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Model Documentation

Coal Market Module

of the National Energy Modeling System

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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 1999 (AEO99)*. 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 the 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 CDS integrates the supply inputs from the CPS to satisfy demands for coal 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 E, 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.1997) 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 producer price index for rail 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 sections 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 section provide supporting documentation for the CMM files currently residing on a computer workstation at EIA. Each Appendix A lists and defines the CMM input data, parameter estimates, forecast variables, and model outputs. A table referencing the equations in which each variable appears is also provided in Appendix A. Each Appendix B contains a mathematical description of the computational algorithms used in the respective submodules of the CMM, including model equations and variable transformations. Each Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of model abstracts, and Appendix E discusses data quality and estimation methods.

Part I—Coal Production Submodule Model Documentation

1. Introduction

Statement of Purpose

This chapter documents the objectives and the conceptual and methodological approach used in the development of the Coal Production Submodule (CPS). It provides a description of the CPS for model analysts and the public. The chapter describes 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 this chapter addresses the relationship between the minemouth price of coal and corresponding levels of coal production, labor productivity, and the costs of factor inputs (mining equipment, mine labor, and fuel).[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 1996. The regression equation, together with projected levels of 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 production.

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.

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[1]The measure used for the price of fuel in the AEO99 coal pricing model was the price of electricity to industrial consumers. According to data published by the U.S. Department of Commerce, electricity accounted for 84 percent of the fuel costs at U.S. underground mines in 1992 and an estimated 36 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 11 percent of the fuel costs at underground mines in 1992 and 42 percent of the fuel costs at surface mines. U.S. Census Bureau, 1992 Census of Mineral Industries, web site www.census.gov (accessed April 9, 1998).

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 1999*.

Name: Coal Production Submodule
Acronym: CPS
Archive Package: NEMS99 (Available from the Energy Information Administration, Office of Integrated Analysis and Forecasting)
Model Contact: Michael Mellish, Department of Energy, EI-82, Washington, DC 20585 (202) 586-2136, or (mmellish@eia.doe.gov)

Report Organization

This report describes the modeling approach used in the Coal Production Submodule. Subsequent sections of this report 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 are included in the Appendices.

2. Model Purpose and Scope

Model Objectives

The objective of the CPS is to develop mid-term (to 2020) annual domestic coal supply curves for the Coal Distribution Submodule (CDS) of the Coal Market Module (CMM) of the National Energy Modeling System (NEMS). The supply curves relate annual production to the marginal cost of supplying coal. Separate supply curves are developed for each unique combination of supply region, mine type (surface or underground), and coal type.

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

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 low, medium, and high. The low sulfur grade corresponds to the limitation on sulfur dioxide emissions that electric utilities are required to meet by 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, 12 coal types (unique combinations of thermal grade, sulfur content, and mine type) are represented in the CPS (Table 1). Thermal grades are in million Btu per ton and sulfur grades are in pounds of sulfur 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.

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,CDB,MDB,HDB	CSB,MSB,HSB,HSL
2. "CA"-Central Appalachia	So.WV,VA & East KY	CDP,CDB,MDB	CSB,MSB
3. "SA"-Southern Appalachia	AL & TN	CDP,CDB,MDB	CSB,MSB
Interior			
4. "EI"-East Interior	West KY, IL & IN	MDB,HDB	MSB,HSB
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		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

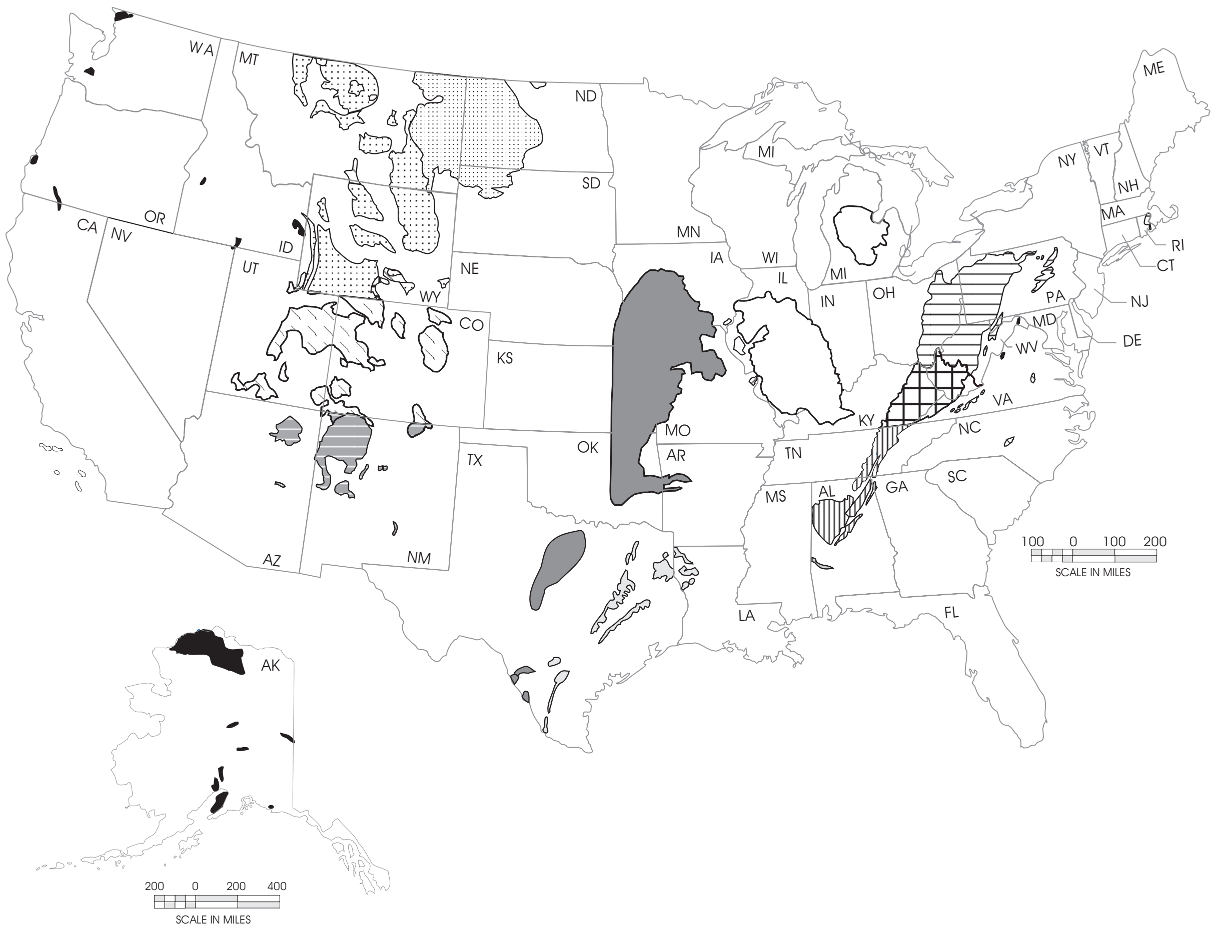
MINE TYPES

"_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

Figure 1. CMM Coal Supply Regions



APPALACHIA	INTERIOR	NORTHERN GREAT PLAINS	OTHER WEST
1. Northern Appalachia	4. Eastern Interior	7. Dakota Lignite	9. Rocky Mountain
2. Central Appalachia	5. Western Interior	8. Powder and Green River Basins	10. Southwest
3. Southern Appalachia	6. Gulf Lignite		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: coal production, 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 index numbers for the annual user-cost of mining equipment. Inputs obtained from other NEMS modules include coal production for year t-1, the minemouth coal price for years t and t-1, and electricity prices (Figure 2). Appendix A includes a complete list of input variables and specification levels.

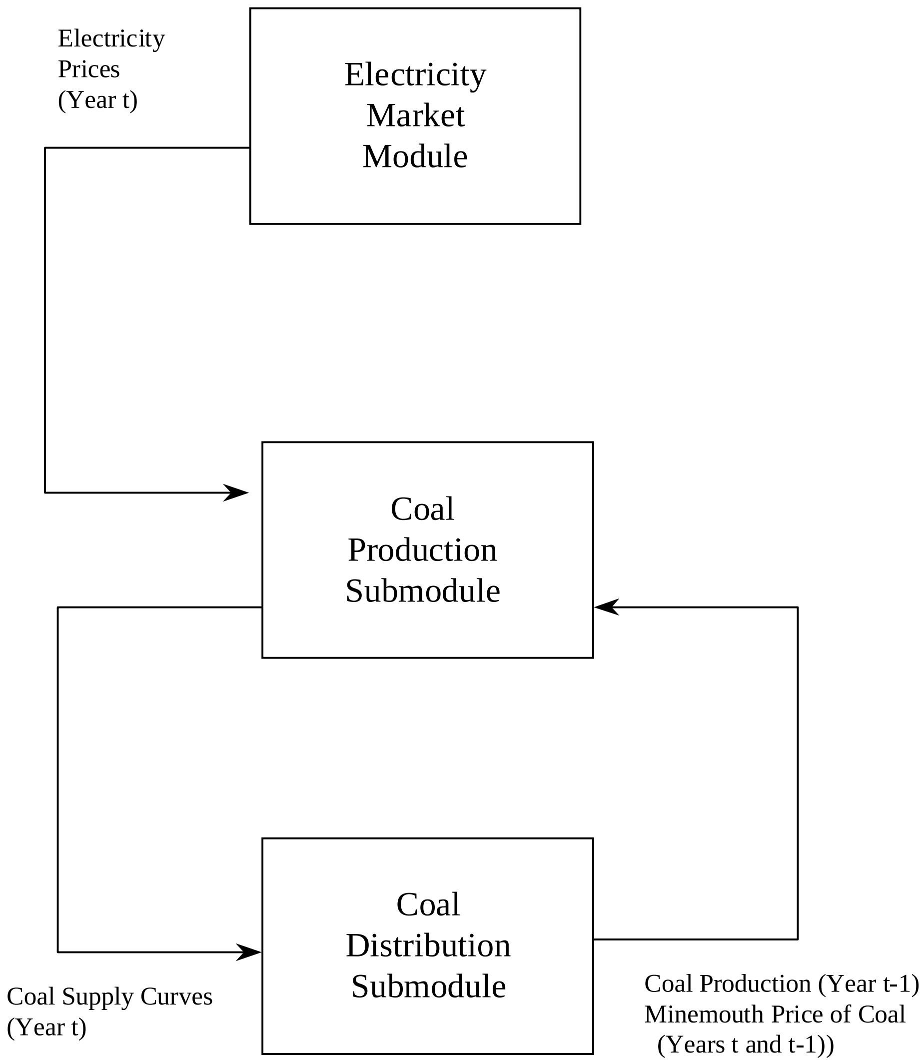
The primary outputs of the model are annual coal supply curves (price/production schedules), provided for each supply region, mine type, and coal type.

Relationship to Other Modules

The model generates regional mid-term (to 2020) coal supply curves. A distinct set of supply curves is determined for each forecast year. The supply curves are required by the CDS submodule 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
- 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 coal production, labor productivity, and the costs of factor inputs (mining equipment, mine labor, and fuel). These relationships are estimated through the use of a regression model that makes use of historical regional level data. The regression equation, together with projected levels of 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 production.

Underlying Rationale

This section presents the econometric model used to produce coal supply curves for the *AEO99* 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 1996, the average mine price of coal in the United States declined by 61 percent, in constant 1992 dollars, from $42.98 per ton in 1978 to $16.89 per ton in 1996 (Figure 3). During the same period, total U.S. coal production increased by 59 percent, from 680 million tons in 1978 to 1,064 million tons in 1996. The inverse relationship between the production of coal and its price over time is attributable to a host of 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 1996, labor productivity at U.S. mines rose from 1.77 tons per miner hour to 5.69 tons per miner hour, representing an increase of 6.7 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 observations (unique combinations of region, mine type, and year) represented in the *AEO99* coal pricing model indicates the strong historical correlation between prices and productivity (Figure 4).

Figure 3. U.S. Coal Production and Prices, 1978-1996

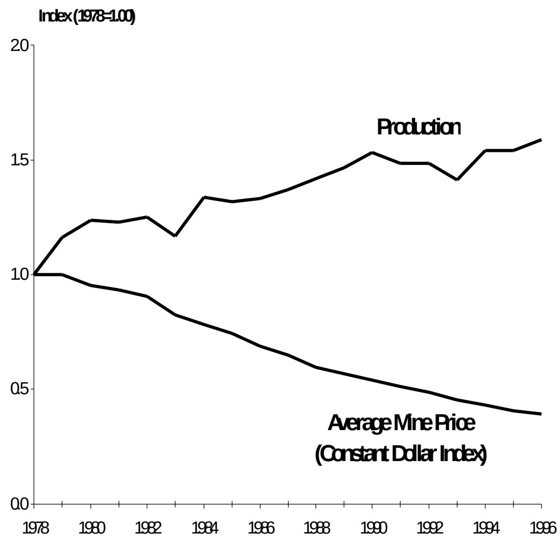
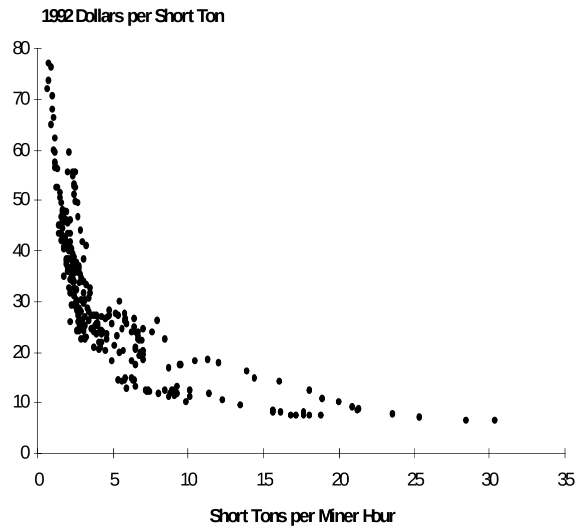


Figure 4. Minemouth Coal Prices and Labor Productivity for CMM Regions and Mine Types, 1978-1996



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.[2] 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.

The formal specification of the coal pricing model for *AEO99* is as follows.

For demand:

$$Q^D = f(P, TRAN, ELEC, INDUSTRY, OTHPROD, EXPORTS, PGAS, WOP, STOCKS, BTU\_TON, SULFUR, P\_UTIL) + e^D \quad (1)$$

Supply:

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

[2]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 an index of electricity generation requirements for each year t.

INDUSTRY is an index of industrial output 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.

P_UTIL is the average delivered price of coal received at electric utility plants in constant 1992 dollars per million Btu 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 from region i, mine type j, in year t in million tons.

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 an index representing the annualized user cost of mining equipment in year t. The index is adjusted to constant 1992 dollars.

PFUEL is the average price of electricity in the industrial sector in 1992 cents per kilowatthour 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, the heat and sulfur content of the coal, and the average delivered price of coal at electric utility plants. On the supply side of the market, the minemouth price is assumed to be determined by the quantity of coal produced, 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 *AEO99* 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 (eS) affects the minemouth price (P); however, in Equation (1), price influences the quantity demanded (QD). As a result, the quantity of coal supplied (QS) 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, 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, as well as the cost of mining equipment. 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.[3] 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 *AEO99*. 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 the constant term) are transformed by taking their natural logarithm. All 285 observations were pooled into a single regression equation. In addition to the overall constant term for the model, intercept dummy variables were included for all regions except Central Appalachia. Regional slope dummy variables were included for the productivity and production 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. The statistical results of the regression analysis and the

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

equation used for predicting future levels of minemouth coal prices by region, mine type, and coal type are provided in Appendix E.

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. 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 and Factor Input Costs

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 an entirely new mining system penetrating the market. One must return to the late 1940's, and the development 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.[4] 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.[5] 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 48 percent in 1995.[6] For surface mines, the size and capacity of the various types of equipment used (including shovels, draglines, front-end loaders, and trucks) has gradually increased over time, leading to steady growth in the average productivity of these mines.

Whether technological change represents improvements to existing technologies or fundamental changes in technology systems, the change has a substantial impact on productivity and costs. With few exceptions, transition in the coal industry to new technology has been gradual, and the effect on productivity and cost also has been gradual.[7] 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:[8]

- A continuation in the trend toward increased continuous miner mining and loading rates

- Introduction of equipment with self-diagnostic capabilities

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[4]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).

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

[6]Energy Information Administration, *Coal Data: A Reference,* DOE/EIA-0064(90) (Washington, DC, November 1991), p. 10; and *Coal Industry Annual 1995,* DOE/EIA-0584(95) (Washington, DC, October 1996), Table 5.

[7]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.

[8]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).

- 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 supersections.

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.

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)

The RAMC generated coal supply curves that were used as input to other EIA models—most notably the CSTM.[9] The CSTM 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.[10] 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).[11] 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 somewhat different methods

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

[10]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.

[11]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).

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.[12]

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.[13]

DRI/Zimmerman Model

The DRI/Zimmerman coal model was used to develop mid-term forecasts for DRI Inc.'s coal analysis and forecasting service.[14] 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.[15] 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.[16] 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.[17] 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.[18] 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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[12]Science Applications International Corporation, "An Econometric Model of Coal Supply: Final Report," (unpublished report prepared for the Energy Information Administration, December 20, 1996).

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

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

[15]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.

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

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

[18]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 detailed description of the model, including a discussion of the key mathematical relationships and procedures for constructing the supply curves. The estimating equations and a flow diagram showing the sequence of computations are included in Appendix B.

The model constructs a distinct set of supply curves for each forecast year in three separate steps, 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 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 supply region, mine type, and coal type. 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 constant value is computed as follows:

$$C_{i,j,k} = BYP_{i,j,k} - MP_{i,j,k}$$

where

$C_{i,j,k}$ = constant to be added to the regression equation for supply region i, mine type j, and coal type k

$BYP_{i,j,k}$ = Actual base year price for region i, mine type j, and coal type k (dollars/ton)

$MP_{i,j,k}$ = Price computed from regression equation using base year values of the independent variables, for region i, mine type j, and coal type k (dollars/ton)

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.

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 *AEO99*, 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-production terms in the regression equation into a single multiplier ($K_{i,j,k}$), computed using the forecast year values of the independent variables. The value of $K_{i,j,k}$ is computed by solving the regression equation for production equal to zero and all other independent variables equal to their forecast year values. A separate value of $K_{i,j,k}$ is computed for each region i, mine type j, and coal type k. The required forecast year values of the various independent variables are defined exogenously, with the exception of electricity prices (which are obtained from the Electricity Market Module), and lagged price and production (which are obtained from the CDS final solution for the year prior to the forecast year). 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 marginal cost regression 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.

The coal-pricing regression model used by the CPS to produce coal supply curves has the following specific form:

$$MMP_{i,j,k,t} = \{EXP[(B + \beta_{i,1}) * (1-\beta_{11})]\} * [(Q_{i,j,k,t})^{(\beta_2 + \beta_{j,3})}] * [(TPH_{i,j,t})^{(\beta_4 + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7})}] *$$

$$[(WAGE_t)^{\beta_8}] * [(PCAP_t)^{\beta_9}] * [(PFUEL_{i,t})^{\beta_{10}}] * [(MMP_{i,j,k,t-1})^{\beta_{11}}] *$$

$$[(Q_{i,j,k,t-1})^{(-\beta_{11} * (\beta_2 + \beta_{j,3}))}] * [(TPH_{i,j,t-1})^{(-\beta_{11} * (\beta_4 + \beta_{j,5} + \beta_{i,6} + \beta_{i,j,7}))}] *$$

$$[(WAGE_{t-1})^{(-\beta_{11} * \beta_8)}] * [(PCAP_{t-1})^{(-\beta_{11} * \beta_9)}] * [(PFUEL_{i,t-1})^{(-\beta_{11} * \beta_{10})}$$

where,

Variables

MMPi,j,k,t	-	average annual minemouth price of coal in supply region i, mine type j, and coal type k
B	-	overall constant term for the model
Qi,j,k,t	-	annual coal production in supply region i, mine type j, and coal type k
$TPH_{i,j,t}$	-	coal mine labor productivity (tons per miner hour) by supply region i, and mine type j
$WAGE_t$	-	average annual wage for coal miners in supply region i
$PCAP_t$	-	index for the annual user cost of capital
$PFUEL_{i,t}$	-	average annual price of electricity in the industrial sector in supply region i

Regression Coefficients

$\beta_{i,1}$ - coefficients for intercept dummy variables for each supply region i
β_2 - coefficient for the production term
$\beta_{j,3}$ - coefficients for the production term by mine type j
β_4 - coefficient for the labor productivity term
$\beta_{i,5}$ - coefficients for the labor productivity term by supply region i
$\beta_{j,6}$ - coefficients for the labor productivity term by mine type j
$\beta_{i,j,7}$ - coefficients for the labor productivity term by supply region i and mine type j
β_8 - coefficient for the labor cost term
β_9 - coefficient for the user cost of capital term
β_{10} - coefficient for the electricity price term
β_{11} - coefficient for the first-order autocorrelation term

Regression results for the marginal cost models are provided in Appendix E.

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 price and percent variations from that price, an 8-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 price that creates the optimal 8-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 price 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 8 prices corresponding to fixed percentages of a target price obtained from the CDS. The model then computes the production corresponding to each of the 8 prices, using the supply curve equations. Finally, prices for each step are adjusted to the year dollars required by the CDS using an exogenously supplied GDP price deflator. 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 CPS equation used for generating the step-function supply curves is as follows:

$$Q_{i,j,k,z,t} = [(P_{i,j,k,z,t} - C_{i,j,k})/K_{i,j,k,t}]^{(1/(\beta_2 + \beta_{j,3}))} - [(P_{i,j,k,z-1,t} - C_{i,j,k})/K_{i,j,k,t}]^{(1/(\beta_2 + \beta_{j,3}))}$$

where

$P_{i,j,k,z}$ - price associated with step z for region i, mine type j, coal type k, and year t
$Q_{i,j,k,z}$ - production associated with step z for region i, mine type j, coal type k, and year t
β_2 - overall coefficient for the production term
$\beta_{j,3}$ - coefficients for the production term by mine type j
$C_{i,j,k}$ - calibration constant for each supply curve
$K_{i,j,k,t}$ - multiplier for the non-production terms in the regression equation

Appendix A

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 NEWS components.

<u>CLUSER</u>. User-specified inputs are listed in Table A-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 *AEO99*, 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 database for coal consumed at electric utilities, and from the EIA-3A and EIA-5A databases for coal consumed at industrial facilities and coke plants, respectively.

The values for the input variables listed in Table A-1 are contained in the file CLUSER--a single "flat" file. This file contains three main groups of data: 1) forecast-year estimates for labor costs, coal-mine productivity, and capital equipment costs; 2) base-year quantities for production, prices, and coal quality (heat content, sulfur content, and carbon dioxide emission factors) by supply curve; and 3) coefficients for the CPS coal-pricing equation.

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

Inputs Provided by Other NEMS Components. Table A-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 and production and prices by CPS supply curve are obtained from the Coal Distribution Submodule.

Table A-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 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 (1997) coal price (surface and deep)	Supply region/ coal type	1987 Dollars/Ton	--	EIA-7A
CAPB	Average mine capacity utilization (surface and deep)	Supply region	Fraction	--	EIA-7A
OCONT	Overall constant for CPS regression model	National	--	B	Regression analysis
LQ	Pricing model coefficient (production term)	National	--	β_2	Regression analysis
LWAGE	Pricing model coefficient (labor cost term)	National	--	β_8	Regression analysis
LPCAP	Pricing model coefficient (cost of capital term)	National	--	β_9	Regression analysis

Table A-1. User-Specified Inputs Required by the CPS (Continued)

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
LPFUEL	Pricing model coefficient (electricity price term)	Supply region	--	β_{10}	Regression analysis
TPH	Pricing model coefficient (overall productivity term)	National	--	β_4	Regression analysis
TPH_DEEP	Pricing model coefficient (mine type productivity)	Mine type	--	$\beta_{j,6}$	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
B_WAGE	Base-Year Hourly Wage	National	1987 Dollars/Hour	WAGE	Bureau of Labor Statistics
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	--	$\beta_{i,5}$	Regression analysis
DPROD	Pricing model coefficients (regional and mine type productivity terms)	Supply region/ mine type	--	$\beta_{i,j,7}$	Regression analysis
PK	Annual user cost of capital	National/year	Index	PCAP	Bureau of Labor Statistics
PCNT_REC	Number of marginal cost curves	National	--	--	File definition
PCNT_ REGION	Numerical supply region identifier	Supply region	--	--	Model definition
PCNT_CTYPE	Numerical coal type identifier	Coal type	--	--	Model definition
PCNT_PRICE	Initial target price used to build step-function curves with 8 steps	Supply region/ mine type/ coal type	1987 Dollars/ton	--	EIA-7A

Table A-1. User-Specified Inputs Required by the CPS (Continued)

CPS Variable Name	Description	Specification Level	Units	Variable Used in this Report	Source(s)
PCNT_PROD	Base year production	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

Table A-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/ million Btu	--	EMM
$O\_MCNT\_PRICE_{t-1}$	Minemouth price in year t-1	Supply region/ mine type/ coal type/year	Dollars/ ton	$MMP_{i,j,k,t-1}$	CDS
$O\_MCNT\_PROD_{t-1}$	Coal production in year t-1	Supply region/ mine type/ coal type/year	Million tons	$Q_{i,j,k,t-1}$	CDS
MCNT_PRICE	Target prices for years t > 1, used to build step-function curves with 8 steps	Supply region/ mine type/ coal type/year	Dollars/ ton	$P_{i,j,k,z=1,t}$	CDS

Model Outputs

The primary output from the model are step-function supply curves provided to the CDS. The general form of equations representing the coal supply curves is as follows:

$$P_{ijk} = C_{ijk} + [K_{ijk} * Q_{ijk}^{(\beta_2 + \beta_{j,3})}] \qquad (1)$$

where

P_{ijk} price in region i, mine type j, and coal type k
Q_{ijk} production in region i, mine type j, and coal type k
C_{ijk} calibration constant
K_{ijk} multiplier for the non-production terms in the regression equation
β_2 overall coefficient for the production term
$\beta_{j,3}$ coefficients for the production term by mine type j

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 and sulfur content, and for carbon dioxide emission factors (Table A-3).

Table A-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_SULFUR	Average sulfur content for each CPS supply curve step provided to the CDS	lbs/MMBtu	--
MCNT_CAR	Average carbon dioxide emission factor for each CPS supply curve step provided to the CDS	lbs/MMBtu	--

Model Endogenous Variables

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

CPS Variable Name	Description	Units	Variable Used in this Report
L_PROD	Labor productivity for NEMS forecast years	Tons/miner hour	--
F_INDEX	Base year price of electricity to industrial consumers	1992 cents/ kilowatthour	--
E_FUEL	Electricity prices for NEMS forecast years	1992 cents/ kilowatthour	--
R_WAGE	Average coal industry wage for NEMS forecast years	1992 dollars/ hour	--
YINT	CPS calibration constant	--	$C_{i,j,k}$
FP	Multiplier for non-production terms in the CPS coal pricing equation	--	$K_{i,j,k,t}$
SC_PRICE	Prices for each of the steps on the 8-step supply curves input to the CDS	1992 dollars/ton	$P_{i,j,k,t}$
SC_QUAN	Quantities for each of the steps on the 8-step supply curves input to the CDS	Million tons	$Q_{i,j,k,t}$

Appendix B

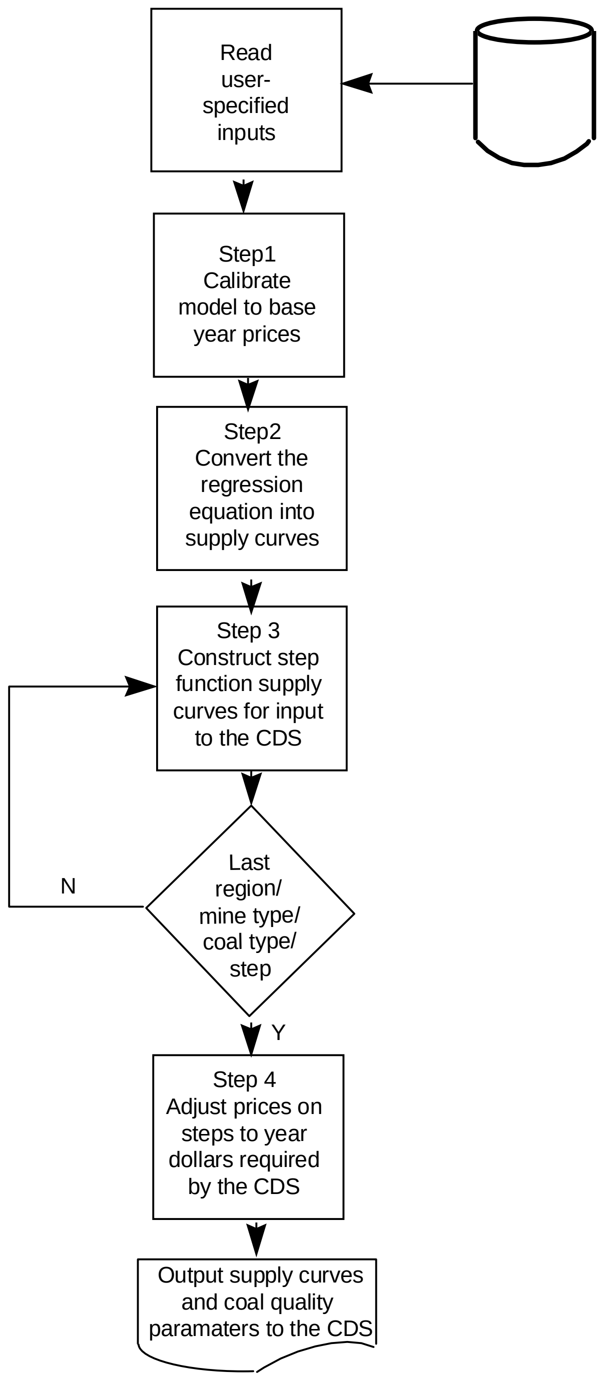
Detailed Mathematical Description of the Model

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
- Step 4: Adjust the supply curves to year dollars required by the CDS

Figure B-1 is a flow chart of the model.

Figure B1. CPS Flowchart



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
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 2.

$$MP_{i,j,k,by} = \{EXP[(B + \beta_{i,1}) * (1-\beta_{11})]\} * [TPH_{i,j,t=1}^{(TPHBM * (1-\beta_{11}))}] * [(Q_{i,j,k,by})^{(\beta_2 + \beta_{j,3})}] * \quad (2)$$

$$[(TPH_{i,j,by})^{(\beta_4 + \beta_{i,5} + \beta_{i,6} + \beta_{i,j,7})}] * [(WAGE_{by})^{\beta_8}] * [(PCAP_t)^{\beta_9}] * [(PFUEL_{i,t})^{\beta_{10}}] *$$

$$[(MMP_{i,j,k,by})^{\beta_{11}}] * [(Q_{i,j,k,by})^{(-\beta_{11} * (\beta_2 + \beta_{j,3}))}] * [(TPH_{i,j,by})^{(-\beta_{11} * (\beta_4 + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7}))}] *$$

$$[(WAGE_{by})^{(-\beta_{11} * \beta_8)}] * [(PCAP_t)^{(-\beta_{11} * \beta_9)}] * [(PFUEL_{i,t})^{(-\beta_{11} * \beta_{10})}]$$

where,

Variables

$MP_{i,j,k,by}$	- 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
B	- 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
$Q_{i,j,k,by}$	- annual coal production in supply region i, mine type j, and coal type k
$TPH_{i,j,by}$	- coal mine labor productivity for supply region i, and mine type j
$WAGE_{by}$	- average hourly wage for coal miners
$PCAP_t$	- index for the annual user cost of capital
$PFUEL_{i,t}$	- average annual electricity price for supply region i
$MMP_{i,j,k,by}$	- average minemouth price of coal for supply region i, mine type j, and coal type k

Regression Coefficients

$\beta_{i,1}$ - coefficients for intercept dummy variables for each supply region i
β_2 - coefficient for the production term
$\beta_{j,3}$ - coefficients for the production term by mine type j
β_4 - coefficient for the labor productivity term
$\beta_{i,5}$ - coefficients for the labor productivity term by supply region i
$\beta_{j,6}$ - coefficients for the labor productivity term by mine type j
$\beta_{i,j,7}$ - coefficients for the labor productivity term by supply region i and mine type j
β_8 - coefficient for the labor cost term
β_9 - coefficient for the user cost of capital term
β_{10} - coefficient for the fuel price term
β_{11} - coefficient for the first-order autocorrelation term

For calibration purposes, base year values of production, 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 3, the calibration constants are determined as the difference between the minemouth price of coal(MPi,j,k,t) calculated with the CPS pricing equation and the corresponding base year price (also provided as an input).

$$C_{i,j,k} = (BYP_{i,j,k,by} - MP_{i,j,k,by}) \qquad (3)$$

where

$C_{i,j,k}$ - 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

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

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

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 4.

$$
\begin{aligned}
K_{i,j,k,t} = {} & \{EXP[(B + \beta_{i,1}) * (1-\beta_{10})]\} * [TPH_{i,j,t=1}{}^{(TPHBM * (1-\beta_{10}))}] * \\
& [(TPH_{i,j,t})^{(\beta_4 + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7})}] * [(WAGE_t)^{\beta_8}] * [(PCAP_t)^{\beta_9}] * \\
& [(PFUEL_{i,t})^{\beta_{10}}] * [(MMP_{i,j,k,t-1})^{\beta_{11}}] * [(Q_{i,j,k,t-1})^{(-\beta_{11} * (\beta_2 + \beta_{j,3}))}] * \\
& [(TPH_{i,j,t-1})^{(-\beta_{11} * (\beta_4 + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7}))}] * [(WAGE_{t-1})^{(-\beta_{11} * \beta_8)}] * \\
& [(PCAP_{t-1})^{(-\beta_{11} * \beta_9)}] * [(PFUEL_{i,t-1})^{(-\beta_{11} * \beta_{10})}
\end{aligned}
\qquad (4)
$$

where,

<u>Variables</u>

$K_{i,j,k,t}$	- annual multiplier, specified by supply region i, mine type j, and coal type k, calculated by solving the CPS coal pricing equation for production for year t equal to zero and all other independent variables set equal to their forecast-year values (for both years t and t-1)
B	- overall constant term for the model
TPHBM	- benchmark factor used for calibrating the equation to the actual value of the minemouth coal price in year one of the forecast period[19]
$TPH_{i,j,t}$	- coal mine labor productivity in 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
$PFUEL_{i,t}$	- average annual electricity price in supply region i and year t
$MMP_{i,j,k,t-1}$	- average minemouth price of coal for supply region i, mine type j, coal type k, and year t-1
$Q_{i,j,k,t-1}$	- annual coal production in supply region i, mine type j, coal type k, and year t-1
$TPH_{i,j,t-1}$	- coal mine labor productivity in 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
$PFUEL_{i,t-1}$	- average annual electricity price in supply region i and year t-1

<u>Regression Coefficients</u>

$\beta_{i,1}$	- coefficients for intercept dummy variables for each supply region i
β_2	- coefficient for the production term
$\beta_{j,3}$	- coefficients for the production term by mine type j
β_4	- coefficient for the labor productivity term

---

[19]This benchmark factor was required because of an adjustment made to the point estimate for the overall productivity coefficient in the *AEO99* forecasts. The point estimate for the productivity coefficient was reduced by two standard deviations, reflecting the view that coal mine operators will not continue to pass along cost savings obtained from productivity improvements to the extent that they have during the preceding 20-year period.

$\beta_{i,5}$ - coefficients for the labor productivity term by supply region i
$\beta_{j,6}$ - coefficients for the labor productivity term by mine type j
$\beta_{i,j,7}$ - coefficients for the labor productivity term by supply region i and mine type j
β_8 - coefficient for the labor cost term
β_9 - coefficient for the user cost of capital term
β_{10} - coefficient for the fuel price term
β_{11} - coefficient for the first-order autocorrelation term

A separate value of $K_{i,j,k}$ is computed for each region i, mine type j, coal type k, and year t. The required forecast year values of the various independent variables are defined exogenously, with the exception of regional electricity prices (which are obtained from the Electricity Market Module), and lagged price and production (which are obtained from the CDS final solution for the year prior to the forecast year).

Incorporating the calibration constant and the production term, the CPS supply curves take on the following form:

$$RMP_{i,j,k,t} = C_{i,j,k} + [K_{i,j,k,t} * Q_{i,j,k,t}^{(\beta_2 + \beta_{j,3})}] \quad (5)$$

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

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 price and percent variations from that price, an 8-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 price that creates the optimal 8-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 price 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 8 prices corresponding to fixed percentages of a target price obtained from the CDS. The model then computes the production corresponding to each of the 8 prices, using the supply curve equations.

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

$$Q_{i,j,k,z,t} = [(P_{i,j,k,z,t} - C_{i,j,k})/K_{i,j,k,t}]^{(1/(\beta_2 + \beta_{j,3}))} - [(P_{i,j,k,z-1,t} - C_{i,j,k})/K_{i,j,k,t}]^{(1/(\beta_2 + \beta_{j,3}))} \quad (6)$$

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. The target price 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.

$Q_{i,j,k,z}$ - production associated with step z for region i, mine type j, coal type k, and year t
β_2 - overall coefficient for the production term
$\beta_{j,3}$ - coefficients for the production term by mine type j
$C_{i,j,k}$ - calibration constant for each supply curve
$K_{i,j,k,t}$ - multiplier for the non-production terms in the regression equation

Step 4: Adjust the supply curves to year dollars required by the CDS

In Step 4, the supply curves are converted into the year dollars required by the CDS as follows:

$$MCNT\_P_{i,j,k,z,t} = P_{i,j,k,z,t} * DEF \quad (7)$$

where

$P_{i,j,k,z,t}$ - unadjusted price associated with each CPS supply curve step generated for input to the CDS

MCN_T_{ijk} - adjusted price associated with each CPS supply curve step generated for input to the CDS

DEF - GDP deflator/inflator (exogenous input)

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

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Appendix D

Model Abstract

Model Name: Coal Production Submodule

Model Acronym: CPS

Description: Produces supply-price relationships for 12 coal types and 11 producing regions, addressing the relationship between the minemouth price of coal and corresponding levels of coal production, 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).

Purpose of the Model: The purpose of the model is to produce annual domestic coal supply curves for the mid-term (to 2020) for the Coal Distribution Submodule of the Coal Market Module of the NEMS.

Model Update Information: November 1998

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
- Petroleum Market Module

Official Model Representative:

Office: Integrated Analysis and Forecasting

Division: Coal and Electric Power

Model Contact: Michael Mellish

Telephone: (202) 586-2136

E-mail: Michael Mellish (mmellish@eia.doe.gov)

Documentation:

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

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Archive Media and Installation Manual: NEMS99 - *Annual Energy Outlook 1999*

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:** 1990 through 2020

- **Product(s):** 12 coal types

- **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 production, 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 and the Petroleum Market Module.

- **Input Data:** Base year values for U.S. coal production, productivity, and prices. Base year electricity prices and wages. Heat and sulfur 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-3A, EIA-5A, EIA-6, and EIA-7A databases. Energy Information Administration, *Electric Power Annual 1997, Volume II*, (DOE/EIA-0348(97) (Washington, DC, October 1998), Table 7 and *State Energy Price and Expenditure Report 1995*, (DOE/EIA-0376(95) (Washington, DC, August 1998). 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#. DRI/McGraw Hill, Yield on Utility Bonds.

Computing Environment:

- **Hardware Used:** IBM/RS6000
- **Operating System:** AIX (UNIX)
- **Language Used:** FORTRAN

Independent Expert Reviews Conducted:

- 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 1999*. No prior evaluation effort has been made as of the date of this writing.

References:

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Appendix E

Data Quality and Estimation

Data Series Used in the 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, and the costs of factor inputs (mining equipment, mine labor, and fuel). 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 *AEO99*. 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 1978 through 1996.[20] In all, the model includes 285 observations (15 observations per year (10 surface and 5 underground) for each of the 19 years represented in the historical data series).

All data were pooled into a single regression equation. In addition to the overall constant term for the model, intercept dummy variables were included for all regions except Central Appalachia. Regional slope dummy variables were included for the productivity and production variables to allow the coefficients for those terms to vary across regions and mine types.[21] 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. Dummy variables were used for the productivity and production variables to allow slope coefficients to vary across regions and mine types.

The two-stage least squares regression equation for the CPS was estimated using the AR1 (first-order serial correlation) procedure in TSP 4.4 with the INST option. The form of the CPS regression equation and the associated regression statistics are presented below and in Table E1, respectively. The sources for the various historical data series used in the regression model are shown in Tables E2 and E3.

[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.

[21]Regional slope dummy variables for the productivity term for the Western Interior, Dakota Lignite, and Rocky Mountain (underground mines) regions were excluded from the coal pricing model, because they were not significant at the 10 percent level.

Based on the regression results shown in Table E1, the equation used for predicting future levels of minemouth coal prices by region, mine type and coal type for *AEO99* is:

$$P_{i,j,k,t} = \psi_{i,j,k,t} + [C_{i,j,k,t} * Q_{i,j,k,t}^{(\beta_2 + \beta_{j,3})} * TPH_{i,j,t}^{((\beta_4 + (k * SE)) + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7})} * WAGE_t^{\beta_8} * \quad (A1)$$

$$PCAP_t^{\beta_9} * PFUEL_{i,t}^{\beta_{10}} * P_{i,j,k,t-1}^{\beta_{11}} * Q_{i,j,k,t-1}^{(-\beta_{11} * (\beta_2 + \beta_{j,3}))} *$$

$$TPH_{i,j,t-1}^{(-\beta_{11} * ((\beta_4 + (k * SE)) + \beta_{i,5} + \beta_{j,6} + \beta_{i,j,7}))} * WAGE_{t-1}^{(-\beta_{11} * \beta_8)} * PCAP_{t-1}^{(-\beta_{11} * \beta_9)} *$$

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

where:

$\psi_{i,j,k,t}$ 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 *AEO99*, prices were calibrated to the average annual mine prices for 1996:

$$C_{i,j,k,t} = e^{(A + \beta_{i,1}) * (1-\beta_{11})} * TPH_{i,j,t=1}^{(k * -SE * (1-\beta_{11}))}$$

where:

The first term ($e^{(A + \beta_{i,1}) * (1-\beta_{11})}$) is the intercept for the model. It includes the overall constant for the model (A) and the regional specific constants ($\beta_{i,1}$).

The second term ($TPH_{i,j,t=1}^{(k * -SE * (1-\beta_{11}))}$) 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_4) for the labor productivity term, and is a constant. For the *AEO99*, 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 15 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.

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
B	overall constant term for the model
$Q_{i,j,k,t}$	annual coal production for supply region i, mine type j, coal type k in year t
$TPH_{i,j,t}$	average annual coal mine labor productivity in tons per miner hour for supply region i, mine type j in year t
$WAGE_t$	average annual wage for coal miners 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.
$PFUEL_{i,t}$	average annual price of electricity in the industrial sector 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 production term
$\beta_{j,3}$ for the production term by mine type j
β_4 for the labor productivity term
$\beta_{i,5}$ for the labor productivity term by supply region i
$\beta_{j,6}$ for the labor productivity term by mine type j
$\beta_{i,j,7}$ for the labor productivity term by supply region i and mine type j
β_8 for the labor cost term
β_9 for the user cost of capital term
β_{10} for the fuel price term
β_{11} for the first-order autocorrelation term

Table E1. Regression Statistics for the Coal Pricing Model

Regression Coefficient	Variable	Parameter Estimate	Standard Error	t- Statistic
A	Overall Constant	2.293	0.403	5.693*
$\beta_{i=1,1}$	DUM_REG_1 (Northern Appalachia (NA))	0.010	0.053	0.186
$\beta_{i=2,1}$	DUM_REG_2 (Southern Appalachia (SA))	0.259	0.077	3.381*
$\beta_{i=3,1}$	DUM_REG_3 (East Interior (EI))	0.040	0.067	0.590
$\beta_{i=4,1}$	DUM_REG_4 (West Interior (WI))	0.233	0.103	2.260**
$\beta_{i=5,1}$	DUM_REG_5 (Gulf Lignite (GL))	-1.101	0.199	5.539*
$\beta_{i=6,1}$	DUM_REG_6 (Dakota Lignite (DL))	-0.021	0.095	0.224
$\beta_{i=7,1}$	DUM_REG_7 (Powder River Basin (PG))	1.335	0.175	7.626*
$\beta_{i=8,1}$	DUM_REG_8 (Rocky Mountain (RM))	0.137	0.085	1.615
$\beta_{i=9,1}$	DUM_REG_9 (Arizona/New Mexico (ZN))	-0.329	0.240	1.372
β_2	ln Q	0.133	0.028	4.827*
$\beta_{j=1,3}$	DUM_MT (Underground) * ln Q	-0.040	0.009	4.287*
β_4	ln TPH	-0.717	0.052	13.909*
$\beta_{i=1,5}$	NA*ln TPH	-0.185	0.061	3.065*
$\beta_{i=2,5}$	SA*ln TPH	0.285	0.050	5.729*
$\beta_{i=3,5}$	EI*ln TPH	-0.043	0.053	0.803
$\beta_{i=5,5}$	GL*ln TPH	0.447	0.099	4.498*
$\beta_{i=7,5}$	PG*ln TPH	-0.415	0.076	5.481*
$\beta_{i=8,5}$	RM*ln TPH	0.165	0.048	3.427*
$\beta_{i=9,5}$	ZN*ln TPH	0.404	0.122	3.321*
$\beta_{j=1,6}$	DUM_MT (Underground) * ln TPH	-0.071	0.036	1.974**
$\beta_{i=1,j=1,7}$	NA * DUM_MT (Underground) * ln TPH	0.300	0.037	8.044*
$\beta_{i=2,j=1,7}$	SA * DUM_MT (Underground) * ln TPH	-0.161	0.045	3.577*
$\beta_{i=3,j=1,7}$	EI * DUM_MT (Underground) * ln TPH	0.092	0.037	2.462**
β_8	ln WAGE	0.313	0.152	2.056**
β_9	ln PCAP	0.061	0.034	1.793***
β_{10}	ln PFUEL	0.181	0.060	3.027*
β_{11}	Autocorrelation Parameter (Rho)	0.390	0.058	6.755*
	Adjusted R squared	0.993		
	Durbin-Watson Statistic	2.035		
	Number of Observations	255[a]		

[a] The Cochrane-Orcutt method was used to correct for the first-order serial correlation in the data. The use of this procedure on pooled time series-cross section data using the TSP 4.4 statistical package results in the loss or dropping of the first two observations for each group of data (combination of region and mine type). As a result, the regression only uses the observations for the years 1980 through 1996 (255 observations), excluding data for 1978 and 1979 (30 observations).

*Significant at one percent.

** Significant at five percent.

*** Significant at ten percent.

Notes: The endogenous explanatory variables in the regression are Q, TPH, WAGE, PCAP, and PFUEL. Instruments excluded from the supply equation are the index of electric utility generation, the index of industrial production, lagged exports, coal inventories at utility plants, lagged production, lagged mine price of coal, lagged mine productivity, the world oil price, the price of natural gas to the electric sector, the average heat and sulfur content for coal received at utility plants, the average delivered price of coal received at utility plants, and an index for coal transportation rates.

Table E2. 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"
$Q_{i,j,t}$	Annual coal production by region and mine type	Million short tons	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	U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers (Coal Mining), Series ID: EEU10120006 .
$PCAP_t$[22]	Annualized user cost of mining equipment (national level)	Percent	**PPI for Mining Machinery and Equipment:** U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU3532#; and **Yield on Utility Bonds:** DRI/McGraw Hill.
$PFUEL_{i,t}$	Average annual price of electricity in the industrial sector	1992 Cents per kilowatthour	Energy Information Administration, *Electric Power Annual 1997, Volume II*, (DOE/EIA-0348(97) (Washington, DC, October 1998), Table 7 and *State Energy Price and Expenditure Report 1995*, (DOE/EIA-0376(95) (Washington, DC, August 1998).

[22]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:

rpt is the opportunity cost of having funds tied up in mine capital equipment;

δpt 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 E3. Data Sources for Instruments Excluded from the Supply Equation

Data Item	Description	Units	Sources
Electric Utility Generation	Industrial production index: utilities	Index (1987=100.0)	Economic Report of the President, (Washington, DC, February 1997), Table B-49.
Industrial Production	Industrial production index: manufacturing sector -- durable goods	Index (1987=100.0)	Economic Report of the President, (Washington, DC, February 1997), Table B-49.
World Oil Price	Refiner acquisition cost of crude oil: imported	1992 Dollars per barrel	Energy Information Administration, *Petroleum Marketing Annual 1996,* (DOE/EIA-0487(96) (Washington, DC, October 1997), 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 1996,* (DOE/EIA-0384(96) (Washington, DC, July 1997), Table 6.9.
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"
Price of coal delivered to electric utilities	Average annual price of coal delivered to electric utilities by CPS supply region and mine type.	1992 Dollars per million Btu	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 (1984=100.0) adjusted to 1992 dollars	U.S. Department of Labor, Bureau of Labor Statistics, Series ID: PCU3532#;
Exports	Annual exports of U.S. coal	Million tons	Energy Information Administration, *Annual Energy Review 1996,* (DOE/EIA-0384(96) (Washington, DC, July 1997), 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 at U.S. electric utilities	Million tons	Energy Information Administration, *Annual Energy Review 1996,* (DOE/EIA-0384(96) (Washington, DC, July 1997), Table 7.5.

Appendix F

CPS Program Availability

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

Office of Integrated Analysis and Forecasting
Energy Information Administration
EI-82
U.S.Department of Energy
1000 Independence Avenue
Washington DC, 20585

Part II-A—Coal Distribution Submodule Model Documentation (Domestic Coal Distribution)

1. Introduction

Statement of Purpose

This section presents the objectives of the approach used in modeling domestic coal distribution, and provides information on the model formulation and application. The report is intended as a reference document for model analysts, users, and the public. The report 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 United States coal supply regions to 13 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.

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 1999.

Name: Coal Distribution Submodule
Acronym: CDS
Archive Package: CDS99 (Available through the National Technical Information Service).
Model Contact: Richard Newcombe, Department of Energy, EI-82, Washington, DC 20585
(202) 586-2415; (rnewcombe@eia.doe.gov)

Report 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 sub-sectors), 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 listing of input data, variable and parameter definitions, model output, and its location in reports (Appendix A)

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

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

- A model abstract (Appendix D)

- A discussion of data quality and estimation for model inputs (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 2020) 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 13 demand regions. Exogenously generated coal demands within the demand regions are subdivided into 5 economic sectors and 18 economic sub-sectors. Coal transportation is modeled using sector-specific arrays of interregional transportation prices. Demands are met by supplies representing the least dollar per million Btu delivered cost. The distribution of coal is constrained by environmental, technical, and service/reliability factors characteristic of domestic coal markets.

The design of the CDS was guided by NEMS planning documents that influenced the functions to be included and the content of the sub-module's classification structures.[21] Comments by the National Research Council's Committee on the National Energy Modeling System determined the general design philosophy: "The current EIA model is extremely detailed, far more so than would be appropriate for NEMS. One priority for NEMS development would be a greater simplification of this model to use in general forecasting and analysis. The simple model would then be used in NEMS. Detailed analyses of coal issues should probably be conducted outside the NEMS."[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 (to enhance the transparency of model operation and maximize the consistency of output with EIA data sources).

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[21]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.

[22]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 1972), p. 58.

Classification Plan

The domestic component of the CDS contains four major structural elements that define the geographic and technical scale of its simulation of coal distribution. First is the typology that represents the significant variation in the heat and sulfur content of coal. The geographic 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 1, above. When this typology is applied to coal reserves in the 11 supply regions, the 34 coal supply sources used in the *AEO99* 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 thirteen demand regions. There are four supply regions east of the Mississippi River that contain 22 of the 34 coal supply sources used for the *Annual Energy Outlook 1999* (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 1996, four of the model's five high sulfur sources are in the east as are 12 of 14 underground mine sources. Production from each supply curve (in 1996 and 1992) and the associated heat, sulfur and ash content as used in the *Annual Energy Outlook 1999* are shown in Table 3.

The thirteen CMM domestic demand regions represent the nine Census divisions, four of which have been divided to represent distinct sub-markets with special characteristics (Figure 5 and 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 Arizona and New Mexico, in which utilities are highly dependent on coal from adjacent captive mines.. These four "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,CDB,MDB,HDB	CSB,MSB,HSB,HSL
2. "**CA**"-Central Appalachia	So.WV,VA & East KY	CDP,CDB,MDB	CSB,MSB
3. "**SA**"-Southern Appalachia	AL & TN	CDP,CDB,MDB	CSB,MSB
Interior			
4. "**EI**"-East Interior	West KY, IL & IN	MDB,HDB	MSB,HSB
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		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

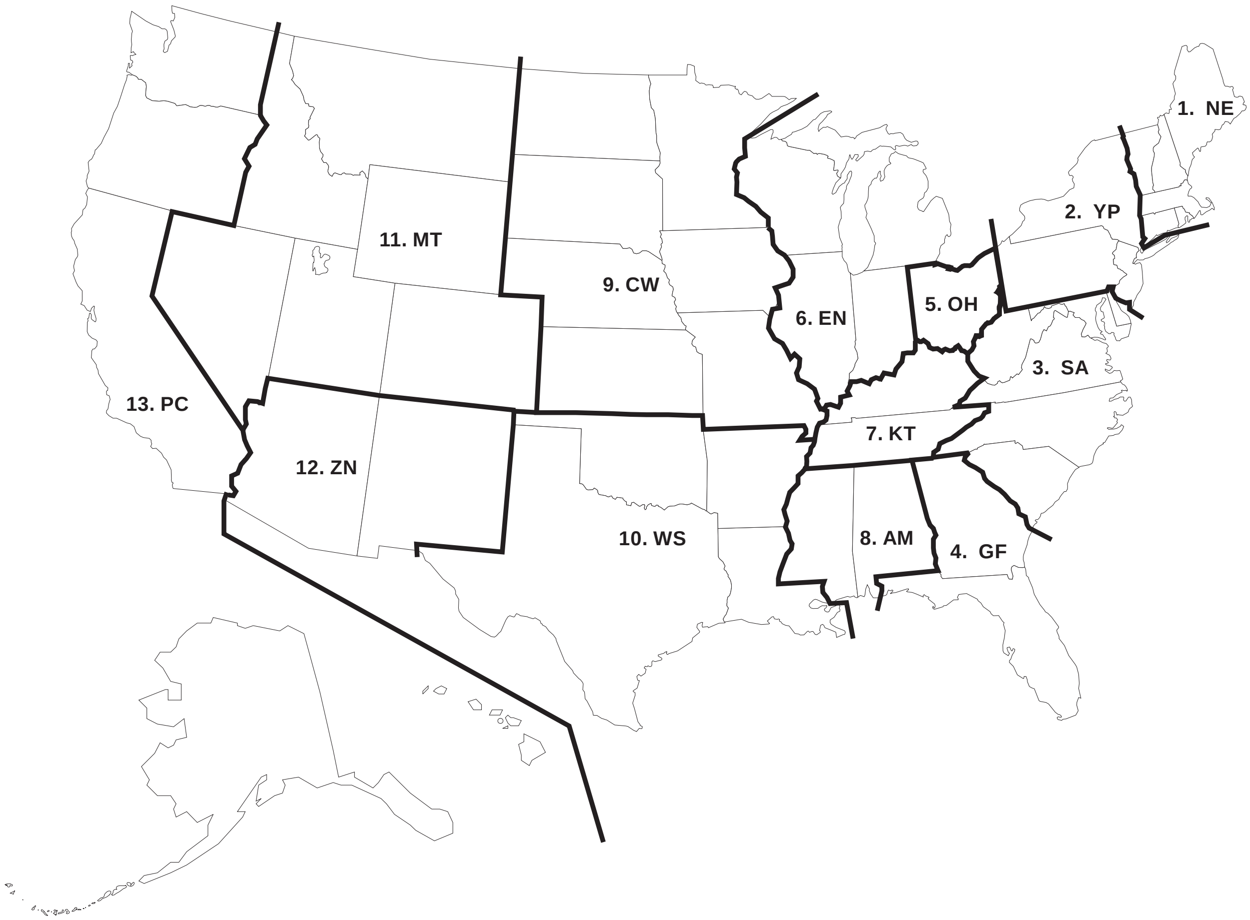
"__P", Premium or metallurgical coal
"__B", Bituminous and anthracite steam coal
"__S", Subbituminous steam coal
"__L", Lignite, bituminous gob or anthracite culm steam coal

Example: "MDP" = Medium sulfur, underground mined metallurgical coal. As shown in Table 3, all “Medium” sulfur coal sources in the CMM actually contain less than the Clean Air Act Amendments of 1990 Phase I emissions limit of 2.5lbs SO2 per million Btu.

Table 3. Average Coal Quality (1992-97) and 1997 Production by Supply Region and Type.

CMM Supply Region	CMM Coal Type Code (see Table 2)	1997 Prod'n (million tons) Deep/Surface	Average Million Btu/ Short Ton	Average Sulfur Percent	Avg.lbs SO2/ million Btu (emissions)	Avg. Ash Percent
1. "NA" (North Appalachia=PA,OH,MD, No.WV)	MDP	7.0/ --	26.80	0.98	1.39	6.18
	CDB/CSB	1.5/2.7	25.48	0.66	0.99	10..04
	MDB/MSB	52.4/14.4	25.51	1.61	2.39	10.32
	HDB/HSB	51.3/23.0	24.45	3.14	4.88	11.09
	HSL	-- /9.4	13.61	1.31	5.00	28.40
2. "CA" (Central Appalachia =So.WV, VA, East KY)	CDP	63.8/ --	26.80	0.79	1.12	5.61
	CDB/CSB	38.1/28.0	25.40	0.69	1.03	9.40
	MDB/MSB	74.4/83.4	25.10	1.08	1.63	9.81
3. "SA" (South Appalachia= AL,TN)	CDP	9.7/ --	26.80	0.72	1.03	5.82
	CDB/CSB	7.8/ --	24.93	0.62	0.95	11.23
	MDB/MSB	2.4/7.9	24.60	1.41	2.19	11.40
4. "EI" (East Interior = IL,IN, West KY)	MDB/MSB	21.5/11.2	23.04	1.39	2.30	8.53
	HDB/HSB	43.2/35.6	22.56	3.03	5.11	10.17
5. "WI" (West Interior = KS, MO, AR, OK,TX, bituminous only)	HSB	0.2/2.5	23.37	2.98	4.85	11.07
6."GL" (TX & LA , lignite only)	MSL	-- /31.3	12.94	0.87	2.03	15.67
	HSL	--/25.2	12.79	1.37	3.21	17.27
7."DL" (ND & MT, lignite only)	MSL	-- /29.8	13.30	0.74	1.67	13.30
8. "PG" (Powder R.,Green R. & Hanna Basins - WY, MT)	CDB	2.9/2.6	21.60	0.62	1.08	6.33
	CSS	-- /272.6	17.37	0.34	0.68	5.09
	MSS	-- /44.5	17.69	0.67	1.33	8.50
9. "RM" (Rocky Mtn. - CO,UT)	CDB	44.5/ --	23.14	0.49	0.80	9.53
	CSS	-- /9.6	20.89	0.44	0.74	8.57
10."ZN" (Southwest - AZ,NM)	CDB/CSB	-- /19.0	21.38	0.49	0.87	11.18
	MSS	-- /19.7	18.42	0.76	1.45	20.82
11."AW" (Northwest - WA,AK)	MSS	-- /5.9	16.34	0.65	1.38	14.67

Figure 5. CMM -- Domestic Coal Demand Regions



Region Code	Region Content
1	New England
2	Middle Atlantic
3	South Atlantic
4	Georgia and Florida
5	Ohio
6	East North Central
7	Kentucky and Tennessee

Region Code	Region Content
8	Alabama and Mississippi
9	West North Central
10	West South Central
11	Mountain
12	Arizona and New Mexico
13	Pacific

Table 4. CMM -- Domestic Coal Demand Regions

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

Coal Demand Sectors and Subsectors

In the CDS, domestic coal demands are further divided into five major sectors and 18 sub-sectors, part or all of which may be utilized in each demand region in each forecast year. The five major sectors are Electricity Generation (utilities and independent power producers), Industrial (steam coal consumption by industry for own use and cogeneration), Coking (metallurgical and by-product coke ovens), Residential/Commercial, and Export. These major sectors are further divided in specialized demands representing sub-markets. In the non-electricity sectors, the sub-sectors provide a level of detail that allows the CMM to capture between 80 to 90 percent of the complexity of historical flows. These sectors often contain small coal flows that represent the end of old distribution patterns or the beginning of new ones, and the model would require many more demands per sector to capture all of them. Also, attempts to capture such flows would mandate many constraints on the optimization within the model as these flows are often priced above market levels. The subsectoral detail used in the *Annual Energy Outlook 1999* is shown in Table 5.

The need for an expanded list of subsectors in the CDS stems from technical and regulatory requirements for different types of coals with different geographical availability and prices; it is the economic and geographic expression of the chemical heterogeneity of coal and the engineering requirements of specialized end-use technologies. A less detailed sectoral structure would severely impair the CDS's ability to correctly model the sources and delivered prices of coal supplied to the broader NEMS sectors, since such demands are often supplied by different types of coals from a half-dozen or more supply regions.

Table 5. Domestic CMM Demand Structure - Sectors and Sub-Sectors

Demand Subsector	Sector	Number of Demands
1. RC1. 2. RC2	Residential/Commercial	13 13
3. IND. PREMIUM (stoker) 4. IND. STEAM (pulverized coal) 5. IND. STEAM (other)	Industrial Steam	13 13 13
6. METALL 1 7. METALL 2	Industrial Coking	7 7
8. EXPORT 1 (metall) 9. EXPORT 2 (metall) 10. EXPORT 3 (steam) 11. EXPORT 4 (steam)	Export	8 8 8 8
12. OLD, LOW SULFUR 13. OLD, MID SULFUR 14. OLD, HIGH SULFUR 15. NEW, LOW SULFUR 16. NEW, MID SULFUR 17. NEW, HIGH SULFUR 18. SCRUBBED BOILERS	Electricity	13 13 13 13 13 13 13
Total Number Of Demands	All Subsectors	202

The subsectoral detail in the residential, commercial and industrial sectors stems primarily from technical requirements of end-use technologies, and is thus specific to the CDS. Residential and commercial coal consumption, taken together, constitute less than 1 percent of total demand, but they are modeled as a pair of demands in the CMM in order to more closely model distribution patterns. Industrial demands are treated as two groups of demands, those for steam coal and those for metallurgical coals.

Industrial steam coal demand is further subdivided into three sub-sectors in the CDS. "Stoker" industrial steam coals are shipped to older industrial boilers, generally exempt from seriously constraining emissions regulation, but which require—for technical reasons—coal fuels with relatively low ash and high thermal energy content. Pulverized coal boilers can accept lower quality coals in terms of ash and Btu content, but are—on the average—newer and larger than "stoker" boilers, and are thus often subject to regulatory restrictions on sulfur oxide emissions. "Other Technology" industrial demands represent a wide range of specialized technologies ranging from new coal-fired fluidized-bed steam boilers through Portland cement kilns to anthracite coals used as a sewage filtration medium. This last group of demands is heterogeneous but quantitatively smaller than the other industrial steam sub-sectors in most demand regions, and is distinguished in order to permit analytical focus on the "Stoker" and "Pulverized" sub-sectors. The use of three subsectors also allows a more detailed representation of industrial steam coal distribution patterns, which are as complex as the pattern of electricity coal demand and supply.

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 $/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.

Disaggregation of electricity demand into subsectors is required by the EMM's treatment of electricity coal demand, which reflects both technical and regulatory requirements that must be economically balanced in that model to realistically portray coal demand in response to emission requirements and the relative economics of different coal and non-coal fuels. Electricity coal demand is partitioned into seven sectors, structured to facilitate the modeling of blending across coal rank boundaries. Demands are separated by sulfur level (low, medium and high sulfur coal, according to the State Implementation requirements to which individual boilers are subject) and by boiler age. It is assumed that boilers constructed before 1965 are technically more limited in their ability to use coal of non-design rank than are newer ones, and therefore, separate demands are maintained for these older boilers. A separate demand is also maintained for scrubbed boilers because they can use coal of any sulfur level and still meet state and federal SO2 emission standards.

In summary, the CDS contains two residential/commercial subsectors, three industrial steam and two domestic coking coal subsectors, two export metallurgical and two export steam subsectors and seven electricity subsectors, making eighteen 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 costs, Btu contents, and tonnages framed in inter-regional coal distribution patterns specific to the individual NEMS economic sectors. 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 and coal export demands from the Coal Export Submodule (CES). In turn, it provides export supply quantities and port-of-exit prices to the CES. 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; (3) energy conversion factors (million Btu per short ton) and sulfur values (pounds sulfur per million Btu) plus delivered coal prices at all destinations for all coal supply curves for which the Electricity Market Module has established demands. This last category of output is provided to the Electricity Market Module during its integrated iteration with the CMM. The domestic distribution portion of the CDS relates to other CMM components (and the Electricity Market Module, when operating in the integrated mode) using its own set of 13 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.

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 Electricity Market Module (EMM) for each of the 13 CDS demand regions. The electric power demands are disaggregated into the 13 CDS demand regions and 7 electricity subsectors by the Electricity Market Module (EMM). 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 sector in the CDS.

The transition from Census divisions to the more detailed domestic CDS demand regions is accomplished using static demand shares specific to the Residential/Commercial, Industrial Steam and Industrial Metallurgical 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. Coal demands by coal rank and sulfur type are received from the EMM and are disaggregated into the CDS’s domestic demand regions by shares located in the EMM.

Other CDS inputs include transportation rates and electric utility coal contracts (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 limit the coal Btu and sulfur categories that may be used to satisfy demand in different subsectors. The parameter input file also serves to store the Btu and sulfur values that define the quality of coal on each supply curve, and the import supply file.

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). If domestic coal market prices were the primary standard by which the acceptability of imports were judged, coal imports would be at a substantially higher level than they have currently reached or are forecast to reach. 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 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. After receiving these 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.

Similarly, 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 quantities 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].

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 20-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 comprise a set of 43 single-year reports detailing sectoral demands received, regional and national coal distribution patterns, transportation costs, and detailed 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.

A more detailed discussion of the output reports is provided in Appendix A.

[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 250 counties in 26 States. Coal deposits are widespread, occurring in 39 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 1,800 mines controlled by several hundred firms.

Coal demand occurs in over 600 counties in 49 States; domestic coal consumption takes place at over 1,500 identifiable locations, and is dominated by the coal consumption of over 200 electric power generators at over 400 different locations - about 89 percent of U.S. coal demand. Each year, coal is transported from mines to consumers over at least 10,000 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

In the last five years, the deregulation of electricity generation and the increasing uncertainty about the long-term environmental acceptability of coal combustion have combined to remove some fo 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. These changes, by removing the need for complex contract constraints, are making coal market modeling simpler and more transparent.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 severely 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 simplest constraints on coal markets, from the modeler's perspective, are due to environmental regulations. Historically, these constraints have imposed regulatory limits on the sulfur oxide emissions from coal consumption. Currently, interest is focused on the electricity generation industry's response to the Clean Air Act Amendments of 1990 (CAAA) as they unfold for Phase I (1995) and Phase II (2000). The CMM coal typology for domestic supply sources provides three grades of coal sulfur content: “compliance”, medium, and high. The compliance sulfur grade corresponds to the limitation on sulfur dioxide emissions that electric utilities are required to meet by 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. The CMM incorporates environmental constraints on coal use by limiting acceptable coal supplies to those within appropriate sulfur categories.

A sulfur penalty calculation was implemented by adding a constraint row in the linear program of the CDS to limit the level of sulfur credits expended so as not to exceed the limits on emissions established by the CAAA. The dual variable for this constraint represents the penalty level. The CMM now determines the least-cost sulfur penalty as well as the mix of coals necessary to meet the annual levels of electricity coal demand projected by the NEMS Electricity Market Module.

In the electric power generation sectors demand is subdivided into 7 subsectors. In each model iteration, the CDS supplies the EMM with least cost delivered price for coal in each subsector, and the Electricity Market Module (EMM) determines the appropriate mix of demands based on regulatory and technological costs. In the EMM, these calculations are a sub-part of the problem of determining the most economical electric power generation technology and fuel from the entire range of fossil, nuclear, and renewable fuel technologies.

In the nonelectric power generation subsectors, a blend of domestic environmental and technical constraints (with their foreign market equivalents for coal exports) combine to restrict choices. For coal export markets, different categories of demand are determined in the international component of the CDS, and transmitted to the domestic distribution portion of the CDS for determination of least cost supply sources. In the domestic, industrial, and residential/commercial sectors, demand is received from other NEMS components in aggregated form and is subdivided into sulfur categories within the CDS using a concept referred to as "coal groups." Each of these "coal groups" specifies one or more of the members of the CMM coal source set that may be used to fill the specified demand, depending on its subsectoral and regional identity. In the industrial sector, for example, demand is specified in each domestic CDS demand region as belonging to one of five subsectors: premium metallurgical coal, blending metallurgical coal, industrial steam coal for stoker boilers, steam coal for pulverized coal boilers, and coal for other applications.

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 and environmental 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. It is, however, important that the CMM should preserve a flexible method for modeling these constraints, for it is likely that environmental concerns related to coal consumption may extend beyond sulfur and carbon oxide emissions to include, for example, heavy metal emissions (gaseous and particulate emissions from combustion and leachates from ash disposal). 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.

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 are 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 desing specification. Many plants have learned that, with relatively minor investments, newer plants can be easily transferred from bituminous to sub-bituminous coal.

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 some current cases, transport costs have exceeded 80 percent of delivered costs.[25] In 1995, coal provided 40.5 percent of all rail tonnage, 25.7 percent of all car loadings, and 21.8 percent of all railroad revenues; since not all railroads serve coal-producing and consuming regions, the importance of coal to those that do is even greater than these statistics suggest.[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 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 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. For each of 18 subsectors within the five major economic sectors (electric power generation, industrial steam generation, domestic metallurgical production, residential/commercial consumption, and exports) a set of transportation prices connects the 13 demand regions with each of the 34

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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, *1996 Rail Facts*.

supply curves. In principle, there are thus 13*34*18=7956 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 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.

Domestic transportation rates in the CDS vary significantly between the same supply and demand region for different economic sectors. This variance 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 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 these dedicated components of the total contract service are wholly or partly financed by the shipper. 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 and Their Impact on 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 less than 14 percent of national production in 1997, and six were required to produce 42 percent of the national total.[27] 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.[28] Coal producers have only incomplete knowledge of even their own future mining costs.[29] Mining firms thus face both geological and market uncertainties.

With the advent of deregulation, generation cost has replaced reliability as the first priority for electricity generators. Coal producers can no longer rely on a utility's need for security of supply to guarantee market stability. Coal prices have been declining in real dollars for 20 years, and there is little evidence that this trend will reverse. 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 five 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 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 equiptment is electricity - in many cases necessarily purchased from the same utility 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 704 thousand tons per year between 1978 and 1997. Labor productivity, measured in tons per miner-day, has increased at an average rate of 7.15 percent per year over the same period (from 12.07 to 44.84 tons per miner-day).[30] As a result of these changes the number of miners has fallen from 246 to 81 thousand, while the number of mines producing more than 10,000 tons per year has fallen from 4703 to 1546 while production has increased from 670 to 1090 million tons per year between 1978 and 1997. These trends show little sign of slowing.

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

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[27]Energy Information Administration, *Coal Industry Annual 1997,* DOE/EIA-0584 (97), December 1998, Table 15, p. 23.

[28]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).

[29]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.

[30]Labor productivity in coal mining is more commonly measured in tons per miner-hour. Since 1978, the number of hours worked in an average week by the average coal-miner has increased from 29.3 to 42.5. Using tons per miner-day as a labor productivity measure captures this increase in the efficiency of labor use as well as the increase in labor productivity measured by tons per miner-hour. The increase in the efficiency of labor use also implies greater intensity in the use of capital equipment.

concerns[31]. NYMEX has announced plans to intiate trading in coal futures contracts, but this has been postponed several times; it is not yet clear that coal markets are sufficiently volatile to make a futures market feasible.[32]

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.[33]

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.[34] Quadratic programming models based on the work of Takayama and Judge developed more sophisticated objective functions, incorporating maximization of producers' and consumers' surpluses.[35] This methodology was applied to the spatial distribution of Appalachian coal.[36]

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.[37] 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.[38]

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 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

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

[32]Editors, The Financial Times Energy, “Coal Futures: a Square Peg for a Round Hole?”, Coal Outlook Supplement, Monday, November 2, 1998.

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

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

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

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

[37]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).

[38]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.

integrated systems are paralleled by similar systems in other environments, such as the Hudson-Jorgenson system and the Brookhaven Integrated Energy/Economy Modeling System.[39, 40]

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.[41]

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 utility 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.[42]

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.[43] 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.

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[39]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.

[40]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.

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

[42]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).

[43]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).

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.

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.[44] 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.[45]

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

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[44]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).

[45]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).

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.[46] Freight network models have been widely used to study regional rate responses to increasing system capacity utilization.

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.[47] 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 entirely of rates determined by subtracting average minemouth costs generated in the CDS from historical delivered costs as collected on Forms EIA-3A, -5A, 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:

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[46]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.

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

- Coal distribution, on a year-by-year basis, and at the required level of regional and sectoral detail can not be shown to be determined by the delivered cost of coal. Yet, in the long run, historic data show that it undoubtedly is. 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.

- 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 employed 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 distrance 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 sulfur content 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 mine capacity requirements by sector, region, mine type, and coal type based on future utility and nonutility coal demand. Transportation costs can be summarized independently by coal supply region, coal rank and sulfur content, and by transportation mode 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".[48] The functions of subroutine "CDS" are shown in Figure 6, which also provides an overview of the operations of the domestic coal distribution code as a whole. "CDS" controls nine other subroutines:

- "CREMTX" creates the linear programming matrix containing the coal demands, supplies, transport activities and lower bounds (provided by utility contracts). "CREMTX", in turn calls the linear program solver, "OML" for the initial iteration in each forecast year.

- "CREVISE" revises the linear programming matrix after the initial iteration and calls the linear programming solver, "OML" after each non-initial iteration 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. Nonutility and utility demand reports, plus a utility 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 15 reports available for each forecast year. Using these reports it is possible to determine exactly what demands the CDS has solved for in a given forecast year, since this output is written before the linear program is called by the "CDS" subroutine.

- "DEMREP" generates coal demand reports that describe demand, transportation, and distribution of coal from supply to demand region by economic sector, with fully adjusted transport rate data provided in both $/ton and $/MMBtu. One of these year-specific reports, the "Detailed Supply and Price Report,"

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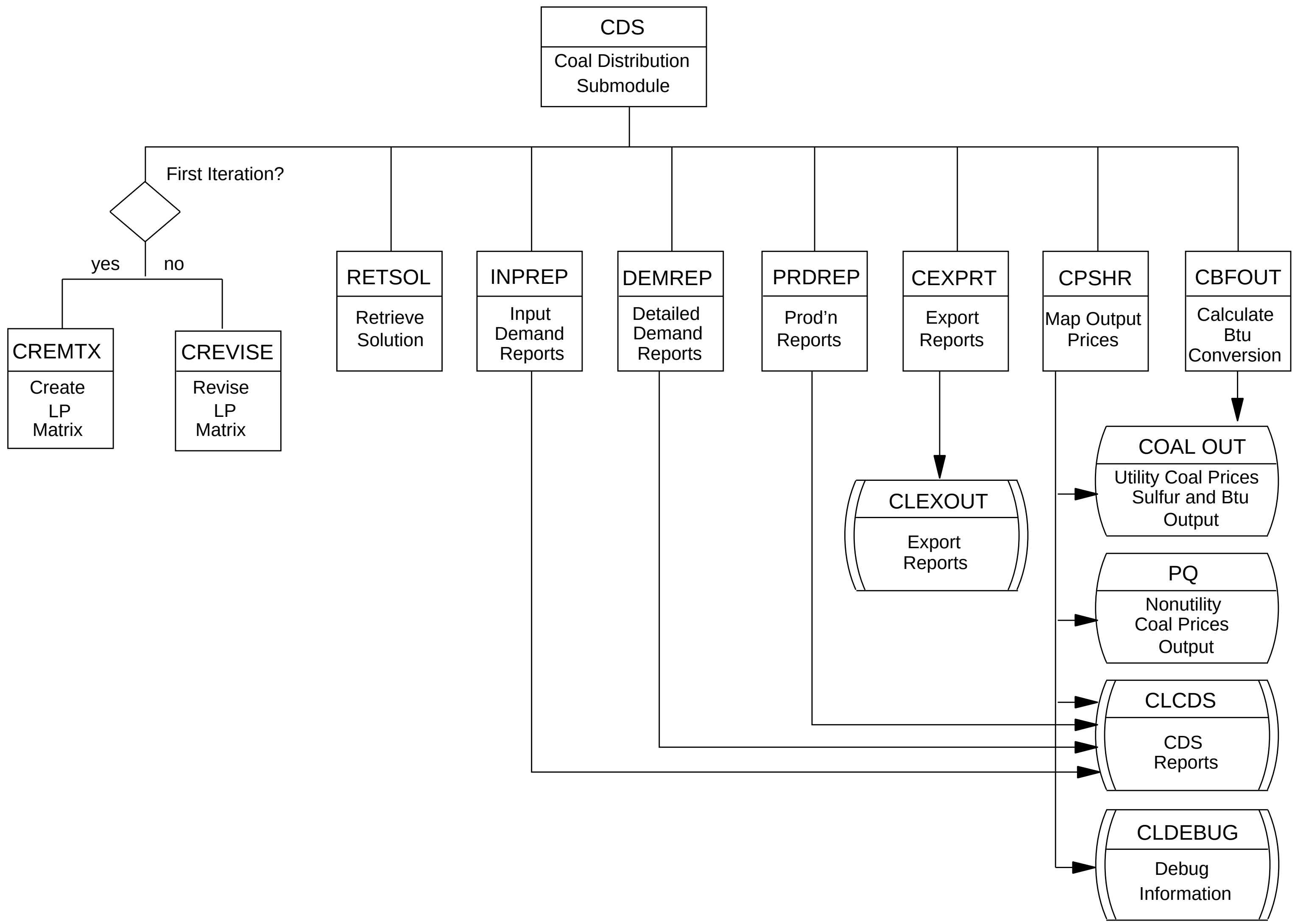
[48]To avoid confusion in the following discussion, subroutine and file names are always written in quotation marks, e.g., "CDS", "EMMOUT".

Figure 6. Calling Order for CDS Subroutines - Overview



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 13 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 13 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) are also available, and are used by both the CDS and the EMM to calculate precise $/MMBtu prices and sulfur contents (in lbs sulfur per MMBtu). The coal production reports are written on physical file "CLCDS".

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

- "CPSHR" writes nonelectric utility coal price output to the common block name "PQ", and delivered coal prices, sulfur and Btu assignments for coals assigned to electric utility demands to the common block name "COALOUT". "CPSHR" writes prices, sulfur, and Btu content for coal meeting utility 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 6. Subroutine "CREMTX" also calls two other subroutines: "RDCDSIN" and "RDCEXIN" (Figure 7):

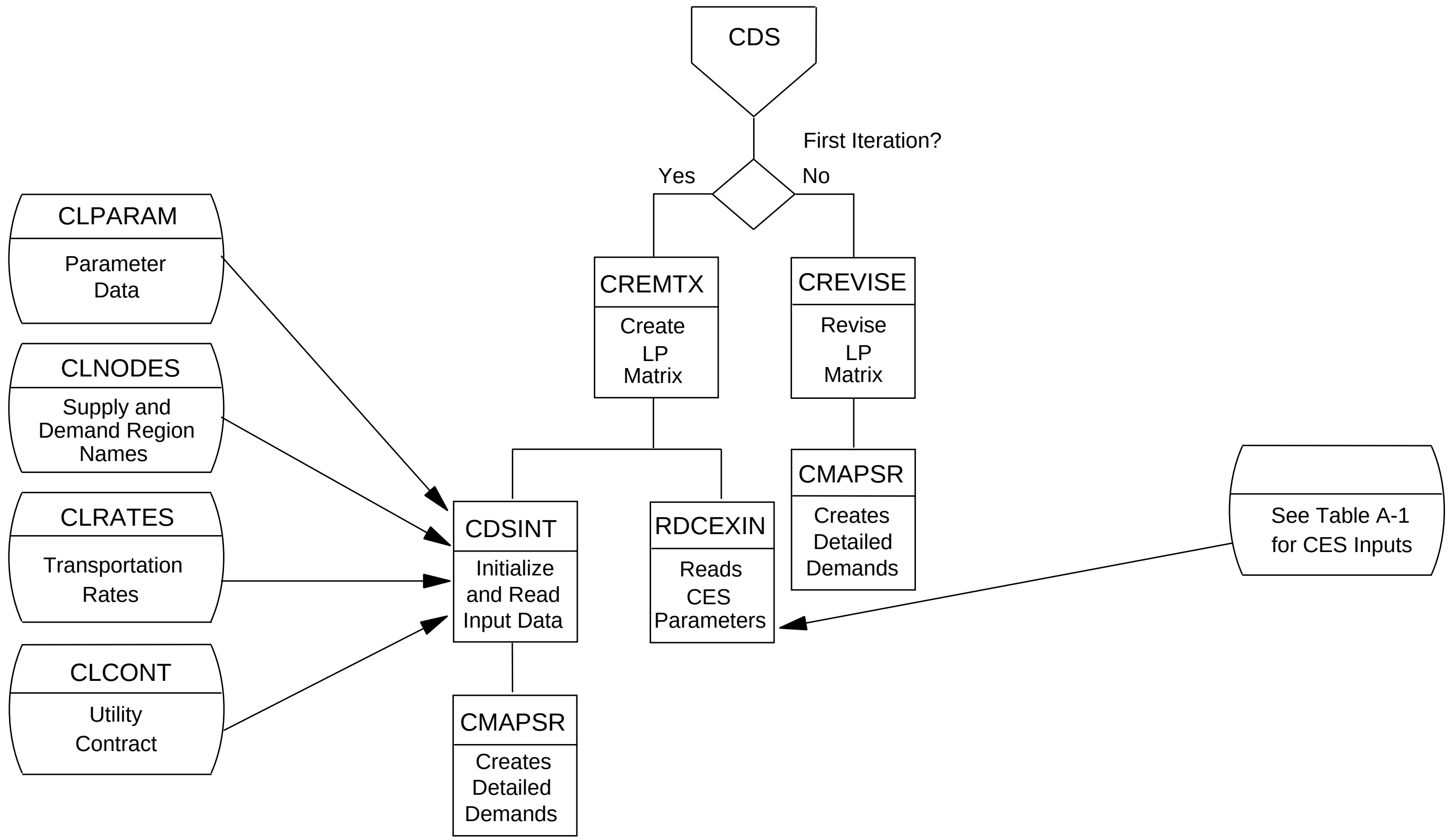
- "RDCDSIN" reads exogenous input arrays containing calibration factors for the CDS, and calls "CMAPSR".

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

The subroutine "CREMTX" (or "CREVISE", depending on whether it is the initial or a subsequent CDS iteration) controls the order in which regionally and sectorally disaggregated demands are solved in the solution algorithm by calling subroutine "RDCDSIN" which functions to initialize 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 A of Part III of this report.)

Figure 7. Functions of Subroutine - "CREMTX"



- "CLNODES" currently contains only 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 A.

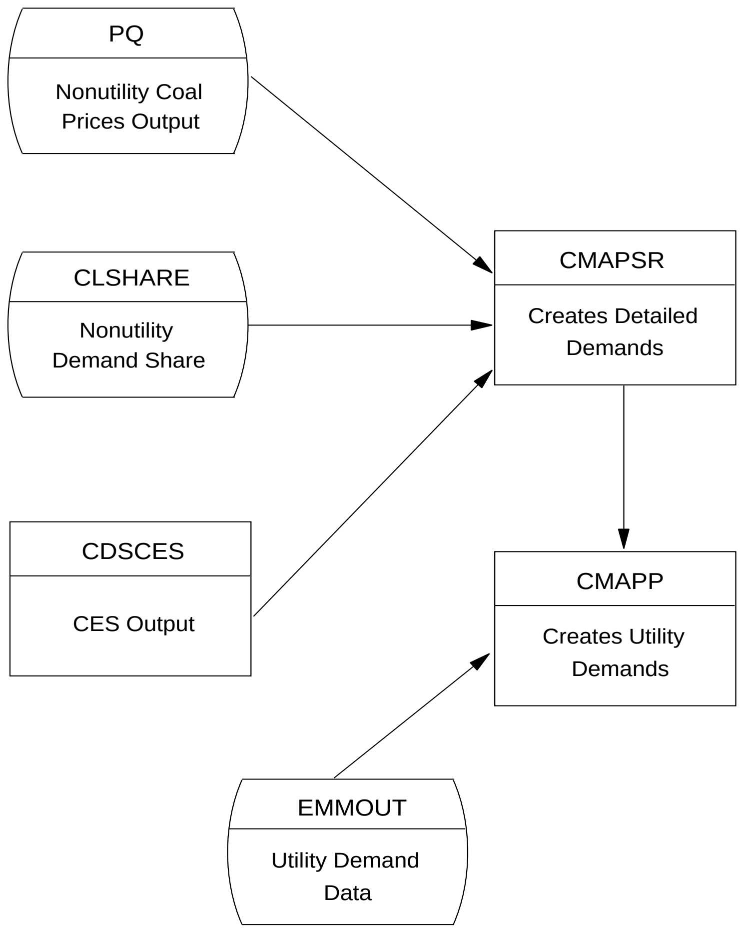
- "CLCONT" contains data defining aggregated existing electric utility coal contracts that are assigned to constrain the selection of coal sources by the CDS solution algorithm. The nature of this input and its use is also discussed in Appendix A.

Figure 8 displays the functions of subroutine "CMAPSR". This 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 electric utility coal contracts. Both these processes are accomplished by subroutine "CREMTX", which is described in association with the discussion of Figures 6 and 7. "CMAPSR" reads common block names "PQ" (which contains the nonelectric utility coal demands) and the physical file "CLSHARE" (which contains the shares disaggregating non-utility demands from Census division to CDS demand region level).

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.

Figure 8. Functions of Subroutine "CMAPSR"



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 utility coal contracts, also change within the forecast horizon.

Appendix A 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 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". 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[49].

As discussed elsewhere, 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" (for the industrial steam and residential/commercial sectors), from the Form EIA 5, "Coke Plant Report" for the domestic coking coal sector, from the Form EM-545 for coal exports, and from the Form FERC 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants" for the Electricity sector.

"CLRATES" contains rates for each possible combination of 18 economic subsectors, 13 demand regions and 34 supply curves, a total of 7956 rates. The requirement for rapid CDS turnaround time imposes the need for a method to rapidly recalibrate this rate area to new survey data. This is accomplished using an off-line program, "BSRZR.FOR.TEST" that is used to adjust rates to base year values calculated from the surveys listed above. This program operates by re-setting a component array in the "CLPARAMS" file named "BSRZR" which provides rate multipliers. It also provides the capability to selectively alter rates for specific inter-regional and sector specific rates when studies of the sensitivity of distribution, production and/or price to rail rate changes are performed.

[49] 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.

Appendix A

Inventory of Input Data, Parameter Estimates, and Model Outputs

Input: Data Requirements

Input to the domestic component of the CDS is read from six 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 data are in 1987 dollars, organized as lines, each containing 18 rates (one for each economic subsector in the model). There are 442 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 18 rates ,two residential/commercial rates are followed by 3 industrial subsector rates, 2 metallurgical subsector rates, 4 export subsector rates and 7 electric utility sector rates. 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 13 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 13 rows contain rational numbers used to disaggregate residential/commercial demands. The second 13 rows contain the shares for industrial demands. The third set of 13 rows contain the shares for metallurgical demands.

This set of 39 rows is immediately followed by an array representing supplies of imported coal in millions of tons. This input is indexed by Census division, domestic CDS demand region, and by the sector to which the demand pertains (i.e., "1"= Electric Utility imports, "2"= Industrial imports, and "3"= Metallurgical imports). Each indexed group contains 26 numbers, one for each year in the model's forecast horizon.

Following this array is one with 13 rows and 3 columns of rational numbers. These assign industrial demands to the three industrial subsectors for each demand region.

The next array is the FERC Form 423 electric utility receipts for 1990, stated in trillion Btu and indexed by number (and alphabetic code). The columns in this array represent the 7 electricity demand subsectors, while the rows represent the 13 electricity demand regions. This array is repeated for the years 1991 through 1995, providing a set of historical electricity demands for these years that are used to calibrate and test the CMM when run in stand-alone mode.

CLEXEXS. This file contains U.S. coal export demands for the historical years of the forecast period. Each group of demands contains 26 numbers representing annual demands 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, (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.

CLCONT. This file contains data describing existing electric utility coal contracts. The information is organized similarly to the above inputs in groups of 26 numbers, each of which expresses the sum of contract demands specific to a supply region, demand region, and coal type for a given year. These contract demands are indexed, from left to right, by line number, demand region, coal type, and supply region.

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.

CLPARAMS. This file contains 11 arrays and vectors. They are described and identified in the order of their appearance. The first array is named "COAL" and contains labels for the CMM coal types.

The next array is a parameter named "BSRZR" that is used to adjust transportation rates by demand region and economic sector. These adjustment factors are indexed at the left by demand region number. Each indexed group of 13 represents the array of subsectors in the CDS, beginning with the Residential/Commercial subsector and terminating with the last electricity subsector. "BSRZR" is produced by an off-line program that uses historical delivered prices and minemouth prices to determine the transportation rate adjustment that will provide the correct delivered price in the base year of the forecast period (1990 in the Annual Energy Outlook 1997).

"BSRZR" is followed by "Sector", a column vector of alphabetic labels for the 18 economic subsectors in the CDS. "Sector", in turn, is followed by a pair of row vectors, "IFED" and "ISEC". "IFED" assigns the 13 domestic CDS demand regions to the 9 Census divisions, while "ISEC" assigns the 18 CDS economic subsectors to the 5 NEMS economic sectors (Residential/Commercial, Industrial steam, Industrial metallurgical, Exports, and Electric Utility).

These vectors are followed by an array defining a parameter named "KCNUR", which is indexed with the demand region numbers and their two-letter alphabetic abbreviations. "KCNUR" assigns coal groups to residential/commercial, industrial steam, and metallurgical coal economic subsectors which are represented, in that order, by the first six columns of integers. These values are followed by three columns of rational numbers, the demand shares by region for the three industrial subsectors. (The identical set of shares is found in the CLSHARES input file and is described above.)

"KCNUR" is followed by a pair of vectors defining transportation cost escalation trends during the 26-year forecast horizon. These are named "BTR" and "BTW" and represent, respectively, rail and water transportation cost escalators. Since the current version of the model does not distinguish between coal transportation modes, only the first vector, "BTR", is in use.

"BTR" and "BTW" are followed by another parameter, "CSDISC", which 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 26 forecast horizon years.

"CSDISC" is followed by a parameter used to assign coal groups to the 7 electricity subsectors. This parameter, "KCUR", is indexed by demand region.

The parameter "ICSET" follows "KCUR", and it 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 13). Coal types are indexed in the order in which the occur in the CLPARAMS array "COAL" (q.v., above).

Listing of Parameters and Variables

Table A-1. Parameter List for CDS (source: CDS)	
NCOALTYP=8	Number of coal types per supply region
NCSET=47	Number of coal sets available
NCUTSET=12	Number of utility coal sets
NFYRS=26	Number of forecasted years
NINTJOBS=600	Maximum number of intermediate demand jobs
NMAXCTRK=600	Maximum number of contracts
NMAXCURV=300	Maximum number of supply curves
NMAXDJOB=900	Maximum number of demand jobs
NMAXEXPT=40	Maximum number of export demands
NMAXPART=20	Maximum number of participants per demand job
NMAXSTEP=4000	Maximum number of curve steps
NSREG=11	Number of coal supply regions
NTOTDREG=13	Total number of demand regions
NTOTSECT=18	Total number of demand sectors
NUTSEC=7	Number of utility sectors
CNCSET=10	Number of coals available within a set
NEMSEC=6	Number of nonutility NEMS sectors (FTAB)
IMPSEC=3	Number of import sectors (utility, metallurgical, industrial)
NOTSEC=7	Number of residential/commercial, industrial, and metallurgical sectors
NXPSEC=4	Number of export sectors
EMISS=4	Number of supply regions East of the Mississippi River
FRCSTYR=2	Number of look-ahead years for production capacity expansion
NUMPTYPE=3	Number of utility plant types (old, new, and scrubbed)
NUMSTYPE=3	Number of SIP types (low-, medium-, and high-sulfur)
APPCDS=3	Number of CMM supply regions in Appalachia
INTCDS=6	End of CMM supply regions belonging to Appalachia and the Interior
NUMSULFLVL=3	Number of sulfur categories (compliance, medium, and high)
USPLIT=6	Utility coal types for reporting (old, new, scrubbed, and low-, medium-, and high-sulfur)
SCRUB=’7'	Scrubbed sector

Table A-1. Parameter List for CDS (source: CDS) (Continued)	
ISCRUB=7	Scrubbed sector--integer version
PREMBTU=26.8	Btu conversion factor for premium coal
SO2_PCB=0.95	Fraction of sulfur left in ash, bituminous coal
SO2_PCS=0.875	Fraction of sulfur left in ash, subbituminous coal
SO2_PCL=0.750	Fraction of sulfur left in ash, lignite

Table A-2. Variables for Common Block CDSCOM1 (source: CDS)	
CPSBF	Total minemouth price in 1987 $/ton
CQEXP	Total export demand in trillion Btu
CQSBFB	Coal production by CDS supply regions in million Btu
CQSBFT	Conversion factor for coal production in million Btu/ton
CSIMP	Coal imports (sector 1=utility, 2=industrial)
PDIN1R	Industrial delivered price in 1987 $/million Btu
PDMT1R	Metallurgical coal delivered price in 1987 $/million Btu
PDRC1R	Residential/commercial delivered price in 1987 $/million Btu
PDUTZR	Utility delivered price by utility sector in 1987 $/million Btu
QDIN1R	Industrial demand in trillion Btu
QDMT1R	Metallurgical coal demand in trillion Btu
QDRC1R	Residential/commercial demand in trillion Btu
QDUTZR	Utility demand by utility sector in trillion Btu
BTUTZR	Btu conversion factor for utility sectors in million Btu/ton
SOUTZR	SO_2 content for utility sectors in lb/million Btu
IMPBTU	Import total in trillion Btu by Census divisions
IMPTON	Import total in million tons by Census divisions
IMPBTUC	Import total in trillion Btu by CDS demand regions
IMPTONC	Import total in million tons by CDS demand regions
TONN	Import tonnage in million tons
EDYRS	Export demand in trillion Btu
IEDR	Demand region index for export sector
IEDZ	Demand sector index for export sector
IEDC	Coal set index for export sector
COALIYR	Internal year index

Table A-3. Variables for Common Block CDSCOM2 (source: CDS)	
RSBTU(NMAXCURV)	Btu content in million Btu/ton
RSULF(NMAXCURV)	Sulfur content in lb/million Btu
VSCUR(NMAXCURV)	Production by supply region/coal type
PSRNG(NMAXCURV)	Minemouth price in 1987 $/ton
USV(NMAXSTEP)	Upper limit before step invoked
BSV(NMAXSTEP)	Slope of supply curve segment
ASV(NMAXSTEP)	Y-Intercept for supply step
DSYRS(NMAXCURV,NFYRS)	Depletion amount by supply region/coal type/years
PD40(NTOTSECT,NDREG)	Coal price for all demand sectors in 1987 $/million Btu
BT40(NTOTSECT,NDREG)	Coal Btu conversion factors for all demand sectors
SO40(NTOTSECT,NDREG)	Coal SO_2 content for utility sectors in lb/million Btu
QDL(NMAXDJOB)	Coal demand per demand job in trillion Btu
SDL(NMAXDJOB)	Shift factors for QDL (see immediately above)
DTJL(NMAXPART,NMAXDJOB)	Coal demand requirement by coal type in million tons
TIJL(NMAXPART,NMAXDJOB)	Coal assigned by coal type in million tons
YDL(NINTJOBS)	Intermediate demand list used for merge in trillion Btu
CDYRS(NMAXCTRK,NFYRS)	Utility contract demand in trillion Btu
EDYRS(NMAXEXPT,NFYRS)	Export demand in trillion Btu
BSRZR(NTOTSECT,NDREG)	Rail route multipliers
BTR(NSREG+1, NFYRS)	Network rail rate multiplier
BTW(NFYRS)	Network water rate multiplier
XC(NCSET)	Contract demand in trillion Btu
XT(NCSET)	Utility demand in trillion Btu
XCH(NCSET)	Sum of contract demand indexed by coal set (trillion Btu)
XTH(NCSET)	Sum of utility demand indexed by coal set (trillion Btu)
IMPBTU(10,3,NFYRS)	Import Btu quantity totals in trillion Btu
CSDISC(NSREG,NFYRS)	Productivity adjustment factors
FRADI(NOTSEC,NDREG)	Fraction for three industrial sectors
QIND(2,NDREG)	Industrial demand (1=exist, 2=new)
IMPTON(10,3,NFYRS)	Import tonnage totals in million tons
TONN(10,3,NFYRS)	Import tonnage in million tons
NODES(5,600)	Node names
SECTOR(3,NTOTSECT)	Sector name
TITLE(20)	First title

Table A-3. Variables for Common Block CDSCOM2 (Continued)	
SBTU(NSREG, NCOALTYP)	Btu conversion factor by supply region and coal type
CBTU(NSREG, NCOALTYP)	Carbon factor by supply region and coal type
SSUL(NSREG, NCOALTYP)	Sulfur level by supply region and coal type
SULFPEN	Sulfur penalty
SULFCONT	Sulfur content
DVLBND	Upper bound for lignite
DVSBND	Upper bound for subbituminous coal
LIGCONST	Lignite constraint
SUBCONST	Subbituminous constraint
DVCONT(90, NFYRS)	Contract constraint
QPROD(NSREG, NCOALTYP)	Coal production (including adjustment for premium coal)
QPRODS(NSREG, NCOALTYP)	Straight 34-curve production (excluding adjustment for premium coal)
PMPROD(NSREG,NCOALTYP)	Value of coal from a supply region (including adjustment for premium coal)
PMN(NSREG,NCOALTYP)	Value of coal from a region
COF(6)	Coefficient for transportation equation
ESCAL	Transportation rate escalator
TITLE2(20)	Second title
COAL(NCOALTYP)	Coal type code
SUPRGN(NSREG)	Supply region
DEMRGN(NTOTDREG)	Demand region
ISVR(NMAXCURV)	Supply region index
ISVC(NMAXCURV)	Coal type index
KSVND(NMAXCURV)	Pointer to last active supply step
KCLR(NMAXCURV)	Linked-list pointers to supply curves by coal type
MCLR(NCOALTYP)	Top of the list for KCLR
IDLR(NMAXDJOB)	Index of demand region by demand job
IDLZ(NMAXDJOB)	Index of demand sector by demand job
IDLC(NMAXDJOB)	Index of coal sets (groups) by demand job
IDLCNT(NMAXDJOB)	Contract line number
JTPH(NMAXDJOB)	Index of highest cost route
MTJ(NMAXDJOB)	Number of routes for job
KXT(NMAXPART,NMAXDJOB)	Pointer to active route for demand job
ISTJ(NMAXPART,NMAXDJOB)	Index of supply region by route and demand job
ICSET(NCSET,NCOALTYP)	Coal set indices

Table A-3. Variables for Common Block CDSCOM2 (Continued)	
JTPL(NMAXDJOB)	Index of lowest cost route
ICSR(NMAXDJOB)	Contract supply region
KCNUR(6,NDREG)	Indices of coal sets for nonutility demands
IYLR(NINTJOBS)	Index of intermediate demand list region
IYLZ(NINTJOBS)	Index of intermediate demand list sector
IYLC(NINTJOBS)	Index of intermediate demand list coal set
ICD(NMAXCTRK)	Contracted demand region
MDLZ(NMAXCTRK)	Index of contract sector
ICS(NMAXCTRK)	Index of supply region for contract
ICC(NMAXCTRK)	Index of coal set for contract
IEDR(NMAXEXPT)	Demand region index for export sector
IEDZ(NMAXEXPT)	Demand sector index for export sector
IEDC(NMAXEXPT)	Coal set index for export sector
KCUR(NUTSEC,NDREG)	Indices of coal sets for utility demands
ISUL(NCOALTYP)	Coal type sulfur
IFED(NTOTDREG)	Converts CDS demand region index to Census division index
ISEC(NTOTSECT)	Converts demand sector index to IFFS sector index
NDRX	Number of demand regions
NNCSET	Number of coal sets

Table A-4. Variables for Common Blocks for CPS/CDS (sources: CPS and CDS)	
CDS_RECORDS	Number of records in the file for the CDS
CDS_SR	Numeric region code used in CDS file
CDS_DR	Numeric demand region code (CDS file)
CDS_CT	Numeric coal type code (CDS file)
CDS_DS	Numeric demand sector code (CDS file)
CPS_NCUR	Number of supply curves for CPS
CPS_REG(300)	Numeric region codes for CPS
CPS_CTYPE(300)	CDS numeric codes for coal types
CDS_QTY	Coal shipments in million tons
CPS_YINT1(300)	Y-Intercept for the first segment of the supply curve
CPS_SLOPE1(300)	Slope for the first segment of the supply curve
CPS_PEND1(300)	Production at the end point of the first segment of the supply curve

Table A-4. Variables for Common Blocks for CPS/CDS (sources: CPS and CDS) (Continued)	
CPS_SURCAP(300)	Production at the endpoint of the second segment of the supply curve
CPS_RINTER2(300)	Constant in the supply curve
CPS_RMULT(300)	Coefficient in the supply curve
CPS_NMCUTIL(300,3)	Exponent1 in the supply curve
CPS_MCUTILX(300,3)	Exponent2 in the supply curve
CPS_YINT3(300)	Y-Intercept for the third segment of the supply curve
CPS_SLOPE3(300)	Slope of the third segment of the supply curve
CPS_PEND3(300)	Production at the end point of the supply curve
CPS_LPROD(300)	Labor productivity
CPS_BTU(300)	Average Btu content for the supply curve in million Btu/ton
CPS_SULFUR(300)	Average sulfur content for the supply curve in lb/million Btu
P_RECORDS	Number of records in capacity file for the CDS
P_SR(2000)	Numeric supply region code for capacity used in the CDS
P_DR(2000)	Numeric demand region code for capacity (CDS file)
P_CT(2000)	Numeric coal type code for capacity (CDS file)
P_DS(2000)	Numeric demand sector code for capacity (CDS file)
P_QTY(2000)	Coal capacity in million tons
P_ISVR(300)	Supply region index for capacity
P_ISVC(300)	Coal type index for capacity
P_KSVND(300)	Pointer to last active capacity step
PWL_CURV	Total number of capacity curves
PWL_REC	Total number of capacity curve steps
P_USV(4000)	Upper limit of capacity before step invoked.
P_BSV(4000)	Slope of capacity curve segment
P_ASV(4000)	Y-intercept for capacity step
P_BTU(300)	Average Btu content for capacity curve in million Btu/ton
P_SULFUR(300)	Average sulfur content for capacity curve in lb/million Btu
FIRSTFLG	Flag to control sequence of capacity calculations
MCNT_REGION	Supply region (marginal cost curve)
MCNT_CTYPE	Coal type (marginal cost curve)
MCNT_REC	Number of record (marginal cost curve)
MCNT_PRICE(600)	Minemouth price (marginal cost curve)
MCNT_BTU(600)	BTU conversion (marginal cost curve)

Table A-4. Variables for Common Blocks for CPS/CDS (sources: CPS and CDS) (Continued)	
MCNT_CAR(600)	Carbon factor (marginal cost curve)
MCNT_SULF(600)	Sulfur level (marginal cost curve)
MCNT_Q(600,8)	Coal quantity for each step (marginal cost curve)
MCNT_P(600,8)	Coal price for each step (marginal cost curve)
MCNT_FRAC(600)	Mine type (marginal cost curve)
MCNT_PROD(600)	Production (marginal cost curve)
MCNT_CAP(600)	Capacity (marginal cost curve)
MCNT_STEP(8)	Step size
PTARG(16,2,16)	Target price
PCNT_REGION	Supply region (capacity curve)
PCNT_CTYPE	Coal type (capacity curve)
PCNT_REC	Number of record (capacity curve)
PCNT_PRICE(600)	Minemouth price (capacity curve)
PCNT_BTU(600)	BTU conversion (capacity curve)
PCNT_CAR(600)	Carbon factor (capacity curve)
PCNT_SULF(600)	Sulfur level (capacity curve)
PCNT_Q(600,8)	Coal quantity for each step (capacity curve)
PCNT_P(600,8)	Coal price for each step (capacity curve)
PCNT_FRAC(600)	Mine type (capacity curve)
PCNT_PROD(600)	Production (capacity curve)

Table A-5. Variables for Common Block CDSSHR (source: CDS)	
CDSIN(NDREG,MNUMCR)	Industrial sector share factors
CRSIN(2,MNUMCR)	Industrial type fractions (1=existing, 2=new)
CDSRC(NDREG,MNUMCR)	Residential/commercial sector share factors
CDSMC(NDREG,MNUMCR)	Metallurgical coal sector share factors
CDSUT(NDREG,12)	Utility sector share factors
NERC(NDREG)	NERC index
CT_USED(16,32)	Coal type used
MAPCEN(NDREG+1)	Maps demand regions to Census regions
MAPCDS(NDREG)	Maps Census regions to demand regions

Table A-6. Variables for Common Block CDSFMGR (sources: CPS and CDS)	
IUNIT	Unit for WRITE statement
IUNITDB	Unit to WRITE to the debug file
IUNITDS	Unit to WRITE to the CDS file
FILE_MGR	File manager

Table A-7. Variables for Coal Module Output Common Block (source: CDS)	
COTN_TM(MNUMCR,MNUMYR)	Coal transportation ton-miles
COPRCLQ(MNUMCR,MNUMYR)	Supply of coal liquids
COPRCLG(MNUMCR,MNUMYR)	Supply of coal gases
COIM(MNUMXR,MNCLTYPE,MNUMYR)	Coal exports
COIMP(MNUMXR,MNCLTYPE,MNUMYR)	Coal export prices
COCCLQ(MNUMCR,MNUMYR)	Delivered costs of coal liquids
COCCLG(MNUMCR,MNUMYR)	Delivered costs of coal gases
COSUPC(MNUMXR,MNCLTYPE,MNUMYR)	Coal supply curves
COELPRC(MNUMNR,MNUMYR)	Utility coal price
CLSYNGPR(17,MNUMYR)	Coal synthetic natural gas price
CLSYNGQN(17,MNUMYR)	Coal synthetic natural gas quantity
CQSBB(3,MNUMYR)	Coal production (East,West Miss, U.S.) in trillion Btu
CQSBT(3,MNUMYR)	Coal Btu conversion factor for production in million Btu/ton
CPSB(3,MNUMYR)	Coal minemouth price in 1987 $/ton
CQDBFT(MNUMCR,6,MNUMYR)	Coal conversion factor for Consumption in million Btu/ton
CQDBFB(MNUMCR,6,MNUMYR)	Coal consumption in trillion Btu
CELNR(NDREG,MNUMYR)	VLS bituminous coal price by CDS regions in 1987 $/million Btu
PBDELNR(NDREG,MNUMYR)	LS bituminous coal price by CDS regions in 1987 $/million Btu
PBMELNR(NDREG,MNUMYR)	MS bituminous coal price by CDS regions in 1987 $/million Btu
PBHELNR(NDREG,MNUMYR)	HS bituminous coal price by CDS regions in 1987 $/million Btu
PSCELNR(NDREG,MNUMYR)	VLS subbituminous coal price by CDS regions in 1987 $/million Btu
PSDELNR(NDREG,MNUMYR)	LS subbituminous coal price by CDS regions in 1987 $/million Btu
PSMELNR(NDREG,MNUMYR)	MS subbituminous coal price by CDS regions in 1987 $/million Btu
PSHELNR(NDREG,MNUMYR)	HS subbituminous coal price by CDS regions in 1987 $/million Btu
PLCELNR(NDREG,MNUMYR)	VLS lignite coal price by CDS regions in 1987 $/million Btu
PLDELNR(NDREG,MNUMYR)	LS lignite coal price by CDS regions in 1987 $/million Btu

Table A-7. Variables for Coal Module Output Common Block (Continued)	
PLMELNR(NDREG,MNUMYR)	MS lignite coal price by CDS regions in 1987 $/million Btu
PLHELNR(NDREG,MNUMYR)	HS lignite coal price by CDS regions in 1987 $/million Btu
BBCELNR(NDREG,MNUMYR)	VLS bituminous coal Btu factor by CDS regions in million Btu/ton
BBDELNR(NDREG,MNUMYR)	LS bituminous coal Btu factor by CDS regions in million Btu/ton
BBMELNR(NDREG,MNUMYR)	MS bituminous coal Btu factor by CDS regions in million Btu/ton
BBHELNR(NDREG,MNUMYR)	HS bituminous coal Btu factor by CDS regions in million Btu/ton
BSCELNR(NDREG,MNUMYR)	VLS subbituminous coal Btu factor by CDS regions in million Btu/ton
BSDELNR(NDREG,MNUMYR)	LS subbituminous coal Btu factor by CDS regions in million Btu/ton
BSMELNR(NDREG,MNUMYR)	MS subbituminous coal Btu factor by CDS regions in million Btu/ton
BSHELNR(NDREG,MNUMYR)	HS subbituminous coal Btu factor by CDS regions in million Btu/ton
BLCELNR(NDREG,MNUMYR)	VLS lignite coal Btu factor by CDS regions in million Btu/ton
BLDELNR(NDREG,MNUMYR)	LS lignite coal Btu factor by CDS regions in million Btu/ton
BLMELNR(NDREG,MNUMYR)	MS lignite coal Btu factor by CDS regions in million Btu/ton
BLHELNR(NDREG,MNUMYR)	HS lignite coal Btu factor by CDS regions in million Btu/ton
SBCELNR(NDREG,MNUMYR)	VLS bituminous coal sulfur factor by CDS regions in lb/million Btu
SBDELNR(NDREG,MNUMYR)	LS bituminous coal sulfur factor by CDS regions in lb/million Btu
SBMELNR(NDREG,MNUMYR)	MS bituminous coal sulfur factor by CDS regions in lb/million Btu
SBHELNR(NDREG,MNUMYR)	HS bituminous coal sulfur factor by CDS regions in lb/million Btu
SSCELNR(NDREG,MNUMYR)	VLS subbituminous coal sulfur content by CDS regions in lb/million Btu
SSDELNR(NDREG,MNUMYR)	LS subbituminous coal sulfur content CDS regions in lb/million Btu
SSMELNR(NDREG,MNUMYR)	MS subbituminous coal sulfur content by CDS regions in lb/million Btu

Table A-7. Variables for Coal Module Output Common Block (Continued)	
SSHELNR(NDREG,MNUMYR)	HS subbituminous coal sulfur content by CDS regions in lb/million Btu
SLCELNR(NDREG,MNUMYR)	VLS lignite coal sulfur content by CDS regions in lb/million Btu
SLDELNR(NDREG,MNUMYR)	LS lignite coal sulfur content by CDS regions in lb/million Btu
SLMELNR(NDREG,MNUMYR)	MS lignite coal sulfur content by CDS regions in lb/million Btu
SLHELNR(NDREG,MNUMYR)	HS lignite coal sulfur content by CDS regions in lb/million Btu

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 87,88, 89 and 90).

- An output file (@.CLCDS) that currently contains 17 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, 87, 88, 89 and 90. 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 for four macro-supply 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 electric utility 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 electric utility 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 87, "Domestic Coal Supply, Disposition and Prices by Case," 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 six aggregated supply regions: Northern and Southern Appalachia, the Interior, the Northern Great Plains, Other West and Non-Contiguous. Table 93 excludes exports.

Table 88, "Coal Production and Minemouth Prices By Region," provides annual summaries of national distribution from the same aggregated supply regions used in Table 93, 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 89, "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 90,"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 Electric Utility).

Single Year Detailed Reports

These detailed reports begin with three summaries of the demands received by the CDS for each sub-sector and region. These demands, shown in trillions of Btu, are indexed to both the domestic CDS region and Census division in which they occur by number. These summaries are divided into a single-page report for the non-electric utility sectors, a single-page report for the 7 electricity sub-sectors that represent different boiler and sulfur coal categories, and a single-page report summarizing electric utility demands by region, coal rank category, and coal sulfur level.

The nonutility demand report is structured as follows, reading the columns from left to right:

- Census division index number, repeated to allow separate indexing of each domestic CDS demand region in each Census division, with subtotals for each Census division; the demand region index number

- Residential/Commercial demands, by region

- Demands for the each of the three industrial demand subsectors are listed in three columns; then the total industrial demand is listed in a fourth; the fifth column for industrial demand contains the import supplies that have been subtracted from industrial demand

- Demands for the two metallurgical subsectors are listed with the subtotal for both subsectors and the import supplies that are subtracted from metallurgical demand

- Export demands for the export subsectors and the subtotal for all export demands
- Total of all nonutility demand.

The Nonutility Demand Report is immediately followed by the Utility Demand Report, again indexed by Census division and domestic CDS demand region with subtotals by Census division. Here the columns represent demands in each of the 7 electric power utility sectors that are keyed to individual coal types. In comparing the demands in this report with the supplies provided (which can be traced in the Detailed Supply and Price Report discussed below), it should be noted that electric power demands can always be met by lower sulfur coals if it is less expensive to do so.

The Utility Demand Report is followed by the Utility Summary Demand Report, which provides demand totals by region for bituminous, subbituminous and lignite coals, and for low, medium, and high sulfur coals.

The next report, the Detailed Supply 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 13 pages in length, depending on the year and scenario reported (usually one page per demand region).

Following the Detailed Supply and Price Report, coal distribution is shown in a series of spreadsheets where rows represent demand regions and columns supply regions. Each of these reports is three and one-half pages in length and reports, for each supply/demand region pair, the tonnage shipped and the minemouth, transport, and delivered prices in dollars per million Btu. Currently, these reports are operational for the industrial, export, and utility sectors and for total coal distribution.

These reports are currently followed by a spreadsheet "Total Transportation Report." As currently formatted, this report shows only the tonnage shipped and the transport rate in dollars per ton.

The distribution spreadsheets are followed by 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.

The Detailed Production Report is followed by 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.

Three more summary reports follow the Census division Report. These show the dollar-per-million-Btu delivered price, Btu conversion factor, and sulfur content of coal shipped to the utility subsectors. These reports are primarily of interest in diagnosing problems between the CMM and EMM, since, in effect, they provide a concise summary of data reported more extensively in other reports. These reports have the same format as the Utility Demand Report described above.

Appendix B

Detailed Mathematical Description of the Model

The CDS model is specified as a Linear Program (LP), which satisfies demands at all points at the minimum overall total production cost plus transportation cost. From the output of the model, it is possible to determine an optimum pattern of supply.

The geographical representation of the domestic portion of the model is a set of coal supply regions and coal demand regions. Each coal supply region has a quantity of coal available for transport to demand nodes, in which the amount available is price dependent. The production cost associated with each quantity of coal available for delivery includes mining and coal preparation costs,

Mathematical Formulation

The table of column activity definitions and row constraints defined in the CDS matrix incorporates assumptions described in Section 3 on Model Rationale and variable definitions which are described in Appendix A. 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 in the model. The next two columns define sets of variables for the production and transportation of coal. The fourth and fifth table columns, labeled Coal Switching define certain specialized activities that relate to allowing low sulfur coal to substitute for higher sulfur demands, provided that the overall economics associated with total delivered cost plus sulfur allowance considerations are favorable. The table column labeled Row Type, shows the equations to be maximums, minimums, or equalities. The objective function row, which is considered a free row, is set up as a linear programming cost minimization problem. 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.

The CDS matrix currently contains several thousand rows (equations) and 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.

CDS Linear Program Structure

Coal Distribution Submodule Block Diagram				
	Produce Coal $QP_{i,u,t,s}$ P(SR)(UM)(S)	Transport Coal $QT_{i,j,k,r}$ T(SR)(UMR)(DR)(SEC)(C)	Row Type	RHS
Objective (Cost)	+p	+t	_	Min
Production S@(SR)(UM)(C)	+1	-1	EQ	0.00
Demand D.(DR)(SEC)(C)		+1	EQ	D
Coal Type Constraint * DV(C)(DR)(SEC)		+1	LE	CS
Contract Constraint * C(SR)(DR)(SEC)(C)		+1	GE	C
Sulfur Constraint * SULFPEN		+s	LE	CAP

Legend
p = production cost
t = transportation cost
s = sulfur content
LE = less than or equal
GE = greater than or equal
D = coal demand
CS = coal type constraint
CAP = sulfur cap
C = contract constraint
* = constraints for utility sectors only

Index Definitions

Index Symbol	Description
(i)	Coal supply region
(j)	Coal demand region
(k)	Demand sector
(r)	Coal rank
(s)	Mine step
(t)	Mine type
(u)	Sulfur level

Column Definitions

Table B-3. Column Definitions

Column Notation		Description
$Qp_{i,u,t,s}$	=	Quantity of coal from step s of the coal supply curve produced from coal supply region i and of sulfur level u and mine type t.
$Qt_{i,j,k,r,u}$	=	Total quantity of coal transported from all steps of coal supply region i to coal demand region j, of sulfur level u and rank r, for coal demand sector k.

Objective Function

The objective function is to minimize delivered costs (i.e., minemouth production, preparation, and transportation costs, and adjusted for coal switching) associated with moving coal from supply regions to demand regions and has been defined for CDS as minimizing:

$$\Sigma_i \Sigma_r \Sigma_u \Sigma_t \Sigma_s \quad QP_{iu,t,ss} * P_{i,r,u,t,s} + \Sigma_i \Sigma_j \Sigma_k \Sigma_r \Sigma_u \quad QT_{i,j,k,r,u} * T_{i,j,k} \tag{1}$$

where the individual terms of the equation represent the costs associated with the activities of production, transportation, and coal switching and

P	=	Production or minemouth price
T	=	Transportation price

Row Constraints

Balance the coal transported from each producing region against the coal produced.

$$\Sigma_s \Sigma_t \, QP_{i,u,t,s} + \Sigma_j \Sigma_k \, QT_{i,j,k,r,u} = 0 \tag{2}$$

Meet the coal demands by rank and type.

$$\Sigma_i \, QT_{i,j,k,u} = \Sigma_u D_{j,k,r,u} = 0 \tag{3}$$

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

Output Variables

$X_{i,j,k,u,t}$ = Quantity of coal rank r and sulfur level u that is transported from coal supply region i to coal import region j for coal demand sector k.

$U_{i,k,t}$ = 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 solution to the CDS model.

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	Activity Represented
P(SR)(U)(M)(S)	Coal production in supply region (SR), sulfur level (U), mine type (M) and step (S).
T(SR)(U)(M)(R)(DR)(S)(C)	Transportation from supply region (SR), sulfur level (U), mine type(M), coal rank(R) to demand region (DR) for demand sector (S) of coal type (C).
PX.(SRI)(I)	Coal supply in international supply region (SRI) of step (I).
TX(SI)(DRI)(TI)	Transportation from supply region (SI) to international demand region (DRI) of coal type (TI).
UX(DR)(SA)	U.S. demand region (DR) for export demand sector (SA).
EXP(SI)(TI)	Sum of exports from supply region (SI) for diversity of international coal type (TI).
IMP(DRI)(TI)	Sum of imports from demand region (DRI) for diversity of international coal type (TI).
S@(SR)(U)(M)(C)	Coal production in supply region (SR) of sulfur level (U), mine type (M), and coal type (C).
D.(DR)(SEC)(C)	Coal demand from demand region (DR) for demand sector (SEC) of coal type (C).
DV(C)(DR)(SEC)	Coal constraint for coal type (C), demand region (DR), demand sector (SEC).
C(SR)(DR)(SEC)(C)	Contract constraint from supply region (SR) to demand region (DR) for demand sector (SEC) and coal type (C)
SULFPEN	Sulfur penalty constraint.
BDX(DRI)(TI)	Export balance row in international demand region (DRI) for export coal type (TI).
SXX(SRI)(TI)	The supply of coal type (TI) in international supply region (SRI).
SDX(DR)(SA)	The sum of U.S. internal exports to ports in demand region (DR) and sector (SA).
BSX(SI)(TI)	Total coal supply for diversity of supply region (SI) of coal type (TI).

Mask	Activity Represented
(SI)DX(DRI)(TI)	Export demand region (DRI) of coal type (TI).
VE(SI)(DRI)	Diversity export constraint on supply region (SI) to demand region (DRI).
VI(DRI)(SI)	Diversity import constraint on demand region (DRI) from supply region (SI).

where,

DR **U.S. DEMAND REGIONS**

NE NEW ENGLAND
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, COLORADO, IDAHO, 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
SA ALABAMA, TENNESSEE
EI ILLINOIS, INDIANA, KENTUCKY (WEST)
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

R **COAL RANK**

L	Lignite	
S	Subbituminous	
B	Bituminous	
P	Premium	

U **SULFUR GRADE**

C	Compliance:	≤ 1.2 lbs SO2 per million Btu
M	Medium:	> 1.2 but ≤3.33 lbs SO2 per million Btu
H	High:	>3.33 lbs SO2 per million Btu

M **MINE TYPE**

D	Underground Mining
S	Surface Mining

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 **SECTOR**

A	RESID/COM = RESIDENTIAL/COMMERCIAL DEMAND
B	RESID/COM
C	IND STOKER
D	IND PVC
E	IND OTHER
F	PREMIUM COKING
G	BLENDING COKING
H	PREMIUM (METALLURGICAL EXPORT)
I	BLEND (METALLURGICAL EXPORT)
J	STEAM 1 EXPORT
K	STEAM 2 EXPORT
1	“OLD” LOW-SULFUR ELECTRICITY
2	“OLD” MEDIUM-SULFUR ELECTRICITY
3	“OLD” HIGH-SULFUR ELECTRICITY
4	“NEW” LOW-SULFUR ELECTRICITY
5	“NEW” MEDIUM-SULFUR ELECTRICITY
6	“NEW” HIGH-SULFUR ELECTRICITY
7	“SCRUBBED” ELECTRICITY

*   **EXPORT TYPE**

X1P Premium (Metallurgical Export)
X2P Blend (Metallurgical Export)
X3S Steam 1 Export
X4S Steam 2 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	India
NET	East Coast Canada (THERMAL)
NIT	Canada internal
SCT	Scandinavia
BTT	United Kingdom
GYT	Germany
OWT	Other Northern Europe
SPT	Iberia
ITT	Italy
RMT	E Europe and Mediterranean
MXT	Mexico
LAT	South America
JAT	Japan
EAT	East Asia
CHT	China Hong Kong (diff. name)
AST	ASEAN
INT	India
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

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Appendix D

CDS Model Abstract

Model Name: Coal Distribution Submodule

Model Acronym: CDS

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

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

- **Model Update Information:** December 1998

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 Export Submodule and the Coal Production Submodule. Within NEMS, the CDS receives Industrial steam and metallurgical coal demands from the NEMS Industrial Demand 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: Richard Newcombe
Telephone: (202) 586-2415
E-mail: Richard Newcombe (rnewcomb@eia.doe.gov)

Documentation:

- Energy Information Administration, *EIA Model Documentation, Coal Market Module of the National Energy Modeling System*, January 1998.

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Archive Media and Installation Manual: CDS99 - *Annual Energy Outlook 1999*.

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

Coverage:

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

- **Time unit/Frequency:** Annual forecasts for 1997-2020 period (24 years).

- **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, 4 Export, and 7 Electric Utility subsectors (a synthetic fuel subsector is present but not operational in the CDS) to 13 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 20 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 sub-sector), 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 7,956 such rates for any forecast year; in practice there are less since many rates are economically infeasible. Coal supplies are delivered to up to 18 demand sectors in each of the 13 demand regions. A single model run represents a single year, but up to 26 consecutive years (1995-2020) may be run in an iterative fashion. Currently the NEMS system provides demand input for the 1996-2020 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 Electricity Market Module provides demands for the electricity generation sectors. The Coal Export Submodule of the NEMS Coal Market Module provides demand for the coal export sector. 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 determine mine capacity utilization percentages for each supply curve and to decrement the coal reserve base (to prevent remining of reserves already depleted in a previous iteration).

- **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) import supplies (millions of short tons)

  — — *Coal supply/transportation contracts:* (1) coal supply regions; (2) coal demand regions; (3) coal quality (Btu and sulfur content); (4) contract annual volumes (trillion Btu); (5) contract expiration dates (forecast year)

  — — *Coal quality data for supply curves:* (1) million Btu per short ton; (2) lbs. sulfur 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 and demand region pair

  — — *Transportation rate escalation factors:* (1) exogenous; (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:* (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, "Coke Plant Report - Quarterly"
— Form EIA-6, "Coal Distribution Report"
— Form EIA-7A, "Coal Production Report"
— FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"
— 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:

- **Language:** FORTRAN
- **Processor:** IBM RS/6000
- **Input/Output Mode:** Batch
- **Average Run Time:** 10 CPU seconds for a single year
- **Turnaround Time:** 2 minutes to 1 hour
- **Average Compile Time:** 10 CPU seconds

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.

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 November in 1998.

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

Appendix E

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 electric utility 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", covers 97 percent of coal receipts to industry (Form EIA-6, below): coal stocks, delivered prices, and consumption.

- Form EIA-3A, "Annual Coal Quality 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, "Coke Plant Report" covers 100 percent of coal receipts at coke plants: consumption, delivered prices, and stocks.

- Form EIA-5A, "Annual Coal 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-6, "Coal Distribution Report" covers 99 percent of production (Form EIA-7A, below): 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; these data were collected on a "Dry" basis.[50]

- 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.

- FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants" covers power 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

[50]Energy Information Administration, *Coal Production 1984*, DOE/EIA-0118(84) (Washington, DC, November 1985), Appendix C.

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 together with the forms EIA-3A and EIA-5A now provides the only coal quality data available, and is restricted to the electric utility, industrial steam and coking coal sectors. Coals consumed by these sectors 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 8 percent of 1997 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, 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 cruve 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 1999* is summarized in Table E-1 which shows the entire EIA data frame as it has been available during the NEMS construction and calibration period.

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

ITEM	UTILITY	IPP	IND.	COKING	RES/COM	EXPORT	IMPORT	MINE
Prices:								
Minemouth	n/a	n/a	n/a	n/a	n/a	n/a	n/a	EIA7A
Delivered	FERC423	n/a	EIA3	EIA5	n/a	EM522	EIA3,EIA5,F 423	n/a
Freight	FERC580	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Transport:								
Mode	FERC580	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Miles	FERC580	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Origin	FERC423	n/a	EIA3A	EIA5A	EIA6	EIA6	IM545	EIA7A
Destination	FERC423	EIA867	EIA3A	EIA5A	EIA6	EM522/ EIA6	EIA3A, EIA5A, FERC423	n/a
Tonnage:								
Production	n/a	n/a	n/a	n/a	n/a	n/a	n/a	EIA7A
Distribution	EIA6	n/a	EIA6	EIA6	EIA6	EIA6	n/a	n/a
Receipts	FERC423	n/a	EIA3	EIA5	n/a	n/a	n/a	n/a
Consumpt.	EIA759	EIA867	EIA3	EIA5	n/a	EM522	n/a	n/a
Stocks	EIA759	n/a	EIA3	EIA5	n/a	n/a	n/a	EIA7A
Quality:								
Rank/grade	FERC423	EIA867	n/a	n/a	n/a	EM522	IM545	EIA7A
Volatiles %	n/a	n/a	n/a	EIA5A	n/a	n/a	n/a	n/a
Btu Content	FERC423	EIA867	EIA3A	n/a	n/a	n/a	EIA3A,	n/a
Sulfur %	FERC423	EIA867	EIA3A	EIA5A	n/a	n/a	EIA5A,	n/a
Ash %	FERC423	EIA867	EIA3A	EIA5A	n/a	n/a	FERC423	n/a
Particulates	EIA767	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SO2	EIA767	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NOX	EIA767	n/a	n/a	n/a	n/a	n/a	n/a	n/a
COX	EIA767	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = Not available.

Appendix F

CDS Program Availability

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

Office of Integrated Analysis and Forecasting
EI-82
Energy Infornation Administration
U.S.Department of Energy
1000 Independence Avenue SW
Washington DC, 20585

Part II-B—Coal Distribution Submodule Model Documentation (International Coal Trade)

1. Introduction

Statement of Purpose

The purpose of this report 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. The report 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 constraint components. The major coal producing countries (United States, Australia, South Africa, Canada, and Poland) are represented, as well as countries that could become major coal exporters (Colombia, Indonesia, Venezuela, and China).

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 1999.

Name: Coal Distribution Submodule--International Coal Trade Flows
Acronym: CDS
Archive Package: NEMS99 (Available through National Technical Information Service.)
Model Contact: Mike Mellish, Department of Energy, EI-82, Washington DC 20585 (202) 586-2136

Report Organization

This report describes the modeling approach used in the Coal Export Submodule. 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 2020) of world coal trade flows. Coal supply in the international area of the CDS is modeled through the incorporation of 3 coal types (Table 6) (unique combination of heat and sulfur content) and 16 geographic supply regions (Table 7 and Figure 9). On the demand side, 2 coal demand sectors (Table 8) are modeled for 20 importing demand regions (Table 9 and Figure 9). The international component of the CDS also provides annual U.S. coal export forecasts to the Coal Market Module (CMM) of the National Energy Modeling System (NEMS).

The 5 regions that define the geography of U.S. coal exports in the CMM are shown in Figure 9. These regions represent aggregations of ports-of-exit through which exported coal passes on its way from domestic supply regions to foreign consumers (Table 10). The U.S share of world coal markets is treated as a two-stage optimization problem, with international demands being solved in the export portion of the model in which the aggregated U.S. ports-of-exit account for 5 of 16 world supply regions, while in the domestic portion of the model, export demands occur in 8 of 13 domestic CDS demand regions and play the role of domestic consumers which find the optimal solution to the their demands for export coal within the domestic coal market, using the 11 domestic coal supply regions as their sources.

Four key user-specified inputs are required. They include coal import demands, coal supply curves, transportation costs, and constraints. The primary outputs are annual world coal trade flows.

Relationship to Other Modules

The model generates regional forecasts for U.S. coal exports for use in the CMM. These export demands are passed to the domestic area of the CDS which solves and returns the price to the international component of the CDS.

Table 6. CDS International Coal Supply Types

Coal Supply Type	Heat Content (mmBtu/short ton)	Sulfur Content (lbs./mmBtu)	Corresponding NEMS CPS/CDS Coal Types
Premium Bituminous	≥25	<1.67	MDP, CDP
Low-Sulfur Bituminous	≥20 but <25	<1.67	CDB, CSB, MDB, MSB
Subbituminous	≥15 but <20	<0.60	CSS

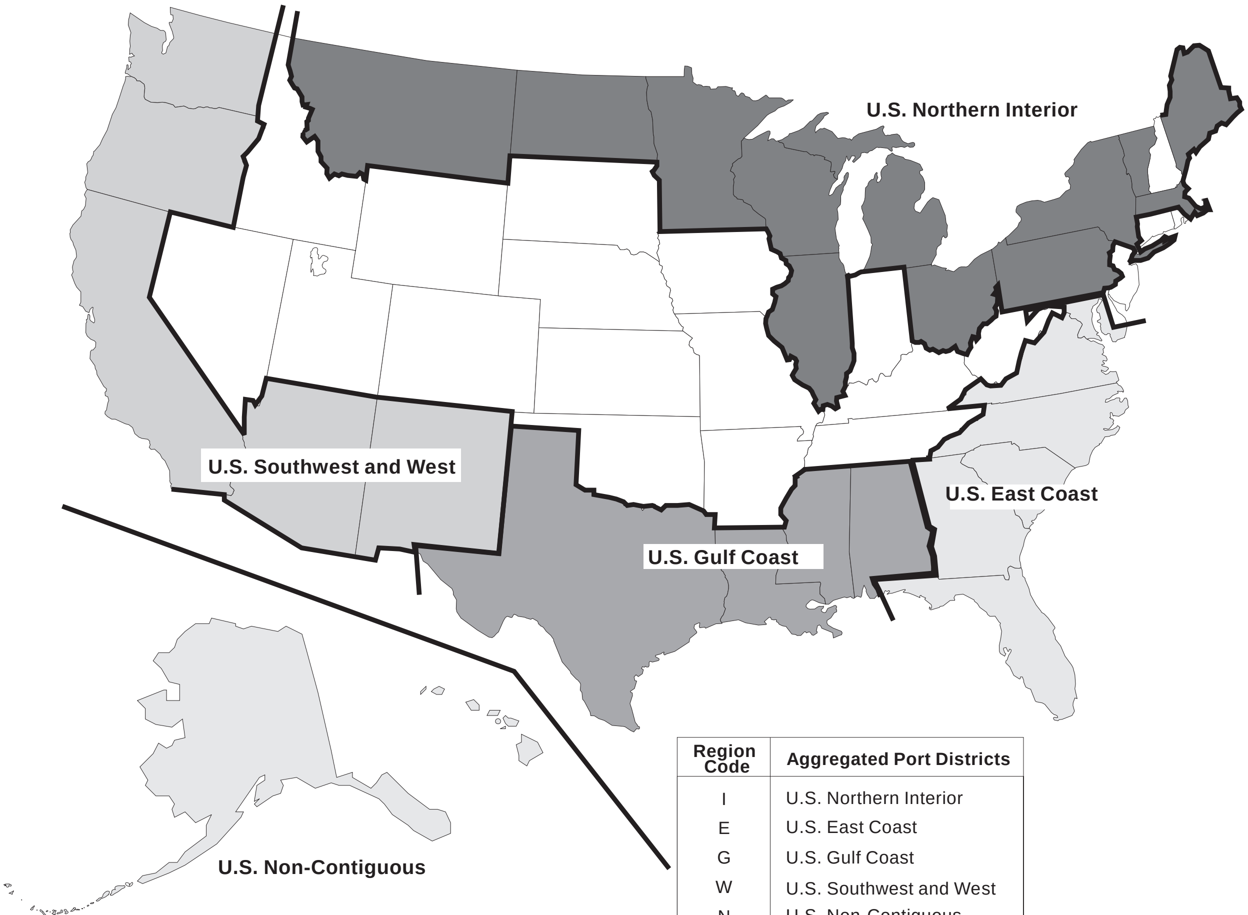
Table 7. CDS Coal Export Regions

1	U.S. East Coast
2	U.S. Gulf Coast
3	U.S. Southwest and West
4	U.S. Northern Interior
5	U.S. Non-Contiguous
6	Australia
7	Canada, Western
8	Canada, Interior
9	South Africa
10	Poland
11	CIS (Europe)
12	CIS (Asia)
13	China
14	Colombia
15	Indonesia
16	Venezuela

Table 8. CDS International Coal Demand Sectors

Demand Sector	Acceptable Coal Supply Types
Coking	Premium Bituminous
Steam	Premium Bituminous Low-Sulfur Bituminous Subbituminous

Figure 9. U.S. Export and Import Regions Used in the CDS



Region Code	Aggregated Port Districts
I	U.S. Northern Interior
E	U.S. East Coast
G	U.S. Gulf Coast
W	U.S. Southwest and West
N	U.S. Non-Contiguous

Table 9. CDS Coal Import Regions

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

Table 10. Port District Aggregation Used to Model U.S. Coal Exports

REGION CODE	REGION NAME	PORT DISTRICTS
I	U.S. NORTHERN INTERIOR	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
E	U.S. EAST COAST	Baltimore, MD Norfolk, VA Charleston, SC Savannah, GA Miami, FL San Juan, PR US Virgin Islands Tampa, FL
G	U.S. GULF COAST	Mobile, AL New Orleans, LA Houston-Galveston, TX Laredo, TX El Paso, TX
W	U.S. SOUTHWEST AND WEST	Nogales, AZ San Diego, CA Los Angeles, CA San Francisco, CA Portland, OR Seattle, WA
N	U.S. NON-CONTIGUOUS	Anchorage, AK

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 capacities 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.

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

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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.

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.

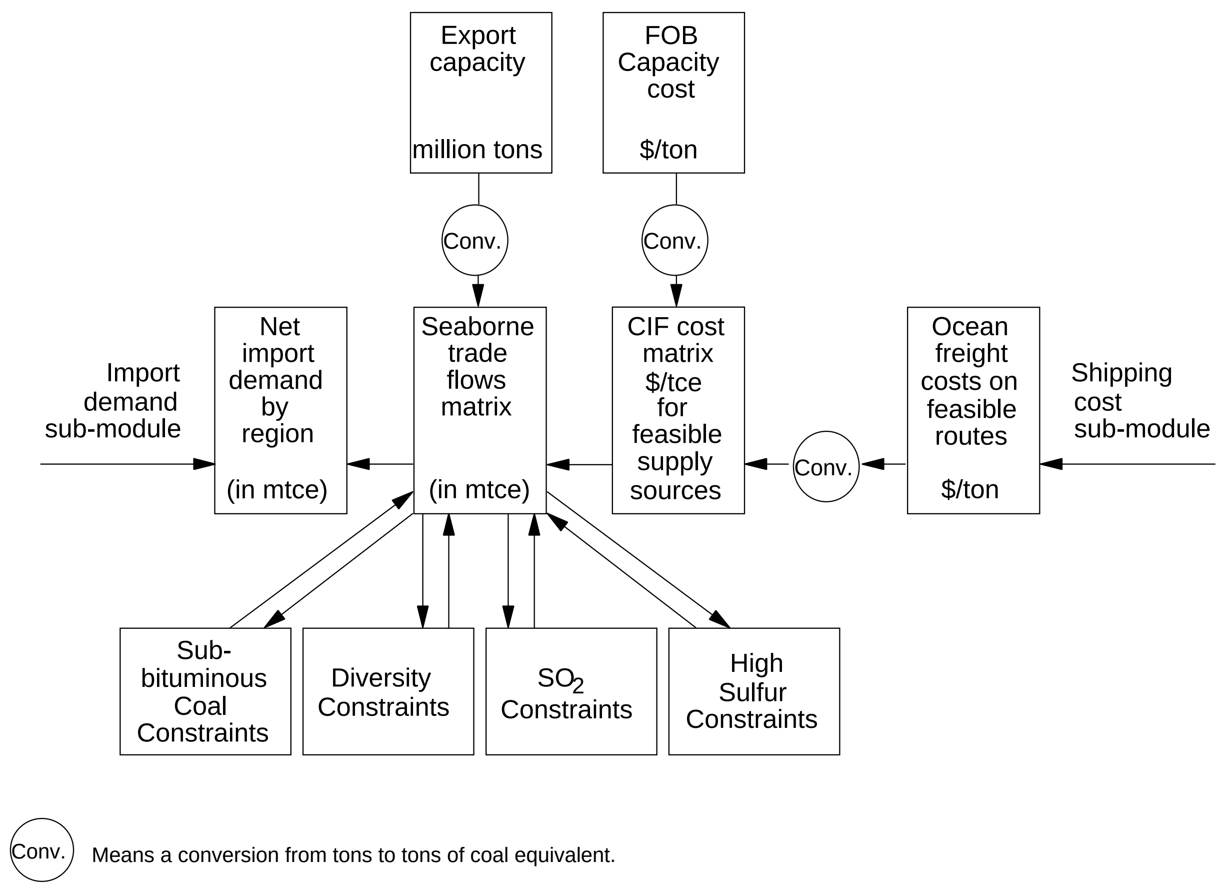
In terms of coal qualities and market segmentation, WOCTES is too restrictive, as it is designed to only analyze the thermal coal market. It also assumes that coal buyers are indifferent between coal types. The ICTM does differentiate between coking and thermal coal, with import demand being similarly 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 10). From the output of the model it is possible to determine an optimum pattern of supply.

Figure 10. Overview of the International Component of the CDS



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 that must be satisfied at the minimum overall cost.

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 A

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 four 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; and 4) the sulfur content in percent sulfur by weight for all forecast years. 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, and 2020.

CLEXDEM. This file contains the coal import demands by international CDS demand region and sector for the years 1990, 1992, 1996, 2000, 2005, 2010, 2015, and 2020. 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 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 U.S. coal export demands for the historical years of the forecast period. Each row includes five indices at the left followed by eight numbers representing annual demands for coal exports in trillion Btu for the years 1990 through 1998. 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 below in the discussion of the "CLPARAMS" input file in Part II-A of the CMM Model Documentation), and (5) the international coal export region to which they pertain.

CLEXIMS. This file contains the coal import diversity constraints specified as percent of the total coal 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 *AEO99* forecasts.

Model Outputs

The key output from international area of the CDS, listed in Table A-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.

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.

Table A-1. User-Specified Inputs

Input	CDS Variable	Specification Level[a]	Units
Coal supply steps	FOBYR	Coal export region/ coal type/forecast year	Dollars per metric ton
Coal shipments from step on a coal supply curve	CAPYR	Coal export region/ coal import region/ coal type/coal demand sector/forecast year	Million metric tons
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/forecast year	Dollars per metric ton
Importer diversity constraints	IMPSHARE	Coal export region/ coal import region/ forecast year	Percentage
Exporter diversity constraints	EXPSHARE	Coal export region/ coal import region/ forecast year	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/forecast year	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/forecast year	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 A-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 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. From the output of the model it is possible to determine 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 A. 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 or s representing the sulfur content of coals. 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								
	$PX_{i,t,s}$	$TX_{i,j,t}$	$UX_{j,t}$	EXP_i	$IMP_{j,t}$	$QT_{1,j,k,r,u}$	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
(t)	Coal type (Thermal or Coking)
(s)	Step on coal export supply curve
(k)	Coal export demand sectors
(l)	Coal export supply regions (U.S.)
(u)	Sulfur level

Column Definitions

Column Notation	Description
$PX_{i,t,s}$	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.
$Qt_{l,j,k,r,u}$	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:

$$\Sigma_i \Sigma_t \Sigma_s PX_{i,t,s} * P_{i,t,s} + \Sigma_i \Sigma_j \Sigma_t TX_{i,j,t} * T_{i,j,t} \quad (1)$$

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.

$$\Sigma_s PX_{i,t,s} - \Sigma_j TX_{i,j,t} = 0 \qquad (2)$$

Balance of coal imported to international demand regions.

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

Balance of coal exported from international supply regions.

$$\Sigma_s PX_{i,t,s} + \Sigma_j UX_{j,t} - EXP_{i,t} = 0 \qquad (4)$$

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

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

Export constraint from supply regions to demand regions.

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

Import constraint on demand regions from supply regions.

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

Meet the coal demands.

$$\Sigma_i TX_{i,j,t} = D_{j,t} \qquad (8)$$

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.

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

Appendix C

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Appendix D

Model Abstract

Model Name: Coal Distribution Submodule (International Coal Flows)

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 constraint components. The major coal producing countries (United States, Australia, South Africa, Canada, and Poland) are represented, as well as countries that could become major coal exporters (Colombia, Venezuela, and China).

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

Model Update Information: November 1998

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

Archive Media and Installation Manual:

NEMS99 - *Annual Energy Outlook 1999*

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—Dr. Guy Doyle, McClosky Coal Information, Ltd., Published trade and business journal articles, including *Coal Week International*, King's *International Coal Trade*, *Financial Times International Coal Report*, *World Coal*, IEA.

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

DOE sources - none

Computing Environment:

- **Hardware:** IBM RS/6000
- **Operating System:** Unix
- **Software:** FORTRAN
- **Estimated Time to Run:** 1 CPU Min
- **Special Features:** None

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 new 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 1999*. No prior 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 III*, DOE/EIA-M060(94) (Washington, DC, March 1994).

- Energy Information Administration, *Model Documentation*, *Coal Market Module of the National Energy Modeling System*, *Part III*, DOE/EIA-M060(95) (Washington, DC, March 1995).

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- Energy Information Administration, *Model Documentation*, *Coal Market Module of the National Energy Modeling System, Part II-B,* DOE/EIA-M060(97) (Washington, DC, February 1997).

- Energy Information Administration, *Model Documentation*, *Coal Market Module of the National Energy Modeling System, Part II-B,* DOE/EIA-M060(98) (Washington, DC, January 1998).

Appendix E

Data Quality and Estimation

Coal Import Demands are basically regional net import demands for both coking and thermal for snap-shot years 1996, 2000, 2005, 2010, 2015, and 2020. 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.

Cash and sustainable costs are built up for each snap-shot year according to the following logic:

- Run-of-mine cash costs are adjusted by washery yield (which is generally between 50-100%) and direct preparation costs are added to give the cash costs at the mine. Taxes and royalties, inland freight costs, and port fees are then added to yield cash free-on-board (FOB) pier costs. An allowance for capital replacement (required to sustain mining operation) is added to give the sustainable costs of supply. Where these costs are all calculated in local currency, in the case of Australia, South Africa, and Canada, an effective exchange is applied to convert costs into constant 1992 U.S. dollars.

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 formula:

$$\text{Rate (1992 dollars/tonne)} = 1.5 + [0.4 + (1.1 * (65/Vs))] * D$$

where,

Vs	=	vessel size in thousand dead weight tons
D	=	distance in thousand nautical miles

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.