

World Energy Projection System Plus Model Documentation 2010: Coal Model

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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 2010 (IEO2010)*. 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 2010 (IEO2010)*.

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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 on 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 on fixed sectoral markups from the wholesale prices. The model exports the prices to the shared restart file 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 groups defined either within or outside of 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 | 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 imports coal consumption and price projections 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 |

The Coal Model imports the exogenous data series listed in Table 3 from the CoalInput.xml file.

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 |
| | DoEElas 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 projects retail coal prices by end-use sector and region as well as wholesale prices by region. Upon completion of a model run, the model exports these values to the WEPS+ restart file for use by other models (Table 4).

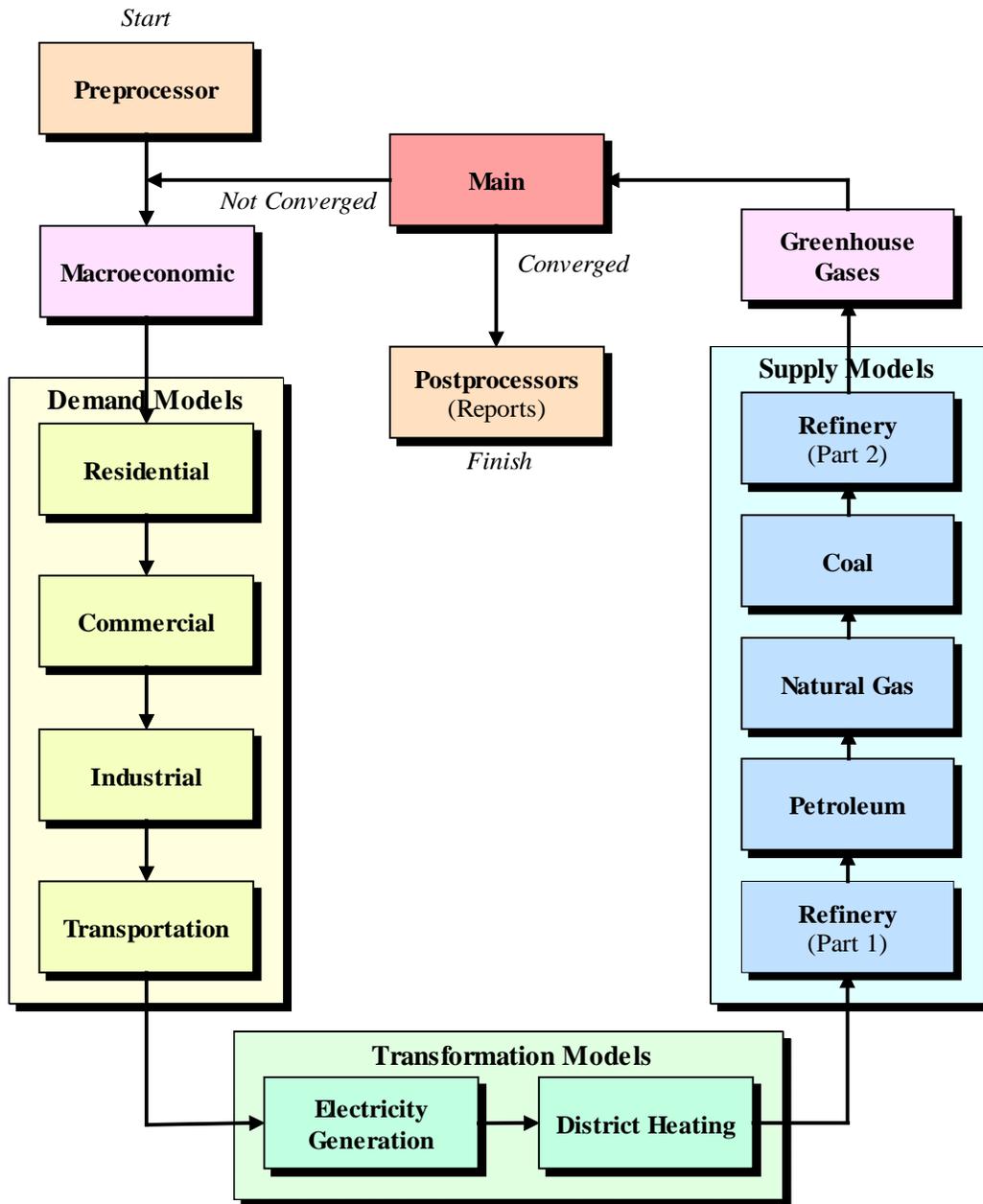
Table 4. Coal Model Outputs and the WEPS+ Models that Use Them

| 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 on other models in the system for some of its key inputs. In turn, the Coal Model provides projections of retail coal prices, which are key inputs for other models in the system (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2010* report is available in a separate *Overview* document.

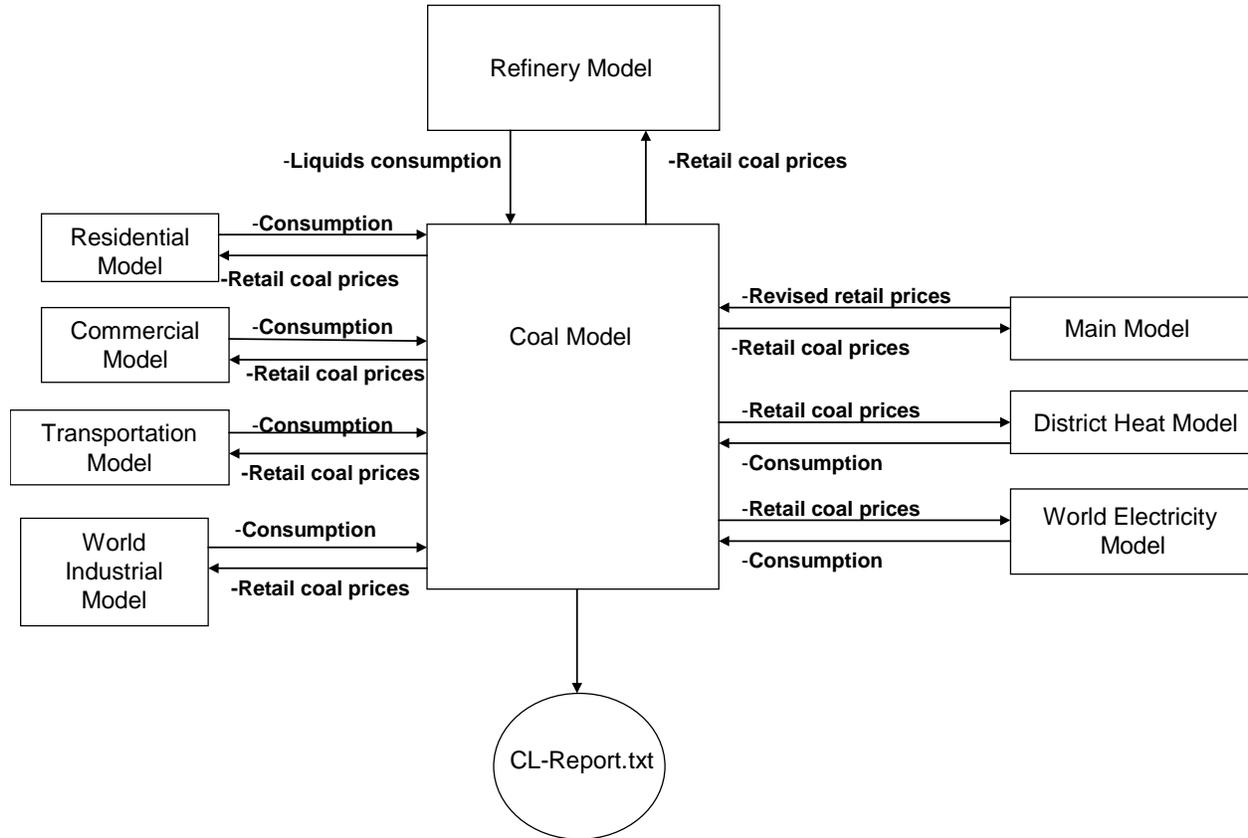
Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence



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 be run as a standalone model. In standalone mode, the Coal Model inputs consumption and price projections from a WEPS+ system “restart” file created in a prior full-system run.

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



3. Model Rationale

Theoretical Approach/ Model Assumptions

The Coal Model assumes that wholesale coal prices in the 16 international WEPS+ regions follow the same pattern of change over time as U.S. wholesale coal prices. This assumption 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 on historical prices for the international WEPS+ regions 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 on changes in regional coal demand. This capability was not used for the *IEO2010*.

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, the major component of the model, which performs most of the model computations. In its final step, the model executes the subroutine that exports all projections to the restart file for use by other WEPS+ models.

The main Coal Model calls the MainCoal subroutine (Figure 4), which in turn calls the CoalInput subroutine. The CoalInput subroutine imports the following data series from the CoalInput.xml data file:

- U.S. coal prices (2007 through 2035, in real 2008 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 though 2035)
- Factor used to adjust coal prices relative to natural gas prices for electricity generation (value between 0 and 1 and year after which factor should be applied—not used in *IEO2010*)

Once the data are imported, the routine begins by adding together all coal consumption estimates (expressed in Btu) in each of the demand and transformation sectors to determine how much coal supply is needed in each sector. Next, the subroutine determines whether the supply elasticity option is to be used (this option was used in *IEO2010*).

The subroutine then begins the price computations. First, it calculates the worldwide wholesale coal price based on the needed world coal supply and the base/reference world coal demand estimates imported by the CoalInput subroutine. After the world wholesale price is computed, the regional end use sector prices imported by CoalInput are adjusted based on the regional

supply elasticities. The price of coal for electricity generation is set equal to the end-use sector price of coal for electricity generation. Regional retail coal prices for electricity generation are calculated based on the ratio of regional natural gas prices to coal prices.

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

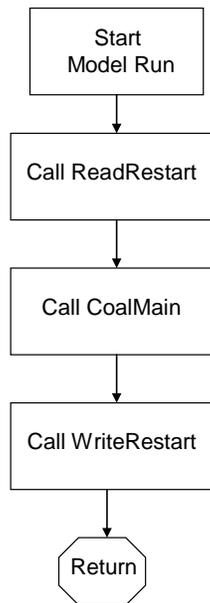
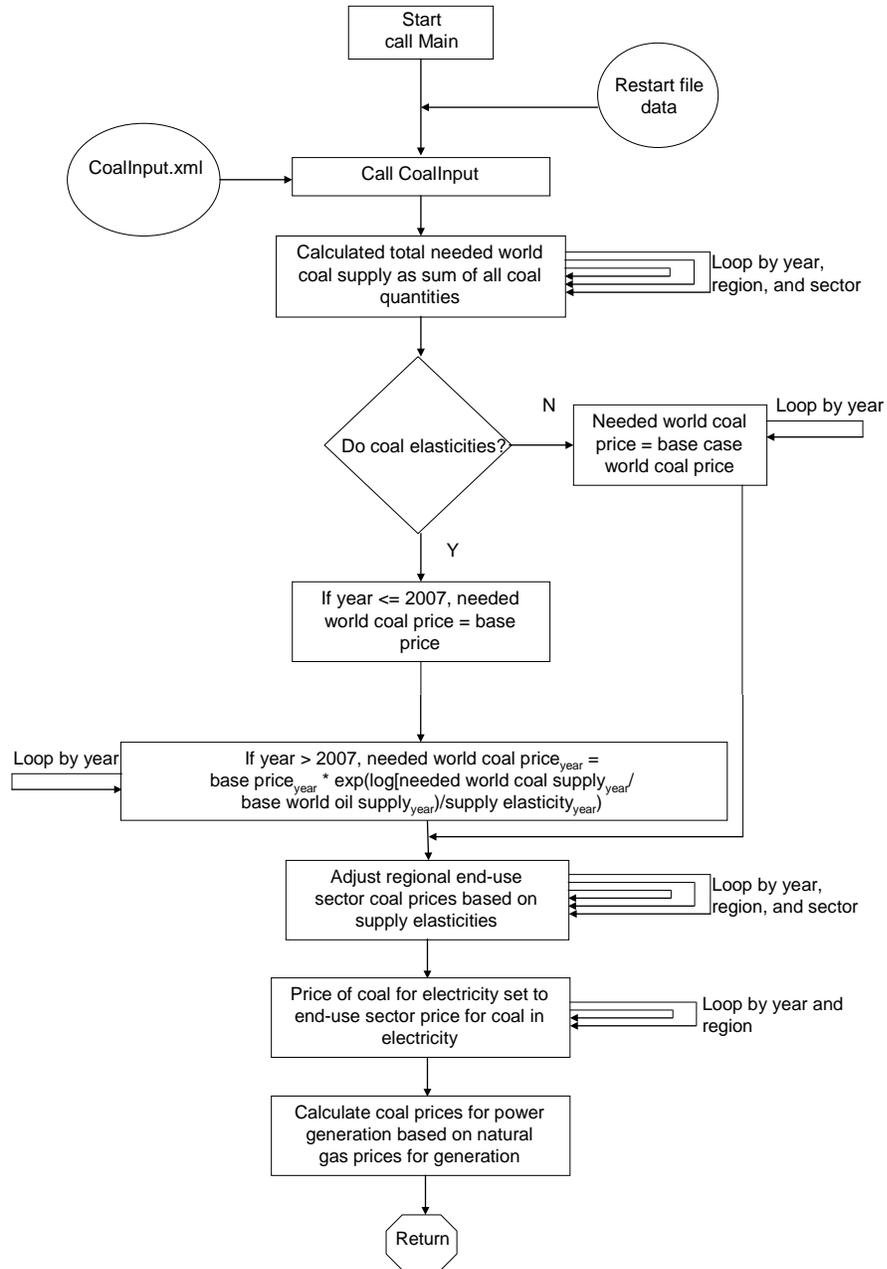


Figure 4. Flowchart for the CoalMain Subroutine



Key Computations

The WEPS+ Coal Model projects regional wholesale coal prices and annual retail prices for each end-use sector through 2035. The wholesale prices are based on the U.S. coal price projections and on the historical relationship of U.S. coal prices to international prices. The model also incorporates an algorithm, described below, that uses supply elasticities to project the wholesale coal prices based on changes in regional coal demand. (This capability was not used for the *IEO2010*.)

The retail price projections are based on fixed sectoral markups from the wholesale prices. Upon completion of the model, the prices are exported into the shared restart file for use by the following demand and transformation models:

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

Using Elasticity to Project Regional Coal Prices

The Coal Model includes an algorithm that projects coal prices based on changes in coal demand. This algorithm uses the U.S. coal price as a benchmark price for coal in the 16 WEPS+ regions. The benchmark coal price path is associated with a reference level of coal supply in each projection year. The price is specified in real 2008 dollars per million British thermal units (Btu). The model imports annual coal price elasticities that relate the benchmark coal price to estimates of coal supply. These elasticities can be used to solve for annual regional coal prices. Ordinarily, the reference level of coal supply would be the same as those in the Reference case. The supply elasticity is defined as:

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

where, for region r and projection year y ,

$NewCoalQty(r, y)$ = new (changed) coal supply/demand quantity

$BaseCoalQty(r, y)$ = base coal supply/demand quantity

$NewCoalPrc(r, y)$ = new (resulting) coal price

$BaseCoalPrc(r, y)$ = base benchmark (U.S.) coal price

$CoalSupElas(r, y)$ = coal supply elasticity

The above equation can be solved for the new coal price, in terms of the new quantity and the elasticity. Given the same old and new quantities, a high elasticity will cause a smaller change in the coal price than will a low elasticity. The model assumes that supply and demand quantities are the same. For the *IEO2010*, high supply elasticities were used in the Reference case, meaning that the prices have only a modest impact. Further, prices used in the *IEO2010* were by and large exogenously specified in the Reference case.

U.S. coal prices were used as the base coal prices. Regional power generation coal prices for 2007 were estimated using exogenous sources and imported into the Coal Model from the CoalInput.xml file. The relationship between these prices and the U.S. price was used as the basis for the price changes in the projection. As the U.S. benchmark price moves over time, 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 regional retail and wholesale prices of coal.

Model Purpose:

The Coal Model estimates annual wholesale coal prices by region and derives annual retail coal prices for each end use sector through 2035. The wholesale prices are based on the U.S. coal price projections and on the historical relationship of U.S. coal price to international prices. The model also incorporates an algorithm in that uses supply elasticities to estimate changes over time in the wholesale coal prices, given on changes in regional coal demand. This capability was not used for the *IEO2010*. The model provides a tool for analysis of international coal supply prices within the WEPS+ system, and can also be run 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+.

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Documentation:

U.S. Energy Information Administration, *Coal Model of the World Energy Projection System Plus: Model Documentation 2010*, DOE/EIA-M082(2010) (Washington, DC, August 2010).

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 2010*.

Energy System Described:

International coal prices

Coverage:

Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico, 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, 2008 through 2035.

Modeling Features:

The Coal Model estimates annual wholesale coal prices by region and derives annual retail coal prices for each end use sector through 2035. The wholesale prices are based on 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 on the wholesale price projections and fixed end use sector-level markup factors

DOE Input Sources:

U.S. Energy Information Administration, *Annual Energy Outlook 2010*, DOE/EIA-0383 (Washington, DC, April 2010).

Non-DOE Input Sources:

International Energy Agency (IEA), *Coal Information 2009*, Paris, 2009.

International Energy Agency (IEA), *Energy Prices and Taxes*, Quarterly Report (various issues), Paris, 2009.

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 (2008 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>IEO2010</i>) |
| $CPrCEU(r,y)$: | End-use sector coal prices by region and year (2008 dollars per million Btu) |
| $CPrCPG(r,y)$: | Coal prices in the electric power sector by region and year (2008 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>IEO2010</i>) |
| $GGRGas(r)$: | Fractional weight by which coal prices rise relative to natural gas prices (value between 0 and 1; not used in <i>IEO2010</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).
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9. International Energy Agency, *Energy Prices and Taxes* (Quarterly report, Paris, France, 2009).
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 2009 Edition* (Paris, France, November 2009).

Appendix D. Data Quality

Introduction

The WEPS+ Coal Model projects world wholesale and retail coal prices for the 16 WEPS+ regions. These projections are based on the data elements detailed in Appendix B of this report. The documentation details transformations, estimation methods, and 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 U.S. data are used as the basis for the international regional projections that appear in the *IEO2010*.
- *International Energy Agency* – The international coal prices were estimated, in part, using information from the International Energy Agency’s *Coal Information 2009* and the quarterly report, *Energy Prices and Taxes*, 2009 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