (NEMS). The supply curves relate annual production to the marginal cost of supplying coal. Separate supply curves are developed for each unique combination of supply region, mine type (surface or underground), and coal type.

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

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, subituminous, and lignite) and a premium grade bituminous coal used primarily for metallurgical purposes. The three sulfur grades represented are compliance (low), medium, and high. The low sulfur grade corresponds to the limitation on sulfur dioxide emissions that electric utilities were required to meet as of January 1, 2000, in accordance with Phase II of the Clean Air Act Amendments of 1990. Phase II imposes a permanent cap on sulfur dioxide emissions, which corresponds to approximately 1.2 pounds of sulfur dioxide per million Btu of heat input for all generating units that existed before 1990. 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). Thermal grades are in million Btu per ton and sulfur grades are in pounds of sulfur dioxide per million Btu.

Coal Supply Regions

Eleven coal supply regions are represented in the model. The coal regions are listed in Table 1 and shown in Figure 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.

[2]For an overview of the National Energy Modeling System see *The National Energy Modeling System: An Overview 2003*. Energy Information Administration, *The National Energy Modeling System: An Overview 2003* DOE/EIA-0581(2003) (Washington, DC, March 2003).

Table 1. Supply Regions and Coal Types Used in the NEMS Coal Market Module

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

KEY TO COAL TYPE AND MINE TYPE ABBREVIATIONS

SULFUR EMISSIONS CATEGORIES

"C__" -"Compliance": ≤1.2 lbs SO2 per million Btu

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

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

MINE TYPES

"_D_" underground mining

"_S_" surface mining

COAL GRADE OR RANK

"__P", Premium or metallurgical coal

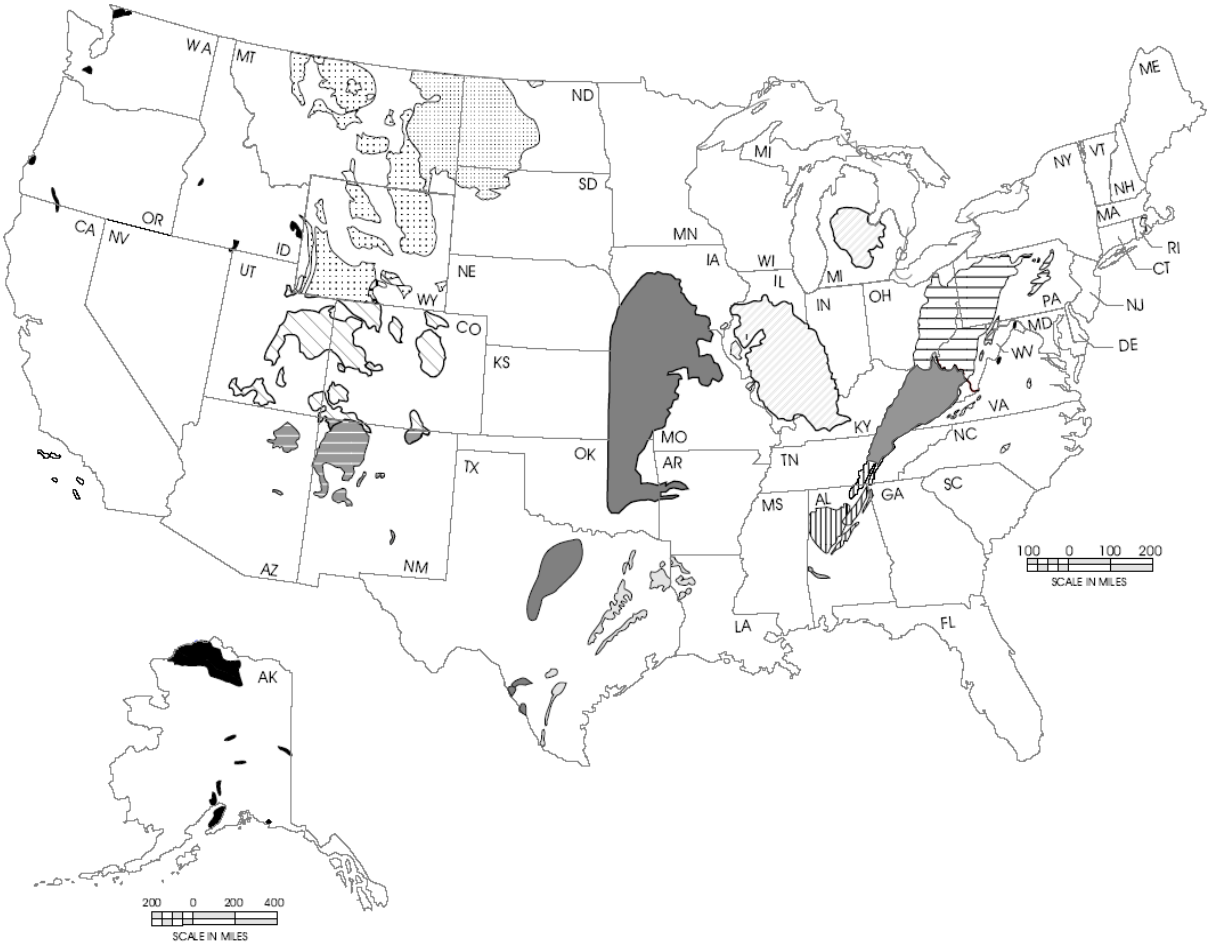
"__B", Bituminous and anthracite steam coal

"__S", Subbituminous steam coal

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

Example: "MDP" = Medium sulfur, underground mined, metallurgical coal.

Figure 1. CMM Coal Supply Regions



APPALACHIA

1. Northern Appalachia
2. Central Appalachia
3. Southern Appalachia

INTERIOR

4. Eastern Interior
5. Western Interior
6. Gulf Lignite

NORTHERN GREAT PLAINS

7. Dakota Lignite
8. Powder and Green River Basins

OTHER WEST

9. Rocky Mountain
10. Southwest
11. Northwest

Model Inputs and Outputs

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

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

User-specified inputs for the base-year include: capacity utilization at mines, productive capacity, minemouth coal prices, miner wages, labor productivity, cost of mining equipment, and the price of electricity. Other user-specified inputs required for the NEMS forecast years include: annual growth rates for labor productivity and wages, and annual producer price indices for the cost of mining machinery and equipment. Inputs obtained from other NEMS modules include coal production for year t-1, the minemouth coal price for years t and t-1, electricity prices, and the real interest rate (Figure 2). Appendix C includes a complete list of input variables and specification levels.

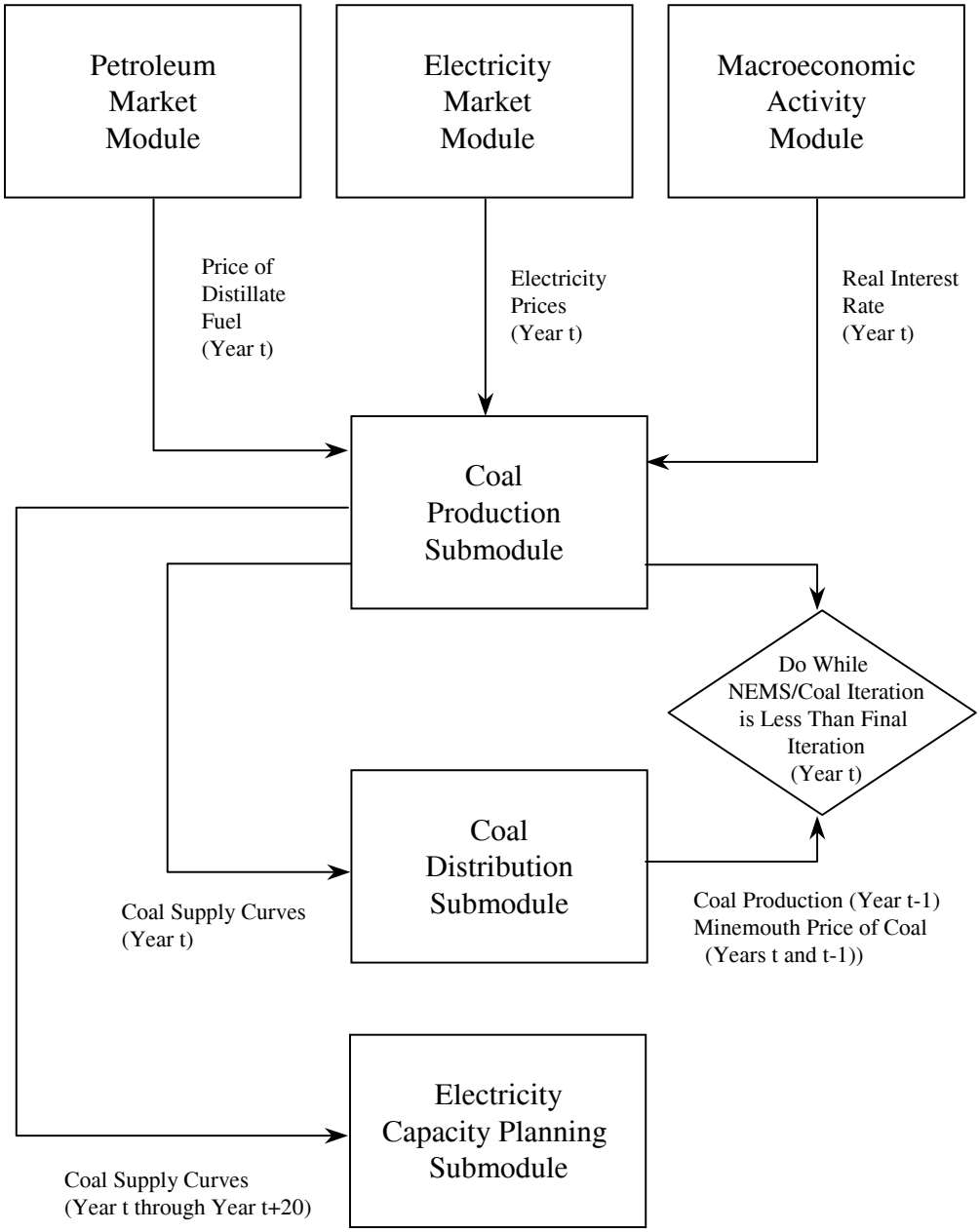
The primary outputs of the model are annual coal supply curves (price/production schedules), provided for each supply region, mine type, and coal type.

Relationship to Other Modules

The model generates regional mid-term (to 2025) coal supply curves. A distinct set of supply curves is determined for each forecast year. The supply curves are required by the CDS sub-module of the CMM. The information flow between the model and other components of NEMS is shown in Figure 2. Information obtained from other NEMS modules is as follows:

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

Figure 2. Information Flow Between the CPS and Other Components of NEMS



3. 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 *AEO2004* 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 2001, the average mine price of coal in the United States, in constant 1996 dollars, fell from $45.32 per ton to $16.08 per ton, a decline of 65 percent (Figure 3). During the same period, total U.S. coal production increased by 68 percent, from 670 million tons to 1,128 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.

Productivity has had a profound effect on competition in the U.S. coal industry. Between 1978 and 2001, 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 6.0 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 represented in the *AEO2004* coal pricing model indicates the strong historical correlation between prices and productivity (Figure 4).

Figure 3. U.S. Coal Production and Prices, 1978-2001

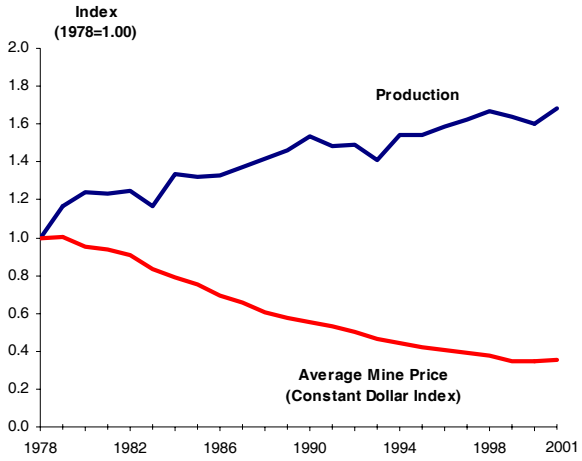
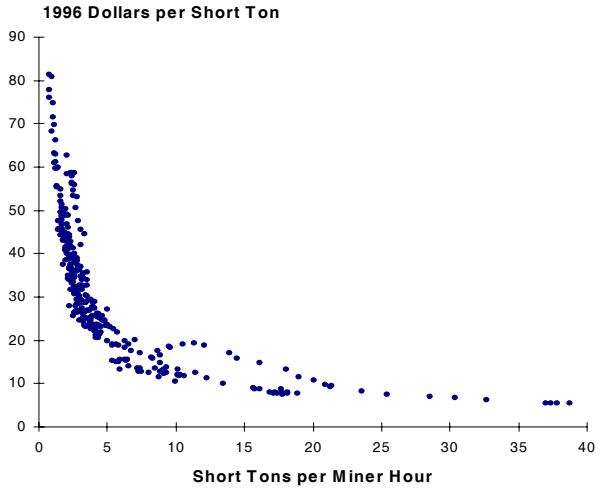


Figure 4. Minemouth Coal Prices and Labor Productivity for CMM Regions and Mine Types, 1978-2001



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 both the supply and demand for coal.[3] The general form of the model is that a competitive market converges toward equilibrium, where the quantity supplied equals the quantity demanded:

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

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

Figure 4. Minemouth Coal Prices and Labor Productivity for CMM Regions and Mine Types, 1978-2001

The formal specification of the coal pricing model for *AEO2004* is as follows.

For demand:

$$Q^{D} = f(P, TRAN, ELEC, INDUSTRY, OTHPROD, EXPORTS, PGAS, WOP, STOCKS, BTU_TON, SULFUR, ASH) + e^{D} \quad (1)$$

Supply:

$$P = f((Q^{S}/PRODCAP), PRODCAP, TPH, WAGE, PCAP, PFUEL) + e^{S} \quad (2)$$

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

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 cost of transporting coal in region I to the regions 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 for each year t.

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 utility sector in constant 1992 dollars per thousand cubic feet.

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 error term corresponding to 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.

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, 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 error term corresponding to 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 *AEO2004* 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) and (2). In equation (2), the error term in the supply equation (e^S) affects the minemouth price (P); however, in Equation (1), 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.[4] 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 results from the second-stage (structural) equation represents the model implemented in the CMM for *AEO2004*. 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 360 observations were pooled into a single regression equation. In

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

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 hypothesis of heteroskadicticity (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 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 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 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, labor productivity and the costs of factor inputs have played an important role in the determination of U.S. coal production and prices. In the coal industry, new technology developments tend to be evolutionary rather than revolutionary in nature in the coal industry. The introduction of longwall mining into the United States in the mid-1960's provides the most recent example of a new mining system penetrating the market. One must return to the late 1940's, and the widespread adoption of continuous mining, to find a technological change comparable in scope to the introduction of longwall mining. Furthermore, these new technologies have increased their market shares gradually over time. For example, the percentage of total underground production from continuous mining increased 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.[5] The percentage of total underground production mined by longwalls rose from less than 1 percent in 1966, to 4 percent in 1976, and to approximately 16 to 20 percent by 1982.[6] Recent data collected by EIA shows continuing penetration during the 1990's, with longwall's share of total underground production rising from approximately 29 percent in 1990 to 51 percent in 2001.[7] 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

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

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

[7]Energy Information Administration, *Coal Data: A Reference,* DOE/EIA-0064(90) (Washington, DC, November 1991), p. 10; and *Annual Coal Report 2001,* DOE/EIA-0584(2001) (Washington, DC, March 2003), Table 3.

also has been gradual.[8] The gradual introduction of new technology development is expected to continue during the NEMS forecasting horizon. Potential technology developments in underground mining during the next 5 to10 years are as follows:[9]

- A continuation in the trend toward increased continuous miner mining and loading rates
- Introduction of equipment with self-diagnostic capabilities
- Automation of longwalls
- Increased depth of cutting drums on longwall shearers
- Continued penetration of improved longwall and continuous mining technology
- Increased utilization of conveyor belt monitoring systems, and extension of monitoring systems to the production equipment
- Introduction of pillaring shields (currently in use at only two mines)
- Increased utilization of continuous haulage systems in thick seams
- Application of longwall mining to above-drainage seams
- Increased utilization of continuous mining super sections.

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.

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[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 longwall technology, the introduction and rapid penetration of the new longwall equipment was unquestionably a major contributing factor.

[9]S. C. Suboleski, et. al., *Central Appalachia: Coal Mine Productivity and Expansion (EPRI Report Series on Low-Sulfur Coal Supplies*) (Palo Alto, CA: Electric Power Research Institute (Publication Number IE-7117), September 1991).

A Review of Other Coal Supply Analysis Models

During the development of the CPS in 1992 and 1993, three alternative mid-term coal supply analysis models were reviewed: the EIA's RAMC; the coal supply module of ICF Inc.'s Coal and Electric Utilities Model (CEUM); and the coal supply portion of the Data Resources, Inc. (DRI)/Zimmerman Model. The approaches to coal supply analysis used in these models are outlined in this section.

Resource Allocation and Mine Costing Model (RAMC)

A previous EIA coal supply model, the CSTM.[10], used RAMC supply curves, in conjunction with its coal transportation network, to determine least cost supplies of coal by supply region for a given set of coal demands by demand sector and region. The RAMC supply curves were used as an exogenous input to EIA's Intermediate Future Forecasting System (IFFS). The most recent and final use of IFFS by EIA was to produce the integrated forecasts of energy production, consumption, distribution, and prices published in the *Annual Energy Outlook 1993*. RAMC supply curves also have been used as input for stand-alone model runs of the CSTM to analyze coal-related issues such as proposed changes in State severance taxes and the potential impact of proposed coal slurry pipelines.

The RAMC used a model mine approach to construct mid-term coal supply curves. The model incorporated 32 supply regions and 30 coal types (combinations of 5 heat content categories and 6 sulfur content categories). With the exception of reducing existing mine steps to reflect the retirement of older mines, the RAMC supply curves remained static over time. New mines were opened only when production from existing mines could not meet a specified level of demand. The RAMC assumed that all mines operate at full capacity utilization under a presumption that coal demand balances production capacity in the long-term. The RAMC adjusted mining costs for projected or assumed changes in the real costs of capital, labor, and power and supplies through the incorporation of separate escalation factors for each of these categories. Adjustments of these escalators were reflected in the calculation of annual levelized costs in the RAMC and could be made only at the national level.

ICF's Coal and Electric Utilities Model

The CEUM is used to analyze coal-related policy issues. It is a successor to the National Coal Model developed by ICF, Inc. for the Federal Energy Administration in 1976.[11] Among the many analyses the CEUM has been used for are western coal development, Federal coal leasing, and acid rain mitigation proposals (including analyses of various legislative proposals leading to the enactment of the Clean Air Act Amendments of 1990 for the Environmental Protection Agency).

The coal supply module of the CEUM uses a model mine approach to produce mid-term coal supply curves. The model incorporates 40 supply regions and 50 coal types (combinations of 7 heat/volatility level categories and 7 sulfur content categories, plus 1 anthracite category).[12] The effects of depletion, changes in labor productivity, and changes in real costs of factor inputs on mining costs are estimated over the forecast period.

The coal supply module of the CEUM and the RAMC share common origins, since both are modified versions of the coal supply model incorporated into the 1976 version of the Energy Information Administration's National Coal Model. However, the two models diverged from each other over time, using

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[10]Energy Information Administration, *Documentation of the Resource Allocation and Mine Costing (RAMC) Model*, DOE/EIA-M021(92) (Washington, DC, January 1992).

[11]ICF, Inc., *The National Coal Model: Description and Documentation*, prepared for the Federal Energy Administration (Washington, DC, October 1976); and Resource Dynamics Corporation, *A Review of Coal Supply Models*, prepared for Assistant Secretary of Fossil Energy, U.S. Department of Energy (Washington, DC, October 1982), p. V-6.

[12]ICF, Inc., *Documentation of the ICF Coal and Electric Utilities Model: Coal Supply Curves Used in the 1987 EPA Interim Base Case*, prepared for the U.S. Environmental Protection Agency (Washington, DC, September 1989).

somewhat different methods for deriving annual levelized mining costs. Most revisions to the models involved the addition of more detailed model mines to better reflect variations in coal geology and coal mining techniques. In addition, longwall model mines were added to reflect the growing importance of longwall technology in the U.S. coal mining industry.[13]

The ICF model and database modifications that differ from RAMC are: (1) the incorporation of mine start-up (i.e., development) and shut-down productivity and production levels into the model's mine costing equations; and (2) the incorporation of intertemporal rents into the algorithm used to calculate a minimum acceptable selling price.[14]

DRI/Zimmerman Model

The DRI/Zimmerman coal model was used to develop mid-term forecasts for DRI Inc.'s coal analysis and forecasting service.[15] In the DRI coal supply module, reserves were allocated to mine cost categories (defined primarily by seam thickness for underground mines and by overburden ratio for surface mines), in contrast to being allocated to coal mines.[16] As a result, the horizontal axis of DRI supply curves reflected the total amount of recoverable coal reserves instead of potential annual production. Long-run marginal costs, which determine the height of each step, were the sum of annual levelized capital costs and current year mine operating costs.[17] Thus, if labor, materials, and supply costs do not increase in real terms over the forecast period, the DRI mine costs are equivalent to an annual levelized cost. On each supply curve, all reserves in the lowest cost category for a particular region and coal type combination are produced before any reserves in the next highest cost category. To limit the amount of new production that can come on-line in a given forecast year, maximum annual percentage increases/decreases in coal production were input by supply region. Intertemporal adjustments to mine costs were made to reflect the impact of expected changes in labor productivity.[18] The model incorporated 10 supply regions and 6 coal types (sulfur content categories).

The primary difference between the DRI model and the RAMC is that in the DRI model all reserves in the lowest cost category for a particular region and coal type are produced before any reserves in the next highest cost category. In contrast, on a RAMC supply curve, where the horizontal axis represents potential annual production, coal of various costs was produced at the same time.[19] Thus, in the RAMC, the producer with the highest mining costs, as determined by the annual level of coal demand, is treated as the price leader. Producers with lower mining costs on the same supply curve earn economic rents.

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

[14]Intertemporal rents are based upon the economic theory of depletable resources.

[15]Resource Dynamics Corporation, *A Review of Coal Supply Models*, p. VII-1.

[16]Benjamin Lev, ed., *Energy Models and Studies* (Amsterdam: North Holland Publishing Company, 1983), Richard L. Gordon, *The Evolution of Coal Market Models and Coal Policy Analysis*, p. 73.

[17]Resource Dynamics Corporation, *A Review of Coal Supply Models*, p. VII-52.

[18]King Lin, Data Resources International, Inc., Personal Conversation, March 18, 1992.

[19]Steps on a RAMC supply curve are ordered from lowest production cost to highest production cost.

4. 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 B.

The model constructs a distinct set of supply curves for each forecast year in three separate steps, as follows (see Figure 3):

- Step 1: Calibrate the regression model to base-year production and price levels by region, mine type and coal type
- Step 2: Convert regression equation into supply curves
- 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.

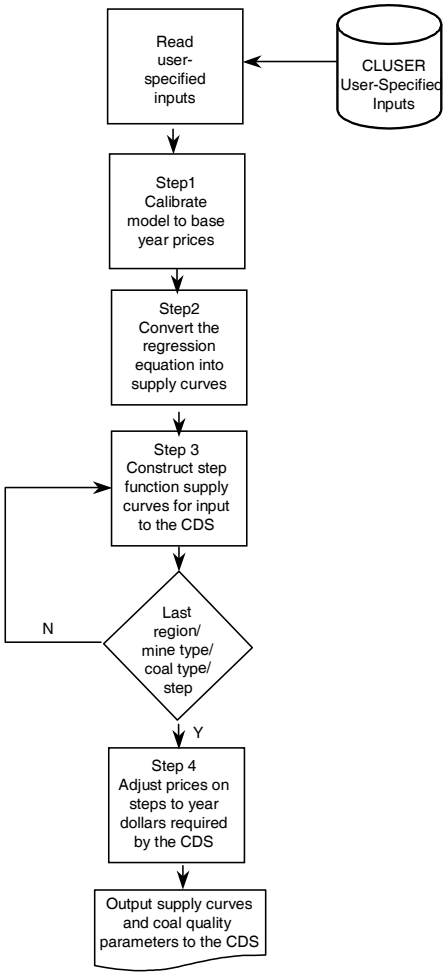
The calibration constants are automatically computed as part of a NEMS run. First, the coal-pricing equation is solved using the base year values for the independent variables. Second, this estimated price is then subtracted from the actual base-year price input by the user. For calibration purposes 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 into 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 *AEO2004*, the CPS generated a set of 34 separate coal supply curves for each year of the NEMS forecast period.

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

Figure 5. CPS Flowchart



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

Appendix A

Submodule Abstract

Model Name: Coal Production Submodule

Model Acronym: CPS

Description: Produces supply-price relationships for 11 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 2025) for the Coal Distribution Submodule of the Coal Market Module of the NEMS.

Model Update Information: October 2003

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

Documentation:

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

- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System, Part I* DOE/EIA-M060(2004) (Washington, DC, March 2004).

Archive Media and Installation Manual: NEMS04 - *Annual Energy Outlook 2004*

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

Coverage:

- **Geographic:** Supply curves for 11 geographic regions

- **Time Unit/Frequency:** 1995 through 2025

- **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

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

- **Input Data:** Base year values for U.S. coal production, capacity utilization, productive capacity, productivity, and prices. Base year electricity prices and wages. Heat, sulfur, and mercury content averages, and carbon emission factors by supply curve. Projections of labor productivity, wages, and the user cost of capital.

- **Data Sources:** DOE data sources: Energy Information Administration: EIA-3, EIA-5, EIA-6A, EIA-7A, and EIA-423 databases. Energy Information Administration, *Electric Power Annual 2001,* DOE/EIA-0348(2001) (Washington, DC, March 2003); U.S. Census Bureau*, 1997 Census of Mineral Industries*, *Bituminous Coal and Lignite Surface Mining, 1997*, EC97N-2121A (Washington DC, October 1999), *Bituminous Coal Underground Mining 1997*, EC97N-2121B (Washington DC, October 1999), *Anthracite Mining 1997*, EC97N-2121C (Washington DC, July 1999); *Petroleum Marketing Annual 2002*, Table 2, DOE/EIA-0487(2002) (Washington, DC, August 2003); and *State*

Energy Price and Expenditure Report 1999, DOE/EIA-0214(99) (Washington, DC, November 2001). Non-DOE data sources: Federal Energy Regulatory Commission, FERC-423 database. U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID: EEU10120006; and PPI for Mining Machinery and Equipment, Series ID: PCU3532#. Global Insight, Yield on Utility Bonds.

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

Independent Expert Reviews Conducted:

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

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

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

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

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

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

Status of Evaluation Efforts Conducted by Model Sponsor: The Coal Production Submodule (CPS) was developed for the National Energy Modeling System (NEMS) during the 1992-1993 period and revised in subsequent years. The version described in this abstract was used in support of the *Annual Energy Outlook 2004*.

An independent expert review of the Coal Market Module's (CMM's) *Annual Energy Outlook 2003* coal forecast was conducted in June 2003 by Energy Ventures Analysis, Inc. (EVA) and the PA Consulting Group.

Some of the key coal supply-related recommendations provided by EVA in their June 2003 review of the *AEO2003* coal forecast are as follows:

EVA Recommendation: Central Appalachia coal production is too high given the relatively poor reserve position. The low cost mines in Central Appalachia are depleting and the new mines will have higher strip ratios, thinner seams, higher ash, lower yield, longer hauls, etc. Although there are sufficient reserves to produce the level of Central Appalachia coal projected by the AEO2003, the projected mine price is too low to allow production to remain around 265 million tons annually.

Actions Taken: Analyzed seam-thickness data for Central Appalachian coal mines for the years 1978 through 2000 as collected on the form EIA-7A, "Coal Production Report." Analysis indicated that seam thickness for Central Appalachian coal mines does not appear to be declining. However, in light of the recent declines in coal mine labor productivity in Central Appalachia in 2001 and 2002, along with additional anecdotal information regarding geological problems and the poor financial health of the Central Appalachian coal industry, downward adjustments were made to the productivity outlook. For the *AEO2004* reference case forecast. it was assumed that productivity for Central Appalachian underground mines would remain constant over the forecast horizon, and that productivity for Central Appalachian surface mines would decline by 0.5 percent per year. By comparison, trend analyses of coal-mining labor productivity by mine type (underground and surface) for the Central Appalachian supply region indicated productivity growth of approximately 0.5 percent per year for both mine types over the forecast period (2002 to 2025).

EVA Recommendation: Review the coefficients of the supply cost regression model to determine if they should be adjusted to increase the slope of the supply curves.

Action Taken: EVA's evaluation of the CPS coal supply curves indicated that several of the relatively minor coal supply curves, in terms of productive capacity, had very flat slopes. OIAF's review revealed a flaw in the implementation of the CPS coal pricing equation in NEMS related to the fact that the levels of productive capacity and minemouth coal prices used to estimate the coal pricing equation were specified by mine type, while the equation is implemented in CMM by mine type and coal type. The implementation of the coal pricing model has been corrected.

EVA Recommendation: Consider moving Tennessee coal supply to Central Appalachia coal supply region from the Southern Appalachia region. All of the production in Tennessee is in the Bureau of Mines (BOM) District 8, which is one of the BOM districts in Central Appalachia. The mining conditions, quality, price, and transportation rates for Tennessee coal production are closer to Central Appalachia than Southern Appalachia.

Action Taken: Reclassified the northern counties of Tennessee (BOM District 8) as part of Central Appalachia. The southern counties of Tennessee (BOM District 13) remain as part of Southern Appalachia.

Some of the key coal supply-related recommendations provided by PA Consulting in their June 2003 review of the *AEO2003* coal forecast are as follows:

PA Consulting Group Recommendation: The rates of growth in labor productivity forecasted by EIA are reasonable, but that the starting levels of productivity assumed by EIA are too high in some cases. PA believes that EIA needs to revise its starting productivity levels for several major coal

supply regions downward to account for the decline in productivity coal mining industry experienced during 2002.

Action Taken: For the *AEO2003*, the base-year productivity inputs were based on data for 2000. The *AEO2004* was updated with data for 2002.

PA Consulting Group Recommendation: Recommend that additional coal supply curves be added for the Powder River Basin (PRB) coal supply region. Details regarding this recommendation are supplied by PA Consulting in their August 2002 independent expert review entitled *Independent Expert Review of the Annual Energy Outlook 2002 Projections of Coal Production, Distribution, and Prices for the National Energy Modeling System.*

Action Taken: OIAF will investigate the need for additional PRB coal supply detail in the CMM for the *Annual Energy Outlook 2005*.

References:

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

- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System, Part I* DOE/EIA-M060(2002) (Washington, DC, January 2002).

Appendix 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

Variable Definitions

The variables used in the model are defined as follows:

Indices

i	=	supply region
j	=	mining method (surface or underground)
k	=	coal type
t	=	year
by	=	base year (for the *AEO2004*, the base year was 2002)
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 B-1. EXP represents the exponential function.

$$P_{i,j,k,by} = \{EXP\,[(A + \beta_{i,1}) * (1-\beta_{12})]\} * [TPH_{i,j,t=1}{}^{(TPHBM * (1-\beta_{12}))}] * \quad \text{(B-1)}$$

$$[PROD_CAP_ADJ_{i,j,k}{}^{((\beta_2 + \beta_{j,3}) * (1-\beta_{12}))}] * [PRI_ADJ_{i,j,k}{}^{(-\beta_{12})}] * PRODCAP_{i,j,k,by}{}^{(\beta_2 + \beta_{j,3})} *$$

$$CAPUTIL_{i,j,k,by}{}^{\beta_4} * TPH_{i,j,by}{}^{((\beta_5 + (k * SE)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8})} * WAGE_{by}{}^{\beta_{j,9}} * PCAP_{by}{}^{\beta_{10}} *$$

$$PFUEL_{i,by}{}^{\beta_{11}} * P_{i,j,k,by}{}^{\beta_{12}} * PRODCAP_{i,j,k,by}{}^{(-\beta_{12} * (\beta_2 + \beta_{j,3}))} *$$

$$CAPUTIL_{i,j,k,by}^{(-\beta_{12} * \beta_4)} * TPH_{i,j,by}^{(-\beta_{12} * ((\beta_5 + (k * SE)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} * WAGE_{by}^{(-\beta_{12} * \beta_{j,9})} *$$

$$PCAP_{by}^{(-\beta_{12} * \beta_{10})} * PFUEL_{i,by}^{(-\beta_{12} * \beta_{11})}$$

where:

Variables

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

A - overall constant term for the model

TPHBM - benchmark factor used for calibrating the coal pricing equation to the actual value of the minemouth coal price in year one of the forecast period

$PROD_CAP_ADJ_{i,j,k}$ - Factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type

$PRI_ADJ_{i,j,k}$ - Factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type

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

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

$TPH_{i,j,by}$ - coal mine labor productivity for supply region i and mine type j for the base year

$WAGE_{by}$ - average annual wage for coal miners for the base year

$PCAP_{by}$ - index for the annual user cost of capital for the base year

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

$P_{i,j,k,by}$ - average minemouth price of coal for supply region i, mine type j, and coal type k for the base year

Regression Coefficients

A overall constant for the model

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

β_2 for the productive capacity term

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

β_4 for the capacity utilization term

β_5 for the labor productivity term

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

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

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

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

β_{10} for the user cost of capital term

β_{11} for the fuel price term

β_{12} for the first-order autocorrelation term

For calibration purposes, base year values of productive capacity, capacity utilization, productivity, labor costs, the fuel price, capital costs, and the average minemouth price are provided as inputs to the equation. Using these base year values, the regression equation is solved for each CPS supply region, mining method, and coal type. Note that

for calibration purposes the simplifying assumption is made that the lagged values of the independent variables (used in those terms of the equation needed to correct for autocorrelation) are the same as the base year values. This assumption obviates the need to provide the model with two years of base data, and is believed to yield a reasonable approximation of the "true" calibration constant.

As shown in equation 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.

$$CAL_FACTOR_{i,j,k} = (BYP_{i,j,k} - P_{i,j,k,by}) \quad \text{(B-2)}$$

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 B-3.

$$K_{i,j,k,t} = \{EXP\,[(A + \beta_{i,1}) * (1-\beta_{12})]\} * [TPH_{i,j,t=1}^{(TPHBM * (1-\beta_{12}))}] * \quad \text{(B-3)}$$

$$[PROD_CAP_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1-\beta_{12}))}] * [PRI_ADJ_{i,j,k}^{(-\beta_{12})}] * PRODCAP_{i,j,k,t}^{(\beta_2 + \beta_{j,3})} *$$

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

$$P_{i,j,k,t-1}^{\beta_{12}} * PRODCAP_{i,j,k,t-1}^{(-\beta_{12} * (\beta_2 + \beta_{j,3}))} * CAPUTIL_{i,j,k,t-1}^{(-\beta_{12} * \beta_4)} *$$

$$TPH_{i,j,t-1}^{(-\beta_{12} * ((\beta_5 + (k * SE)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} * WAGE_{t-1}^{(-\beta_{12} * \beta_{j,9})} *$$

$$PCAP_{t-1}^{(-\beta_{12} * \beta_{10})} * PFUEL_{i,t-1}^{(-\beta_{12} * \beta_{11})}$$

where:

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 factor used for calibrating the coal pricing equation to the actual value of the minemouth coal price in year one of the forecast period

$PROD_CAP_ADJ_{i,j,k}$ - Factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type

$PRI_ADJ_{i,j,k}$ - Factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by mine type, while the model is implemented in NEMS by mine type and coal type

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

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

$WAGE_t$ - average annual wage for coal miners in year t

$PCAP_t$ - index for the annual user cost of capital 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

$PCAP_{t-1}$ - index for the annual user cost of capital 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

Regression Coefficients

A overall constant for the model

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

β_2 for the productive capacity term

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

β_4 for the capacity utilization term

β_5 for the labor productivity term

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

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

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

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

β_{10} for the user cost of capital term

β_{11} for the fuel price term

β_{12} for the 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 B-4):

$$P_{i,j,k,t} = CAL_FACTOR_{i,j,k} + [K_{i,j,k,t} * CAPUTIL_{i,j,k,t}^{\beta_4}] \quad \text{(B-4)}$$

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 ($Q_{i,j,k,t}$)

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

$K_{i,j,k,t}$ - annual multiplier, specified by supply region i, mine type j, and coal type k, calculated by solving the CPS coal pricing equation for production equal to zero for year t equal to zero and all other independent variables set equal to their forecast-year values (for years t and t-1)

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

β_4 - regression coefficient for the capacity utilization term

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

The CDS is formulated as a linear program (LP) and cannot directly use the supply curves generated by 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 B-5 shows the CPS equation used for generating the prices for the step-function supply curves.

$$P_{i,j,k,z,t} = CAL_FACTOR_{i,j,k} + [K_{i,j,k,t} * CAPUTIL_HIST_{i,j,k}^{(\beta_4 - (\beta_4 * \psi)} * (Q_{i,j,k,z,t} / PRODCAP_{i,j,k,t})^{(\beta_4 * \psi)}] \quad \text{(B-5)}$$

where

$$\psi = (CAPUTIL_HIST_{i,j,k} / (Q_{i,j,k,z,t} / PRODCAP_{i,j,k,t})^{\eta}$$

and where

$P_{i,j,k,z}$ - price associated with step z for region i, mine type j, coal type k, and year t specified as a percent variation from the target price.

$C_{i,j,k}$ - 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.

β_4 - regression coefficient for the capacity utilization term

$K_{i,j,k,t}$ - multiplier for the non-production terms in the regression equation
$PRODCAP_{i,j,k,t}$ - annual productive capacity of coal mines for supply region i, mine type j, coal type k, and year t
$CAPUTIL_HIST_{i,j,k}$ - representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated for supply region i, mine type j, and coal type k
ψ - scalar used to adjust regression coeficient for the capacity utilization term for levels of average coal-mine capacity utilization that lie outside the range of utilizaion rates contained in the coal pricing model's historical database
η - Exponent representing the theoretical functional form of the capacity utilization term for levels of capacity utilization that are outside the range of utilization rates contained in the coal pricing model database

The scalar for the capacity utilization term reflects the basic premise that mining costs will increase rapidly 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 2001, the average annual capacity utilization for Gulf Lignite (Texas and Louisiana) production ranged from a low of 90.3 percent in 1991 to a high of 97.6 percent in 1997. During this same period, the average annual capacity utilization for surface coal mines in the Powder River Basin (Wyoming and Montana), taken as a whole, ranged from a low of 74.8 percent in 1993 to a high of 90.1 percent in 2001.

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

$$STEP_Q_{i,j,k,z,t} = Q_{i,j,k,z,t} - Q_{i,j,k,z-1,t} \quad \text{(B-6)}$$

where

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

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

Appendix 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 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 *AEO2004*, labor productivity estimates were derived by assuming that, in the first year of the forecast period, productivity increases at a rate equal to the average annual productivity increase over the recent past and that the initial rate of increase diminishes gradually over the remainder of the forecast period. 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 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 (for the *AEO2004*, these inputs were used to limit the near-term production capacity of lignite in the Eastern Interior supply region and deep-mined bituminous coal in the Powder and Green River Basin supply region); and 6) capacity utilization trigger points by region and mine type used to determine when to add or retire coal-mining productive capacity. Each trigger point is assigned a unique multiplier used to adjust annual productive capacity either upward or downward.

The indices used in the tables are defined as follows:

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

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
WAGE	Real labor cost escalator	National/year	--	--	EIA projection
L_PROD	Base year productivity	Supply region/ mine type	Tons/miner hour	$LP_{i,j,by}$	EIA-7A
FR_PROD	Forecast year productivity (as a fraction of L_PROD)	Supply region/ mine type/year	--	$LP_{i,j,t}$	EIA projection
ADJ_FORE	Price adjustment variable (currently set to zero)	Supply region/ mine type/year	Dollars/ton	--	EIA estimate
SBAS_REGION	Alphabetic supply region code	Supply region	--	--	Model definition
NBAS	Number of production records	Supply region	--	--	File definition
CPROD_TYPE	Alphabetic coal type code	Supply region/ coal type	--	--	Model definition
B_PROD	Base year (2002) production (surface and deep)	Supply region/ mine type/coal type	MMTons	$P_{i,j,k,by}$	EIA-*7A*
BTU	Average heat content (surface and deep)	Supply region/ mine type/coal type	MMBtu/ton	--	FERC-423
SULFUR	Average sulfur content (surface and deep)	Supply region/ mine type/coal type	Lbs/MMBtu	--	FERC-423
CAR	Average carbon dioxide emission factor (surface and deep)	Supply region/ coal type	Lbs/MMBtu	--	EIA estimate
PRI	Base-Year (2002) coal price (surface and deep)	Supply region/ coal type	1987 Dollars/Ton	--	EIA-7A
MERCURY	Average mercury content (surface and deep)	Supply region/ mine type/coal type	Lbs/trillion Btu	--	U.S. EPA
B_CAP_UTIL	Base-Year (2002) capacity utilization of coal mines (surface and deep)	Supply region/ mine type	Fraction	$CAPUTIL_{i,j,k,by}$	EIA-7A
B_PROD_CAP	Base-Year (2000) productive capacity (surface and deep)	Supply region/ mine type/coal type	MMTons	$PRODCAP_{i,j,k,by}$	EIA-7A

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
B_PROD_CAP_ADJ	Factor used to adjust intercept for the model to account for the fact that the levels of productive capacity used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content)	Supply region/ mine type/coal type	--	$PROD_CAP_ADJ_{i,j,k,by}$	EIA-7A
PRI_ADJ	Factor used to adjust intercept for the model to account for the fact that the minemouth coal prices used to estimate the coal pricing equation were specified by region and mine type, while the model is implemented in NEMS by region, mine type and coal type (unique combination of heat and sulfur content)	Supply region/ mine type/coal type	--	$PRI_ADJ_{i,j,k,by}$	EIA-7A
UTIL_HIST	Representative coal-mine capacity utilization for the time period over which the coal pricing model is estimated (surface and deep)	Supply region/ mine type/coal type	Percent	$CAPUTIL_HIST_{i,j,k}$	EIA specification
ELEC_SHARE	Share of total fuel costs at mines represented by electricity	Supply region/ mine type	Fraction	--	U.S. Census Bureau
DIST_SHARE	Share of total fuel costs at mines represented by diesel fuel	Supply region/ mine type	Fraction	--	U.S. Census Bureau
OCONT	Overall constant for CPS regression model	National	--	A	Regression analysis
LUTIL	Pricing model coefficient (capacity utilization term)	National	--	β_4	Regression analysis
LPCAP	Pricing model coefficient (cost of capital term)	National	--	β_{10}	Regression analysis
LPFUEL	Pricing model coefficient (electricity price term)	National	--	β_{11}	Regression analysis
TPH	Pricing model coefficient (overall productivity term)	National	--	β_5	Regression analysis

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
TPH_DEEP	Pricing model coefficient (mine type productivity term)	Mine type	--	$\beta_{j,7}$	Regression analysis
LPRODCAP	Pricing model coefficient (overall productive capacity term)	National	--	β_{2}	Regression analysis
RHO	Pricing model coefficient (first-order autocorrelation term)	National	--	β_{11}	Regression analysis
PDUMM	Pricing model adjustment factor applied to overall constant term	National	--	--	Regression analysis
DEEPRODCAP	Pricing model coefficient (mine type productive capacity term)	Mine type	--	$\beta_{j,3}$	Regression analysis
DEEPWAGE	Pricing model coefficient (mine type labor cost term)	Mine Type	--	$\beta_{j,9}$	Regression analysis
B_WAGE	Base-year hourly wage	National	1987 Dollars/Hour	WAGE	Bureau of Labor Statistics
F_INDEX	Base-year electricity/ distillate hybrid fuel price (industrial sector)	Supply region	1992 Dollars/ MMBtu	PFUEL	EIA
SDS	Pricing model coefficients (intercept dummy variables, surface mines)	Supply region	--	$\beta_{i,1}$	Regression analysis
SDD	Pricing model coefficients (intercept dummy variables, underground mines)	Supply region	--	$\beta_{i,1}$	Regression analysis
SPROD	Pricing model coefficients (regional productivity terms)	Supply region	--	$\beta_{i,6}$	Regression analysis
DPROD	Pricing model coefficients (regional and mine type productivity terms)	Supply region/ mine type	--	$\beta_{i,j,7}$	Regression analysis
P_EQUIP	PPI for mining machinery and equipment	National/year	Constant dollar index (1992 dollars)	--	Bureau of Labor Statistics
PCNT_REC	Number of marginal cost curves	National	--	--	File definition
PCNT_ REGION	Numerical supply region identifier	Supply region	--	--	Model definition

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
PCNT_CTYPE	Numerical coal type identifier	Coal type	--	--	Model definition
PCNT_PRICE	Base-year minemouth coal price	Supply region/ mine type/ coal type	1987 Dollars/ton	--	EIA-7A
PCNT_PROD	Initial target production used to build step-function curves with 11 steps	Supply region/ mine type/ coal type	MMTons	--	EIA-7A
MCNT_REC	Number of marginal cost curves	National	--	--	File definition
MCNT_ REGION	Numerical supply region identifier	Supply region	--	--	Model definition
MCNT_CTYPE	Numerical coal type identifier	Coal type	--	--	Model definition
MCNT_PRICE	Initial target price used to build step-function curves with 8 steps	Supply region/ mine type/ coal type	1987 Dollars/ton	$P_{i,j,k,z=1,t}$	EIA-7A
MCNT_PROD	Base year production	Supply region/ mine type/ coal type	MMTons	--	EIA-7A
MCNT_STEP	Variations from the target price used to build step-function curves with 8 steps	National	Fraction	--	EIA estimate
SCLIMIT_CNT	Numerical supply curve code	Supply curve	--	--	Model definition
SCLIMIT_REG	Numerical supply region code	Supply region	--	--	Model definition
SCLIMIT_ REGNAME	Alphabetic supply region code	Supply region	--	--	Model definition
SCLIMIT_ CPSCT	Numerical coal type code	Coal type	--	--	Model definition
SCLIMIT__ CDSCT	Alphabetic coal type code	Coal type	--	--	Model definition
IYR	Supply curve limit	Supply curve	MMTons	--	EIA estim.
SCURVE_ LIMIT_MAX	Maximum supply curve limit	National	MMTons	--	EIA specification

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
MMP_ADJ_1	Factor used to adjust target price downward when price returned from the CDS LP exceeds maximum price on the CPS supply curve and step 6 on the CPS supply curve has zero quantity	National	Fraction	--	EIA specification
MMP_ADJ_2	Factor used to adjust target price downward when price returned from the CDS LP exceeds maximum price on the CPS supply curve and step 6 on the CPS supply curve has a quantity greater than zero	National	Fraction	--	EIA specification
MMP_ADJ_3	Factor used to adjust target price upward when price returned from the CDS LP exceeds maximum price on the CPS supply curve and: 1) step 6 on the CPS supply curve has a quantity greater than zero, but step 11 has a zero quantity; or 2) cumulative capacity of the CPS supply curve steps is less than less than 98 percent of CMM's allowable productive capacity for the year	National	Fraction	--	EIA specification
SCURVE_UTIL_CHECK	Capacity utilization used in conjunction with MMP_ADJ_3 to assess capacity utilization represented by the quotient of cumulative capacity of the CPS supply curve steps divided by CMM's allowable annual productive capacity	National	Fraction	--	EIA specification

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

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
UTIL_EXP	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 range of utilizaion rates contained in the coal pricing model database	National	--	--	EIA specification
UTIL_MAX_ SURF	Upper capacity utilization amount used to trigger additions to surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MAX_ UNDG	Upper capacity utilization amount used to trigger additions to underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MID_ SURF	Mid-level capacity utilization amount used to trigger additions to surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MID_ UNDG	Mid-level capacity utilization amount used to trigger additions to underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MIN_ SURF	Lower capacity utilization amount used to trigger retirements of surface productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MIN_ UNDG	Lower capacity utilization amount used to trigger retirements of underground productive capacity	Supply region	Fraction	--	EIA specification
UTIL_MAX_ SURF_ADJ	Factor used to increase surface productive capacity when capacity utilization ≥ UTIL_MAX_SURF	Supply region	Fraction	--	EIA specification
UTIL_MAX_ UNDG_ADJ	Factor used to increase underground productive capacity when capacity utilization ≥ UTIL_MAX_UNDG	Supply region	Fraction	--	EIA specification

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

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

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

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

Model Outputs

The primary output 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 C-3).

Table C-3. CPS Model Outputs

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

Endogenous Variables

Variables endogenous to the model are included in Table C-4. Table 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 C-4. CPS Endogenous Variables

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

Appendix D

Data Quality and Estimation

Development of the CPS Regression Model

As discussed previously in Part I of the CMM Model Documentation, the two-stage least squares regression technique was used to estimate the relationship between the minemouth price of coal and the corresponding levels of production, labor productivity, the costs of factor inputs (mining equipment, mine labor, and fuel), and production capacity contributions from new mines. In the first stage of the estimation, the endogenous explanatory variables are regressed on the exogenous and predetermined variables. The product of this estimation are predicted values of the endogenous explanatory variables that are uncorrelated with the error term. In turn, these 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 results from the second-stage (structural) equation represents the model implemented in the CMM for the *AEO2004*. 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. 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 ten CPS supply regions and two mine types (surface and underground) for the years 1980 through 2001, excluding the years 1986-1992.[20] In all, 225 observations are included (15 observations per year (10 surface and 5 underground) for each of the 15 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 D-1, respectively. The sources for the various historical data series used in the regression model are shown in Tables D-2 and D-3.

[20]Data for coal mines in the AW (Alaska and Washington) supply region were not included in the regression model. The average mine price of coal for those States is withheld from EIA publications to avoid disclosure of individual company data. Productive capacity data for 1987 through 1990 were not included in the regression model because they were not published and therefore were not subjected to a complete data verification process.

Indicative of the high R^2 statistic (see Table 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 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 (OLSQ).
A summary of the calculations used for generating the R^2 statistic in TSP is provided below.

For OLSQ:

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

where:

$e_t = y_t - \hat{y}$ and $\hat{y}_t = X_t b$

For 2SLS:

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

Where the residuals, e_t, are the "structural residuals" and not the "second-stage residuals." The "second stage residuals" would be obtained by doing two-stage least squares literally in two stages, which would involve replacing some columns of X with predicted values from a first stage.

The adjusted R^2 or $\overline{R}^2$ is calculated in as follows:

$$\overline{R}^2 = (R^2 (T-1) + 1 - K) / (T - K) \quad \text{(D-2)}$$

In the above equations:

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

Based on the regression results shown in Table D-1, the equation used for predicting future levels of minemouth coal prices by region, mine type and coal type for *AEO2004* is:

$$P_{i,j,k,t} = CAL_FACTOR_{i,j,k,t} + [C_{i,j,k,t} * PRODCAP_{i,j,k,t}^{(\beta_2 + \beta_{j,3})} * CAPUTIL_{i,j,k,t}^{\beta_4} * \quad \text{(D-3)}$$

$$TPH_{i,j,t}^{((\beta_5 + (k * SE)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8})} * WAGE_{j,t}^{\beta_{j,9}} * PCAP_t^{\beta_{10}} *$$

$$PFUEL_{i,t}^{\beta_{11}} * PRODCAP_{i,j,k,t-1}^{(-\beta_{12} * (\beta_2 + \beta_{j,3}))} * CAPUTIL_{i,j,k,t-1}^{(-\beta_{12} * \beta_4)} *$$

$$TPH_{i,j,t-1}^{(-\beta_{12} * ((\beta_5 + (k * SE)) + \beta_{i,6} + \beta_{j,7} + \beta_{i,j,8}))} * WAGE_{j,t-1}^{(-\beta_{12} * \beta_{j,9})} *$$

$$PCAP_{t-1}^{(-\beta_{12} * \beta_{10})} * PFUEL_{i,t-1}^{(-\beta_{12} * \beta_{11})}]$$

where:

$CAL_FACTOR_{i,j,k,t}$ 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 *AEO2004*, prices were calibrated to the average annual minemouth coal prices for 2002.

$$C_{i,j,k,t} = e^{(A + \beta_{i,1}) * (1-\beta_{12})} * TPH_{i,j,t=1}^{(k * -SE * (1-\beta_{12}))} * \quad \text{(D-4)}$$

$$[PROD_CAP_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1-\beta_{12}))}] * [PRI_ADJ_{i,j,k}^{(-\beta_{12})}]$$

where:

The first term ($e^{(A + \beta_{i,1}) * (1-\beta_{12})}$) 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 ($TPH_{i,j,t=1}^{(k * -SE * (1-\beta_{12}))}$) is a required component of a feature added to the model. This feature provides the ability to adjust the overall coefficient for the labor productivity term for modeling runs of the Coal Market Module. Specifically, the term k is the parameter by which the adjustment is made. The SE term is the standard error of the parameter estimate (β_5) for the labor productivity term, and is a constant. For the *AEO2004*, k was set equal to 2. This reflects the assumption that coal mine operators will not continue to pass along cost savings obtained through productivity improvements to the same extent that they have during the past 20 years. The basis for this assumption is that, as a result of strong competitive pressures, the coal industry has been realizing a lower rate of return than other comparative industries in recent years, and, therefore, coal industry earnings need to improve somewhat in order to continue to attract sufficient amounts of investment.

The third term ($PROD_CAP_ADJ_{i,j,k}^{((\beta_2 + \beta_{j,3}) * (1-\beta_{12}))}$) 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).

The fourth term ($PRI_ADJ_{i,j,k}^{(-\beta_{12})}$) 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)

Remaining Variables

$P_{i,j,k,t}$	average annual minemouth price of coal in constant 1992 dollars for supply region i, mine type j, coal type k in year t
A	overall constant term for the model
$PRODCAP_{i,j,k,t}$	annual productive capacity of coal mines for supply region i, mine type j, coal type k in year t
$CAPUTIL_{i,j,k,t}$	average annual capacity utilization (the ratio of annual production to annual productive capacity) of coal mines for supply region i, mine type j, coal type k in year t (modeled as a percentage)
$TPH_{i,j,t}$	average annual coal mine labor productivity in tons per miner hour for supply region i, mine type j in year t

$WAGE_{j,t}$	average annual wage for coal miners for mine type j in year t
$PCAP_t$	index representing the annualized user cost of mining equipment in year t. The index is adjusted to constant 1992 dollars.
$PFUEL_{i,t}$	a weighted average of the annual price of electricity in the industrial sector and the U.S. price of No. 2 diesel fuel (excluding taxes) to end users for supply region i in year t

Regression Coefficients

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

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

Regression Coefficient	Variable	Parameter Estimate	Standard Error	t- Statistic
A	Overall Constant	-0.286	0.310	-0.922
$\beta_{i=3,1}$	DUM_REG$_3$ (Southern Appalachia (SA))	0.792	0.087	9.091*
$\beta_{i=5,1}$	DUM_REG$_5$ (West Interior (WI))	1.119	0.081	13.817*
$\beta_{i=6,1}$	DUM_REG$_6$ (Gulf Lignite (GL))	-0.278	0.056	-4.970*
$\beta_{i=7,1}$	DUM_REG$_7$ (Dakota Lignite (DL))	1.307	0.157	8.351*
$\beta_{i=8,1}$	DUM_REG$_8$ (Powder River Basin (PG))	1.813	0.148	12.247*
$\beta_{i=9,1}$	DUM_REG$_9$ (Rocky Mountain (RM))	0.785	0.050	15.745*
$\beta_{i=10,1}$	DUM_REG$_{10}$ (Arizona/New Mexico (ZN))	0.486	0.059	8.176*
β_2	ln PRODCAP	0.450	NA[a]	NA[a]
$\beta_{j=1,3}$	DUM_MT (Underground) * ln PRODCAP	-0.084	0.035	-2.363**
β_4	ln CAPUTIL	0.318	0.058	5.504*
β_5	ln TPH	-0.400	0.060	-6.677*
$\beta_{i=3,6}$	SA*ln TPH	0.386	0.087	4.435*
$\beta_{i=5,6}$	WI*ln TPH	0.317	0.070	4.500*
$\beta_{i=7,6}$	DL*ln TPH	-0.556	0.062	-8.932*
$\beta_{i=8,6}$	PG*ln TPH	-0.899	0.063	-14.218*
$\beta_{j=1,7}$	DUM_MT (Underground) * ln TPH	-0.471	0.044	-10.625*
$\beta_{i=1,j=1,8}$	NA * DUM_MT (Underground) * ln TPH	0.212	0.032	6.637*
$\beta_{i=3,j=1,8}$	SA * DUM_MT (Underground) * ln TPH	-0.314	0.080	-3.922*
$\beta_{i=4,j=1,8}$	EI * DUM_MT (Underground) * ln TPH	0.265	0.041	6.462*
$\beta_{j=1,9}$	DUM MT (Underground) * ln WAGE	0.157	0.062	2.511**
β_{10}	ln PCAP	0.114	0.031	3.659*
β_{11}	ln PFUEL	0.168	0.055	3.043*
β_{12}	Autocorrelation Parameter (Rho)	0.435	0.062	6.981*
	Adjusted R squared	0.997		
	Durbin-Watson Statistic	2.005		
	Number of Observations	225[b]		

NA = Not available.

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

[b]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 2001, excluding the years 1986-1992. In all, 225 observations are included (15 observations per year (10 surface and 5 underground) for each of the 15 years represented in the historical data series).

*Significant at one percent.

**Significant at five percent.

***Significant at ten percent.

Notes: The endogenous explanatory variables in the regression are PRODCAP, CAPUTIL, TPH, WAGE, PCAP, and PFUEL. Instruments excluded from the supply equation are lagged electric utility generation, lagged industrial coal consumption, lagged exports, coal inventories at utility 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, the average heat, sulfur and ash content for coal received at utility plants, and an index for coal transportation rates.

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

Variable	Description	Units	Sources
$P_{i,j,t}$	Average annual minemouth price of coal by CPS supply region and mine type	1992 Dollars per short ton	Energy Information Administration, Form EIA-7A, "Coal Production Report"
$PRODCAP_{i,j,t}$	Annual coal productive capacity by region and mine type	Million short tons	Energy Information Administration, Form EIA-7A, "Coal Production Report"
$CAPUTIL_{i,j,t}$	Average annual capacity utilization at coal mines by region and mine type	Percent	Energy Information Administration, Form EIA-7A, "Coal Production Report"
$TPH_{i,j,t}$	Average annual labor productivity by region and mine type	Short tons per miner hour	Energy Information Administration, Form EIA-7A, "Coal Production Report"
$WAGE_t$	Average hourly coal industry wage (national level)	1992 Dollars per miner hour	U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID: EEU10120006 .
$PCAP_t$[21]	Annualized user cost of mining equipment (national level)	Constant dollar index (1992 dollars)	**PPI for Mining Machinery and Equipment:** U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU3532#; and **Yield on Utility Bonds:** Global Insight.
$PFUEL_{i,t}$	Weighted average annual price of electricity in the industrial sector and the U.S. price of No. 2 diesel fuel (excluding taxes)	1992 Dollars per million Btu	Energy Information Administration, *Electric Power Annual 2002 – Spreadsheets* (Washington, DC, December 2003), web site www.eia.doe.gov; EIA, *Petroleum Marketing Annual 2002,* DOE/EIA-0487(2002) (Washington, DC, August 2003), Table 2; and EIA, *State Energy Price and Expenditure Report 1999*, DOE/EIA-0376(99) (Washington, DC, November 2001).

[21]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 yield on utility bonds minus the percentage change in the implicit GDP deflator;

δ is the rate of depreciation on mining equipment, assumed to equal 10 percent; and

p_t is the PPI for coal mining equipment, adjusted to constant 1992 dollars using the GDP deflator.

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;

δp_t is the compensation to the mine owner for depreciation; 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 D-3. Data Sources for Instruments Excluded from the Supply Equation

Data Item	Description	Units	Sources
Total Electricity Net Generation	Annual fossil-fired net electricity generation	Billion Kilowatthours	Energy Information Administration, *Annual Energy Review 2002,* DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 8.2a.
Industrial coal consumption	Annual industrial coal consumption (steam and coking)	Million short tons	Energy Information Administration, *Annual Energy Review 2002,* DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 7.3.
World Oil Price	Refiner acquisition cost of crude oil: imported	1992 Dollars per barrel	Energy Information Administration, *Petroleum Marketing Annual 2002,* DOE/EIA-0487(2002) (Washington, DC, August 2003), Table 1.
Price of Natural Gas	Annual average price of natural gas delivered to electric utilities	1992 Dollars per thousand cubic feet	Energy Information Administration, *Annual Energy Review 2002,* DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 6.8.
Heat content of coal	Average annual heat content of coal for receipts at electric utility plants by CPS supply region and mine type.	Million Btu per short ton	Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
Sulfur content of coal	Average annual sulfur content of coal for receipts at electric utility plants by CPS supply region and mine type.	Pounds of sulfur per million Btu.	Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
Ash content of coal	Average annual ash content of coal for receipts at electric utility plants by CPS supply region and mine type.	Percent by weight	Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
Cost of coal transportation	Annual PPI for railroads, line-haul operating: coal	Index (1985=100.0) adjusted to 1992 dollars	U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU4011#A03.
Exports	Annual exports of U.S. coal	Million tons	Energy Information Administration, *Annual Energy Review 2002,* DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 7.1.
Other Production	Total U.S. production minus production for the current observation	Million tons	Energy Information Administration, Form EIA-7A, "Coal Production Report"
Coal Inventories	Coal stocks at the end of the year for U.S. electric power sector	Million tons	Energy Information Administration, *Annual Energy Review 2002,* DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 7.5.

Appendix E

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Appendix 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

Part II-A—Coal Distribution Submodule -Domestic Component

1. Introduction

Statement of Purpose

This Part of the report presents the objectives of the approach used in modeling domestic coal distribution and provides information on the model formulation and application. Part II-A is intended as a reference document for model analysts, users, and the public. Part II-A 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

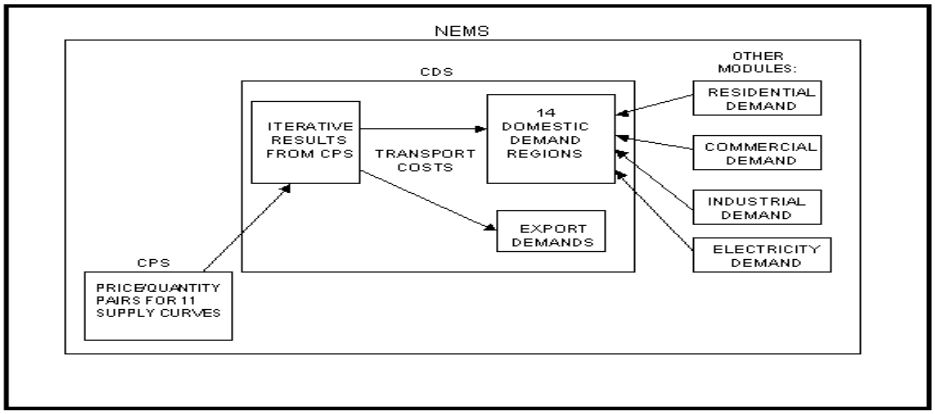
The domestic component of the CDS forecasts coal distribution from 11 U.S. coal supply regions to 14 domestic demand regions. The model consists of a linear program with constraints representing environmental, technical and service/reliability constraints on delivered coal price minimization by consumers. 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 6).

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 2004.*

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)

Figure 6. Model Summary



Part II-A Organization

This section describes the modeling approach used in the domestic portion of the Coal Distribution Submodule. Subsequent sections of this report describe:

- 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 (Chapter 2)
- The theoretical approach, assumptions, major constraints, and other key features (Chapter 3)
- 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 (Chapter 4).

Six appendices to the text of this section contain:

- A model abstract (Appendix A)
- A detailed mathematical description of the model (Appendix B)
- A listing of input data, variable and parameter definitions, model output, and their location in reports (Appendix C)
- A discussion of data quality and estimation for model inputs (Appendix D)
- A bibliography of technical references for the model structure and the economic systems modeled (Appendix E)
- A description of CDS program availability (Appendix F).

2. Model Purpose and Scope

Model Objectives

The purpose of the CDS is to provide annual forecasts (through 2025) 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), 11 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[22], 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

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

significant variation in the heat and sulfur content of coal. The geographic regionalization 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 2. When this typology is applied to coal reserves in the 11 supply regions, the 34 coal supply sources used in the *AEO2004* result.

Coal Supply and Demand Regions

Eleven 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 34 coal supply sources used for the *Annual Energy Outlook 2004* (Table 2). The seven supply regions west of the Mississippi River contain the remaining 12 coal sources. The apparent imbalance in regions and supply curves reflects longer distances between suppliers and consumers, and the absence of high sulfur steam and low sulfur metallurgical production in Western regions. In the East, fewer regions are needed to reflect transportation cost differences, but three of four regions produced metallurgical coal in 2002, four of the model's five high sulfur sources are in the East as are 11 of 14 underground mine sources. Production from each supply curve (and the associated heat, sulfur and ash content) as used in the *AEO2004* are shown in Table 3.

The 14 CMM domestic demand regions (Figure 7) represent the nine Census divisions, four of which have been divided to represent distinct sub-markets with special characteristics (Table 4). 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. These five "extra" regions also simplify the task of re-aggregating demands from the Census divisions into the North American Electricity Reliability Council (NERC) regions - a task performed in the NEMS Electricity Market Module.

Table 2. Supply Regions and Coal Types Used in the NEMS Coal Market Module

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

KEY TO COAL TYPE ABBREVIATIONS

SULFUR EMISSIONS CATEGORIES

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

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

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

MINE TYPES

"_D_" underground mining

"_S_ "surface mining

COAL GRADE OR RANK

"__P", Premium or metallurgical coal

"__B", Bituminous and anthracite steam coal

"__S", Subbituminous steam coal

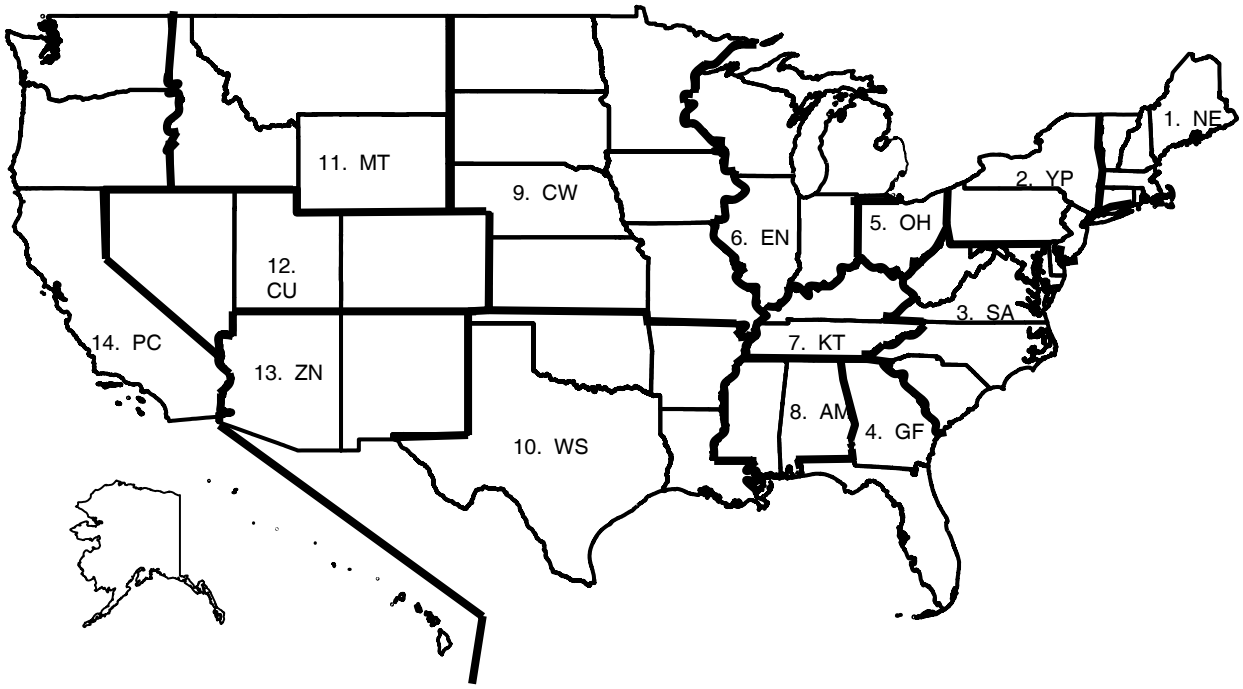
"__L", Lignite, bituminous gob or anthracite culm steam coal

Example: "MDP" = Medium sulfur, underground mined metallurgical (premium) coal.

Table 3. Average Coal Quality and Production by Supply region and Type, 2002

CMM Supply Region	Coal Type	Production (million tons)	Average MMBtu/Ton	Average lbs Sulfur/MMBtu	Sulfur % by Weight	Average Ash %
1. "**NA**"	MDP	2.8	27.43	0.77	1.06	6.14
(North Applachia = PA, OH, MD,	MDB/MSB	66.6	25.37	1.25	1.59	10.24
No. WV)	HDB/HSB	59.4	24.75	2.48	3.07	10.99
	HSL	11.1	12.31	1.88	1.16	38.32
2. "**CA**"	MDP	34.0	27.43	0.60	0.82	5.64
(Central Appalachia	CDB/CSB	63.9	25.26	0.54	0.68	10.06
= So. WV, VA, East KY, No. TN)	MDB/MSB	151.2	24.93	0.84	1.05	10.48
3. "**SA**"	CDP	4.6	27.43	0.48	0.66	7.54
(South Appalachia = AL, So. TN)	CDB/CSB	3.1	24.66	0.57	0.70	11.99
4. "**EI**" (East Interior =	MDB/MSB	11.4	24.53	1.06	1.30	11.23
IL, IN, West KY, MS)	MDB/MSB	33.0	22.68	1.13	1.28	8.16
	HDB/HSB	60.7	22.85	2.74	3.13	10.49
	MSL	2.3	11.26	0.98	0.55	16.55
5. "**WI**" (West Interior = KS, MO, AR, OK,						
TX, bituminous only)	HSB	1.9	23.58	2.28	2.69	15.14
6. "**GL**" (TX, LA, lignite only)	MSL	26.7	13.11	1.24	0.81	16.27
	HSL	22.3	13.08	2.07	1.35	14.72
7. "**DL**" (ND, MT, lignite only)	MSL	31.1	13.24	1.15	0.76	8.78
8. "**PG**" (Powder R., Green R.,	CDB	--	21.93	0.51	0.56	6.32
& Hanna Basins - WY, MT)	CSS	372.1	17.44	0.35	0.31	5.07
	MSS	38.2	17.57	0.76	0.67	7.72
9. "**RM**"	CDB	50.4	23.25	0.40	0.45	9.80
(Rocky Mtn. - CO, UT)	CSS	10.0	20.61	0.39	0.40	6.72
10. "**ZN**"	CSB	23.0	21.40	0.47	0.50	10.80
(Southwest - AZ, NM)	MSS	16.9	18.69	0.85	0.79	20.41
	MDB	1.8	19.52	0.72	0.70	22.64
11. "**AW**" (Northwest- WA, AK)	MSS	7.0	15.63	1.13	0.88	17.63

Figure 7. CMM – Domestic Coal Demand Regions



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

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

Table 4. CMM -- Domestic Coal Demand Regions

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

Coal Demand Sectors and Subsectors

In the CDS, domestic coal demands are further divided into six major sectors and 49 subsectors, part or all of which may be utilized in each demand region in each forecast year. The six major coal demand sectors are Electricity generation, Industrial Steam, Industrial Coking, Industrial Coal-to-liquids (CTL), Residential/Commercial, and Exports. Electricity generation includes generation from utilities, independent power producers, and combined heat and power facilities whose main purpose is the sale of electricity. The Industrial Steam sector includes other combined heat and power facilities as well as industrial consumers of steam from coal. The Industrial Coking sector includes metallurgical and by-product coke ovens. The CTL sector includes facilities where coal is converted to liquid petroleum products. This sector only becomes active in certain scenarios where oil prices rise to a level in which CTL becomes economically viable, for example, the *AEO2004* high world oil price scenario. 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.

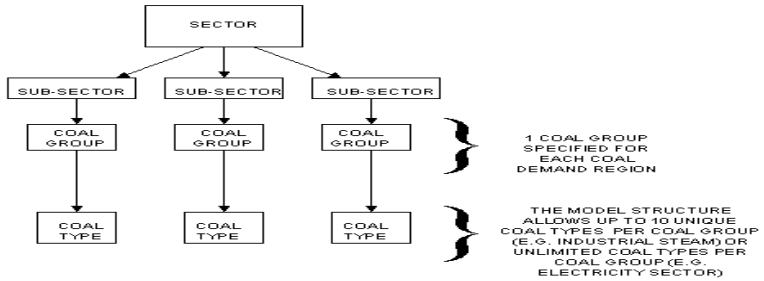
Coals of different types and quality, geographic availability, and prices tend to be associated with satisfying demands of particular sectors. These coals may not necessarily represent the least expensive option for a sector when factors such as quality or type are not considered, however. If minimization 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 2004* is shown in Table 5.

Table 5. Domestic CMM Demand Structure - Sectors and Subsectors

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

For all of the subsectors, a "coal group" is defined for each demand region. Each of these coal groups references a particular set of coal types. An example of a coal type is medium sulfur, surface-mined, bituminous coal from Northern Appalachia. Some of the coal groups allow unlimited choices of coal types while others are more restrictive and only allow a choice of two or three. For example, for the coking coal subsectors, only metallurgical grade coal is permitted. For *AEO2004*, the Electricity sector is allowed an unlimited choice of coal types using the coal structure methodology. (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", page 71.) A general schematic of the sectoral structure present in the coal model is displayed in Figure 8.

Figure 8. 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 6 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. Many of the configurations listed in Table 6, however, are not active in a typical reference run of the model. Many are only relevant in a scenario where mercury emissions are constrained and emission control technology upgrades are required.

Table 6. Electricity Subsectors

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

SC = Supplemental Cooling

FF = Fabric filter

NA = Not Applicable

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. Also, the specific types of coal available to the CTL market are predicated on the assumed geographic location of the CTL facilities rather than the unique technical characteristics of the plants themselves. The CTL modeling has been simplified by only allowing certain representative coals to be used in these facilities. 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. Coal groups then specify which coal types may be used to satisfy the demand.

The four subsectors used for export coals are established in much the same way as the industrial sectors. American 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 a major world source in the declining market for 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.

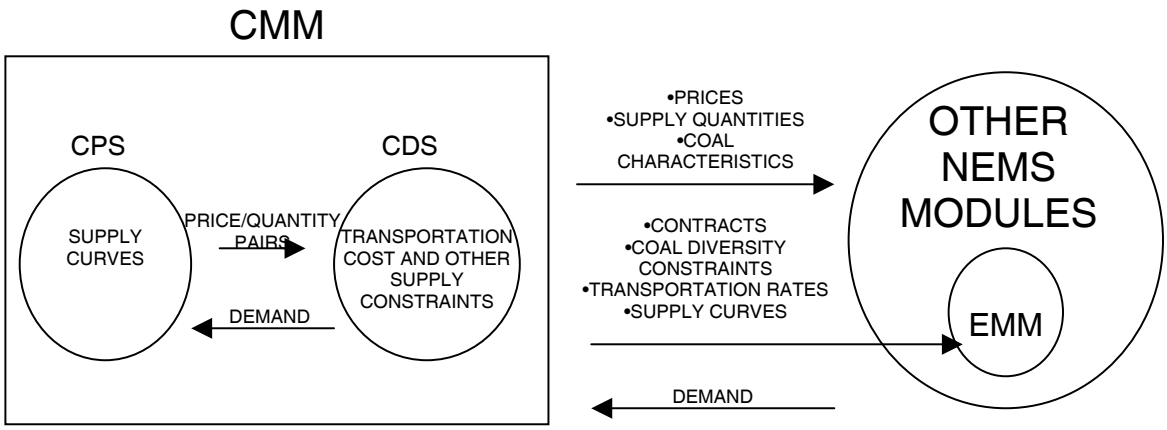
Relationship to Other NEMS Modules

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 8). Within the Coal Market Module (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 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.

For *AEO2004*, the relationship between the CMM and the Electricity Market Module (EMM) has become even more interdependent. Both models 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 increase in detail shared between the two models stems from a goal of improving overall NEMS convergence and convergence speed.

Figure 9. General Relationship to Other NEMS Modules



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 received 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 Coal-to-liquids (CTL) sector represents a potential technology which might become economic when low-sulfur distillate prices are high. Demands for CTL are specified by the Petroleum Market Module's (PMM) five demand regions. The relationship between the PMM demand regions and the CMM demand regions is shown below in Table 7. The modeling of CTL is simplified by only allowing certain coal demand regions to participate in the CTL sector.

Table 7. PMM Demand Region Composition for the CTL sector

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

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 and coal contracts for the electricity sector (both discussed in Chapter 3), a parameters file 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 contains the parameters that are used to define "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.

The supply of coal imports to the United States for each forecast year is prepared as an input file. Coal imports are not priced due to the substantial and varying uncertainties associated with import dependence (the magnitude of which is usually seen as varying significantly with the particular national import source). This exogenous import forecast is specified by economic sector and subtracted from sectoral demand totals in each relevant domestic demand region prior to the operation of the CDS's linear program.

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.[23].

For the coal-to-liquid demands, the CDS also sends delivered prices and volumes by PMM region to the Petroleum Market Module. It also provides the PMM with price, quantity, and elasticities enabling the PMM to derive its own 3-step coal supply curves. These curves are used to estimate delivered coal prices and determine the economic feasibility of constructing a coal-to-liquids facility. 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 25-year 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.

[23] 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.

3. 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 2002. 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 34 coal supply sources.

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 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 sulfur dioxide limits established by the Clean Air Act Amendments of 1990 (CAAA90) and more recently potential mercury emissions limits being considered by Congress. 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 the 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, the SO_2 allowance price, and the mercury allowance price. Hence, any sort of 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 or "compliance", medium, and high. The compliance sulfur grade corresponds to the limitation on sulfur dioxide emissions that electric utilities are required to meet in accordance with Phase II of the Clean Air Act Amendments of 1990, which is now in effect. Phase II imposes a permanent annual cap on SO_2 emissions of 8.95 million tons of SO_2 for all existing generating units with an output capacity of greater than 25 megawatts as well as new generating units. This translates to approximately 1.2 pounds of SO_2 per million Btu of heat input.

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.

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. 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 SO_2 allowance price projections.

In the case of mercury, activated carbon injection (ACI) during the coal combustion process may be used on an incremental basis to achieve various levels of Hg emission reductions. 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 sectors, 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. However, the published NEMS SO_2 emissions from coal are derived from the CMM.

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. 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 SO_2 scrubber retrofit decisions and in the case of mercury, other technology investment 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 contain 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 *AEO2004*, 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.[24] 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.[25] 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.[26]

Coal distribution modeling mandates recognition that coal transportation rates only approach marginal costs of service in the presence of intermodal competition. Further, the difference

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

[25] 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.

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

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 either costs or 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. These rates also reflect the assumption that CTL facilities will be built near sources of supply. 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 34 supply curves. In principle, there are thus 14*34*49=23,324 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 is connected to the lower 48 States only by water, air and unpaved road. While Alaska has a coal dock used to export coal, the State contains no facilities for unloading coal from ship to shore. 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. Here not all 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 fouling/slagging, derates, and other production problems that are not currently accounted for in the electricity model. The net effect of this transportation rate is to add roughly $0.10 per million Btu (2000 dollars) to the transportation rate for incremental volumes of subbituminous coal.[27]

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

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.

Recent Developments in Coal Markets

While the coal mining industry has become more concentrated in recent years, by the standards applied in industrial economics, coal production is not a highly concentrated industry. The largest coal producer accounted for 13.7 percent of national production in 2002, and five were required to produce 46 percent of the national total.[28]Coal mining has low barriers to entry and substantial barriers to exit. Brief periods of high prices bring rapid expansion of mining capacity; long periods of stable and declining prices yield excess capacity and fierce competition during which mines continue to produce, so long as price exceeds variable cost and some contribution to fixed costs can be made. Mining costs, even in well known coal fields, vary acre by acre.[29]Coal

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[28] Energy Information Administration, *Annual Coal Report 2002,* DOE/EIA-0584 (2002), January 2002, Table 10, p. 21, http://www.eia.doe.gov/cneaf/coal/page/acr/acr.pdf.

[29] Illinois State Geological Survey and the U.S. Department of the Interior, U.S. Bureau of Mines, *Engineering Study of Structural Geologic Features of The Herrin (No. 6) Coal and Associated Rock in Illinois, Volume 2, Detailed Report, NTIS PB-219462* (Washington, DC, June 1979).

producers have only incomplete knowledge of even their own future mining costs.[30] Mining firms thus face both geological and market uncertainties.

Coal prices declined in real dollars for over 25 years. However, for two years in a row, 2001 and 2002, free-on-board mine prices increased over the previous year. 2001 coal prices were 2 percent higher than 2000 and 2002 coal prices were 1 percent higher than 2001 (2002 dollars). These two-year price increases were accompanied by declines in productivity. While productivity was 6.99 short tons per hour in 2000, in 2001, productivity fell to 6.82 and then to 6.80 in 2002. These differences from the historical trend indicate that we may see productivity improve at a slower pace than historical levels as geological and regulatory difficulties are encountered. This could have some positive impact on prices.

On the other hand, the unpredictable pace of both financial deregulation and increasingly stringent environmental restrictions on coal combustion have encouraged electricity generators to pass on financial uncertainties to coal producers. Coal consumers have become much less willing to sign long-term coal contracts with mining firms than they were even several years ago. Producers, in turn, find themselves surmounted by twin layers of market power - in recent years, the nation's railroads have consolidated so that most mines have access to only a single railroad by which their coal must be delivered, and transportation costs often result in many mines competing for the business of a small and stable group of coal-fired power plants. Individual mining firms do not have the market power to pass on revenue reductions to their suppliers (the most widely used fuel for mining equipment is electricity - in many cases necessarily purchased from the same generator to which the mine sells its coal).

Coal producers have adopted three strategies to reduce these uncertainties. First, in order to preserve profit margins in an era of falling prices, they are moving to ever-larger scale mines with larger and more efficient machinery. These changes have caused the average mine size to increase from 142 to 767 thousand tons per year between 1978 and 2002. Labor productivity, measured in tons per miner-hour, has increased at an average rate of 5.77 percent per year over the same period (from 1.77 to 6.80 tons per miner-hour). As a result of these changes the number of miners has fallen from 246,000 to 75,500 and the number of mines producing more than 10,000 tons per year has fallen from 4703 to 1196 while production has increased from 670 to 1094 million tons per year between 1978 and 2002.

The second strategy has been a concurrent reduction in the number of operating companies through mergers and purchases. As an industry that was once dominated by hundreds of small family-owned firms implodes into one dominated by a half-dozen national scaled entities, more effective management by budgetary professionals using computer based systems has reduced overhead costs associated with mine management, permitting, sales and reserve development.

The third strategy of survival is to use over-the-counter trading of coal and electricity for future delivery to provide improved price stability over periods of a month to a year. These "coal tolling" agreements function in much the same way as short-term contracts, and have proven beneficial to both mining and electricity generating concerns.[31] NYMEX has initiated trading in coal futures contracts; it is not yet clear what effect this will ultimately have on coal markets.

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[30] Richard Gordon, *Coal Industry Problems, Final Report, EA 1746, Project 1009-4*, Pennsylvania State University, prepared for the Electric Power Research Institute (Palo Alto, CA, June, 1979), pp. 2-43, 2-44.

[31] Energy Information Administration, *Challenges of Electric Power Industry Restructuring for Fuel Suppliers,* DOE/EIA-0623, September 1998, pp.5-23.

Comparison of the CDS to Other Coal Distribution Models

Stimulated by increased interest in energy supply and distribution costs associated with events subsequent to the Arab oil embargo of September 1973, rapid development of new modeling techniques took place. The models most relevant to development of the NEMS CDS are programming and spatial equilibrium models developed on the foundation of James Henderson's study of coal industry efficiency.[32]

These models include regionalized linear programming models that differentiate coal products by mining method (surface versus underground) and by distinguishing multiple levels of Btu and sulfur content. Coal blending at the demand point was incorporated.[33]Quadratic programming models based on the work of Takayama and Judge developed more sophisticated objective functions, incorporating maximization of producers' and consumers' surpluses.[34]This methodology was applied to the spatial distribution of Appalachian coal.[35]

Recursive programming models were adapted to model decisions over time in which subsequent solutions depended on the results of earlier executions. Feedback equations were employed to simulate constrained optimization including adaptation to current conditions. This approach is well suited to modeling decisions under "adaptive price expectations" where the feedback may come from preliminary executions for time period 2 and affect final decisions in time period 1. Of course, such a methodology imposes execution time penalties that are of concern in a large, integrated system such as NEMS. An early application was used to explain the historical adoption of improved mining technologies and their effects on the coal mining industry.[36]Programming models have been adapted to simulation of markets characterized by imperfect competition. An early and representative example is the work performed on the Project Independence Evaluation System (PIES) at EIA to model regulated gas prices and tariff adjustments/oil entitlements.[37]

The development of large scale integrated modeling systems such as the PIES, the Midterm Energy Forecasting System (MEFS), IFFS, and NEMS has meant that the sharp edges of individual modeling approaches are blurred by the characteristics of the integrated system. System sub-models act both as components of the integrated modeling system and as stand-alone

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32 James M. Henderson, *The Efficiency of The Coal Industry, An Application of Linear Programming* (Cambridge, MA: Harvard University Press, 1958).

33 Libbin, J.J. and X.X. Boehle, "Programming Model of East-West Coal Shipments," *American Journal of Agricultural Economics*, Vol. 27, 1977

34 Takayama, T., and G. Judge, *Spatial and Temporal Price and Allocation Models* (Amsterdam: North-Holland, 1971).

35 Labys, W.C. and Yang, C.W., "A Quadratic Programming Model of The Appalachian Steam Coal Market," *Energy Economics*, Vol. 2, pp. 86-95.

36 Day, R.H. and W.K. Tabb, 1972, *A Dynamic Microeconomic Model of The U.S. Coal Mining Industry*, SSRI Research Paper (Madison, WI: University of Wisconsin, 1972).

37 Murphy, F.H., *The Structure and Solution of The Project Independence Evaluation System*, Energy Information Administration (Washington, DC, 1980); Murphy, F.H., R.C. Sanders, S.H. Shaw and R.L. Thrasher, "Modeling Natural Gas Regulatory Proposals Using the Project Independence Evaluation System," *Operations Research*, Vol. 29, pp. 876-902.

models that must be quickly adaptable to analyses of, for example, the impacts of proposed legislation at the State or sub-State region level. Modeling systems with central integrating models allow the freedom to join econometric demand components with structural/engineering supply components. All the above systems have been the responsibility of EIA and/or its predecessor agencies. The EIA integrated systems are paralleled by similar systems in other environments, such as the Hudson-Jorgenson system and the Brookhaven Integrated Energy/Economy Modeling System.[38,39]

PIES consisted of a linear programming integrating model that computed an equilibrium solution for demands generated by an econometric demand model with supplies generated by a programming model. Equilibrium output from the integrating model was input to a macroeconomic model, an environmental impact model, and an international model.[40]

Most models of coal supply and distribution fall into two categories. The first is a series of models largely developed by ICF, Inc., for EIA, but also marketed to other clients. The EIA representative of this "family" of models is the National Coal Model (NCM), which has had various capabilities in its two decades of existence. The other coal supply model "family" of the 1970's was designed by Martin Zimmermann and subsequently incorporated into the DRI, Inc., modeling system as the central analytical tool of the DRI Coal Service. Both the NCM and DRI models are linear programming models that treat coal transportation costs as an interregionally specific markup over minemouth costs.

Both the DRI model and the NCM can operate independently (with exogenously supplied demands) or as part of an integrated system. The NCM contains a capacity planning and dispatch submodel that receives electricity demand, and allocates this demand among coal, oil, gas, and nuclear generation capacity according to relative cost. The NCM disaggregates coal demand, using technical and sectoral environmental constraints, testing the economic efficiency of low-sulfur coals against high-sulfur coals that require scrubbing.[41]

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[38] Hudson, E.A. and D.W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975-2000," *Bell Journal of Economics and Management Science*, Vol. 5, pp. 461-514.

[39] Groncki, P.J. and W. Marcuse, "The Brookhaven Integrated Energy/Economy Modeling System and Its Use in Conservation Policy Analysis," *Energy Modeling Studies and Conservation*, ECE, ed., prepared for the United Nations, (NY: Pergamon Press, 1980), pp. 535-556.

[40] Energy Information Administration, *Documentation of the Project Independence Evaluation System* (Washington, DC, 1979).

[41] Description of the NCM is taken from: ICF, Inc, The National Coal Model: Description and Documentation, Final Report (Washington, DC, October 1976; Energy Information Administration, Mathematical Structure and Computer Implementation of The National Coal Model, DOE/EI/10128-2 (Washington, DC, January 1982); Energy Information Administration, National Coal Model (NCM), Users Manual (Washington, DC, January 1982). Description of the Zimmermann-DRI model is taken from: Zimmermann, M.B., "Modeling Depletion in a Mineral Industry: The Case of Coal," Bell Journal of Economics, Vol. 8, No. 4 (Spring, 1977), pp. 41-65; Zimmermann, M.B., "Estimating a Policy Model of U.S. Coal Supply," Advances in the Economics of Energy and Resources, Vol. 2. (New York: JAI Press, 1979), pp. 59-92; Pennsylvania State University, "Zimmermann Coal Model," Economic Analysis of Coal Supply: An Assessment of Existing Studies, Volume 3, Final Report, EPRI EA-496, Project 335-3 (Palo Alto, CA: the Electric Power Research Institute, June 1979); Data Resources, Inc., Coal Service Documentation (Lexington, MA, March 1981).

The DRI and NCM models can be contrasted in several regards. First the NCM, in all its versions, has had a more detailed classification scheme. The NCM has had from 40 to 60 coal types; the DRI-Zimmermann model has 36. Both models' supply curves are in the form of step functions, but the NCM has over 400 while the DRI-Zimmermann model has 35. The NCM has 31 supply regions while the DRI-Zimmermann model has 6. The NCM has 44 demand regions while the DRI-Zimmermann model has, in various versions, either 13 or 18. Interregional supply-demand links in the NCM total about 1,000, while different versions of the DRI-Zimmermann model have either 78 or 108. A version of the NCM, as modified for recent use by the U.S. Environmental Protection Agency, contains hundreds of demand and supply centroids, and over 2,000 interregional coal shipment routes.[42] Each of these routes is represented by a detailed description of the carriers, link mileages, locomotive horsepower, and other cost related factors. These, in turn allow detailed engineering cost estimates for each route. Such an accounting model approach to coal transportation allows very precise estimates of costs, but as discussed above, coal transportation rates may not be determined by costs. Thus, in spite of the extreme detail input to this model, it may underestimate delivered coal costs.

As linear programming models were adapted to model coal distribution, it became increasingly apparent that available data on such costs, when combined with accurate minemouth costs, did not necessarily produce recognizable coal distribution patterns. A logical strategy in resolving this dilemma was to increase the number of supply and demand regions to allow the model to capture idiosyncratic rail rates to localized regions. This method achieved a measure of success; at least in capturing historical patterns, as the number of demand regions began to approach the number of coal using electric power utilities (approximately 200). At this level of detail it is possible to synthesize reasonably plausible rates that accurately portray past coal distribution. Even at this level of detail, the rate differences between routes with neighboring origins and destinations may be quite large, and due to the lack of coal transportation cost data for many regions, such a rate system is difficult to document other than through reliance on "analytical judgment." Maintaining a system of rates involving routes between up to 100 supply regions and 200 demand regions has an impact on scenario turnaround time. Models containing this level of detail are simply too cumbersome for a system like NEMS.

Another primary difference between the NCM and the DRI models is in the treatment of resource depletion. In both models, minemouth costs are developed by supply curves relating annualized production of recoverable reserves to mining costs that rise with progressive depletion. Each has its own approach to estimation of supply curves. The NCM is empirical, using curves developed by the RAMC from the Demonstrated Reserve Base, the Coal Analysis Files, and mine costing models. For the DRI-Zimmermann model, the supply curves were originally developed from the assumption that coal reserves were log-normally distributed by seam thickness and/or overburden ratio, the two primary determinants of reserve-related mining costs in both models. The hypothesis of log normal reserve distribution by seam thickness has never been proved, and there is evidence that it is descriptively incorrect.

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42 ICF Resources, Inc., *Documentation of the ICF Coal and Electric Utilities Model: Coal Transportation Network used in the 1987 EPA Interim Base Case*, the U.S. Environmental Protection Agency (Washington, DC, September 1989).

Freight Network Equilibrium Models

The central concept of the freight network equilibrium model is a straightforward application of the shortest path algorithm in a network model as developed in introductory management science and operations research texts.[43] The early 1980's saw rapid development and application of the technique in response to contemporary concern that the national rail network might not be able to transport expected coal tonnages at reasonable costs. As subsequent events have shown, railroads have provided the required capacity while reducing real dollar average transportation costs per ton-mile.[44]

The distinguishing feature of freight network models is a network composed of connecting links, each independently costed. These models develop route transportation costs by finding the optimal path through the network for each origin/destination pair. Since links have independent cost functions, networks can represent multimodal routes with loading, transloading, and unloading options. Optimal routes can be defined as those with the lowest costs, or as those generating maximum revenues. Link costing functions can range from flat fees through volume-sensitive capacity utilization functions to complete engineering cost models, depending on the functions of the model in question.

Very large networks may be used to describe mode-specific transportation capacities for the entire United States. Applications to coal supply modeling generally use simplified networks of up to a few thousand links. The time required to execute a freight network model increases rapidly as a function of network size and complexity. Since the network links connect actual places, they represent actual distances and freight capacities in geographic space, and have the computational properties associated with true geographic scale. In such networks, rates may be constructed by multiplying the sum of a "base rate" and a volume sensitive capacity utilization function by function of link distance. The source of such base rates may be the error term in a linear regression predicting rates from distance.

Freight network models often contain an equilibrium algorithm, which is required by the use of volume-sensitive capacity utilization functions to price transportation across links. Since the solution begins with estimated volumes, flows through the network will not reach equilibrium unless actual flows equal estimated flows. Since freight prices vary with volume shipped, estimated and actual flows are unlikely to be equal. Successive iterations may not converge to an equilibrium assignment of volumes on different routes. Heuristic algorithms were adopted to shift small percentages of route volume toward more optimal routes until equilibrium is attained. The combination of exact shortest path and heuristic equilibrium assignment algorithms provides a powerful method of processing very large quantities of transportation detail. Given a sufficiently detailed method of estimating link-specific costs, such models can provide accurate estimates of the route specific variable costs incurred by coal carriers.[45] Freight network models have been widely used to study regional rate responses to increasing system capacity utilization.

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[43] See, for example, Wagner, Harvey M., "Network Models," Chapter 6 in *Principles of Management Science with Applications to Executive Decisions* (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1970).

[44] United States General Accounting Office, *Railroad Regulation, Economic and Financial Impacts of the Staggers Rail Act of 1980, GAO/RCED-90-80* (Washington, DC, May 1990).

[45] Vyas, A.D., "Overview of Coal Movement and Review of Transportation Methodologies," *Proceedings of Coal Transportation Costing and Modeling Seminar, October 15, 1984* (Kansas City, MO: Argonne National Laboratory, July 1985), p. 7.

The ability to model transportation costs at a link-specific level of detail does not come without drawbacks, however. Freight network models depend heavily on detailed input describing freight flows, rates, and exact routes.[46] Coal distribution networks have been developed with from 269 to over 18,000 links; the bigger the network, the more difficult and expensive it is to maintain, and the greater the model's execution time requirements. In smaller networks, scale problems such as the "centroid problem" inevitably emerge. This problem emerges as the number of origins and destinations decreases, and the accuracy and stability of interregional tonnage-weighted distances diminishes. If a node is not the true tonnage-weighted center of the region it represents, the use of actual ton-mile rates will produce inaccurate route prices. True centroids constantly shift in a freight network, just as the population center of the United States has been hopping in a southwesterly direction across the midwestern United States after each decennial Census in this century. This means that simple networks require painstaking annual adjustments if reasonable rates are to be maintained. In the real world, an individual link may have widely different ton-mile rates as a component of different contractual movements priced at "what the market will bear." Simplified networks also reduce the ability to model competition on parallel routes between the same origin and destination.

A strength of freight network models is their ability to provide detail about comparative route geography and link-specific economics. However, this detail has few applications in national energy policy analyses as addressed by the NEMS. It *is* useful to be able to model coal transportation competition on a carrier/route basis. The current depiction of transportation consists of rates determined by subtracting average minemouth costs generated in the CDS from historical delivered costs as collected on Forms EIA-3, -5, -423 and FERC Form 423. Thus the model remains compact and speedy, and the rates generated are based on the only set of available data providing universal coverage of recent historical coal transportation rates.

Summary of the CDS versus Other Coal Distribution Models

Coal distribution models have evolved as approaches to solving fundamental problems encountered as attempts have been made to apply the models to a broader and broader array of topics associated with the coal supply and distribution industries. These models have faced the challenge of successfully addressing a growing range of purposes, while under pressure to remain compact, transparent, easy to maintain, and quick to execute. As discussed above, these problems can be summarized:

- The year-by-year variations in coal distribution, in the short-term, and at the required level of regional and sectoral detail is difficult to model based only on the delivered cost of coal. In the long run, historic distribution trends can be represented. It has been argued that this is due to the short- and mid-term price elasticity of demand for coal, and the concurrent existence of localized market power in the coal transportation industry. The primary descriptor of coal markets' adaptation to such market power is long-term coal supply and transportation contracts.

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[46] Vyas, A.D., "Overview of Coal Movement and Review of Transportation Methodologies," p. 7.

- Historically, coal distribution models have attempted to resolve this problem by including greater and greater levels of regional and sectoral detail, accompanied by highly detailed attempts to portray coal transportation rates. Such models contain detail beyond that appropriate for a NEMS component and, often, past the point where the transportation rate structure can be shown to have an explicitly factual basis.

- Technical limitations on the operation of different end-use technologies with sub-optimal coals constrain attempts to minimize delivered prices. Unfortunately, the available documentation of such issues focuses on engineering issues rather than cost impacts, and so can only be incorporated into models in a general way. Again, precise modeling of such constraints would both require data that are not available and a level of detail in modeling that is inappropriate for the NEMS. Most coal distribution models, including NEMS, use a simplified coal typology. Perhaps for this reason, explicit recognition of these constraints is rare in the coal modeling literature, although common in the combustion engineering literature.

The CDS has been constructed to reconcile the need for speed and simplicity with the need for adaptability. Deregulation of electricity generation has reduced the need to employ detailed constraints on cost minimizing solutions provided by the model's linear programming algorithm. Depiction of the chemical and physical heterogeneity of coal is restricted to the use of sulfur levels reflecting regulatory constraints and coal rank levels that impact boiler performance and long distance transportation costs. The treatment of domestic coal transportation in the CDS is simple, using transport rates that are inferred from annual surveys of minemouth and sectoral delivered prices.

4. 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".[47] The functions of subroutine "CDS" are shown in Figure 10, 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, "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 for each forecast year. Using these reports it is possible to determine exactly what demands the CDS has solved for in a given forecast

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

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".

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

- "CPSHR" writes nonelectric 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, and this order is shown in Figure 10. Subroutine "CREMTX" also calls other subroutines: "RDCDSIN," "RDCEXIN," "RCMMDB,""COALDEFS," and "WRCINDB" (Figure 11):

- "RDCDSIN" reads exogenous input arrays containing calibration factors for the CDS, and calls "CMAPSR," "CDSINT," and "CBFOUT."

- "RDCEXIN" reads exogenous input arrays containing calibration factors for the international portion of the CDS. These inputs are described in Part II-B - Coal Distribution Submodule -International Component, Table D-1.

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 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 C.

- "CLCONT" contains data defining electricity coal distributions that are assigned to constrain the selection of coal sources by the CDS solution algorithm. For *AEO2004*, 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 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 10 and 11. "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 10. Calling Order for CDS Subroutines - Overview

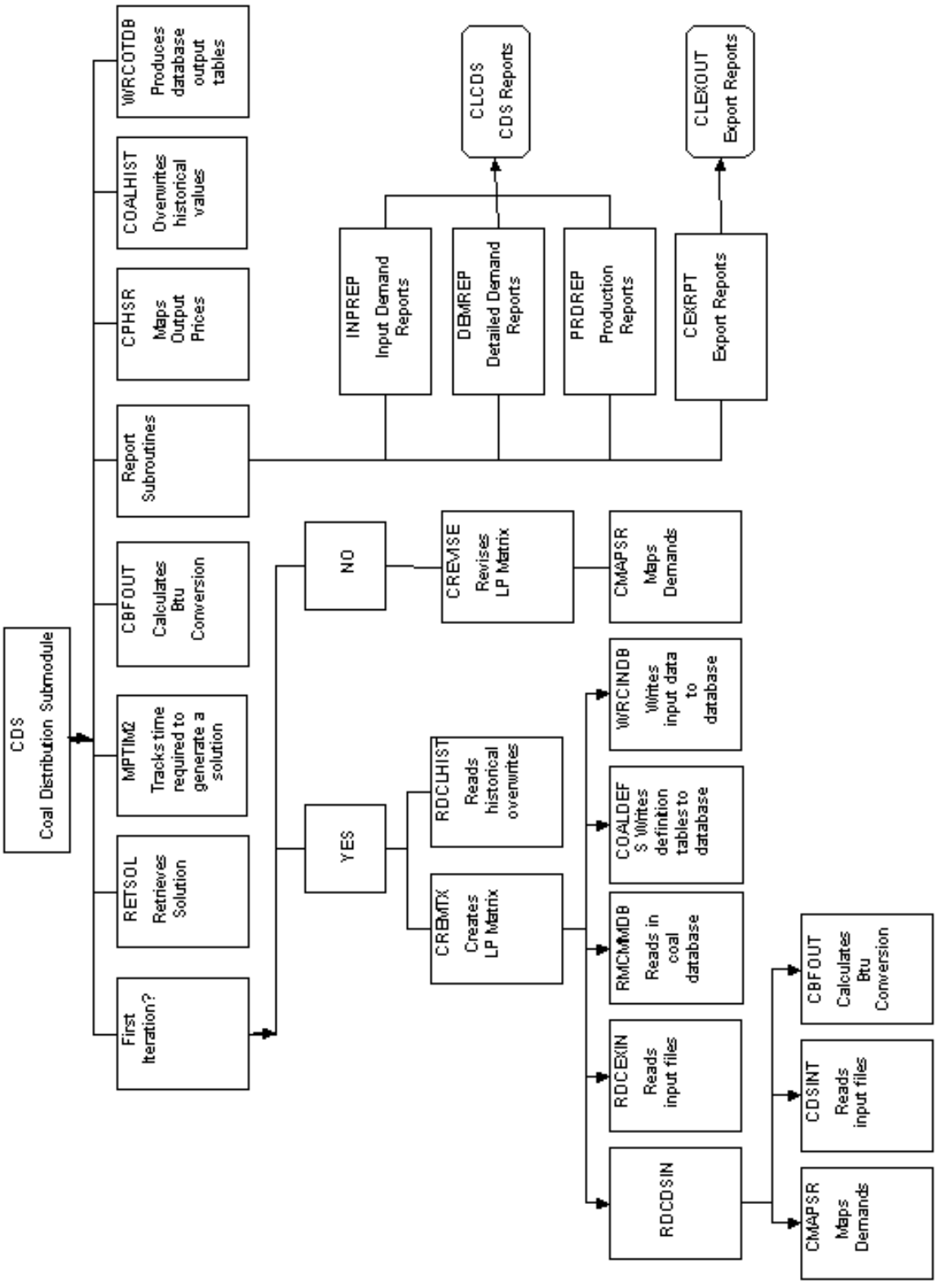
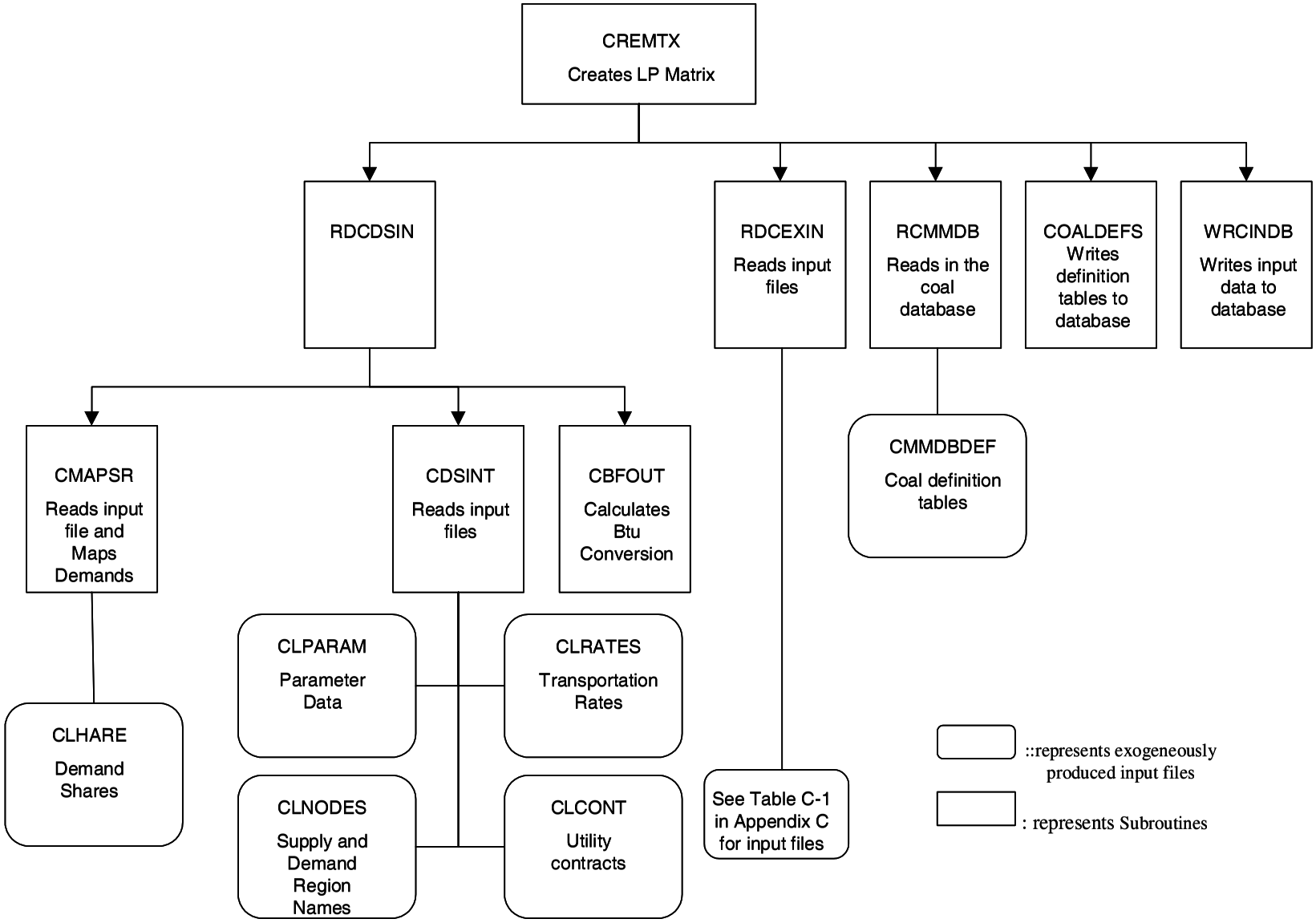


Figure 11. Functions of Subroutine – "CREMTX"



Key Computations and Equations

The CDS uses a linear programming (LP) formulation to find minimum cost coal supplies to meet domestic sectoral coal demands received from the Electricity Market Module, the Residential, Commercial and Industrial Demand Modules and international demands as determined in the international 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 other submodules of the CMM 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 C describes model inputs, parameter estimates and model output. Appendix 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. The model relies on Optimization and Modeling (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 F of Part II-B 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 34 supply curves. During the forecast period, these rates are escalated or de-escalated to reflect projected changes in input factor costs for transportation by several parameters read from "CREVISE". The escalators used to adjust transportation rates year-by-year are generated endogenously using a regression model[48].

The escalator in *AEO2003*, as discussed in Jim Watkin's article, "Forecasting Annual Energy Outlook Coal Transportation Rates," was based on a regression where the independent variables included trend (a proxy for productivity), rail wage, the price of diesel fuel to the industrial sector, and the producer price index (PPI) for transportation equipment. For *AEO2004*, the methodology has been modified by substituting the user cost of capital for transportation equipment for the PPI for transportation equipment. The user cost of capital is intended to capture the true cost of purchasing transportation equipment. Unlike the PPI, the user cost of capital accounts for the opportunity cost of the moneys 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. In addition, average rail wages for the

[48] Watkins, Jim, "Forecasting **Annual Energy Outlook** Coal Transportation Rates,"*Issues in Midterm Analysis and Forecasting 1997,* DOE/EIA-0607(97), (Washington, DC, Energy Information Administration), July 1997, pp. 75-82.

forecasted values is used in place of a national wage rate. For the *AEO2004*, an exogeneous forecast of average rail wage is based on a simple linear trend of historical rail wages.

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).

A two tier transportation rate structure has been implemented for those regions which, in response to rising demands or changes in demands, may expand their market share beyond historical levels. This change is intended to capture an increase in shipping distances within large demand regions that would be necessary to meet these levels of demand. In addition, this change can capture costs associated with the use of subbituminous coal at units which are not originally designed for its use. This two tier transportation rate structure is used only for select transportation routes satisfying electricity demand.

For the case of increased shipping distances, the second step 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.[49] 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.

[49] $0.10/mmBtu, the estimated cost of switching to subbituminous coal, was derived by Energy Ventures Analysis, Inc., and recommended for use in the CMM as part of an Independent Expert Review of the *Annual Energy Outlook 2002*'s Powder River Basin production and transportation rates.

Appendix 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:** December 2003

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:

- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System,* Part II-A, DOE/EIA-M060(2003) (Washington, DC, April 2004).

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

Archive Media and Installation Manual: NEMS04 - *Annual Energy Outlook 2004.*

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 2025

- **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 34 supply sources) depicting coal reserve base are exogenous to CDS and are reported in the CDS from 11 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 treated as a static input that is subtracted from demand before solving the CDS. Imports are reported to NEMS and detailed in some single-year reports.

- 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 34 coal supply sources representing 12 types of coal produced in 11 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 23,324 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 36 consecutive years (1990-2025) may be run in an iterative fashion. Currently the NEMS system provides demand input for the 1990-2025 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 eachforecast 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) based on estimates of factor input costs (labor, fuel, etc.); (3) 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 AEO2004):* (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

— **Ecological:** none

- **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"
— Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"—FERC Form 580, "Interrogatory on Fuel and Energy Purchase Practices"
— U.S. Department of Commerce, Form EM-545
— U.S. Department of Commerce, Form IM-145
— Association of American Railroads, *AAR Railroad Cost Indices* (Washington, DC, quarterly)
— Rand McNally and Co., *Handy Railroad Atlas of The United States* (Chicago, IL, 1988)
— Caplan, Abby, et al, eds., *1996-1997 Fieldston Coal Transportation Manual* (Washington, DC, 1996)

- **Output Data:**

— **Physical:** Forecasts of annual coal supply tonnages (and trillion Btu) by economic sector and subsector, coal supply region, coal Btu and sulfur 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 transporation 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 September 2003.

References: Previous documentation editions are listed with the component design report above, on the first and second pages of this model abstract.

Appendix 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 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 sulfur dioxide and other emissions for certain scenarios (i.e. mercury and carbon) 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 Part II-A, Chapter 3, on Model Rationale and variable definitions that are described in Appendix C. The general structure of the LP matrix is shown as a block diagram in Table 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.[50]The activated carbon features are only used in scenarios where the effects of emissions limits on mercury are of interest and are not used in the reference case of the *Annual Energy Outlook 2004*. 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" on page 98. 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.

[50] This part of the matrix was not used in the *AEO2004* reference or side cases. This structure has been used in service reports requested by Congress in which the potential effects of a mercury cap were analyzed.

The CDS matrix currently contains about 3,500 rows (equations) and 5,500 column variables (activities). The block diagram in Table 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 Part II-B of this document.

Table B-1

CDS Linear Program Structure

Coal Distribution Submodule Block Diagram

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

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

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:

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

where the indexes are defined as:

Index Definitions

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

where the columns are defined as:

Column Definitions

Column Notation		Description
$Qp_{i,r,s,t,u,}$	=	Quantity of coal from step s of the coal supply curve produced from coal supply region i, of sulfur level u, mine type t, and rank r. Corresponds to Block Diagram Column: P(SR)(U)(M)(S).
$Qt_{i,j,p,r,t,u,v}$	=	Total quantity of coal transported from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for

		the electricity plant type p, and activated carbon step v (if relevant to scenario). Corresponds to Block Diagram Columns: 1(SR)(U)(M)(R)(DR)(PT)(C) and (ACSTEP)(SR)(U)(M)(R)(DR)(PT)(C)
$Q2t_{i,j,k,r,t,u}$	=	Total quantity of coal transported from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for the demand subsector k for the non-electricity sectors **or** Total quantity of coal transported at 2nd tier transportation rate from all steps of coal supply region i to coal demand region j, of sulfur level u, rank r, and mine type t, for the demand subsector k for the electricity sector Corresponds to Block Diagram Columns: T(SR)(U)(M)(R)(DR)(PT)(C)
A_v	=	Total quantity of activated carbon from activated carbon supply curve step v. Corresponds to Block Diagram Column: ACIXSS(ACSTEP)Y
H	=	Quantity of mercury getting mercury cap price (only relevant for specific mercury scenarios) Corresponds to Block Diagram Column: MERCEV
C	=	Quanity 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 feasibile. By assisting in maintaining feasibility in early model runs, the linear supply curves can be moved along the supply functions in search of an optimal, minimum cost solution that is feasible without the escape vectors

Row Constraints

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

SUPPLY BALANCE

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

DEMAND BALANCE
EQUATIONS: For specific j and k: $\Sigma_{i,r,t,u,v} Qt_{i,j,k,r,t,u,v} = D_{j,k}$ (B-3)
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: $\Sigma_{p,v,w,} Qt_{i,j,p,r,t,u,v,w}$ – escape vector quantity > = $B_{i,j,r,t,u,w}$, (B-4)
where "B" equals contract quantity and "w" indicates whether plant type p is scrubbed or unscrubbed.
DEFINITION: Require minimum quantities of coal, "B", of a specific coal quality from particular supply regions to satisfy electricity contracts from particular demand regions for scrubbed and unscrubbed plants.
CORRESPONDING ROWS IN BLOCK DIAGRAM: F(SR)(DR)X(C) and C(SR)(DR)X(C)

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

$$\Sigma_{i,t,u,} Qt_{i,j,p,r,t,u,} < = B_{j,p,r} \quad \text{(B-5)}$$

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: $Qt_{i,j,p,r,t,u} - Qt2_{i,j,p,r,t,u} < = T$ (B-6)
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: $\Sigma_{i,j,p,r,t,u} [s_{i,r,t,u} * Qt_{i,j,p,r,t,u}] < = S$ (B-7)
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 content of the coal and "S" equals the emissions limit.
CORRESPONDING ROW IN BLOCK DIAGRAM: SULFPEN

MERCURY EMISSION RESTRICTIONS
EQUATIONS: $\Sigma_{i,j,k,r,t,u} [m_{i,r,t,u} * Qt_{i,j,k,r,t,u}]$ – H – escape vector quantity < = M (B-8)
DEFINITION: For mercury studies only, 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: $\Sigma_{i,j,p,r,t,u,v} [a_{p,v} * Qt_{i,j,p,r,t,u,v}] - 10 * A_v <= 0$ (B-9)
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: ACIXXXY

CARBON TAX
EQUATIONS: $\Sigma_{i,r,t,u} [c_{i,r,t,u} * Qt_{i,j,p,r,t,u}] - C <= 0$ (B-10)
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

The Coal Export Submodule constraints are set forth separately in Part II of this publication.

Output Variables

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

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

Row and Column Structure 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 compliance grade, from underground mines, and from existing mines (step 1 of a supply curve) is represented by the column vector P(NA)(B)(C)(U)(1).

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

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
		constraint for demand region (DR) and electricity plant type (PT). Not active in final solution.
DSS(DR)(PT)	Column	Escape column vector for subbituminous diversity constrain for demand region (DR) and electricity plant type (PT). Not active in final solution.
DVL(DR)(PT)	Row	Coal diversity constraint for lignite coal, demand region (DR), electricity subsector (PT).
DVS(DR)(PT)	Row	Coal diversity constraint for subbituminous coal, demand region (DR), electricity subsector (PT).
DX.(DRI)(TI)	Row	Export demand region (DRI) of coal type (TI)
EXP(SI)(TI)	Column	Sum of exports from supply region (SI) for diversity of international coal type (TI)
F(SR)(DR)X(C)	Column	Escape vector allowing contracts to be ignored for supply region (SR) to demand region (DR) of coal type (C) for the scrubbed electricity subsectors if infeasibility encountered. Not active in final solution.
F(SR)(DR)X(C)	Row	Contract constraint from supply region (SR) to demand region (DR) of coal type (C) for the scrubbed electricity subsectors
FAB(DR)(C)	Row (free)	Used to calculate average heat content of coal used in electricity sector by demand region (DR) and coal type (C)
FAC(DR)(C)	Row (free)	Used to calculate total carbon (million metric tonnes of carbon equivalent) of coal by demand region (DR) and coaltype (C) for electricity sector
FAM(DR)(C)	Row (free)	Calculates uncontrolled total mercury in coal (in lbs) by demand region (DR) and coal type (C) for the electricity sector
FHG(DR)(PT)	Row (free)	Calculates total mercury emissions from coal in consideration of use of emission control technology (controlled emissions) by demand region (DR) and electricity plant type (PT)
FP(SR)(U)(R)	Row (free)	Calculates coal production from supply region (SR), sulfur level (U), and coal rank (R)
HOURS	Row (free)	Estimates number of miner hours required to produce coal from a supply region (SR)
IMP(DRI)(TI)	Column	Sum of imports from demand region (DRI) for diversity of international coal type (TI)
LB(CR)L1	Row (free)	Calculates millions of tons of coal used for CTL by census region (CR)
LC(CR)L1	Row (free)	Determines total carbon present in coal used for CTL by census region (CR)
LCEN(CR)L1	Row (free)	Calculates total trillion Btu of coal used in CTL

MASK	ROW OR COLUMN	ACTIVITY REPRESENTED
		by census region (CR)
LIQUPMM(PMM)	Row (free)	Determines coal used for CTL by PMM region (PMM)
LP(M)(DR)(PMM)L	Row (free)	Sums CTL coal distribution by minetype (M), demand region (DR), and PMM region (PMM)
LP(SR)(U)(M)(R)(PMM)	Row (free)	Sums CTL coal distribution by supply region (SR), sulfur level (U), minetype (M), coal rank (R), and PMM region (PMM)
MERCAC01	Row (free)	Calculates total amount of mercury tons removed using activated carbon injection
MERCEV	Column	Provides upper bound for mercury allowance price
MERCP01	Row	Mercury penalty constraint for electricity sector (mercury scenarios only)
MOREHGXX	Column	Escape vector allowing more mercury to be emitted if tight mercury constraint causes infeasibility. Not active in final solution.
P(SR)(U)(M)(S)	Column	Coal production in supply region (SR), sulfur level (U), mine type (M), and step (S)
PX.(SRI)(I)	Column	Coal supply in international supply region (SRI) of step (I)
S@(SR)(U)(M)(C)	Row	Coal production in supply region (SR) of sulfur level (U), mine type (M), and coal type (C)
SULFPEN	Row	Sulfur penalty constraint for electricity sector
SXX(SRI)(TI)	Row	The supply of coal type (TI) in international supply region (SRI)
T(SR)(U)(M)(R)(DR)(SEC)(C)	Column	For electricity sector, the volume transported at 2nd tier rate (rate required to expand coal flows into this region) and, for non-electricity sectors, total transportation volume from supply region (SR), sulfur level (U), minetype (M), rank (R), to demand region (DR), subsector (SEC), of coal type (C)
TX(SI)(DRI)(TI)	Column	Transportation from supply region (SI) to international demand region (DRI) of coal type (TI)
UX(DR)(SA)	Column	U.S. demand region (DR) for export demand sector (SA)
VE(SI)(DRI)	Row	Diversity export constraint on supply region (SI) to demand region (DRI)
VI(DRI)(SI)	Row	Diversity import constraint on demand region (DRI) from supply region (SI)
WAGES	Row (free)	Estimates total wages required to produce coal

where,

DR **U.S. DEMAND REGIONS**

NE	CONNECTICUT, MASSACHUSETTS, MAINE, NEW HAMPSHIRE, RHODE ISLAND, VERMONT
YP	NEW YORK, PENNSYLVANIA, NEW JERSEY
SA	WEST VIRGINIA, DELAWARE, WASHINGTON DC., 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	ILLINOIS, INDIANA, KENTUCKY (WEST), MISSISSIPPI
WI	IOWA, MISSOURI, KANSAS, OKLAHOMA, ARKANSAS, TEXAS (BITUMINOUS)
GL	TEXAS (LIGNITE), LOUISIANA
DL	NORTH DAKOTA, MONTANA (LIGNITE)
PG	WYOMING, MONTANA (BITUMINOUS & 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 Compliance (Low): ≤ 1.2 lbs SO_2 per million Btu
- M Medium: > 1.2 but ≤3.33 lbs SO_2 per million Btu
- H High: >3.33 lbs SO_2 per million Btu

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

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

SEC **SUBSECTOR**
1 RESID/COM = RESIDENTIAL/COMMERCIAL DEMAND
2 RESID/COM
3 IND STEAM 1
4 IND STEAM 2
5 IND STEAM 3
6 COKING 1
7 COKING 2
8 COAL-TO-LIQUIDS
9 METALLURGICAL 1 EXPORT
10 METALLURGICAL 2 EXPORT
11 METALLURGICAL 3 EXPORT
12 STEAM 1 EXPORT
13 STEAM 2 EXPORT
14 STEAM 3 EXPORT
15 ELECTRICITY – B1
16 ELECTRICITY – B2
17 ELECTRICITY – B3
18 ELECTRICITY – B4
19 ELECTRICITY – B5
20 ELECTRICITY – B6
21 ELECTRICITY – B7
22 ELECTRICITY – B8

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

PT **PLANT TYPE**
See SUBSECTORS #15-49 above or Table 6 for more details

ACSTEP **ACTIVATED CARBON SUPPLY CURVE STEPS**
Step 1

* **EXPORT TYPE**
X1P Metallurgical Export 1
X2P Metallurgical Export 2
X3P Metallurgical Export 3
X4S Steam 1 Export
X5S Steam 2 Export
X6S Steam 3 Export

SRI **INTERNATIONAL SUPPLY REGIONS**
* COKING
NWC West Coast Canada
POC Poland
REC CIS Europe
RAC CIS Asia
SFC South Africa
HIC China
AUC Australia

* THERMAL

NWT	West Coast Canada
NIT	Interior Canada
CLT	Columbia
VZT	Venezuela
POT	Poland
RET	CIS Europe
RAT	CIS Asia
SFT	South Africa
INT	Indonesia
HIT	China
AUT	Australia

SI **GENERIC INTERNATIONAL SUPPLY REGIONS**

US	US
UA	US All
UG	US Gulf
UI	US Interior
UN	US Noncontiguous
UW	US West coast
UE	US East coast
NA	Canada
CL	Columbia
VZ	Venezuela
PO	Poland
RI	CIS
SF	South Africa
IN	Indonesia
HI	China
AU	Australia
RS	All of Russia

UI **INTERNATIONAL SULFUR LEVELS**

1	Compliance
2	Medium

TI **INTERNATIONAL COAL TYPES**

C	Coking
T	Thermal

DRI **INTERNATIONAL DEMAND REGIONS**

NIC	Canada Internal
SCC	Scandinavia
UKC	United Kingdom
BTC	United Kingdom (alternate)
GYC	Germany
OWC	Other N. Europe
SPC	Iberian Peninsula
ITC	Italy
RMC	E. Europe & Medit.

MXC	Mexico
LAC	South America
JAC	Japan
EAC	East Asia
CHC	China, Hong Kong
ASC	ASEAN
INC	Indian Subcontinent, S. Asia
NET	East Coast Canada (THERMAL)
NIT	Canada internal
SCT	Scandinavia
BTT	United Kingdom, Ireland
GYT	Germany, Austria
OWT	Other Northern Europe
PST	Iberia
ITLT	Italy
RMT	E. Europe and Mediterranean
MXT	Mexico
LAT	South America
JAT	Japan
EAT	East Asia
CHT	China, Hong Kong
AST	ASEAN
INT	Indian Subcontinent, S. Asia
UET	US Eastern
UGT	US Gulf
UIT	US Interior
UNT	US Noncontiguous

I **INTERNATIONAL SUPPLY 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

C **COAL GROUPS**

1	Premium and Bituminous
2	Subbituminous
3	Lignite
" "	None

Appendix 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). There are 504 lines representing all possible supply curve and demand region pairs 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.subsector 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.

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 of14 rows contain the shares for residential/commercial demands. The third set of 14 rows contain 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 36 numbers, one for each year beginning in 1990 and ending in 2025.

The next array has a 14 x 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 2004. 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 final input data in the clshare file is electricity imports in trillion Btu. This information is used to calculate the corresponding SO_2 emissions which are derived from coal imports used for electricity generation.

CLEXEXS. The first set of values in this file refers to the percentage of each exporters 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 (1990-2004) 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 represent 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.

The first section of the file contains a list of 54 “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.

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 certain shipment levels are exceeded and is only applied to the volume in excess of this shipment level.

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 *AEO2004*, new and unidentified plants are allowed unlimited use of subbituminous coal.

In the final section of the clcont file, 3085 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.

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. 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 the CDS Linear Program Structure described on page 101.)

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

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

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

For the diversity profiles, the process is similar except the level of aggregation (Step 4) is different. Here, the diversity profiles are specified by plant type (Table 6) 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, 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 *AEO2004*,"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 2025.

“MINEBYR” establishes the base year that corresponds to the number of miners appearing in the next section.

“MINERS BY SUPPLY REGION FOR MINEBYR” is the base year data from which subsequent coal mine employment for the forecast years is calculated.

"SECTOR" 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 six rational numbers located after “KCNUR” are coefficients for calculation of the transportation escalator.

“RAIL WAGE INDEX” projections are forecasted values for average wages for railroad workers. They are used to forecast the transportation escalator.

"BTR" previously defined rail transportation cost escalators. (“BTR” is not used in the *AEO2004*.)

"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 11 CMM coal supply regions, with each group containing a value for each of the 36 years (1990-2025).

"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 11) 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 1998-2002.

CMMDBDEF. This file contains the coal database definition tables.

Table C-1. Parameter and Variable List for CDS

Variable	Include File	Definition
ABSULF(4,MNUMYR)	coalrep	Appalachia bituminous coal (million tons)
ALLCOALS(40)	cdscom2l	Supply coal type combinations (e.g. NACDB, NAMDB,etc.)
APPCDS=3	cdsparms	Number of CMM supply regions in Appalachia
APSULF(4,MNUMYR)	coalrep	Appalachian premium coal (million tons)
ASTN(MAXTNAM)	cdsrevise	Assigned tons
ASTR(MAXTNAM)	cdsrevise	Assigned trillion Btu
BASEYR	parametr	Base calendar year corresponding to CURIYR = 1
BSRZR(NTOTSECT,NDREG)	cdscom2l	Rail route multipliers by demand region; read in from clparam.txt; currently set to 1.0
BSRZR_UTIL(NFYRS)	cdscom2l	Input from clparam.txt; used to calibrate delivered utility coal prices
BTR(NSREG+1, NFYRS)	cdscom2l	Network rail rate multiplier; currently not used in the model
BTUTZR(NUTSEC,NDREG)	cdscom1l	Btu conversion factor for utility sectors (million Btu/ton)
BTW(NFYRS)	cdscom2l	Network water rate multiplier; currently not used in the model
C_ECP_BTU(MX_SO2T,NUTSEC+1,NDREG)	uso2grp	Trillion Btus by sulfur category, utility sector, and coal demand region
C_ECP_PRC(MX_SO2T,NDREG)	uso2grp	Coal price by sulfur category and by coal demand region ($/mmBtu)
C_ECP_SO2(MX_SO2T,NDREG)	uso2grp	SO2 content by sulfur category and coal demand region (lbs/mmBtu)
CBTU(NSREG, NCOALTYP)	cdscom2l	Carbon factor by supply region and coal type
CDSIN(NDREG,MNUMCR)	cdsshr	Industrial sector share factors (read in from clshare.txt)
CDSMC(NDREG,MNUMCR)	cdsshr	Metallurgical coal sector share factors (read in from clshare.txt)
CDSRC(NDREG,MNUMCR)	cdsshr	Residential/commercial sector share factors (read in from clshare.txt)
CDTN(MAXTNAM)	cdsrevise	Calculated delivered price/ton
CDTR(MAXTNAM)	cdsrevise	Calculated delivered price/MMBtu
CDYRS(NMAXCTRK,NFYRS)	cdscom2l	Utility contract demand (trillion Btu)
CESIO	omlbuf	Memory required by coal LP model
CLITR	cdscpsp	Coal iteration
CLMAXITR	cdscpsp	Maximum number of coal iterations allowed
CLSULF(11,4,3,MNUMYR)	coalrep	Coal production by supply region (million tons)
CLSYNGQN(17,MNUMYR)	coalout	Coal synthetic natural gas quantity
CNCSET=10	cdsparms	Number of coals available within a set
CNTR(MAXTNAM)	cdsrevise	Contract trillion Btu (lower bounds)
COAL(NSREG,NCOALTYP)	cdscom2l	Coal type code (e.g. CSS (compliance/surface/subbituminous))
COALIYR	cdscom1l	Internal year index
COALPRICE(MNUMLR,MNUMYR)	coalrep	Coal price ($/short ton)

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

Variable	Include File	Definition
COF(6)	cdscom2l	Coefficients for transportation equation
CPSB(3,MNUMYR)	coalout	Coal minemouth price in ($/ton)
CPSBF(NSREG,NFYRS)	cdscom1l	Total minemouth price ($/ton)
CPSFLG	cdscpsp	=0 before the CPS submodule is called and 1 afterwards
CQDBFB(MNUMCR,NEMSEC,MNUMYR)	coalout	Coal consumption (trillion Btu)
CQDBFT(MNUMCR,NEMSEC,MNUMYR)	coalout	Coal conversion factor for consumption (million Btu/ton)
CQEXP	cdscom1l	Total export demand (trillion Btu)
CQSBB(3,MNUMYR)	coalout	Coal production (East,West Miss, U.S.) (trillion Btu)
CQSBFB(NSREG,NFYRS)	cdscom1l	Coal production by CDS supply regions (million Btu)
CQSBFT(NSREG,NFYRS)	cdscom1l	Conversion factor for coal production (million Btu/ton)
CQSBT(3,MNUMYR)	coalout	Coal Btu conversion factor for production (million Btu/ton)
CRTN(MAXTNAM)	cdsrevise	Calculated rate/ton
CSDISC(NSREG,NFYRS)	cdscom2l	Productivity adjustment factors
CT_USED(16,32)	cdsshr	Coal type used
CTRK_INDX(2,NCOALTYP, NSREG,NTOTDREG)	cdscom2l	Index for contracts (e.g. =1 for 1st contract, 2 for 2nd contract, etc.)
CURITR	ncntrl	Current iteration index
CURIYR	ncntrl	Current iteration year index
DEMDEX(MAXTNAM)	cdsrevise	Index needed for sorting
DEMKEY(MAXTNAM)	cdsrevise	Key (8 digits demand, supply, sector, and coal type)
DEMRGN(NTOTDREG)	cdscom2l	Demand region (e.g. NE, YP, etc.)
DFCLOSE(DBFILE)	dfinc2	Function which terminates processing of a database file
DFMCBND(BNDNAME,CNAME,LVALUE,UVALUE)	dfinc2	Creates or changes a bound value
DFMCRTP(RNAME,TYPE)	dfinc2	Declares or changes the row type
DFMCVAL(CNAME,RNAME,VALUE)	dfinc2	Creates or changes a value for a row/column intersection
DFMEND()	dfinc2	Function which terminates matrix processing
DFMINIT(DB,MODE)	dfinc2	Initializes a database for matrix processing
DFOPEN(DBFILE,ACTFILE)	dfinc2	Opens the datafile for the LP problem
DFPINIT(DB,DBFILE,ACTPROB)	dfinc2	Initializes processing of the LP problem in the current database
DPTR(MAXTNAM)	cdsrevise	Decision price
DTJL(NMAXPART,NMAXDJOB)	cdscom2l	Coal demand requirement by coal type for the nonutility sector (million tons)
DVCONT(90, NFYRS)	cdscom2l	Contract constraint
DVLBND	cdscom2l	Upper bound for lignite
DVSBND	cdscom2l	Upper bound for subbituminous coal
EDYRS(NMAXEXPT,NFYRS)	cdscom1l	Export demand (trillion Btu)
EMCOALPROD(numcoalch4regs+1,2,MNUMYR)	emission	Coal production by emission regions plus US

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

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

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

Variable	Include File	Definition
IMPTONC(NDREG,3,NFYRS)	cdscom1l	Import total in by CDS demand regions (million tons)
INTCDS=6	cdsparms	CMM supply regions belonging to Appalachia (1-3) and the Interior (4-6)
IRETOPT	cdscom2l	Optimal solution flag returned from the LP (0 indicates feasibility; 1 indicates infeasibility)
ISCRUB=7	cdsparms	Integer representing number of scrubbed sectors
ISEC(NTOTSECT)	cdscom2l	Converts detailed 21 demand sectors to 6 sectors (resid/comm, industrial, metallurgical, coal-to-liquids, exports, and electricity)
ISTJ(NMAXPART,NMAXDJOB)	cdscom2l	Index of supply region by route and demand job
ISUL(NCOALTYP)	cdscom2l	Coal type sulfur
ISVC(NMAXCURV)	cdscom2l	Coal type index
ISVR(NMAXCURV)	cdscom2l	Supply region index
IUNIT	cdsfmgr	Unit for WRITE statement
IUNITDB	cdsfmgr	Unit to WRITE to the debug file
IUNITDS	cdsfmgr	Unit to WRITE to the CDS file
KCNUR(NOTSEC,NDREG)	cdscom2l	Indices of coal sets for nonutility demands
KCUR(NUTSEC,NDREG)	cdscom2l	Indices of coal sets for utility demands
L_PROD(11,2,MNUMYR)	cdscom2l	Labor productivity (tons/hour) assumptions; read in from cluser.txt
LABPRODGROWTH(MNUMYR)	coalrep	Growth in labor productivity from 2001
LASTYR	ncntrl	Last forecast year index (e.g. 36)
LCTNO(MAXTNAM)	cdsrevise	Contract line number
LCVBTU(MNUMPR,MNUMYR)	coalout	Coal supply curve heat content (mmBtu/ton)
LCVELAS(MNUMPR,MNUMYR)	coalout	Elasticity of coal supply curve for coal-to-liquids
LCVTONP(MNUMPR,MNUMYR)	coalout	Coal supply curve delivered price ($/ton)
LCVTONQ(MNUMPR,MNUMYR)	coalout	Coal supply curve production (million tons)
LIGCONST	cdscom2l	Lignite constraint in clparam.txt
LIQUCARB(MNUMCR,MNUMYR)	coalout	Carbon content of coal to coal-to-liquids (kilograms/mmBtu)
LIQUSULF(MNUMPR,MNUMYR)	coalout	Sulfur content of coal to coal-to-liquids (lbs/mmBtu)
LTRNTON(MNUMPR,MNUMYR)	coalout	Transportation rate ($/ton)
MAPCDS(NDREG)	cdsshr	Maps census regions to coal demand regions
MAPCEN(NDREG+1)	cdsshr	Maps coal demand regions to census regions
MAXDNAM=550	cdsrevise	Names of demand rows
MAXPNAM=250	cdsrevise	Names of production activities
MAXTNAM=3500	cdsrevise	Names of transportation activities
MC_ECIWSP(MNUMYR)	macout	Empl Cost Index, private wages & manufacturing salary; 1989 = 1.00
MC_PCWGDP(-2:MNUMYR)	macout	Implicit GDP deflator; 1987 = 1.00
MC_WPI14(MNUMYR)	macout	Producer price index for transportation equipment
MCNT_BTU(600)	cdscpsp	BTU conversion (marginal cost curve)
MCNT_CAR(600)	cdscpsp	Carbon factor (marginal cost curve)
MCNT_CTYPE	cdscpsp	Coal type (marginal cost curve)
MCNT_FRAC(600)	cdscpsp	Mine type (marginal cost curve)

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

Variable	Include File	Definition
MCNT_P(600,8)	cdscpsp	Coal price for each step (marginal cost curve)
MCNT_PRICE(600)	cdscpsp	Minemouth price (marginal cost curve)
MCNT_PROD(600)	cdscpsp	Production (marginal cost curve)
MCNT_Q(600,8)	cdscpsp	Coal quantity for each step (marginal cost curve)
MCNT_REC	cdscpsp	Number of record (marginal cost curve)
MCNT_REGION	cdscpsp	Supply region (marginal cost curve)
MCNT_STEP(8)	cdscpsp	Step size
MCNT_SULF(600)	cdscpsp	Sulfur level (marginal cost curve)
MDLZ(NMAXCTRK)	cdscom2l	Index of contract sector
MNUMCR=11	parametr	Census regions (9 + CA + US)
MNUMLR=17	parametr	Coal supply regions (16 + US)
MNUMYR=36	parametr	Maximum number of forecast years
MPTN(MAXTNAM)	cdsrevise	Minemouth price/ton
MPTR(MAXTNAM)	cdsrevise	Minemouth price/trillion Btu
MTJ(NMAXDJOB)	cdscom2l	Number of routes for job
NCESIO=200000	omlbuf	Size of workspace for coal matrix
NCOALS	cdscom2l	Number of supply region/coaltype combinations; currently 36
NCOALTYP=8	cdsparms	Number of coal types per supply region
NCSET=36	cdsparms	Number of coal sets available
NCUTSET=12	cdsparms	Number of utility coal sets
NDREG=14	parametr	Coal demand regions
NDV	cdscom2l	Number of lignite and subbituminous constraints in clparam.txt
NEMSEC=7	cdsparms	Number of NEMS sectors (NTOTSECT + imports)
NFYRS=36	cdsparms	Number of forecasted years
NMAXCTRK=350	cdsparms	Maximum number of contracts
NMAXCURV=300	cdsparms	Maximum number of supply curves
NMAXDJOB)	cdsparms	Coal demand requirement by coal type (million tons)
NMAXDJOB=900	cdsparms	Maximum number of demand jobs
NMAXEXPT=50	cdsparms	Maximum number of export demands
NMAXPART=20	cdsparms	Maximum number of participants per demand job
NMAXSTEP=4000	cdsparms	Maximum number of curve steps
NOCONTR	cdscom2l	Number of contracts in contract file
NODES(5,60)	cdscom2l	Supply and demand region abbreviations; NODES(1,1-11)= supply regions; NODES(1,12-24)= demand regions
NONUTIL=14	cdsparms	Number of detailed nonutility sectors (R1,R2,IP,IS,IO,M1,M2,L1,and X1-X6)
NOTSEC=8	cdsparms	Number of residential/commercial, industrial, metallurgical, and coal-to-liquids sectors
NSREG=11	cdsparms	Number of coal supply regions
NTOTDREG=14	cdsparms	Total number of demand regions

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

Variable	Include File	Definition
NTOTSECT=21	cdsparms	Total number of demand sectors (R1,R2,IP,IS,IO,M1,M2,L1,X1-X6, and U1-U7)
NUMSTYPE=3	cdsparms	Number of coal types (low-, medium-, and high-sulfur)
NUMSULFLVL=3	cdsparms	Number of sulfur categories (compliance, medium, and high)
NUTSEC=7	cdsparms	Number of utility sectors
NXPSEC=6	cdsparms	Number of export sectors
ODTRATE(NSREG,NCOALTYP,NTOTDREG,NTOTSECT)	cdscom1l	Transportation rates from clrates.txt
PABSULF(4,MNUMYR)	coalrep	Price of Appalachian bituminous coal ($/ton)
PALSULF(4,MNUMYR)	coalrep	Price of Appalachian lignite coal ($/ton)
PAPSULF(4,MNUMYR)	coalrep	Price of Appalachian premium coal ($/ton)
PCLCM(MNUMCR,MNUMYR)	ampblk	Price of coal for the commercial sector ($/mmBtu)
PCLCM(MNUMCR,MNUMYR)	mdblk	Coal price for commercial sector ($/mmBtu)
PCLEL(MNUMCR,MNUMYR)	ampblk	Price of coal for the electricity sector ($/mmBtu)
PCLEL(MNUMCR,MNUMYR)	mdblk	Coal price for electricity sector ($/mmBtu)
PCLEX(MNUMCR,MNUMYR)	coalrep	Coal export price ($/mmBtu)
PCLIN(MNUMCR,MNUMYR)	ampblk	Price of coal for the industrial sector ($/mmBtu)
PCLIN(MNUMCR,MNUMYR)	mdblk	Coal price for industrial sector ($/mmBtu)
PCLRFPD(MNUMPR,MNUMYR)	coalout	Price of coal for coal-to-liquids ($/mmBtu)
PCLRS(MNUMCR,MNUMYR)	ampblk	Price of coal for the residential sector ($/mmBtu)
PCLRS(MNUMCR,MNUMYR)	mdblk	Coal price for residential sector ($/mmBtu)
PCLSULF(11,4,3,MNUMYR)	coalrep	Coal price by supply region ($/ton)
PCNT_BTU(600)	cdscpsp	BTU conversion (capacity curve)
PCNT_CAR(600)	cdscpsp	Carbon factor (capacity curve)
PCNT_CTYPE	cdscpsp	Coal type (capacity curve)
PCNT_FRAC(600)	cdscpsp	Mine type (capacity curve)
PCNT_P(600,8)	cdscpsp	Coal price for each step (capacity curve)
PCNT_PRICE(600)	cdscpsp	Minemouth price (capacity curve)
PCNT_PROD(600)	cdscpsp	Production (capacity curve)
PCNT_Q(600,8)	cdscpsp	Coal quantity for each step (capacity curve)
PCNT_REC	cdscpsp	Number of record (capacity curve)
PCNT_REGION	cdscpsp	Supply region (capacity curve)
PCNT_SULF(600)	cdscpsp	Sulfur level (capacity curve)
PD(NSREG)	cdscom2l	Production for deep mines (million tons)
PDUTZR(NUTSEC,NDREG)	cdscom1l	Utility delivered price by utility sector ($/million Btu)
PIBSULF(4,MNUMYR)	coalrep	Price of Interior bituminous coal ($/ton)
PILSULF(4,MNUMYR)	coalrep	Price of Interior lignite coal ($/ton)
PMCIN(MNUMCR,MNUMYR)	ampblk	Price of coal for the metallurgical sector ($/mmBtu)
PMCIN(MNUMCR,MNUMYR)	mdblk	Metallurgical coal price for industrial sector ($/mmBtu)
PMN(NSREG,NCOALTYP)	cdscom2l	Value of coal from a region ($/ton)
PMPROD(NSREG,NCOALTYP)	cdscom1l	Value of coal from a supply region (including adjustment for premium coal)

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

Variable	Include File	Definition
PMPRODR(NSREG,NCOALTYP,NFYRS)	cdscom1l	Value of coal from a supply region (including adjustment for premium coal) for a given year
PREMBTU=27.43	cdsparms	Btu conversion factor for premium coal
PRTDBGC	ncntrl	Print debug
PS(NSREG)	cdscom2l	Production for surface mines (million tons)
PSRMT(NSREG,2)	cdscom2l	Production by supply region and minetype
PSRMTYR(NSREG,2,NFYRS)	cdscom2l	Production by supply region, minetype, and forecast year (extra variable not in use)
PSRNG(NMAXCURV)	cdscom2l	Minemouth price in 1987 $/ton
PTARG(16,2,16)	cdscpsp	Target price
PWBSULF(4,MNUMYR)	coalrep	Price of western bituminous coal ($/ton)
PWLSULF(4,MNUMYR)	coalrep	Price of western lignite coal ($/ton)
PWSSULF(4,MNUMYR)	coalrep	Price of western subbituminous coal ($/ton)
QCLCM(MNUMCR,MNUMYR)	qblk	Quantity of coal for commercial sector (trillion Btu)
QCLCML(MNUMCR)	cdsces	Lagged commercial production (trillion Btu)
QCLEL(MNUMCR,MNUMYR)	qblk	Quantity of coal for electricity sector (trillion Btu)
QCLIN(MNUMCR,MNUMYR)	qblk	Quantity of coal for industrial sector (trillion Btu)
QCLINL(MNUMCR)	cdsces	Lagged industrial production (trillion Btu)
QCLNHNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with high emission standards (can burn any type of coal)
QCLNLNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with low emission standards (can only burn compliance coal)
QCLNMNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at new units with medium emission standards (can burn compliance or medium sulfur coal)
QCLOHNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with high emission standards (can burn any type of coal)
QCLOLNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with low emission standards (can only burn compliance coal)
QCLOMNR(NDRGG,MNUMYR)	coalemm	Demand for coal (trillion Btu) at old units with medium emission standards (can burn compliance or medium sulfur coal)
QCLRS(MNUMCR,MNUMYR)	qblk	Quantity of coal for residential sector (trillion Btu)
QCLRSL(MNUMCR)	cdsces	Lagged residential production (trillion Btu)
QCLSBNR(NDRGG,MNUMYR)	coalemm	Demand for coal at scrubbed units (trillion Btu)
QCLSN(MNUMCR,MUNMYR)	qblk	Quantity of coal synthetics (trillion Btu)
QDIN1R(NDREG)	cdscom1l	Industrial demand (trillion Btu)
QDL(NMAXDJOB)	cdscom2l	Coal demand per demand job in trillion Btu
QDL11R(NDREG)	cdscom1l	Coal-to-liquid coal demand (trillion Btu)
QDMT1R(NDREG)	cdscom1l	Metallurgical coal demand (trillion Btu)
QDRC1R(NDREG)	cdscom1l	Residential/commercial demand (trillion Btu)
QDUTZR(NUTSEC,NDREG)	cdscom1l	Utility demand by utility sector (trillion Btu)
QMCIN(MNUMCR,MNUMYR)	qblk	Quantity of metallurgical coal (trillion Btu)

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

Variable	Include File	Definition
QMCINL(MNUMCR)	cdsces	Lagged metallugical coal production (trillion Btu)
QPROD(NSREG, NCOALTYP)	cdscom1l	Coal production (including adjustment for premium coal)
QPRODR(NSREG,NCOALTYP,NFYRS)	coalcds	Coal production (including adjustment for premium coal) by year
QPRODS(NSREG, NCOALTYP)	cdscom2l	Straight 35-curve production (excluding adjustment for premium coal)
R_WAGE(11,MNUMYR)	cdscom2l	Real wage by supply region and forecast year
RPTN(MAXTNAM)	cdsrevise	Transportation rate/ton
RPTR(MAXTNAM)	cdsrevise	Transportation rate/trillion Btu
RQTN(MAXTNAM)	cdsrevise	Required tons
RQTR(MAXTNAM)	cdsrevise	Required trillion Btu
RSBTU(NMAXCURV)	cdscom2l	Btu content (million Btu/ton)
SBTU(NSREG, NCOALTYP)	cdscom2l	Btu conversion factor by supply region and coal type (million Btu/ton)
SECNAM(NTOTSECT)	cdscom2l	Demand sector name (e.g. R1,R2,IP,IS,etc); input from clparam.txt
SECTOR(3,NTOTSECT)	cdscom2l	Sector name (e.g. RESID/COMM1, IND. PREM, etc.)
SO2_PCB=1.000	cdsparms	1.0 minus fraction of sulfur left in ash, bituminous coal
SO2_PCL=0.960	cdsparms	1.0 minus fraction of sulfur left in ash, lignite coal
SO2_PCS=0.980	cdsparms	1.0 minus fraction of sulfur left in ash, subbituminous coal
SO2TX(MAXTNAM)	cdsrevise	SO2 penalty ($/mmBtu)
SOUTZR(NUTSEC,NDREG)	cdscom1l	SO2 content for utility sectors (lb/million Btu)
SSUL(NSREG, NCOALTYP)	cdscom2l	Sulfur level by supply region and coal type
STARTYR=6	cdsparms	First year the coal model LP should solve; set to 1995
SUBCONST	cdscom2l	Subbituminous constraint in clparam.txt
SULFCONT	cdscom2l	Sulfur content (considers the sulfur removed at plant) (lbs/mmBtu)
SULFPEN	cdscom2l	Row name for sulfur constraint
SUPNO(16,32)	cdscom2l	Supply curve number
SUPRGN(NSREG)	cdscom2l	Supply region
TIJL(NMAXPART,NMAXDJOB)	cdscom2l	Coal assigned by coal type (million tons)
TONN(10,25,3,NFYRS)	cdscom1l	Import tonnage (million tons)
TOTALHOURS(NFYRS)	cdscom2l	Total labor hours by forecast year
TOTALWAGES(NFYRS)	cdscom2l	Total wages by forecast year
TOTLABPROD(MNUMYR)	coalrep	Total labor productivity in a given forecast year (tons/hour)
TOTPROD(NFYRS)	cdscom2l	Total production by forecast year
TRN_INDX(NUTSEC,NCOALTYP,NSREG, NTOTDREG)	cdscom2l	Index indicating whether transportation vector is required (0=Not required; 1=Required)
UPEBYR	uso2grp	End banking year (year banked allowance cannot be used)
UPSLWFCTR	uso2grp	SO2 penalty price lower bound factor (currently 0.00)

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

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

Output and Composition of Reports

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

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

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

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

NEMS Tables

Prices and quantities produced by the CDS occur throughout the NEMS tables. However, the bulk of domestic CDS output is reported in five NEMS tables dedicated entirely to coal: Tables 16, 109, 110, 111 and 112. These reports can be found at http://www.eia.doe.gov/oiaf/aeo/pdf/aeotab_16.pdf for Table 16 and http://www.eia.doe.gov/oiaf/aeo/supplement/pdf/sup_ogc.pdf for the other reports. These reports are organized to show selected NEMS coal quantities and prices for each year in the forecast period. Table 16, "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, "Domestic Coal Supply, Disposition and Prices," occurs in a national version (where it repeats the consumption, delivered price and discrepancy numbers for the domestic coal consuming sectors that are shown in Table 16). In addition to sectoral consumption and prices, this table shows the regional origin of coal consumed for aggregated supply regions: Appalachia,

the Interior, the Northern Great Plains, Other West and Non-Contiguous. Table 109 excludes exports.

Table 110, "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 111, "Coal Production By Region and Type" lists production in millions of short tons per forecast year for the 11 supply regions by coal rank and sulfur level.

Table 112,"Coal Prices By Region and Type" lists minemouth prices in real base year dollars per short ton for the 11 supply regions by coal rank and sulfur level for each forecast year.

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 16). 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 D
Data Quality and Estimation

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 E-1, 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 only 4 percent of 2002 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 carriage in significant quantity in the last 50 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 2004* is summarized in Table D-1.

Table D-1. Survey Sources for CMM Inputs by Demand Sector

ITEM	UTILITY	IPP	INDUSTRIAL	COKING	RES/COM	EXPORT	IMPORT	MINE
Prices:								
Minemouth	NA	NA	NA	NA	NA	NA	NA	EIA-7A
Delivered	EIA/F423	NA	EIA-3	EIA-5	NA	EM522	EIA-3/ EIA-5/ EIA/F423	NA
Freight	FERC 580	NA	NA	NA	NA	NA	NA	NA
Transport:								
Mode	FERC 580	NA	NA	NA	NA	NA	NA	NA
Miles	FERC 580	NA	NA	NA	NA	NA	NA	NA
Origin	EIA/F423	NA	EIA-3	EIA-5	EIA-6A	EIA-6A	IM545	EIA-7A
Destination	EIA/F423	EIA–860B	EIA-3	EIA-5	EIA-6A	EM522/ EIA-6A	EIA-3/ EIA-5/ EIA/F423	NA
Tonnage:								
Production	NA	NA	NA	NA	NA	NA	NA	EIA-7A
Distribution	EIA-6A	NA	EIA-6A	EIA-6A	EIA-6A	EIA-6A	NA	NA
Receipts	EIA/F423	NA	EIA-3	EIA-5	NA	NA	NA	NA
Consumption	EIA- 759	EIA-860B	EIA-3	EIA-5	NA	EM522	NA	NA
Stocks	EIA- 759	NA	EIA-3	EIA-5	NA	NA	NA	EIA-7A
Quality:								
Rank/Grade	EIA/F423	EIA-860B	NA	NA	NA	EM522	IM545	EIA-7A
Volatiles%	NA	NA	NA	EIA-5	NA	NA	NA	NA
Btu Content	EIA/F423	EIA-860B	EIA-3	NA	NA	NA	EIA-3	NA
Sulfur %	EIA/F423	EIA-860B	EIA-3	EIA-5	NA	NA	EIA-5	NA
Ash %	EIA/F423	EIA-860B	EIA-3	EIA-5	NA	NA	EIA/F423	NA
Particulates	EIA-767	NA	NA	NA	NA	NA	NA	NA
SO2	EIA-767	NA	NA	NA	NA	NA	NA	NA
NOX	EIA-767	NA	NA	NA	NA	NA	NA	NA
COX	EIA-767	NA	NA	NA	NA	NA	NA	NA

EIA/F423= EIA-423 & FERC 423
NA=Not available

Appendix E

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Appendix 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

Part II-B—Coal Distribution Submodule – International Component

1. Introduction

Statement of Purpose

The purpose of Part II-B 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 16 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 supply, demand, trade and transportation components. The major coal exporting countries represented include: the United States, Australia, South Africa, Canada, Indonesia, China, Colombia, Venezuela, Poland, and the countries of the Former Soviet Union.

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 2004*.
Name: Coal Distribution Submodule--International Coal Trade Flows
Acronym: CDS
Archive Package: NEMS04 (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)

Part II-B Organization

This part of the report describes the modeling approach used in the International Coal Trade Component of the CDS. Subsequent sections of this report describe:

- The model objective, input and output, and relationship to other models (Chapter 2)
- The theoretical approach, assumptions, and other approaches (Chapter 3)
- The model structure, including key computations and equations (Chapter 4).

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

2. Model Purpose and Scope

Model Objectives

The objective of the international component of the CDS is to provide annual forecasts (through 2025) of world coal trade flows. For this portion of the model documentation, exports and supply can be considered synonymous while imports and demand can also be considered synonymous.

Coal supply in the international area of the CDS is modeled using 3 coal types, premium bituminous, low-sulfur bituminous, and subbituminous coals (Table 8). These coal types represent unique combinations of heat and sulfur content. There are 16 geographic supply regions (Table 9) including 5 U.S. export regions, 2 Canadian export regions, and 9 additional major coal exporting countries. The 5 U.S. coal export regions in the CMM (Figure 12) 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 supply 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 9.

The coking and steam sectors define the international coal demand sectors. The CMM coal types available to satisfy demand for the two international coal sectors are listed in Table 8. There are 20 coal import demand regions represented in the CMM (Table 10). 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 demands, coal supply curves, transportation costs, and constraints (Figure 13). 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 export demands are shared with to the domestic portion of the CDS so that sufficient production is allocated to U.S. exports.

Table 8. CDS International Coal Supply Types and Demand Sectors

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

Note: For definitions of NEMS CPS/CDS coal types see Table 1 of this report.

Figure 12. U.S. Export and Import Regions Used in the CDS

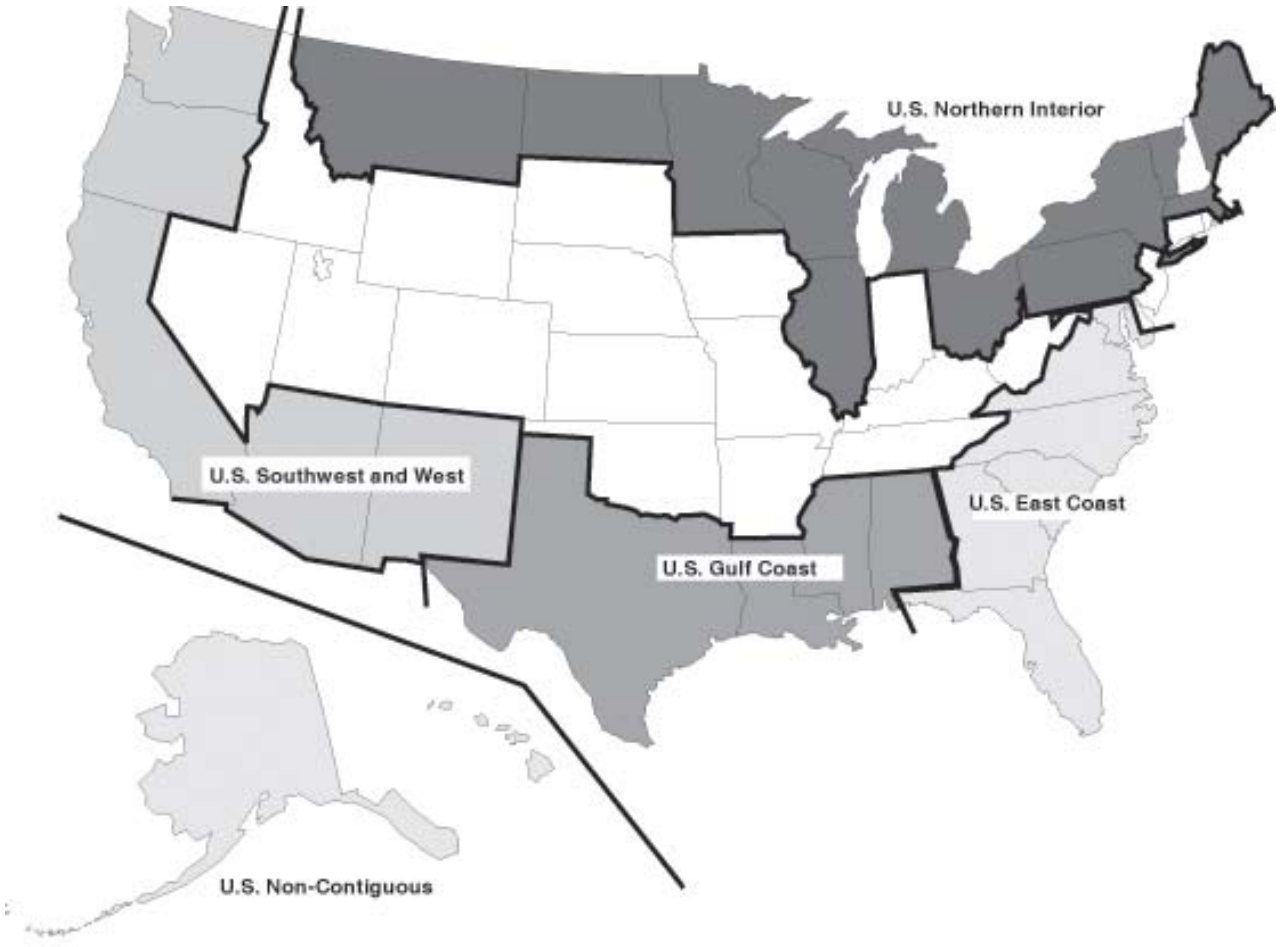


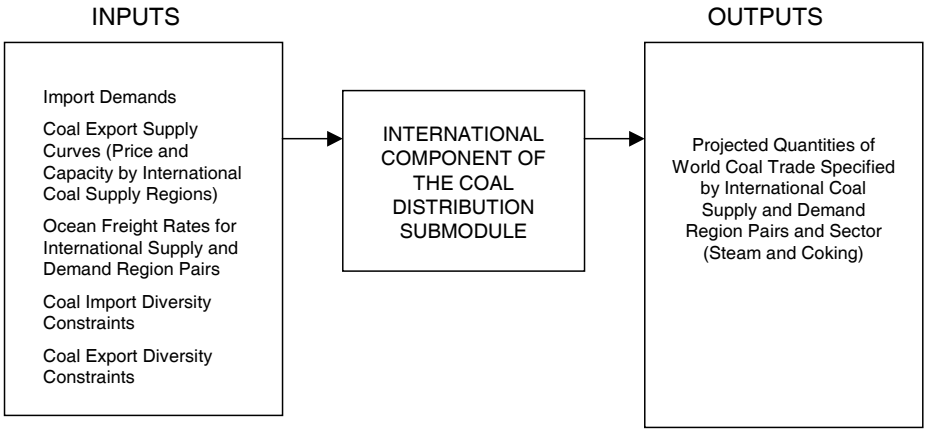
Table 9. CDS Coal Export Regions

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

Table 10. CDS Coal Import Regions

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

Figure 13. International Component Inputs/Outputs



3. 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 pre-specified set of regional net import demands. It does this subject to a number of constraints:

- Export capacity of supply regions
- Maximum share that any importing region can take from one supply region
- Maximum share that any exporting region will sell to one importing region
- Maximum shares of both high sulfur and subbituminous coal which each importing region can take
- Maximum sulfur emission associated with imports for each importing region.

Fundamental Assumptions

The key assumptions regarding the international area of the CDS are as follows:

- The coal market is competitive: In other words, no large suppliers or grouping of producers are able to influence the price through adjusting their output. Producers' decisions on how much and who they supply to are driven by their costs, and prices are set by their perceptions of what the market can bear. In this situation the buyer gains the full consumer surplus.
- The market is always in a sustainable equilibrium, as suppliers adjust their output to exactly match demand. This implies that there are no barriers to entry and exit.
- The world is a comparatively static one, and there are no linkages between periods. Thus, the results of period t are not influenced by those in period t-1, or any other past time periods.
- 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. Similarly, producers will choose not to rely on any one buyer, and will diversify their sales.
- Coking coal is treated as homogeneous: This is a heroic, but a necessary assumption. There are too many important quality parameters (fluidity, swell, expansion characteristics, volatility, ash, phosphorus, and sulfur) and complex synergies to make a differentiated coal model workable.
- Suppliers sell at the same FOB price irrespective of who they are supplying. In practice, suppliers often fix different prices depending on which market they are selling into and whether the coal is being sold on long term or short term basis.

- While subbituminous coal is included, its consumption is constrained by the capacity of coal-fired plants that can burn it and the extent that it can be substituted/blended.

- SO_2 emission regulations are modeled in two ways. First, the share of thermal coal imports that can be satisfied by high sulfur coal can be set for each thermal coal buyer. Second, in order to capture the effect of bubble emission caps, an SO_2 emission allowance associated with using imported coal can be set for each region. Emissions are calculated on the basis of fuel sulfur levels and the share of imports used in facilities which remove (or neutralize) sulfur.

Alternative Approaches and Reasons for Selection

A number of alternative approaches to modeling international coal trade incorporate other features, such as dynamic linkages, the ability of major buyers and sellers to influence pricing and the effects of contracts in locking in supply patterns. None of these are based on linear programming procedures.

The two most notable models are EIA's own International Coal Trade Model (ICTM) and Resource Economics Corporation's World Coal Trade Expert System (WOCTES).

The *ICTM*, a linear optimization model and database, was designed to provide a methodology for forecasting and analyzing the unique role of the United States in world coal trade.[51] The model projects world coal trade flows from 20 coal exporting regions of the world to 9 demand regions for 3 types of coal (metallurgical, low-sulfur steam, and high-sulfur steam). The objective function at the heart of the ICTM solution algorithm maximizes total producer and consumer surplus for coal traded internationally, subject to a system of linear constraints that describe the physical, technical, and contractual relationships among the individual trade activities represented.[52] Questions were raised in the planning for the National Energy Modeling System (NEMS) over the need for an approach with such a broad scope and whether a simpler solution algorithm in NEMS might be more desirable.[53]

WOCTES is the most powerful PC-based model for examining international thermal coal trade. The model has the capability to handle 20 supply regions and 20 demand regions. Up to four coal types can be included, with coals defined by their heat content. The WOCTES model is a spatial equilibrium methodology (which uses an advanced complementary algorithm) to determine trade patterns and prices. Coal importers look at prices offered by all suppliers, and choose the best supplier. It is assumed that suppliers price the coal as high as they can without driving customers away.

WOCTES allows the modeling of noncompetitive market behavior, but is invariably used in the competitive market mode by its major users. The EIA, the only user of the ICTM, has produced all its long term forecasts since 1985 on the assumption that no suppliers or buyers exert market influence. Similarly, the major users of WOCTES, (which include the United Kingdom's PowerGen and National Power, Australia's ABARE, and the EC Commission) all generate forecasts using constrained, competitive market description.

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[51]See Energy Information Administration, *International Coal Trade Model: Executive Summary*, DOE/EIA-0444(EX) (Washington, DC, May 1984) for a description of the ICTM model itself and the underlying supply and ocean transportation models.

[52]For a complete discussion of the ICTM solution see the following reports: Energy Information Administration: *Description of the International Coal Trade Model*, DOE/EI/11815-1 (Washington, DC, September 1982); *Mathematical Structure of the International Coal Trade Model*, DOE/NBB-0025 (Washington, DC, September 1982); *International Coal Trade Model, Version 2, Preliminary Description*, by William Orchard-Hayes (Washington, DC, June 10, 1985; *International Coal Trade Model—Version 2 (ICTM-2) User's Guide* (Washington, DC, March 1987); and The George Washington University, Department of Operations Research, *Oligopoly Theories and the International Coal Trade Model*, GWU/IMSE/Serial T-494/84, by James E. Falk and Garth P. McCormick (Washington, DC, July 1984).

[53]National Research Council, *The National Energy Modeling System* (Washington, DC, January 1992), p. 58.

It is possible to examine the impacts of producers' power, using a competitive market model (such as the CDS) by restricting the supply of one or more major suppliers. This will give an indication of the impact on prices and trade patterns. It doesn't however, throw any light on what happens to the suppliers' profits as the model still assumes producers' supply at cost.

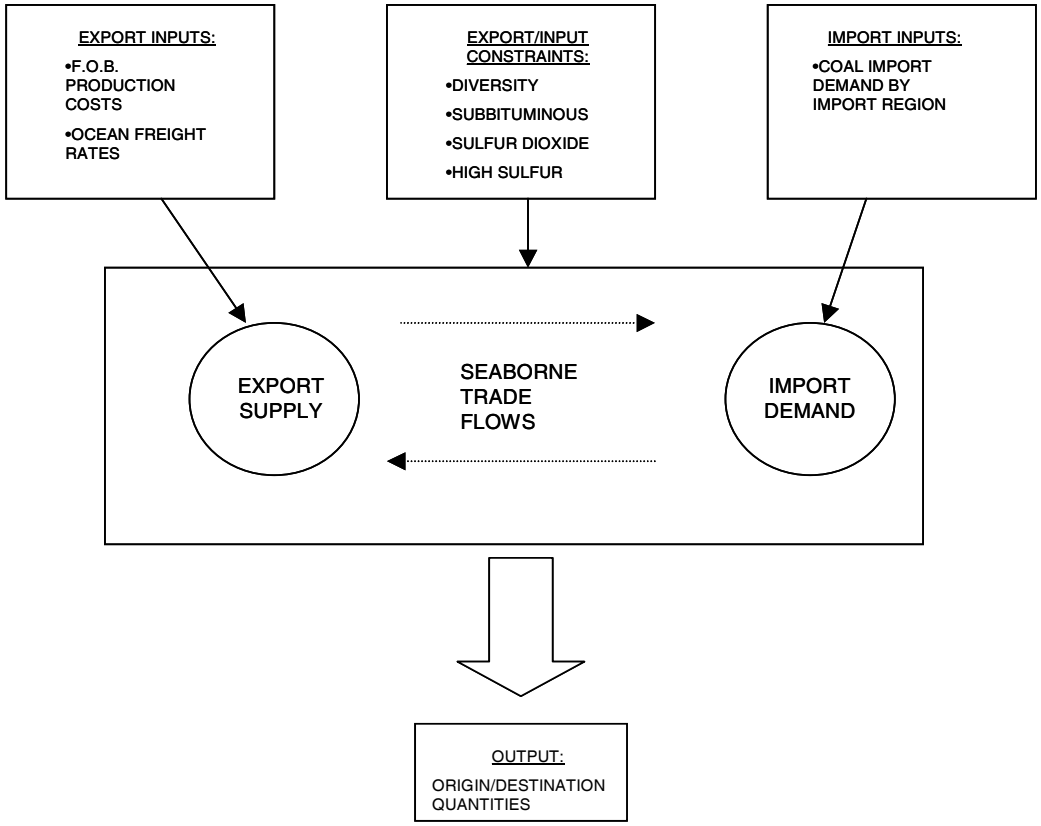
In terms of coal qualities and market segmentation, WOCTES is too restrictive, as it is designed to only analyze the thermal coal market. It also assumes that coal buyers are indifferent between coal types. The ICTM does differentiate between coking and thermal coal, with import demand being similarly differentiated. Demand is specified separately for each coal type with no possibility of cross-supply. This is also too restrictive, because in practice, thermal coal users are able to use coking coals.

The CDS incorporates this linkage between the market segments. This is done by allowing suppliers of coking coal to ship to thermal coal buyers. Suppliers of the different thermal coal grades are not, of course, allowed to ship to coking coal buyers. In order to capture the effects of reduced coal washing costs in producing thermal coal as opposed to coking coals, CDS takes a washery credit off the cost of shipping "coking coal" to thermal coal buyers.

4. Model Structure

The international component of the CDS is specified as part of the overall CDS Linear Program (LP). It satisfies demands at all points at the minimum overall "world" coal cost plus transportation cost (Figure 14). From the output of the model it is possible to determine an optimum pattern of supply.

Figure 14. Overview of the International Component of the CDS



The geographical representation of the "world" is a set of coal export regions (Table 9) and coal import regions (Table 10). 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. This model is driven by fixed (input) coal demands that must be satisfied at the minimum overall cost. Diversity constraints limit the portion of a import region's demands by sector that can be met be each of the individual supply export regions. Subbituminous constraints limit the amount of subbituminous coal that a specific region can import. Sulfur dioxide restrictions constrain each import region to a certain level of sulfur dioxide emissions. Importing countries are also constrained by a maximum expectation of high sulfur coal as a share of their total imports. The linear program minimizes the

costs associated with supplying/exporting coal from one region to a demand/importing region while considering the constraints described above.

Appendix 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 16 coal-exporting regions (5 of which are in the United States) to 20 demand or 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 supply, demand, trade and transportation components. The major coal exporting countries represented include: the United States, Australia, South Africa, Canada, Indonesia, China, Colombia, Venezuela, Poland, and the countries of the Former Soviet Union.

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

Model Update Information: October 2003

Part of Another Model: Yes, optional part of:

- Coal Market Module
- National Energy Modeling System

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

- Coal Distribution Submodule (Domestic Coal Distribution)

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)

Documentation:

- *Coal Export Submodule Component Design Report*, Energy Information Administration, April 1993.
- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System, Part II-B,* DOE/EIA-M060(2004) (Washington, DC, March 2004).

Archive Media and Installation Manual:

NEMS04 - *Annual Energy Outlook 2004*

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

Coverage:

- **Geographic:** 16 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 demands at the lowest cost given specified supply and transportation.
- **Modeling Technique:** The model is a Linear Program (LP), which satisfies demands at all points at the minimum overall "world" coal cost plus transportation cost and is embedded within the Coal Market Module..
- **Special Features:** The model is designed for the analysis of legislation concerned with SO_2 emissions and the trade nonconventional coals (subbituminous coal).
- **Input Data:** Non-DOE sources—SSY Consultancy and Research, McClosky Coal Information, Ltd., International Energy Agency. Published trade and business journal articles, including *Platts: International Coal Report, Energy Publishing: Coal Americas*, *Financial Times: International Coal Report*, *McCloskey Coal Report, World Coal*.

  — Coal Import Demands
  — Coal Supply Curves
  — Ocean Freight Rates
  — Diversity Constraints
  — Sulfur Emission Constraints
  — Subbituminous and High-Sulfur Coal Constraints

DOE sources - none

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

Independent Expert Reviews Conducted:

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

Status of Evaluation Efforts Conducted by Model Sponsor: The international component of the CDS is a model developed for the National Energy Modeling System (NEMS) during the 1992-1993 period and revised in 1994. The version described in this abstract was used in support of the *Annual Energy Outlook 2004*. No subsequent evaluation effort has been made as of the date of this writing.

References:

- Energy Information Administration, Coal *Export Submodule Component Design Report (draft)*, April 1993.

- Energy Information Administration, *Model Documentation, Coal Market Module of the National Energy Modeling System, Part II-B,* DOE/EIA-M060(2003) (Washington, DC, February 2003).

Appendix 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 demands at all points at the minimum overall "world" coal cost plus transportation cost. The model output provides an optimum pattern of supply.

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. This model is driven by fixed (input) coal demands which must be satisfied at the minimum overall cost.

The mathematical specification for the international coal trade optimization program incorporates the following modeling enhancements discussed in Chapter 2. 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 will be accounted for in the model as flow constraints.

Mathematical Formulation

The table of column activity definitions and row constraints defined in the international coal trade matrix incorporate assumptions described in Section 3 on Model Rationale and variable definitions which are described in Appendix D. The general structure of the matrix is shown as a block diagram in Table 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 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, imports, and exports 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, either a (+/-) 1.0. The last table column, labeled RHS contains symbols that represent the physical limitations such as supply capacities or demands.

Table B-1. Linear Program Structure for International Coal Trade

Matrix Structure for International Coal Trade								
	$PX_{i,s,t}$	$TX_{i,j,t}$	$UX_{j,t}$	EXP_i	$IMP_{j,t}$	$QT_{l,j,k,r,u}$	Row Type	RHS
Objective (Cost) EQN (1)	+p	+t						MIN
Production Shipping balance EQN(2)	+1	-1					=	0
Demand balance EQN(3)		+1			-1		=	0
Supply balance EQN(4)	+1		+1	-1			=	0
U.S. export supply balance EQN(5)		-1	+1				=	0
Export constraints EQN(6)		+1		-EC			<	0
Import constraints EQN(7)		+1			-IC		<	0
Demand EQN(8)		+1					=	D
U.S. export demand balance EQN(9)			-1			+1	=	0

p = Production cost
t = Transportation cost
EC = Exporter Constraint
IC = Importer Constraint
D = Demand
MIN = Minimize

Index Definitions

Index Symbol	Description
(I)	Coal export supply region
(j)	Coal export demand region
(k)	Coal export demand sectors
(l)	Coal export supply regions (U.S.)
(s)	Step on coal export supply curve
(t)	Coal type (Thermal or Coking)
(u)	Sulfur level

Column Definitions

Column Notation	Description
$PX_{i,s,t}$	Quantity of coal from step s of export supply curve in export supply region I of coal type t.
$TX_{i,j,t}$	Quantity of coal transported from supply region I to demand region j of coal type t.
$UX_{j,t}$	Quantity of coal exported from (U.S.) Demand region j of coal type t.
EXP_{i}	Sum of coal exported from supply region I.
$IMP_{j,t}$	Sum of coal type t imported from demand region j.
$Qt_{j,k,l,r,u}$	Quantity of coal transported from (U.S.) supply region l to demand region j of coal rank r, sulfur level u for export sector k.

Objective Function

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 export regions to import regions and has been defined as:

$$\sum_{i,s,t} PX_{i,s,t} * P_{i,s,t} + \sum_{i,j,t} TX_{i,j,t} * T_{i,j,t} \quad (1)$$

where,

$P_{i,t,s}$ is the cost from step s of the export supply curve for coal from export region I of coal type t.

$T_{i,j,t}$ is the cost of transportation coal from export region I to coal import region j of coal type t.

Row Constraints

Balance of coal produced and transported from international supply regions.

$$\sum_s PX_{i,s,t} - \sum_j TX_{i,j,t} = 0 \quad (2)$$

Balance of coal imported to international demand regions.

$$\sum_I TX_{i,j,t} - IMP_{j,t} = 0 \quad (3)$$

Balance of coal exported from international supply regions.

$$\sum_s PX_{i,s,t} + \sum_j UX_{j,t} - EXP_{i,t} = 0 \quad (4)$$

Balance of coal transported and exported from U.S. supply regions.

$$UX_{j,t} - \sum_j TX_{i,j,t} = 0 \quad (5)$$

Export constraint from supply regions to demand regions.

$$TX_{i,j,t} - EC_{i,j,t} * EXP_i < 0 \quad (6)$$

Import constraint on demand regions from supply regions.

$$TX_{i,j,t} - IC_{i,j,t} * IMP_{j,t} < 0 \quad (7)$$

Meet the coal demands.

$$\sum_I TX_{i,j,t} = D_{j,t} \quad (8)$$

where,

$D_{j,t}$ Is coal import demand for import region j of coal type t.

Balance of coal transported to meet export demands from U.S. export demand regions.

$$\sum_l QT_{j,k,l,r,u} - UX_{j,t} = 0 \quad (9)$$

Appendix C

Main Subroutines

The functions of the subroutines for the international component of the CDS are described below.

CDS Main controlling subroutine.

Purpose: CDS is the driver subroutine for both the domestic and international components of the Coal Distribution Submodule. It uses a FORTRAN code controlling structure, NEMS integrating model common variables, and its own internal variables to set up and process the LP and to update NEMS variables based on an optimal LP solution.

Equations: None.

CREMTX Create LP Matrix.

Purpose: Creates the rows and columns for both the domestic and international areas of the coal matrix for the first iteration in the first NEMS year. Allocates computer memory and calls the OML subroutine WFOPT to obtain an optimal solution.

Equations: Converts input supply in metric tons to metric tons of coal equivalent:

UBND = CAPYR*(CV/12.6)

where,

CAPYR = coal capacity on each supply step (million metric tons)
CV = Btu conversion for each supply step (thousand Btu/lb)

The factor 12.6 is in units of thousand Btu/lb. This factor represents the heat content per pound in a metric ton of coal equivalent (12.6 thousand Btu/lb = 27.778 million Btu per metric ton of coal equivalent ÷ 2204.623 pounds per metric ton).

Converts costs from 1992 dollars to 1987 dollars in metric tons of coal equivalent:

FLOWCOST=

((FREIGHT+FOBYR)*(12.6/CV))/(1992 GDP deflator/1987 GDP deflator)

where,

FREIGHT = shipping cost (1992 dollars/metric ton)
FOBYR = cost of coal on each supply step (1992 dollars/metric ton)
CV = Btu conversion for each supply step (thousand Btu/lb)

RDCEXIN Reads international data from flat files for CDS matrix coefficients.

Purpose: Reads freight rates, export capacities, demands, diversity shares, conversion factors, and sulfur content for each coal type.

Equations: None.

CREVISE Revise LP matrix and optimize

Purpose: Revises the international portion of the LP matrix and obtains a new optimal solution.

Equations: Converts input supply in metric tons to metric tons of coal equivalent:

UBND = CAPYR*(CV/12.6)

where,

CAPYR = coal capacity on each supply step (million metric tons)
CV = Btu conversion for each supply step (thousand Btu/lb)

The factor 12.6 is in units of thousand Btu/lb. This factor represents the heat content per pound in a metric ton of coal equivalent (12.6 thousand Btu/lb = 27.778 million Btu per metric ton of coal equivalent ÷ 2204.623 pounds per metric ton).

Converts costs from 1992 dollars to 1987 dollars in metric tons of coal equivalent:

FLOWCOST=

((FREIGHT+FOBYR)*(12.6/CV))/(1992 GDP deflator/1987 GDP deflator)

where,

FREIGHT = shipping cost (1992 dollars/metric ton)
FOBYR = cost of coal on each supply step (1992 dollars/metric ton)
CV = Btu conversion for each supply step (thousand Btu/lb)

CEXRPT Produce international coal trade reports

Purpose: Extracts solution values for quantities and prices from the optimal solution and produces formatted reports.

Equations: Trade flows are reported in short tons using the Btu conversion factor for each supply step.

Appendix D

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 A-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. supply regions. The first column contains the international supply region and step identifier. The next five columns contain: 1) the export price of coal (minemouth price plus inland transportation cost) in 1992 dollars per metric ton for 1992; 2) the estimated coal export capacity in million metric tons for 1992; 3) the heat content in thousand BTUs per pound for all forecast years; 4) the sulfur content in percent sulfur by weight for all forecast years; and 5) scalar that permits the user to adjust the international coal supply curves over time at rates that vary from the price path for U.S. export coal. The remaining 12 columns contain estimates of export prices and capacities for each of the coal export supply steps represented in the CDS for the years 1995, 2000, 2005, 2010, 2015, 2020, and 2025.

CLEXDEM. This file contains the coal import demands by international CDS demand region and sector for the years 1990, 1999, 2000, 2001, 2005, 2010, 2015, 2020, and 2025. The first column in the file indicates the year for the import demands contained in each row of the file. The remaining columns contain the coal import demands in metric tons of coal equivalent for each specific combination of international CDS demand 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).

CLEXFRT. This file contains a matrix of ocean transportation rates for coal shipments. The transportation rates are specified by international CDS demand region, supply region, and demand sector (coking and thermal). Each column heading represents a specific international CDS demand region, and each row represents a specific combination of international CDS supply region and demand sector. The rates are specified in 1992 dollars per metric ton.

CLEXEXS. This file contains international import demands for U.S. coal exports for the historical and *Short-Term Energy Outlook* years of the forecast period.[54] Each row includes five indices at the left followed by twelve numbers representing annual demands for U.S. coal exports in trillion Btu for the years 1990 through 2004. 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 Part II-C of the CMM Model Documentation), and (5) the international coal export region to which they pertain.

[54]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 import demands. Each column heading represents a specific combination of international CDS demand region and demand sector (coking and thermal), and each row represents a specific international CDS supply region. The constraints limit the portion of a demand region's import demands by sector that can be met by each of the individual supply regions. For example, an input of 40 for the JAT demand region/sector and US supply 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:** portion of an international CDS demand region's thermal coal import demand that can be met by high-sulfur coal; **Subbituminous Percent:** portion of an international CDS demand region's thermal coal import demand that can be met by subbituminous coal; **Percent Low-Sulfur Coal Scrubbed:** portion of an international CDS demand region's low-sulfur coal import demand that is scrubbed; **Percent High-Sulfur Coal Scrubbed:** portion of an international CDS demand region's high-sulfur coal import demand 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 demand region. These constraints were not used for the *AEO2004* forecasts.

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 D-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 D-1. User-Specified Inputs

Input	CDS Variable	Specification Level[a]	Units
Coal export prices (FOB port of exit)	FOBYR	Coal export region/ coal type/supply-curve step/ forecast year	Dollars per metric ton
Coal export capacity	CAPYR	Coal export region/ coal type/supply-curve step/ forecast year	Million metric tons
Price adjustment factor for non-U.S. supply curves	SCALINT	Coal export region/ coal type/supply-curve step/ forecast year	Scalar
Coal import demand	DEMAND	Coal import region/ coal demand sector/ forecast year	Million metric tons of coal equivalent
Ocean freight rates	FREIGHT	Coal export region/ coal import region/ coal type/coal demand sector	Dollars per metric ton
Importer diversity constraints	IMPSHARE	Coal export region/ coal import region	Percentage
Exporter diversity constraints	EXPSHARE	Coal export region/ coal import region	Percentage
Limit on total SO_2 emissions	MAXSUL	Coal import region/ forecast year	Thousand metric tons
SO_2 emissions "pass-through" rate	LSPCT HSPCT	Coal import region/ coal demand sector/ forecast year	Fraction
Sulfur content assignment for coal supply curve	SULCON	Coal export region/ coal type/supply-curve step	Thousand metric tons of SO_2 emissions per metric ton of coal equivalent
Btu conversion assignment for coal supply curve	CV	Coal export region/ coal type/supply-curve step	Thousand Btu per pound
Maximum share of high-sulfur coal imports	HSMAX	Coal import region/ forecast year	Fraction
Maximum share of subbituminous coal imports	SUBMAX	Coal import region/ forecast year	Fraction

[a]For example, inputs specified at the coal export region/coal type/forecast year level require separate values for each supply region, coal type, and forecast year.

Table D-2. Outputs

Output	CDS Variable	Specification Level	Units
World coal trade flows	SOLVAL	Coal export region/ coal import region/ coal type/coal demand sector/forecast year	Trillion Btu

Appendix E

Data Quality and Estimation

Coal Import Demands are basically regional net import demands for both coking and thermal for snap-shot years 1990, 1999, 2000, 2001, 2005, 2010, 2015, 2020 and 2025. In both cases, demand is projected and domestic production is subtracted to give net imports.

Coking coal demand is generated according to the following process:

- The user assumes pig iron output (in million tons), split between blast furnaces equipped with pulverized coal injection (PCI) and those without. Then applying a coke rate (expressed in tons per ton of hot metal) for the furnace without PCI, and a PCI rate (tons per ton of hot metal), an adjusted coke rate is calculated for the furnaces equipped with PCI. Multiplying the respective pig iron outputs by the corresponding coke rates and summing the results then gives total demand for blast furnace coke in million tons.

- An estimate of any nonblast furnace coke (in million tons) must be added to this figure to give total demand for coke. This total coke demand indicates an import requirement. The amount of domestically produced coke is then multiplied by the average coke oven rate (expressed as tons of feed coal per ton of coke) to give the total demand for coking coal.

Steam coal demand is calculated separately for utility and nonutility sectors.

Utility sector coal demand is calculated according to one of two processes depending on whether utility coal burn is affected or unaffected by load growth, and developments in noncoal capacity.

The following is the logic where coal is the "swing" generation type.

- Future electricity demand is estimated by applying an electricity coefficient of GDP growth and then compounding the initial year demand figure. The generation requirement is then calculated by adding net imports and subtracting transmission losses.

- The next stage calculates generation from nuclear, lignite, orimulsion, and baseload gas plant by applying average plant load factors to expected capacity. These generation figures, along with estimates of renewable and minimum oil generation, are then subtracted from the generation requirement to give potential generation from hard coal plant.

- This potential coal generation is then met successively by generation from advanced coal plants, controlled coal plants (conventional units with desulfurization installations), and finally un-controlled coal plants. In each case, coal generation (calculated with reference to capacity and maximum load factors) is compared with the remaining generation needed, and the plant is dispatched until either it reaches its maximum availability or demand is met. Any remaining generation requirement that is not met after all the coal capacity has been fully dispatched then is assumed to be met by oil plants.

- Coal burn is then calculated by applying the relevant average station efficiencies to generation from each type of coal plant and summing the products.

- In the simplified procedure, coal generation is calculated without reference to electricity demand growth, simply by applying reasonable load factors to projected capacity. Coal generation is expressed as a share

of total generation, so the model user can check that coal generation is reasonable. As in the previous method, coal burn is calculated by applying average station efficiencies to coal generation.

Nonutility thermal coal use, excepting that for PCI installations, is exogenously estimated by the user for the following three categories:

- Cement industry
- Other industry
- Domestic users.

PCI coal use, which is calculated in the steel sector component, is the product of output of blast furnace equipped with PCI and the average PCI injection rate.

Coal 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 and Btu) can 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 supply for each exporting country determine the prices associated with steps on the supply curves representing new mine capacity.

Shipping Costs start from a matrix of feasible supply 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 = distance in thousand nautical miles (1 nautical mile = 6076.115 feet)
tonne = metric ton (2204.623 pounds)
dwt = deadweight ton (2240 pounds)

Users can adjust freight rates using an add-factor matrix to take account of backhaul savings, canal tolls, slow unloading terms, etc. This add-factor matrix incorporates a $2.00/t "washery credit" which is subtracted from every freight rate between a coking coal supplier and a thermal coal buyer.

Appendix F

Optimization and Modeling Library (OML) Subroutines and Functions

This appendix provides a summary of the OML routines that are called by the international area of 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 G

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