

World Energy Projection System Plus Model Documentation 2011: Coal Model

August 12, 2011

**U.S. Energy Information Administration
Office of Energy Analysis
U.S. Department of Energy
Washington, DC 20585**

This report was prepared by the U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy. By law, EIA's data, analyses, and forecasts are independent of approval by any other officer or employee of the United States Government. The views in this report therefore should not be construed as representing those of the Department of Energy or other Federal agencies.

Contents

1. Introduction.....	1
Purpose of This Report	1
Model Summary	1
Model Archival Citation	1
Model Contact.....	2
Organization of This Report	2
2. Model Purpose	3
Model Objectives	3
Model Inputs and Outputs.....	3
Relationship to Other Models	5
3. Model Rationale.....	8
Theoretical Approach	8
Model Assumptions	8
4. Model Structure	9
Overview.....	9
Appendix A. Model Abstract.....	14
Appendix B. Input Data and Variable Descriptions	17
Appendix C. References	19
Appendix D. Data Quality	20
Introduction.....	20
Quality of Input Data	20

Tables

Table 1. Regional Coverage of the World Energy Projection System Plus Model	3
Table 2. WEPS+ Models that Provide Inputs to the Coal Model	4
Table 3. Major Exogenous Coal Model Input Data Series	4
Table 4. Coal Model Outputs and the WEPS+ Models that Use Them.....	5

Figures

Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence	6
Figure 2. The Coal Model Relationship to Other WEPS+ Models	7
Figure 3. Flowchart for the Coal Model	10
Figure 4. Flowchart for the CoalMain Subroutine.....	11

1. Introduction

Purpose of This Report

The Coal Model of the World Energy Projection System Plus (WEPS+) is a computer-based energy supply modeling system that is primarily used to estimate the retail and wholesale price of coal regionally. This report describes the version of the Coal Model that was used to produce the projections published in the *International Energy Outlook 2011 (IEO2011)*. The Coal Model is one of 13 components of the WEPS+ energy modeling system, but it can also be run as a separate, individual model. The WEPS+ is a modular system, consisting of a number of separate energy models that are joined together through the overall system model in order to communicate and work with each other. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a common and shared database (the “restart” file) that allows all the models to communicate with each other when they are run in sequence over a number of iterations. The overall WEPS+ system uses an iterative solution technique that allows for convergence of consumption and price to a simultaneous equilibrium solution.

This report documents the objectives, analytical approach and development of the WEPS+ Coal Model. It also catalogues and describes critical assumptions, computational methodology, parameter estimation techniques, and model source code. This document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, it meets the legal requirement of the U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 93-275, section 57.b.1*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake and analyze their own model enhancements, data updates, and parameter refinements for future projects.

Model Summary

The WEPS+ Coal Model projects the retail price of coal, by region and end use sector, for use in the demand, supply, and transformation models of the WEPS+ system. In addition, wholesale coal prices are also estimated by region. The Coal Model projects coal prices for each of the 16 WEPS+ regions, annually through 2035, for six end uses (residential, commercial, industrial, transportation, electric power, and district heat). Inputs for the model include quantities of coal consumed in each of the end use sectors. The retail coal prices generated by the Coal Model are exported to the shared restart file for use by the other WEPS+ models.

Model Archival Citation

This documentation refers to the WEPS+ Coal Model, as archived for the *International Energy Outlook 2011 (IEO2011)*.

Model Contact

Brian Murphy
U.S. Energy Information Administration
Renewable Electricity Analysis Team
EI-81/Forrestal Building
United States Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585
Telephone: (202) 586-1398
E-mail: Brian.Murphy@eia.gov

Organization of This Report

Chapter 2 of this report discusses the purpose of the Coal Model, the objectives and the analytical issues it addresses, the general types of activities and relationships it embodies, the primary input and output variables, and the relationship of the model to the other models in the WEPS+ system. Chapter 3 of the report describes the rationale behind the Coal Model design, providing insights into further assumptions utilized in the model. Chapter 4 describes the model structure in more detail, including flowcharts, variables, and equations.

2. Model Purpose

Model Objectives

The primary objective of the WEPS+ Coal Model is to calculate wholesale coal prices by region, as well as retail coal prices for each end use demand and transformation sector by year. The wholesale prices are based upon the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also is able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based upon changes in regional coal demand. The retail prices are based upon fixed sectoral markups from the wholesale prices. Upon completion of the model, the prices are exported into the shared restart file and thus made available for use by the demand and transformation models.

As part of the WEPS+ system, the Coal Model provides projections for the 16 WEPS+ world regions (Table 1). These regions consist of countries and country groupings within the broad divide of the Organization of Economic Cooperation and Development (OECD) membership.

Table 1. Regional Coverage of the World Energy Projection System Plus Model

OECD Regions	Non-OECD Regions
United States	Russia
Canada	Other Non-OECD Europe and Eurasia
Mexico/Chile	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia/New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Central and South America

Model Inputs and Outputs

Inputs

The Coal Model uses coal consumption and price projections that are imported from the WEPS+ restart file. These inputs have been previously projected by the source models listed in Table 2.

Table 2. WEPS+ Models that Provide Inputs to the Coal Model

Coal Model Input	Source
Residential coal consumption	Residential Model
Commercial coal consumption	Commercial Model
Industrial coal consumption	World Industrial Model
Transportation coal consumption	International Transportation Model
Electricity coal consumption	World Electricity Model
District heat coal consumption	District Heat Model
Revised retail coal prices	Main Model

A number of exogenous data series are also imported into the Coal Model from the CoalInput.xml file (Table 3).

Table 3. Major Exogenous Coal Model Input Data Series

Source Input File	Model Input
CoalInput.xml	U.S. coal prices (in real 2008 dollars)
	World coal demand (in quadrillion Btu)
	Supply elasticities
	DoElas switch (0=no, 1=yes)
	Regional wholesale price of coal
	End-use sector price ratio of coal
	End-use sector coal price
	Coal prices for power generation
	Natural gas price growth rate relative to coal
	First year after which to apply natural gas price growth rate relative to coal

Outputs

The Coal Model produces projections of retail coal prices by end-use and region. The model also calculates the wholesale price of coal by region. Upon completion of a model run, these values are exported into the WEPS+ restart file for use by other models (Table 4).

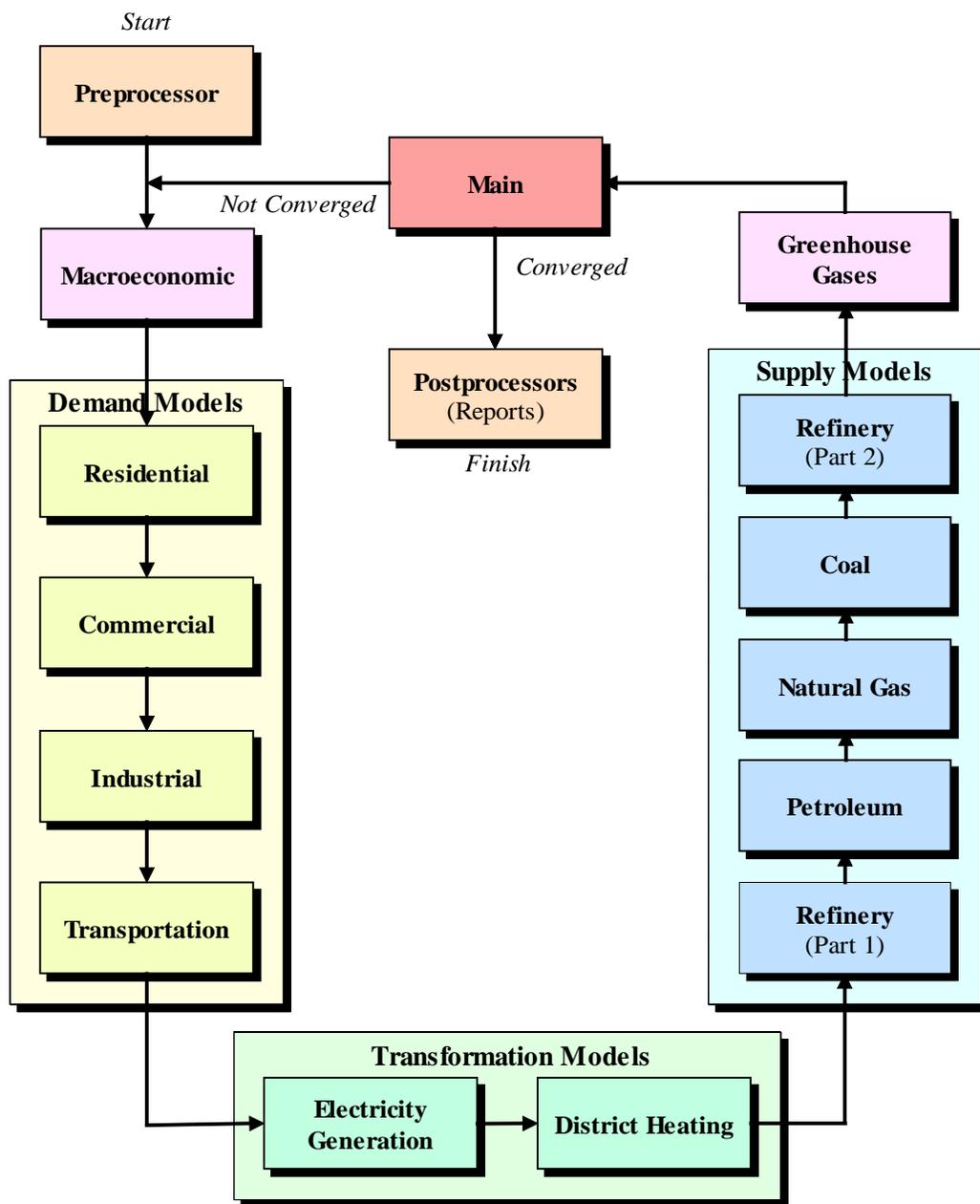
Table 4. Coal Model Outputs and the WEPS+ Models that Use Them

Coal Model Output	Destination
Retail price of coal in the residential sector	Residential Model
Retail price of coal in the commercial sector	Commercial Model
Retail price of coal in the industrial sector	World Industrial Model
Retail price of coal in the transportation sector	International Transportation Model
Retail price of coal in the electric power sector	World Electricity Model
Retail price of coal in the district heat sector	District Heat Model
Wholesale price of coal	--

Relationship to Other Models

The Coal Model is an integral component of the WEPS+ system and depends upon other models in the system for some of its key inputs. In turn, the Coal Model provides projections of coal retail prices, which other models in the system depend upon for their key inputs (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2011* report is available in a separate *Overview* documentation.

Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence

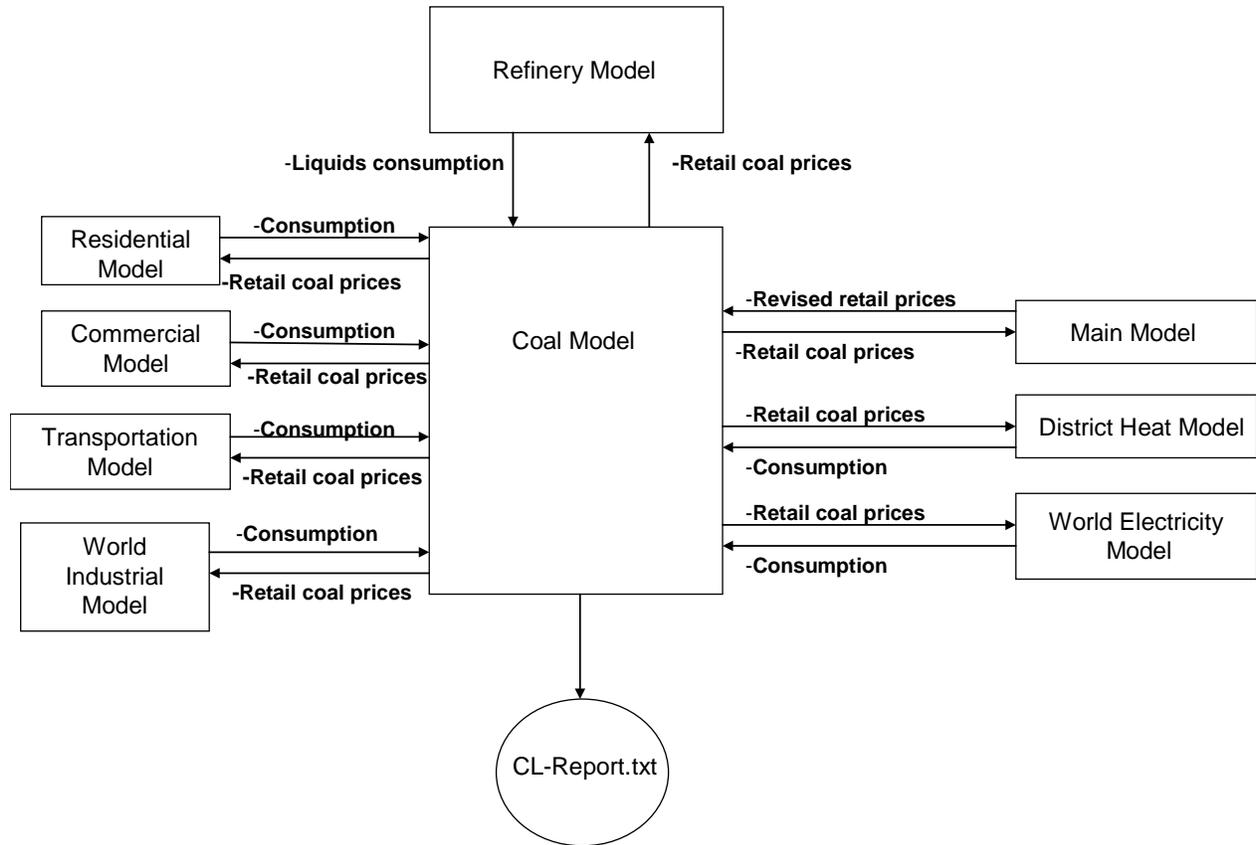


Through the system, the Coal Model receives coal consumption projections from the demand and transformation models (Figure 2). It also receives revised coal retail price projections from the Main Model. In turn, the Coal Model provides price projections, through the system, back to the demand, supply, and transformation models, as well as the Main Model.

Although the Coal Model is an integral part of the WEPS+ system, it can also run easily as a standalone model, outside of the system. To do that, the Coal Model would input consumption

and price projections from the WEPS+ system “restart” file as created in a prior run of the system.

Figure 2. The Coal Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical Approach/ Model Assumptions

The Coal Model assumes that changes in regional wholesale coal prices are the same as changes in U.S. wholesale coal prices. These price assumptions can be overridden by analyst judgment, when appropriate. Retail coal price projections are derived from the wholesale coal prices using retail markups that are fixed over time.

4. Model Structure

Structural Overview

The main purpose of the Coal Model is to estimate wholesale and retail coal prices for use by the demand and transformation models of the WEPS+ system. In the Coal Model, price projections are based upon historical regional prices and projections of U.S. coal prices that are used as a benchmark for changes over time in the rest of the world. The model also includes an algorithm by which supply elasticities are used to change the wholesale coal prices based upon changes in regional coal demand. This capability was not used for the *IEO2011*.

The basic structure of the Coal Model is illustrated in Figure 3. A call from the WEPS+ interface to the Coal Model initiates importation from the restart file of the supporting information needed to complete the projection calculations. The Coal Model then executes the MainCoal subroutine, which is the major component of the model and the location in which most of the model computations are made. In its final step, the model executes the subroutine that exports all projections to the restart file for use by other WEPS+ models.

The MainCoal subroutine (Figure 4) is initiated by a call from the main Coal Model. Exogenous data series that are required by the model are imported through a call to the CoalInput subroutine. The CoalInput subroutine imports data from the CoalInput.xml data file. CoalInput.xml includes:

- U.S. coal prices (in real 2009 dollars per million Btu)
- World coal demand (2005 through 2035)
- Supply elasticities (2005 through 2035—five year increments)
- Regional wholesale coal prices (2007)
- End use sector coal prices by region (2005 through 2035)
- Coal prices for electricity generation by region (2005 through 2035)
- Fractional weight by which coal prices rise relative to natural gas prices (and year after which factor applied)

Once the data are imported, the routine begins by adding together all coal consumed in each of the demand and transformation sectors to determine how much coal supply is needed. Next, a determination of whether the supply elasticity option is to be utilized (this option is used in *IEO2011*) and the worldwide wholesale coal price is calculated based upon the needed world coal supply and the base/reference world coal demand imported in the CoalInput subroutine. After the wholesale price is computed, the regional end use sector prices imported in CoalInput are adjusted based upon the supply elasticities, the wholesale price of coal for electricity is set to the end use sector price for coal in electricity, and retail coal prices for electricity generation are calculated based on the ratio of regional natural gas prices to coal.

After the CoalMain subroutine has completed, the WriteRestart subroutine is executed. WriteRestart provides projections to the restart file for use in future iterations of WEPS+. These output data series include end-use sector retail prices and wholesale prices associated with coal.

Flow Diagrams

Figure 3. Flowchart for the Coal Model

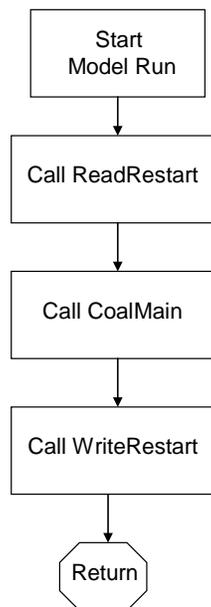
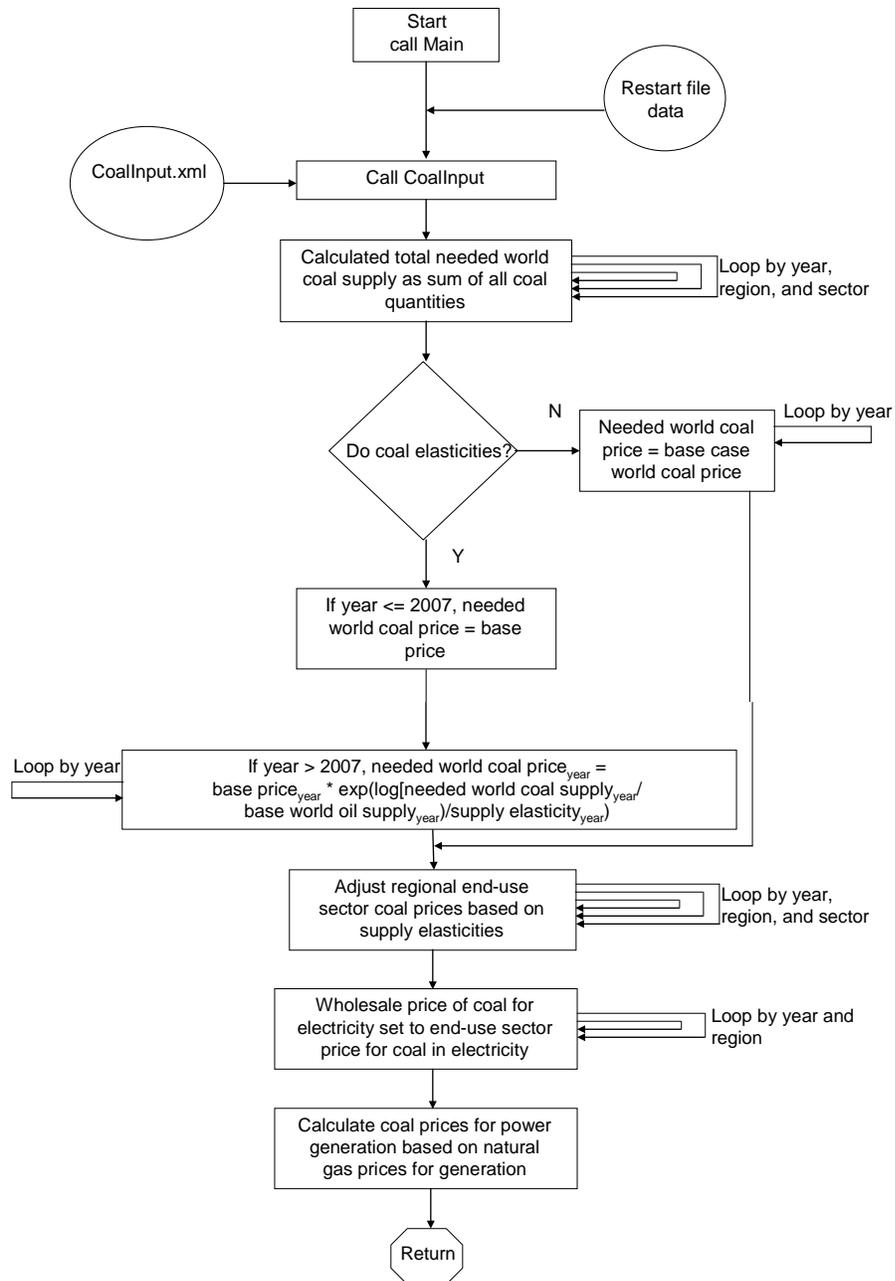


Figure 4. Flowchart for the CoalMain Subroutine



Key Computations

The WEPS+ Coal Model determines wholesale coal prices by region and subsequently derives the retail prices for each end use annually through 2035. The wholesale prices are based upon the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also is able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based upon changes in regional coal demand. This capability was not used for the *IEO2011*.

The retail price projections are based upon fixed sectoral markups from the wholesale prices. Upon completion of the model, the prices are exported into the shared restart file and then made to the demand and transformation models through the shared restart file:

- Residential
- Commercial
- Industrial
- Transportation
- Electric Power
- District Heat

An algorithm is included in the Coal Model to allow coal prices to change based upon changes in coal demand. This algorithm uses a benchmark price for coal, which is assumed to be the U.S. coal price. The benchmark coal price path is associated with a reference level of coal supply in each projection year. The price is specified in real 2009 dollars per million British thermal unit (Btu). The input file includes coal price elasticities by year that defines the relationship of the benchmarked coal price to changes in coal supply. These elasticities can be used to solve for different benchmark coal prices. Ordinarily, the reference level of coal supply would be the same as those in the Reference case.

The model treats the elasticity with coal price as a supply elasticity so that the relationship is defined as:

$$CoalSupElas(r) = \frac{\ln\left(\frac{NewCoalQty(r, y)}{BaseCoalQty(r, y)}\right)}{\ln\left(\frac{NewCoalPrc(r, y)}{BaseCoalPrc(r, y)}\right)}$$

Where: *NewCoalQty* and *BaseCoalQty* are the new (changed) and base coal supply/demand quantity

NewCoalPrc and *BaseCoalPrc* are the new (resulting) and base benchmark coal price

CoalSupElas is the coal supply elasticity

The above equation can be used to solve for the changes in coal prices due to changes in coal supply. Thus, large elasticities cause small changes in the coal prices and vice versa. For the *IEO2011*, large supply elasticities were used in the Reference case, meaning that the prices have only a modest impact. Further, prices used in the *IEO2011* were by and large exogenously specified in the Reference case.

U.S. coal price were used as the basis of coal prices in other regions. Regional power generation coal prices for 2007 were determined using exogenous sources and were imported into the Coal Model from the CoalInput.xml file. The relationship between these prices and the U.S. price are used as the basis for the price changes in the projection. As the U.S. benchmark price moves over time as described above, the other regional coal prices move in a similar fashion.

Appendix A. Model Abstract

Model Name:

Coal Model of the World Energy Projection System Plus

Model Acronym:

None

Model Description:

The Coal Model of the World Energy Projection System Plus is a computer-based energy supply modeling system that is primarily used to estimate the retail and wholesale price of coal regionally.

Model Purpose:

The Coal Model determines wholesale coal prices by region and subsequently derives the retail coal prices for each end use annually through 2035. The wholesale prices are based upon the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also is able to employ an algorithm in which supply elasticities can be used to change the wholesale coal prices based upon changes in regional coal demand. This capability was not used for the *IEO2011*. The model provides a tool for analysis of international coal supply prices within the WEPS+ system, and can also run independently as a standalone model.

Most Recent Model Update:

December 2009.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

The Coal Model receives inputs from and provides outputs to the other models in the WEPS+ system, through the common, shared interface file of the WEPS+.

Official Model Representative:

Brian Murphy
U.S. Energy Information Administration
Renewable Electricity Analysis Team
EI-81/Forrestal Building
United States Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Telephone: (202) 586-1398
E-mail: Brian.Murphy@eia.gov

Documentation:

U.S. Energy Information Administration, *Coal Model of the World Energy Projection System Plus: Model Documentation 2011*, DOE/EIA-M082(2011) (Washington, DC, August 2011).

Archive Information:

The model is archived as part of the World Energy Projection System Plus archive of the runs used to generate the *International Energy Outlook 2011*.

Energy System Described:

International coal prices

Coverage:

Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico/Chile, OECD Europe, Japan, Australia/New Zealand, South Korea, Russia, Other non-OECD Europe and Eurasia, China, India, other non-OECD Asia, Middle East, Africa, Brazil, and other Central and South America.

Mode: wholesale and retail regional coal prices.

Time Unit/Frequency: Annual, 2009 through 2035.

Modeling Features:

The WEPS+ Coal Model determines wholesale coal prices by region and subsequently derives the retail prices for each end use annually through 2035. The wholesale prices are based upon the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The retail price projections are based upon fixed end use sector markup factors from the wholesale prices.

DOE Input Sources:

U.S. Energy Information Administration, *Annual Energy Outlook 2011*, DOE/EIA-0383 (Washington, DC, April 2011).

Non-DOE Input Sources:

International Energy Agency (IEA), *Coal Information 2010*, Paris, 2010.

International Energy Agency (IEA), *Energy Prices and Taxes*, Quarterly Report (various issues), Paris, 2010.

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows XP (or other Windows OS).

Language/Software Used: Fortran 90/95 (Currently using Compaq Visual Fortran), not required at runtime.

Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 20MB storage.

Special Features: None.

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file CoalInput-BM122409.xml.

Classification: Input variable.

$BWCP(y)$:	Average minemouth price of coal in the United States by year (2009 dollars per million Btu)
$BWCS(y)$:	Baseline world coal demand by year (quadrillion Btu)
$EWCP(y)$:	Supply elasticities by year
$DoCElas$:	Switching indicating whether supply elasticities will be used in the run (0=no, 1=yes)
$CRWPFacIn(r)$:	Regional coal prices (in 2007 dollars per metric ton) [<i>Note: this variable is recalculated as the ratio between the price in a region relative to the price in the United States</i>]
$CPPFac(x,y)$:	By-end-use-sector price ratio to the regional wholesale price (not used in <i>IEO2011</i>)
$CPrCEU(r,y)$:	End-use sector coal prices by region and year (2009 dollars per million Btu)
$CPrCPG(r,y)$:	Coal prices in the electric power sector by region and year (2009 dollars per million Btu)
$GGRFyr(r)$:	Year after which coal prices increase as a weighted average of the original coal price and the wholesale natural gas price by region (not used in <i>IEO2011</i>)
$GGRGas(r)$:	Fractional weight by which coal prices rise relative to natural gas prices (value between 0 and 1; not used in <i>IEO2011</i>)

The following variables represent data input from the restart file.

Classification: Input variable from the Residential Model, Commercial Model, World Industrial Model, Refinery Model, Petroleum Model, Natural Gas Model, and World Electricity Model.

$QCLRS(r,y)$:	Amount of coal consumed in the residential sector by region and year (2005 through 2035)
$QCLCM(r,y)$:	Amount of coal consumed in the commercial sector by region and year (2005 through 2035)
$QCLIN(r,y)$:	Amount of coal consumed in the industrial sector by region and year (2005 through 2035)
$QCLTR(r,y)$:	Amount of coal consumed in the transportation sector by region and year (2005 through 2035)

<i>QCLPG(r,y):</i>	Amount of coal consumed in the electric power sector by region and year (2005 through 2035)
<i>QCLDH(r,y):</i>	Consumption of coal used for district heat generation by region and year (2005 through 2035)

The following variables represent data calculated in the subroutine CoalInput

Classification: Computed variable.

<i>CPPFac(x,y):</i>	End Use sector price ratio by sector and year is imported in 5-year increments and interpolated between years to get annual factors
<i>CRWPFacIn(r):</i>	Imported as a price variable, but then the variable is changed into a ratio of regional wholesale coal prices relative to U.S. values

The following variables represent data calculated in the subroutine CoalMain

Classification: Computed variable.

<i>PCLRS(r,y):</i>	Retail price of coal used in the residential sector by region and year
<i>PCLCM(r,y):</i>	Retail price of coal used in the commercial sector by region and year
<i>PCLIN(r,y):</i>	Retail price of coal in the industrial sector by region and year
<i>PCLTR(r,y):</i>	Retail price of coal in the transportation sector by region and year
<i>PCLDH(r,y):</i>	Retail price of coal for district heat generation by region and year
<i>PCLPG(r,y):</i>	Retail price of coal in the electric power sector by region and year
<i>PNGPG(r,y):</i>	Retail price of natural gas in the electric power sector by region and year
<i>PCLWD(r,y):</i>	Wholesale price of coal by region and year

Appendix C. References

1. Walter Nicholson, *Microeconomic Theory: Basic Principles and Extensions* (Harcourt College Publishers, Fort Worth: Texas, 1972).
2. Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (McGraw-Hill Book Company, NY: NY, 1967).
3. Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).
4. Energy Information Administration, *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010).
5. Energy Information Administration, *Annual Energy Outlook 2011*, DOE/EIA-0383(2011) (Washington, DC, April 2011).
6. Energy Information Administration, *Coal Market Module of the National Energy Modeling System: Model Documentation 2010*, DOE/EIA-M060(2010) (Washington, DC, June 2010).
7. SSY Consultancy and Research, Ltd., *SSY's Coal Trade Forecast*, Vol. 17, No. 1 (London, United Kingdom, July 2008).
8. International Energy Agency, *Coal Information 2010* (Paris, France, 2010).
9. International Energy Agency, *Energy Prices and Taxes* (Quarterly report, Paris, France, 2010).
10. International Energy Agency, *Energy Statistics and Balances of OECD Countries*, web site www.iea.org (subscription site).
11. International Energy Agency, *Energy Statistics and Balances of Non-OECD Countries*, web site www.iea.org (subscription site).
12. International Energy Agency, *World Energy Outlook 2010 Edition* (Paris, France, November 2010).

Appendix D. Data Quality

Introduction

The WEPS+ Coal Model develops projections of world wholesale and retail coal prices for 16 regions of the world. These projections are based upon the data elements as detailed in Appendix B of this report. The documentation details transformations, estimation methodologies, and resulting inputs required to implement the model algorithms in Chapter 4: Model Structure. The quality of the principal sources of input data is discussed in Appendix D. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Source of Input Data

- *Annual Energy Outlook* – The Energy Information Administration provides projections of U.S. average minemouth coal price projections through 2035. These data are used as the historical basis for regional projections that appear in the *IEO2011*.
- *International Energy Agency* – The international coal prices were estimated, in part, using information from the International Energy Agency’s *Coal Information 2010* and the quarterly report, *Energy Prices and Taxes*, 2010 editions.

Data Quality Verification

As a part of the input and editing procedure, an extensive program of edits and verifications was used, including:

- Checks on world and U.S. retail coal prices, based on previous values, responses, and regional and technical knowledge
- Consistency checks
- Technical edits to detect and correct errors, extreme variability