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# World Energy Projection System Plus: Overview

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# Contents


Table of Tables .......... 2

Table of Figures .......... 2

1. Introduction .......... 3

    Purpose of this report .......... 3

    System summary .......... 3

2. Initialization Database and the Restart File .......... 7

3. Global Activity Model .......... 9

4. Residential Model .......... 10

5. Commercial Model .......... 12

6. Industrial Model .......... 14

7. Transportation Model .......... 18

8. Electricity Model .......... 20

9. District Heat Model .......... 23

10. Petroleum Model .......... 25

11. Natural Gas Model .......... 26

12. Coal Model .......... 28

13. Refinery Model .......... 29

14. Greenhouse Gases Model .......... 31

15. Main Model and Convergence Process .......... 32

# Table of Tables

Table 1: Core models ..... 4
Table 2. Regional aggregation ..... 6
Table 3. Residential model input data series ..... 10
Table 4. Residential model output data series ..... 11
Table 5. Commercial model input data series ..... 12
Table 6. Commercial model output data series ..... 13
Table 7. Industrial model input data series ..... 16
Table 8. Industrial output data series ..... 16
Table 9. Transportation model input data series ..... 18
Table 10. Transportation model input data series ..... 19
Table 11. Transportation model output data series ..... 19
Table 12. Electricity model input data series ..... 22
Table 13. Electricity model output data series ..... 22
Table 14. District heat model input data series ..... 23
Table 15. District heat model output data series ..... 24
Table 16. Petroleum model input data series ..... 25
Table 17. Petroleum Model Output Data Series ..... 25
Table 18. Natural gas model input data series ..... 27
Table 19. Natural gas model output data series ..... 27
Table 20. Coal model input data series ..... 28
Table 21. Coal model output data series ..... 28
Table 22. Refinery model input data series ..... 29
Table 23. Refinery model output data series ..... 30
Table 24. Summary of the convergence process ..... 33

# Table of Figures

Figure 1. World energy projection system plus (WEPS+) model sequence ..... 5
Figure 2. Data sharing between models and the restart file ..... 8
Figure 3. Stock/flow capacity adjustments over time ..... 15
Figure 4. Flowchart for the electricity model ..... 21
Figure 5. Illustration of convergence in WEPS+ ..... 32

# 1. Introduction

## Purpose of this report

This documentation provides a summary description of the World Energy Projection System Plus (WEPS+) that was used to generate the projections of energy consumption, prices, and production for the *International Energy Outlook 2016* (*IEO2016*). This overview presents a brief description of the methodology and scope of each of the component modules of WEPS+, along with a brief description of the modeling system. Further details on each of the component modules of WEPS+ are provided by individual model documentation reports. 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 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.

## System summary

The World Energy Projection System Plus (WEPS+) is the energy modeling system used to produce the *IEO2016*. The complete WEPS+ system contains three main sections:

- A database of historical energy data, at the appropriate level of detail.
- Energy models that represent the various sector-demand, -transformation and -supply projection activities.
- A run control system that keeps track of the data and models and executes the models.

Each of the models that compose WEPS+ has been separately documented, and each documentation report is available through the EIA web site.

WEPS+ is a modular system, consisting of a number of separate energy models joined together through the overall system model, which enables them to communicate and work with each other. These models are each developed independently but are designed with well-defined guidelines or protocols for system communication and interactivity. One of the primary virtues of this WEPS+ system is that it allows model developers to independently develop and implement individual models without destabilizing the entire system. The individual models that make up this system are in various stages of development for the *IEO2016*; some are more improved from the previous year than others. These models range from basic dynamic simulations to complex stock/flow models using technology competition to determine market shares. 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.

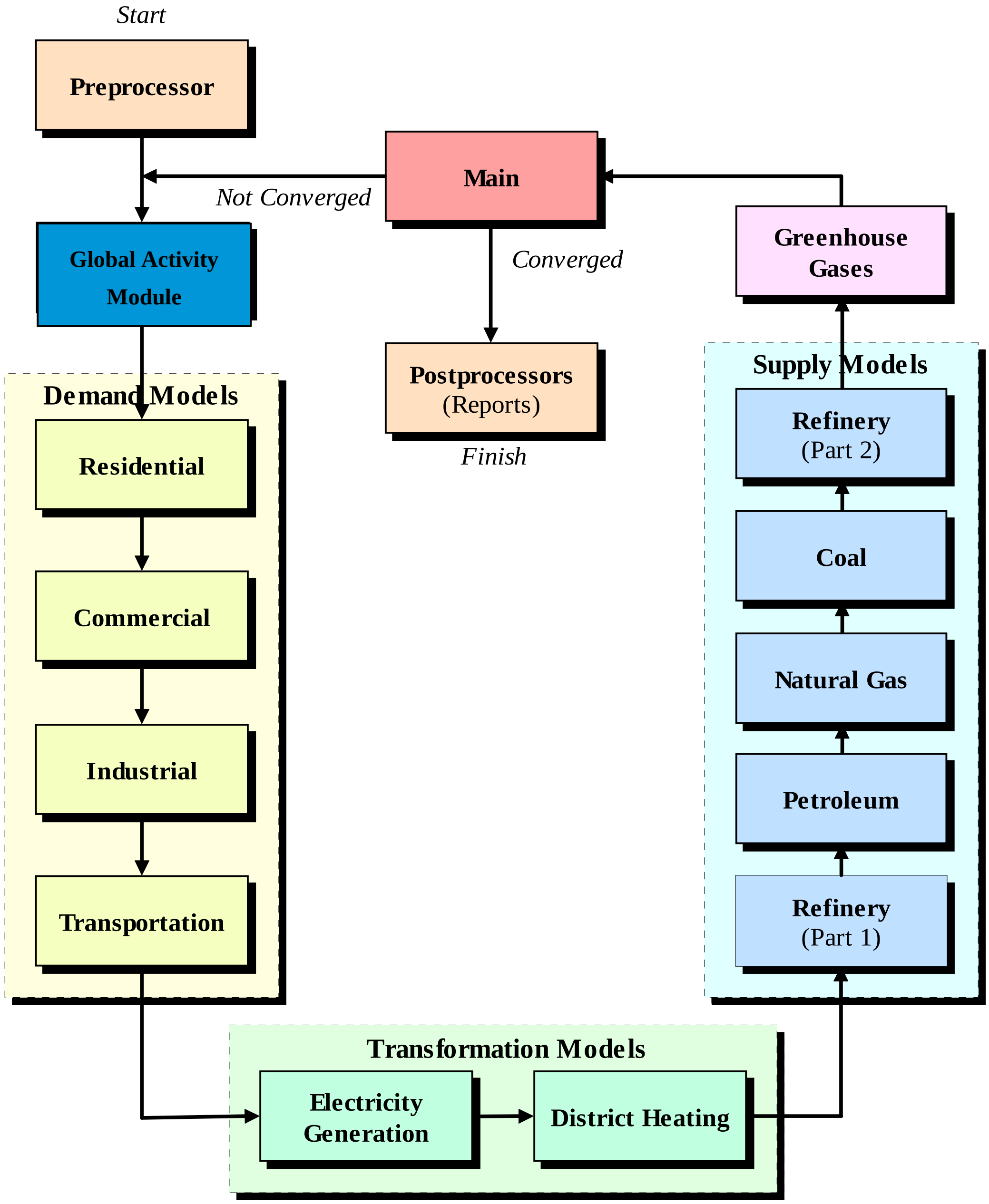
The overall WEPS+ system is complex, and it requires continuous development and maintenance work. The core WEPS+ models are designed to comprise a complete set of models that can simulate the complete international energy system, along with a greenhouse gas emissions and policy model. The system also includes models that perform preprocessing and post-processing, including various final reporting programs. The current core set of models is outlined in Table 1.

**Table 1: Core models**

| Type of Activity | WEP+ Model |
|---|---|
| | 1. Global Activity Model |
| Demand Models | 2. Residential Model |
| | 3. Commercial Model |
| | 4. Industrial Model |
| | 5. Transportation Model |
| Transformation Models | 6. Electricity Model |
| | 7. District Heat Model |
| Supply Models | 8. Petroleum Model |
| | 9. Natural Gas Model |
| | 10. Coal Model |
| | 11. Refinery (Part 1 & 2) |
| | 12. Greenhouse Gases Model |
| | 13. Main Model |

The flowchart in Figure 1 illustrates the sequence of model operations in WEPS+. Each model is run independently but reads and writes to a common and shared database (the "restart" file) in order to communicate with other models (not shown in the flowchart). Each model completes its execution before the next model in the sequence is started up. The system begins with a restart file from some previous system run so that it starts with "seed" values for prices and consumption. Each model is run in turn before the system runs the main model, which then determines if the system has converged (this is described in greater detail in Chapter 15). If the system does not converge, it begins another sequence (iteration). If it does converge, it then finishes up with report writing.

**Figure 1. World energy projection system plus (WEPS+) model sequence**




These separate WEPS+ models operate together in a complete system. The models all share a variety of common variables, specifically macroeconomic, energy consumption, and energy price variables. These common variables are all used to compute projections for the sixteen WEPS+ world regions for each year in the *IEO2016* projection horizon.

The sixteen WEPS+ world regions consist of countries and country groupings within the broad divide of Organization of Economic Cooperation and Development (OECD) countries and non-OECD countries. These regions are shown in Table 2.

**Table 2. Regional aggregation**

| 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 |

WEPS+ is an evolving system of models and, as such, includes models that are fairly rudimentary at present. For instance, the supply models, except for the Refinery Model, are largely placeholders for other, more complex modeling systems. The Natural Gas Model is actually a reduced form of the International Natural Gas Model and the Petroleum Model will eventually be replaced by the International Petroleum Production Model currently under development. Nevertheless, each of the models was used for the *IEO2016* report.

The following report provides an overview of the WEPS+ system programs for the *IEO2016*. This overview addresses the database and each of the current core models, along with some discussion of the direction of further development.

## System archival citation

This documentation refers to the World Energy Projection System Plus (WEPS+) Overview, as archived for the *International Energy Outlook 2016* (*IEO2016*).

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## Organization of this report

Chapter 2 of this report provides detail on the data sources used by WEPS+ as well as an explanation of how data is shared by the component models within the system. Chapters 3 – 15 each provide an overview of one of the component models within WEPS+, including the data inputs and outputs for each model. Chapter 15 also explains and illustrates the model convergence process. Appendix A provides a description and schematic of the WEPS+ run control system.

# 2. Initialization Database and the Restart File

To support the models in WEPS+ and to produce *IEO2016,* it is necessary to begin with a detailed historical-quantity database. There are two key historical data sources used for WEPS+:

- The primary historical data source is the international data that is published by the Energy Information Administration (EIA) in the International Energy Annual (IEA). This data provides country-level consumption data for liquids, natural gas, coal, and nuclear, as well as for hydroelectric and other renewables for electricity generation. It also includes data for end-use electricity consumption as well as capacity and generation for the power generation sector.

- The more detailed historical data source is the international data produced and maintained by the International Energy Agency in Paris (referred to as IEA/Paris) as part of its energy balances database. Like the EIA data source, this data source provides country-level consumption data, but the data are available for a wide variety of "flows" (sectors and users) and for a wide variety of "products" (detailed petroleum products, coal types, renewable sources, etc.).

The EIA data source provides the overall consumption levels, while the IEA/Paris data provides consumption information at more detailed levels. The IEA/Paris data therefore must be calibrated (or "shared") to agree with the EIA data.

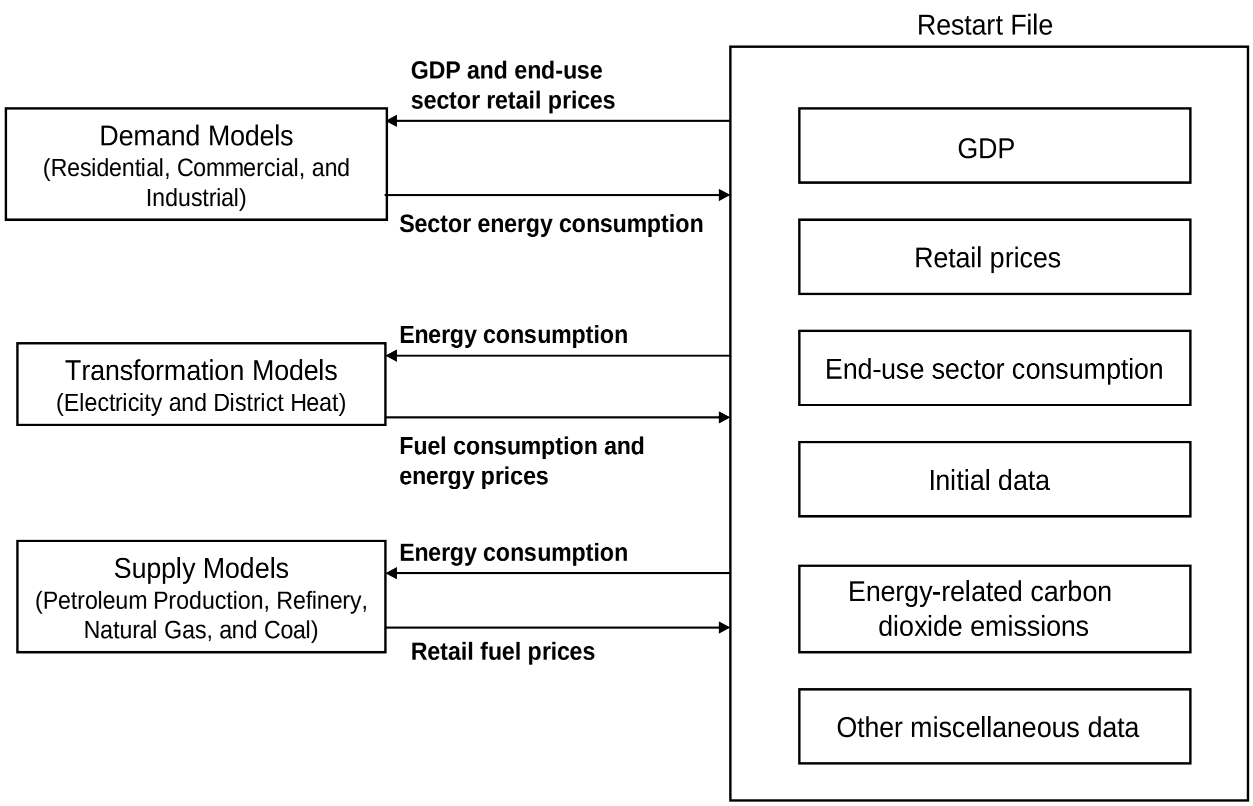
Because of the detail and subtlety of the underlying IEA/Paris data, and because of the need for calibrating it to the EIA data, a considerable amount of effort goes into the organization and processing of this initial data. This high level of effort is also necessary to accomplish the following objectives:

- Provide industry-level detail for the World Industrial Model
- Provide mode-level detail for the International Transportation Model
- Coordinate with capacity and generation data at various levels for the World Electricity Model
- Find and correct any errors, data gaps, or inconsistencies

The process is largely automated, but it has been necessary to carefully review and modify it each year. The resulting detailed data are made available to each of the models for their initialization. To do this, the historical data are put into the common, shared database known as the "restart" file.

The primary purpose of the restart file, however, is to function as a repository for the wide range of variables that are communicated and shared among all the models making up the system. Any individual model may use much more detailed data from its own input files if necessary, but it will communicate with other models using the common level of detail in the restart file. Each model, when it is executed, first reads the common restart file to obtain the shared data that it needs as it runs. When the model is finished with its calculations, it writes results to the common restart file for use by the other models. This process is illustrated in the flowchart in Figure 2 (all consumption data are measured in British thermal units).

**Figure 2. Data sharing between models and the restart file**




For example, the residential demand model will obtain the projections of GDP, population, and retail prices for the residential sector from the restart file. Once the residential model has finished running, it will write the levels of consumption for the various residential energy sources (petroleum products, natural gas, coal, electricity, etc.) into the restart file. Later, when the World Electricity Model is executed, it obtains this residential demand for electricity along with the electricity demand from the other sectors from the restart file. It also obtains the prices for fuels for the electricity generation sector. The model then calculates how much fuel of each type is consumed by electricity generation, and the resulting electricity prices for each sector, including the residential sector. These values are then put back into the restart file so that in the next iteration, each model – including the residential model – begins with a new electricity price. Basic descriptions of the data that are communicated for each of the models in the system are provided in the following chapters of this report.

# 3. Global Activity Model

The commercially-available Oxford Economics Global Economic Model (GEM) and Global Industry Model (GIM) are used to generate projections of gross domestic product (GDP) and gross output for the various *IEO2016* countries and regions and their respective industrial sectors, given energy inputs from WEPS+. The theoretical structure of GEM differentiates between the short-term and long-term projections for each country, with extensive coverage of the links among different economies. GEM produces GDP outputs for use with WEPS+ and also provides drivers for GIM. The structure of GIM, which calculates gross output in the IEO sectors for each country or region in WEPS+, is based on input-output relationships. It calculates gross output in the IEO sectors for each country or region in WEPS+

# 4. Residential Model

The WEPS+ Residential Model projects household energy consumption, excluding on-road transportation, which is projected in the Transportation Model. The model focuses on nine energy sources in each of the sixteen WEPS+ regions over the projection horizon. The Residential Model primarily uses a dynamic econometric equation for the key energy sources, basing the projection on GDP assumptions, residential retail energy prices for seven fuels, and an assumed future trend. The dynamic equation uses a lagged dependent variable to imperfectly represent fuel stock accumulation in the calculation of retail fuel prices for each region over time. The GDP forecast and the price projections are available to the Residential Model from the WEPS+ global activity model and supply models through the restart file, which is shared by all the models. The trend factor is meant to represent continuing impacts on energy use not directly represented in the GDP and price, and may include the effects of a variety of behavioral, structural, and policy-induced activities.

The Residential Model obtains macroeconomic and price projections from the restart file. These values come from previous system iterations by the Global Activity Model and by various transformation and supply models. Residential Model inputs are summarized in Table 3.

**Table 3. Residential model input data series**

| Residential Model Input | Source |
|---|---|
| Gross domestic product | Global Activity Model |
| Residential distillate retail price | Refinery Model |
| Residential kerosene retail price | Refinery Model |
| Residential LPG retail price | Refinery Model |
| Residential natural gas retail price | Natural Gas Model |
| Residential coal retail price | Coal Model |
| Residential electricity retail price | Electricity Model |
| Residential district heat retail price | District Heat model |

The Residential Model projects consumption for multiple energy sources and writes the projections to the restart file for use by the other models. These outputs are summarized in Table 4.

## Table 4. Residential model output data series

| Residential Model Output | Destination |
|---|---|
| Distillate consumption | Petroleum and Refinery Models |
| Kerosene consumption | Petroleum and Refinery Models |
| LPG consumption | Petroleum and Refinery Models |
| Natural Gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Electricity consumption | Electricity Model |
| Heat consumption | District Heat Model |
| Biomass consumption | (Placeholder) |
| Solar consumption | (Placeholder) |

# 5. Commercial Model

The WEPS+ Commercial Model projects energy use that takes place in commercial buildings and activities. It also includes municipal activity, such as street lighting. The model projects commercial consumption for eleven energy sources in each of the sixteen WEPS+ regions. The Commercial Model primarily uses a dynamic econometric equation for consumption of key energy sources, basing the projection on GDP assumptions, commercial retail energy prices for nine fuels, and an assumed future trend. The dynamic equation uses a lagged dependent variable to imperfectly represent stock accumulation in the calculation of retail fuel prices for each region over time. The GDP forecast and the price projections are available to the Commercial Model from the WEPS+ global activity and supply models through the restart file, which is shared by all the models. The trend factor is meant to represent continuing impacts on energy use not directly represented in the GDP and price and may include the effects of a variety of behavioral, structural, and policy-induced activities.

The Commercial Model reads macroeconomic and price projections from the restart file. These values come from previous system iterations by the Global Activity Model and by various transformation and supply models. Commercial Model inputs are summarized in Table 5.

### Table 5. Commercial model input data series

| Commercial Model Input | Source |
|---|---|
| Gross domestic product | Global Activity Model |
| Commercial motor gasoline retail price | Refinery Model |
| Commercial distillate retail price | Refinery Model |
| Commercial residual retail price | Refinery Model |
| Commercial kerosene retail price | Refinery Model |
| Commercial LPG retail price | Refinery Model |
| Commercial natural gas retail price | Natural Gas Model |
| Commercial coal retail price | Coal Model |
| Commercial electricity price | Electricity Model |
| Commercial district heat retail price | District Heat model |

The Commercial Model projects consumption for a variety of energy sources and puts the projections into the restart file for use by the other models. These outputs are summarized in Table 6.

### Table 6. Commercial model output data series

| Commercial Model Output | Destination |
|---|---|
| Motor gasoline consumption | Petroleum and Refinery Models |
| Distillate consumption | Petroleum and Refinery Models |
| Residual consumption | Petroleum and Refinery Models |
| Kerosene consumption | Petroleum and Refinery Models |
| LPG consumption | Petroleum and Refinery Models |
| Natural gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Electricity consumption | Electricity Model |
| Heat consumption | District Heat Model |
| Biomass consumption | (Placeholder) |
| Solar consumption | (Placeholder) |

# 6. Industrial Model

The WEPS+ Industrial Model projects the amount of energy that is directly consumed as a fuel or as a feedstock by industrial processes and activities. It includes both manufacturing industries and non-manufacturing industries such as construction, agriculture and mining. It projects industrial consumption for eighteen energy sources in each of the sixteen WEPS+ regions over the projection horizon. The Industrial Model is a structured, industry-level, stock/flow model that uses gross output from the Global Activity Model as its primary driver. The model also uses retail energy prices for twelve energy sources. These drivers are available to the Industrial Model from the WEPS+ global activity and supply models through the shared restart file.

WIM projects energy consumption in eight separate industries identified according to their energy consumption characteristics. The eighth category – called "all other" – contains all industries not covered by the first seven categories, including the non-manufacturing sectors consisting of agriculture, construction and mining. The list of industries includes

- Food
- Paper
- Chemicals
- Refinery
- Iron and Steel
- Non-Ferrous Metals (primarily aluminum)
- Non-Metallic Minerals (primarily cement)
- All Other

WIM uses a stock/flow modeling approach. The model is initialized with an existing stock of productive capacity for each industry, and that capacity consumes energy based upon its energy intensity—energy consumed per dollar of GDP. For each projection year, WIM estimates how the productive capacity has changed in three vintage categories:

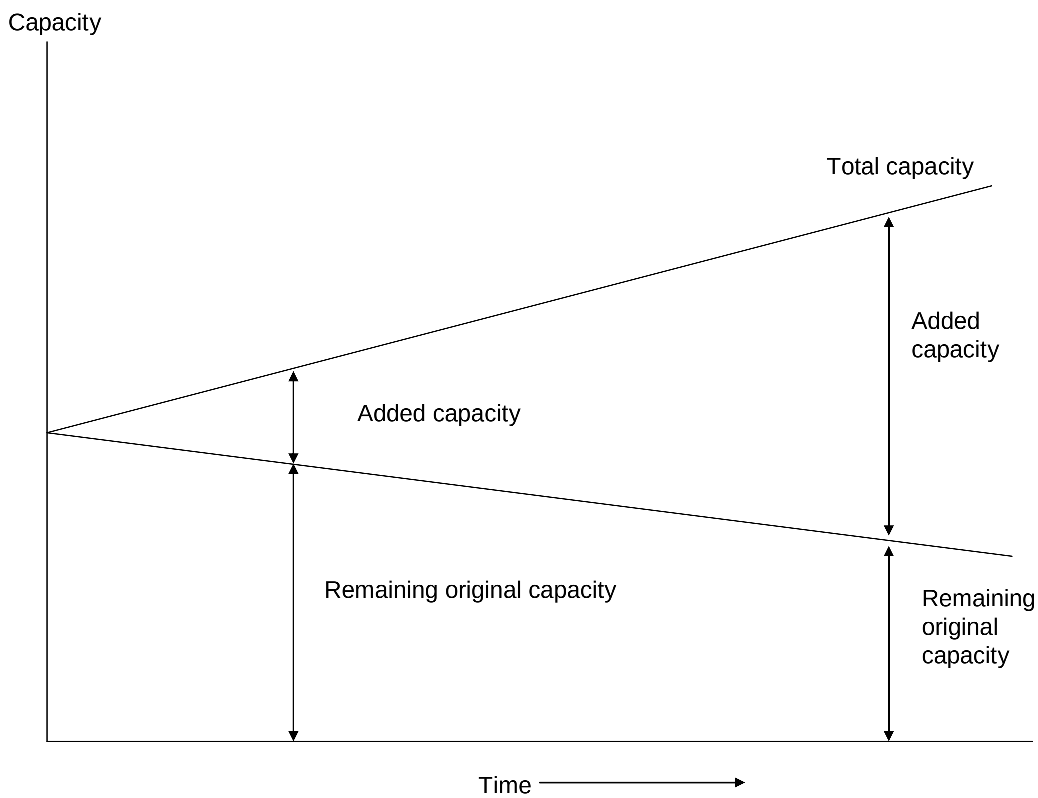
- ***Original Existing Capacity*** – For each year, the model uses a retirement rate to determine how much of the original existing capacity is remaining (was not retired). It also projects changes in energy intensity (from incremental non-capital improvements) and changes in the fuel mix.

- ***Previously Added Capacity*** – For each year, the model projects changes in energy intensity (from incremental non-capital improvements) and changes in the fuel mix for the cumulative amount of previously added capacity.

- ***New Capacity –*** For each year, the model determines how much new capacity is added, based on the original capacity still available, previously added capacity, and the required capacity based on the growth in gross output for the industry. The model projects the energy intensity for this new capacity, which is generally much better than that for the overall stock. The model also projects a new fuel mix for this new capacity.

The total energy consumption in each vintage category is given by the gross output multiplied by the energy intensity. The energy consumption for each fuel in each vintage category is given by the total consumption multiplied by the fuel shares. The overall total industry consumption for each fuel is given by the sum of consumption over the vintage categories. This approach takes into account the growth in output in each industry and the rate at which new, typically more efficient, capacity is added to the industry. Over time, in rapidly growing industries, the newly added capacity becomes a much more important determinant of energy consumption than in slowly growing industries. A simplified representation of the stock/flow approach is shown in Figure 3.

**Figure 3. Stock/flow capacity adjustments over time**




WIM reads macroeconomic and price projections from the restart file. These values come from previous system iterations by the Global Activity Model and by various transformation and supply models. World Industrial Model inputs are summarized in Table 7.

### Table 7. Industrial model input data series

| Industrial Model Input | Source |
|---|---|
| Gross domestic product | Global Activity Model |
| Industrial motor gasoline retail price | Refinery Model |
| Industrial distillate retail price | Refinery Model |
| Industrial residual fuel oil retail price | Refinery Model |
| Industrial kerosene retail price | Refinery Model |
| Industrial LPG retail price | Refinery Model |
| Industrial other petroleum retail price | Refinery Model |
| Industrial natural gas retail price | Natural Gas Model |
| Industrial coal retail price | Coal Model |
| Industrial electricity retail price | Electricity Model |
| Industrial district heat retail price | District Heat Model |

The Industrial Model projects consumption for multiple energy sources and writes the projections to the restart file for use by the other models. These outputs are summarized in Table 8.

### Table 8. Industrial output data series

| Industrial Model Input | Source |
|---|---|
| Motor gasoline consumption | Petroleum and Refinery Models |
| Distillate consumption | Petroleum and Refinery Models |
| Residual consumption | Petroleum and Refinery Models |
| Kerosene consumption | Petroleum and Refinery Models |
| LPG consumption | Petroleum and Refinery Models |
| Petroleum coke consumption | Petroleum and Refinery Models |
| Sequestered petroleum consumption | Petroleum and Refinery Models |
| Other petroleum consumption | Petroleum and Refinery Models |
| Crude oil consumption (direct use) | Petroleum and Refinery Models |
| Natural gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Electricity consumption | Electricity Model |
| Heat consumption | District Heat Model |
| Waste consumption | Reporting |
| Biomass consumption | Reporting |
| Geothermal consumption | Reporting |
| Solar consumption | Reporting |
| Other renewable consumption | Reporting |

The Industrial Model requires a significant amount of initial data, along with many coefficients. The data for the initial consumption is available from the IEA/Paris database (calibrated to the EIA data) described earlier. The coefficients are based on an analysis that compared existing industrial energy intensities among various regions particularly with a view towards the efficiency "gap" that is found between developed and developing regions. Based upon this comparison, analyst judgment was used to determine the relative new energy intensities. Analyst judgment was also used to develop several other coefficients such as drivers for retirement rates, rates of change of remaining and added energy intensities, and sensitivities to fuel prices.

# 7. Transportation Model

The WEPS+ Transportation Model (ITEDD) projects the amount of energy that is consumed to provide passenger and freight transportation services. This includes personal household on-road transportation in light duty vehicles (counted here rather than in the residential sector model). This also includes fuel consumed by natural gas pipelines, and small amounts of lubricants and waxes. The model projects transportation consumption for fourteen energy sources in each of the sixteen WEPS regions over the projection horizon. The Transportation Model provides an accounting framework that considers energy service demand and service intensity (efficiency) for the overall stock of vehicles. The service demand is a measure of overall passenger miles for passenger services and overall ton miles for freight services. The service intensity is a measure of passenger miles per unit of energy expended (in Btu) for passenger services and ton miles per unit of energy expended (in Btu) for freight services.

The Transportation Model categorizes transportation services for passengers and freight in four modes consisting of road, rail, water and air. These modes are also broken down into sub-modes as shown in Table 9.

**Table 9. Transportation model input data series**

| Transportation Mode | Transportation Sub-Mode |
|---|---|
| 1. Road | 1a. Light Duty Vehicles |
| | 1b. Two/Three Wheel Vehicles |
| | 1c. Buses |
| | 1d. Freight Trucks |
| | 1e. Other Trucks |
| 2. Rail | 2a. Passenger |
| | 2b. Freight |
| 3. Water | 3a. Domestic |
| | 3b. International |
| 4. Air | 4a. All Air |

The Transportation Model performs the following functions:

- Uses a bottoms-up approach to estimate demand for transportation energy by mode (road, rail, air, and marine) and vehicle type (light-duty vehicles, freight trucks, passenger rail, etc.);
- Estimates transportation energy consumption by fuel and region;
- Estimates vehicle stocks by vehicle type and region.

The Transportation Model reads macroeconomic and price projections from the restart file. These values come from previous system iterations by the Global Activity Model and various transformation and supply models. Transportation Model inputs are summarized in Table 10.

### Table 10. Transportation model input data series

| Transportation Model Input | Source |
|---|---|
| Gross domestic product | Global Activity Model |
| Population | Global Activity Model |
| Transportation motor gasoline retail price | Refinery Model |
| Transportation distillate (diesel) retail price | Refinery Model |
| Transportation residual retail price | Refinery Model |
| Transportation LPG retail price | Refinery Model |
| Transportation jet fuel retail price | Refinery Model |
| Transportation natural gas retail price | Natural Gas Model |
| Transportation coal retail price | Coal Model |
| Transportation electricity retail price | Electricity Model |
| Transportation ethanol (E85) retail price | Refinery Model |
| Transportation biofuels retail price | Refinery Model |
| Transportation hydrogen retail price | (Placeholder) |

The Transportation Model projects consumption for multiple energy sources and writes the projections to the restart file for use by the other models. These outputs are summarized in Table 11.

### Table 11. Transportation model output data series

| Transportation Model Output | Destination |
|---|---|
| Motor gasoline consumption | Petroleum and Refinery Models |
| Distillate (diesel) consumption | Petroleum and Refinery Models |
| Residual consumption | Petroleum and Refinery Models |
| LPG consumption | Petroleum and Refinery Models |
| Jet fuel consumption | Petroleum and Refinery Models |
| Sequestrated petroleum consumption | Petroleum and Refinery Models |
| Other petroleum consumption | Petroleum and Refinery Models |
| Crude oil consumption | Petroleum and Refinery Models |
| Natural gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Electricity consumption | Electricity Model |
| Ethanol (E85) consumption | Petroleum and Refinery Models |
| Other biofuels consumption | Petroleum and Refinery Models |
| Hydrogen consumption | (Placeholder) |

# 8. Electricity Model

The WEPS+ Electricity Model, also known as the World Electricity Model (WEM), projects the generation of electricity to satisfy the electricity demands projected by the end-use demand models. The model forecasts fuel consumed, electricity generated, and generation capacity by each technology for thirteen energy sources in each of the sixteen international regions over the projection horizon. The Electricity Model also projects end-use electricity prices for each of four demand sectors in each of the sixteen international regions.

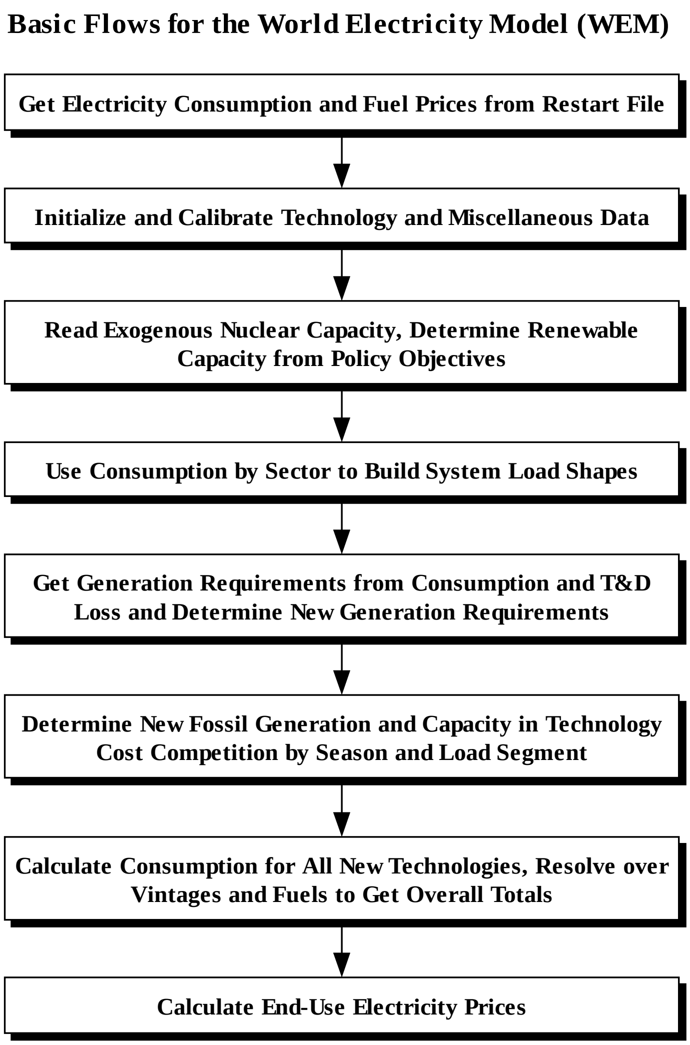
The Electricity Model is a technology-based, least-cost model that uses a logit function to estimate levelized cost for new generation technology in three load segments. It then uses the levelized costs to project market shares for each technology. The model accounts for a slate of available new technologies along with their corresponding characteristics. These technology characteristics vary by region and include heat rates (efficiency), capital cost (per kilowatt-hour), fixed operating cost, variable operating cost, availability factor, and more. For each fuel type, the model features different technology representations, including carbon capture and storage (CCS) technologies.

The Electricity Model initially estimates the total amount of generation that is required in each region by adding up the electricity demand from each sector and accounting for losses from transmission and distribution. These generation requirements are allocated to seasons and load segments based upon an overall system load curve. Each load curve describes how much of the annual load is consumed within specified periods of time in three seasons (summer, winter, and spring/fall). The periods of time are specified as percentages of the year and the amounts of the load are specified as percentages of the load. The model builds the system load curve based upon the load curves for each sector and each region and the relative weight of demand in each sector and region. The model then retires the existing capacity as necessary and determines how much total capacity is available for generation in each load segment and season.

Both nuclear capacity and renewable capacity are determined outside of the least-cost logit competition for fossil fuels. The total amount of nuclear capacity is generally policy driven and is exogenous to the model. However, to a large extent, renewable policies are input to the model and the model determines the amount of renewable capacity based upon policies that relate it to fossil capacity or to other goals. For each renewable and nuclear technology, the model determines the amount of new capacity added in a given year by looking at the difference between the total capacity for that year and the capacity available (and surviving) from the previous year.

The Electricity Model then uses a load dispatch algorithm to determine how the surviving capacity, along with the new nuclear and renewable capacity, is used to generate electricity. That consequently determines the amount of generation currently available. The generation available is compared to the generation requirements to determine how much new fossil generation is required. The new fossil generation is determined in a capacity planning algorithm that calculates levelized cost for each new technology that is available in the slate. The technology costs are then competed against each other in a logit-based, market share algorithm that gives more market share to lower cost technologies – the amount of market share is based upon a logit coefficient. The load dispatch and capacity planning algorithms are run within different load segments with different tradeoffs between fixed and variable costs resulting in different technology choices and capacity factors. The model also takes into account a reserve margin and has a learning algorithm for costs and heat rates.

**Figure 4. Flowchart for the electricity model**




The capacity choices that are made in capacity planning, the determination of how capacity is used for generation in the load dispatch, and the heat rates (efficiencies) determine the amount of fuel consumed by each technology. The Electricity Model compiles these data by fuel category and provides the resulting consumption data to the system through the restart file. It then calculates retail electricity prices based upon the fuels that are consumed and the changes in the overall fuel costs, along with some fixed markups from wholesale to end-use sector prices.

The Electricity Model reads electricity consumption and retail price projections from the restart file. These values come from previous system iterations by the various demand and supply models. Inputs to the World Electricity Model are summarized in Table 12.

### Table 12. Electricity model input data series

| Electricity Model Input | Source |
|---|---|
| Residential electricity consumption | Residential Model |
| Commercial electricity consumption | Commercial Model |
| Industrial electricity consumption | Industrial Model |
| Transportation electricity consumption | Transportation Model |
| Electricity generation distillate retail price | Refinery Model |
| Electricity generation residual retail price | Refinery Model |
| Electricity generation natural gas retail price | Natural Gas Model |
| Electricity generation coal retail price | Coal Model |

The WEM projects consumption for a variety of energy sources and puts the projections into the restart file for use by the other models. It also projects retail electricity prices for the demand sectors. (The model also writes generation and capacity projections to the restart file, but they are not explicitly shown here.) These outputs are summarized in Table 13.

### Table 13. Electricity model output data series

| Electricity Model Output | Destination |
|---|---|
| Distillate consumption | Petroleum and Refinery Models |
| Residual consumption | Petroleum and Refinery Models |
| Crude Oil consumption | Petroleum and Refinery Models |
| Natural gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Waste consumption | Reporting |
| Biomass consumption | Reporting |
| Hydroelectric consumption | Reporting |
| Geothermal consumption | Reporting |
| Solar consumption | Reporting |
| Wind consumption | Reporting |
| Other renewable consumption | Reporting |
| Nuclear consumption | Reporting |
| Residential electricity retail price | Residential Model |
| Commercial electricity retail price | Commercial Model |
| Industrial electricity retail price | Industrial Model |
| Transportation electricity retail price | Transportation Model |

# 9. District Heat Model

The WEPS+ District Heat Model projects the generation of district heat (steam or hot water from an outside source used as an energy source in a building) to satisfy the demands projected by the Residential Model, Commercial Model, and World Industrial Model for each region. For each fuel, the model estimates the amount of heat generated and the amount consumed, as well as the end-use price of heat for each of the three demand sectors. In addition, the model projects fuel consumed and heat generated in each of the sixteen international regions over the projection horizon for eight energy sources. The model uses prices from the supply models for distillate, residual, natural gas, and coal.

The District Heat Model uses a stock/flow approach in which it adds new heat generation capability each year as necessary, based upon the heat generation requirement from the end-use demand sectors. The model takes into account the amount of heat that is available from combined heat and power (CHP) plants in the electricity generation sector.

Because the IEA/Paris data account for district heat, WEPS+ explicitly adjusts for it in its estimated fuel balances. The District Heat Model uses some assumptions regarding efficiency and capacity in order to perform this necessary accounting function for the larger system. The amount of district heat consumed is typically small and the assumptions affect only a few regions. In much of the reporting, the amount of fuel consumption for district heat is not reported directly, but is instead reported in the sectors where heat is consumed. For example, if in a particular region the residential sector represents 25 percent of the total heat consumption, then 25 percent of the natural gas consumed for district heat is allocated to the residential sector and added to its natural gas total.

The District Heat Model reads heat consumption and retail price projections from the restart file. These values come from previous system iterations by the various demand and supply models. District Heat Model inputs are summarized in Table 14.

### Table 14. District heat model input data series

| District Heat Model Input | Source |
|---|---|
| Residential heat consumption | Residential Model |
| Commercial heat consumption | Commercial Model |
| Industrial heat consumption | Industrial Model |
| District heat distillate retail price | Refinery Model |
| District heat residual retail price | Refinery Model |
| District heat natural gas retail price | Natural Gas Model |
| District heat coal retail price | Coal Model |

The District Heat Model projects consumption by energy source and writes the projections to the restart file for use by the other models. It also projects retail district heat prices for the demand sectors. These outputs are summarized in Table 15.

### Table 15. District heat model output data series

| District Heat Model Output | Destination |
|---|---|
| Distillate consumption | Petroleum and Refinery Models |
| Residual consumption | Petroleum and Refinery Models |
| Crude Oil consumption | Petroleum and Refinery Models |
| Natural gas consumption | Natural Gas Model |
| Coal consumption | Coal Model |
| Waste consumption | Reporting |
| Biomass consumption | Reporting |
| Geothermal consumption | Reporting |
| Residential heat retail price | Residential Model |
| Commercial heat retail price | Commercial Model |
| Industrial heat retail price | Industrial Model |

# 10. Petroleum Model

The WEPS+ Petroleum Model provides world oil prices to the WEPS+ system. World oil prices are exogenously specified from an input file; the Petroleum Model accepts the price data and exports them to the restart file for use by other models. The model also has the capability of using an algorithm in which supply elasticities can be used to change the world oil prices based on changes in total world oil demand; however, this feedback capability is not generally used.

In order to estimate the sources and components of crude oil production given world oil prices, the Petroleum Model must import total world crude oil demand projections. The WEPS+ system demand estimates for crude oil are not modeled directly by the demand and transformation models in the WEPS+ system but are implied indirectly through the demand for petroleum products and for petroleum product substitutes in the various demand and transformation models. For example, a certain quantity of crude oil will be required to meet the demand for motor gasoline in the transportation sector model. The demand for products translates into a demand for crude oil through the refinery transformation process. WEPS+ uses a two-part refinery model. The first part adds demand projections for petroleum products across sectors and translates the demand for products and their substitutes into the total world demand for crude oil. Thus the input to the Petroleum Model is the total world crude oil demand read in from the restart file (Table 16), which is projected by the first part of the Refinery Model.

### Table 16. Petroleum model input data series

| Petroleum Model Input | Source |
|---|---|
| Total world crude oil demand | Refinery Model (part 1) |

The Petroleum Model projects the world oil price and writes it to the restart file for subsequent use by the Refinery Model (Table 17).

### Table 17. Petroleum Model Output Data Series

| Petroleum Model Output | Source |
|---|---|
| World oil price | Refinery Model (part 2) |

# 11. Natural Gas Model

The WEPS+ Natural Gas Model projects wholesale natural gas prices for each of the sixteen regions. The wholesale prices are then used to calculate retail prices using fixed sectoral markups. The retail prices are written to the shared restart file for use in the other demand and transformation models.

The Natural Gas Model is a reduced-form model that is estimated from perturbations of demand in the separate, stand-alone International Natural Gas Model (INGM). This reduced-form model is a response-surface type of model that starts with a base price at a base level of consumption, and then models changes to the base price due to changes in the level of consumption. The base consumption, from a run of the WEPS+ system, is provided to the INGM through an interface file. In turn, INGM provides base price and reduced-form model coefficients to WEPS+, which then uses the reduced-form model for subsequent runs, until there is a significant change. In the discussion below, the WEPS+ reduced-form Natural Gas Model will be referred to as the RFNG Model.

Currently, the INGM[1] is used to estimate the details of natural gas production, imports, exports, LNG, and other supply components that are published in the *IEO2016*. In addition to the base price and consumption and the reduced-form model coefficients, the INGM also passes some additional information at a regional level to the RFNG Model. This includes natural gas production, natural gas liquids production, fuel consumed in LNG operations, fuel consumed in gas-to-liquids (GTL) operations and as a feedstock, production of oil by GTL operations, and reinjection. (Currently, pipeline use and lease and plant use are determined in the INGM, but the RFNG Model makes its own separate forecast.) As the overall demand levels change in WEPS+, these components of supply are adjusted or calibrated in fairly straightforward algorithms by the RFNG Model. However, these algorithms and the components of supply are currently being used as placeholders, and the actual published data is done in a subsequent run of the INGM. With an eye towards bringing much of this more interactively into WEPS+, it is expected that the RFNG Model will be expanded and enhanced to incorporate some of this other information.

The key output of the RFNG Model is the wholesale price of natural gas in each region. Additional regional markups are used in each region to allocate these wholesale prices to the retail price in each demand sector. It is expected that this methodology will be enhanced in the future to directly account for market relationships, subsidies, and taxes.

The RFNG Model reads natural gas consumption projections from the restart file. These values come from previous iterations by the various demand and transformation models. RFNG inputs are summarized in Table 18.

[1] A separate documentation report for the International Natural Gas Model (INGM) is available at the EIA web site.

### Table 18. Natural gas model input data series

| Natural Gas Model Input | Source |
|---|---|
| Residential natural gas consumption | Residential Model |
| Commercial natural gas consumption | Commercial Model |
| Industrial natural gas consumption | Industrial Model |
| Transportation natural gas consumption | Transportation Model |
| Electricity generation natural gas consumption | Electricity Model |
| District heat natural gas consumption | District Heat Model |

The RFNG Model projects retail prices for the demand and transformation sectors and stores the results in the restart file for use by the other models. These outputs are summarized in Table 19.

### Table 19. Natural gas model output data series

| Natural Gas Model Output | Destination |
|---|---|
| Residential natural gas retail price | Residential Model |
| Commercial natural gas retail price | Commercial Model |
| Industrial natural gas retail price | Industrial Model |
| Transportation natural gas retail price | Transportation Model |
| Electricity generation natural gas retail price | Electricity Model |
| District heat natural gas retail price | District Heat Model |

# 12. Coal Model

The WEPS+ Coal Model projects the wholesale prices and sectoral retail prices of coal in each region. The regional wholesale prices are based on an exogenous supply curve, which is based on historical prices and analyst judgment. Retail prices are based on fixed sectoral markups from the wholesale prices.

Coal Model inputs are summarized in Table 20.

### Table 20. Coal model input data series

| Coal Model Input | Source |
|---|---|
| Supply Curve | CoalInput.xml |
| Residential coal consumption | Residential Model |
| Commercial coal consumption | Commercial Model |
| Industrial coal consumption | Industrial Model |
| Transportation coal consumption | Transportation Model |
| Electricity generation coal consumption | Electricity Model |
| District heat coal consumption | District Heat Model |

Coal Model outputs are summarized in Table 21.

### Table 21. Coal model output data series

| Coal Model Output | Destination |
|---|---|
| Residential coal retail price | Residential Model |
| Commercial coal retail price | Commercial Model |
| Industrial coal retail price | Industrial Model |
| Transportation coal retail price | Transportation Model |
| Electricity generation coal retail price | Electricity Model |
| District heat coal retail price | District Heat Model |

# 13. Refinery Model

The WEPS+ Refinery Model has two main functions, and it is split into two separate models that run at different points in the WEPS+ modeling stream. The first part runs before any of the other supply models; its function is to determine the total amount of crude oil that needs to be produced. Part 1 adds up the total petroleum products consumed by the demand and transformation models, and then compares this data to the total amount of crude oil required. For example, the model accounts for the amount of blends in motor gasoline, so that if a portion of the motor gasoline in a region is blended with ethanol, then less motor gasoline product is required and less global crude oil production is required. The model also accounts for amounts of oil that are produced in GTL operations. Ultimately, this first part of the Refinery Model determines the amount of crude oil that needs to be produced and puts that data into the restart file for subsequent use by the Petroleum Model.

The second part of the Refinery Model runs after the supply models run, and it is used to determine the wholesale and retail product prices. The Refinery Model is based upon the concept of a “marginal” refinery and includes three separate international specifications of a marginal refinery. These three specifications are for the U.S. Gulf Coast, Northwest Europe, and Singapore. The marginal refinery model takes the world oil price as specified by the Petroleum Model and then uses that, along with the petroleum product yields, to determine the wholesale product prices that cover the crude and other costs for each refinery. These local refinery prices are then allocated to each of the WEPS+ regions based upon transportation costs and transportation relationships. These regional wholesale product prices are then allocated to the demand and transformation sectors based upon historical relationships. The retail prices are put into the shared restart file to be used in the other models.

The Refinery Model reads petroleum consumption projections from the restart file. These values come from previous iterations by the various demand and transformation models. Refinery Model inputs are summarized in Table 22.

### Table 22. Refinery model input data series

| Refinery Model Input | Source |
|---|---|
| Residential distillate, kerosene, and LPG consumption | Residential Model |
| Commercial motor gasoline, distillate, residual, kerosene, and LPG consumption | Commercial Model |
| Industrial motor gasoline, distillate, residual, kerosene, LPG, petroleum coke, sequestered petroleum, other petroleum, and crude oil consumption | Industrial Model |
| Transportation, motor gasoline, distillate, residual, LPG, jet fuel, sequestered petroleum, other petroleum, and crude oil consumption | Transportation Model |
| Electricity generation distillate, residual, and crude oil consumption | Electricity Model |
| District heat distillate, residual, and crude oil consumption | District Heat Model |

The Refinery Model projects retail prices for the demand and transformation sectors, and exports them to the restart file for use by the other models. These outputs are summarized in Table 23.

### Table 23. Refinery model output data series

| Refinery Model Output | Destination |
|---|---|
| Residential distillate, kerosene, and LPG retail prices | Residential Model |
| Commercial motor gasoline, distillate, residual, kerosene, and LPG retail prices | Commercial Model |
| Industrial motor gasoline, distillate, residual, kerosene, and LPG retail prices | Industrial Model |
| Transportation motor gasoline, distillate, residual, LPG, jet fuel, other petroleum, ethanol, and other biofuels retail prices | Transportation Model |
| Electricity generation distillate and residual retail prices | Electricity Model |
| District heat distillate and residual retail prices | District Heat Model |

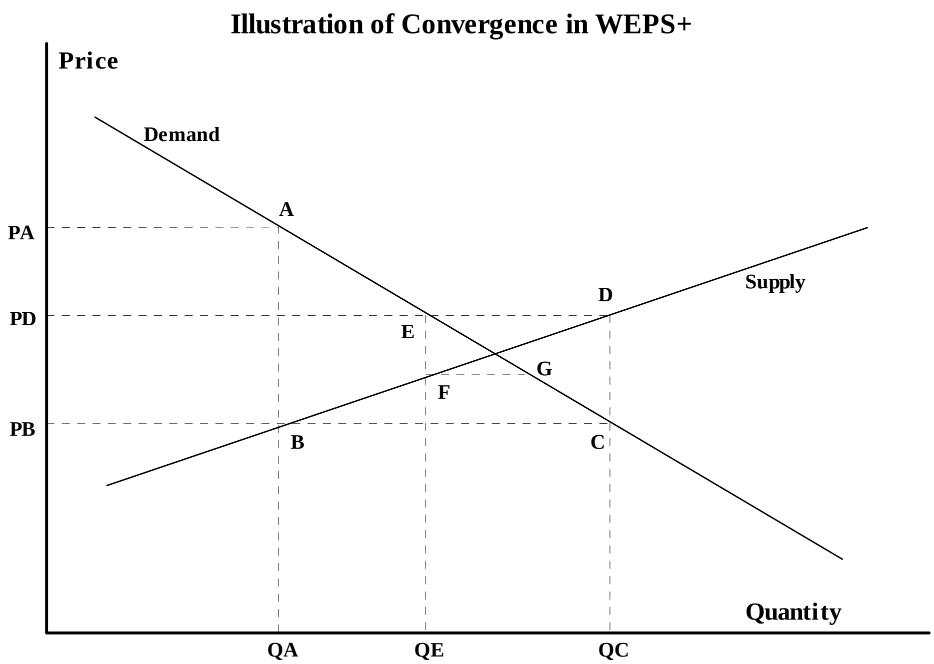
# 14. Greenhouse Gases Model

The Greenhouse Gases Model projects energy-related carbon dioxide emissions by taking all of the consumption projections of the other models from the restart file and applying carbon dioxide emissions factors to them. The emissions factors are calibrated to recent historical data from EIA's International Energy Statistics database. The model does not count emissions from fuel used as a feedstock or "sequestered" or consumed in a carbon capture and storage technology. The model does not address carbon dioxide emissions from non-energy consumption sources, nor does it account for non-carbon dioxide greenhouse gas emissions.

# 15. Main Model and Convergence Process

The primary objective of the WEPS+ Main Model is to evaluate and facilitate the convergence of the modeling system. This process is at the heart of the interactive nature of the entire WEPS+ system and is made possible by the way in which all the models communicate with each other to converge to an overall equilibrium solution. Driving this process is the basic economic concept of dynamic markets using prices to equilibrate demand and supply. In the modeling, the process is fairly straightforward for individual relationships, but becomes quite elaborate when all the energy sources, sectors, and regions are taken into account. The illustration in Figure 5, along with the discussion below, helps to explain the convergence process.

**Figure 5. Illustration of convergence in WEPS+**




The WEPS+ models for demand, transformation, and supply relate consumption to prices – on a demand curve – and relate supply to prices – on a supply curve. The illustration shows an abstraction of one demand and one supply curve. The WEPS+ modeling starts with the demand models and with a seed price. It gets this seed price from a restart file that was created in a previous run (which ideally is a similar run to the current run). In Figure 5, the process starts with the price of PA. Solving on the demand curve at point A, the quantity demanded at that price is QA. Thus, the demand model has solved for a quantity of QA, and the model puts that quantity into the restart file for subsequent use by the supply model.

Later in this first iteration, the supply model reads the QA level of demand from the restart file and determines from its supply schedule that that amount can be supplied for a price of PB. This is shown in the illustration at the point B. The supply model puts this new price of PB into the restart file for subsequent use by the demand model. At the end of this first iteration, the main model is executed and it looks to see if there is a convergence of the quantities and the prices. It knows what the quantities and prices were at the end of the previous iteration (or in this first iteration it knows what the starting seed quantities and prices were). In the previous iteration, the quantity was QX (some unknown value that is not illustrated above) and the price was PA. In the current iteration the quantity is QA, and the price is PB. QX is probably not close to QA, and, as seen in the illustration above, PA is not close to PB. Therefore, the system has not converged. The system will move to a new iteration and all the models will be run again.

In the second iteration, the demand model reads the price PB from the restart file (it was put there by the supply model in the previous iteration). With the price of PB, the demand model determines from its demand schedule that it demands the quantity QC (this is at the point C) and puts that into the restart file. Later in the second iteration, the supply model reads the QC level of demand and determines from its supply schedule that it wants the price PD (this is at the point D) and puts that into the restart file. Again, at the end of this second iteration the Main Model is executed and checks for convergence of quantities and prices. At the end of the previous iteration the quantity was QA and the price was PB; now at the end of this iteration they are QC and PD, respectively. The differences are now smaller than last time around but are still probably too large, so the system will not have converged. The system will again move to a new iteration and all the models will be run again.

In the third iteration, much the same happens as demand moves to point E and supply moves to point F. But, as can be seen in Figure 5, the differences between the starting points and the ending points for consumption and prices are becoming much smaller. In the end, when the differences are less than the convergence tolerance (which is set by the user), then the system will be close enough to the equilibrium point and it will have "converged." The iteration process stops when the system has converged, and the system does whatever post-processing is necessary (typically report writing). A detailed description of the three iteration steps is available in Table 24.

### Table 24. Summary of the convergence process

| | | |
|---|---|---|
| **Iteration 1** | | |
| | Demand | Seed price of PA, solves at A for quantity QA |
| | Supply | Quantity QA, solves at B for price PB |
| | Main | Has not converged, continues iterations |
| **Iteration 2** | | |
| | Demand | Price PB, solves at C for quantity QC |
| | Supply | Quantity QC, solves at D for price PD |
| | Main | Compare QA to QC and PB to PD, not converged, continues iterations |
| **Iteration 3** | | |
| | Demand | Price PD, solves at E for quantity QE |
| | Supply | Quantity QE, solves at F for price PF (not shown) |
| | Main | Compare QC to QE and PD to PF, closer, at some point ending iterations |

The convergence process as described above is a simplification for illustration purposes. The actual process in WEPS+ also includes a price “relaxation” (explained below) whenever the Main Model checks for convergence. Price relaxation is done for two primary reasons. First, it is possible that the shapes of the demand and supply curves are such that they do not converge and they actually diverge (this depends upon the relative elasticity of each curve). Price relaxation makes this much more unlikely. Second, price relaxation can greatly reduce the number of iterations and speed the movement to convergence.

The model uses price relaxation when the system has not converged and is moving to the next iteration. Instead of using the price from the current iteration to start the next iteration, the Main Model makes a guess at the equilibrium price and instead puts this new price guess into the restart file for use in the next iteration. To understand price relaxation, it is helpful to consider the illustration above and revisit the second iteration. From the end of the first iteration to the end of the second iteration, the process has moved from point B to point C to point D, and the price has changed from PB to PD. Ordinarily, the system would start the next iteration with the price PD in the restart file. But with price relaxation, instead of using the price PD, the Main Model makes a simple guess at the equilibrium price by choosing the price midway between PB and PD. The original price PD, which the supply model put into the restart file, is replaced in the restart file by the Main Model with this alternative midpoint price. It can be clearly seen from the illustration that this simple midpoint guess puts the price much closer to the equilibrium price. When the demand model is run in the next iteration, this alternative price will cause the projected demand to be much closer to the equilibrium demand. This simple price relaxation has greatly improved the convergence process.

There are several other simplifications in the illustration above. First, the system does not consist of one single demand and supply schedule but instead considers a large number of energy sources in a number of sectors in a variety of regions. Moreover, some of the demand and supply schedules may be interrelated, and in some cases the supply schedule is an aggregate of many demands (for example, solving for an overall regional natural gas wholesale price or solving for a worldwide world oil price). Second, the actual convergence criteria in use are based on an overall weighted average rating, which can be over several fuels or for a particular region or other aggregates. This is referred to as the convergence “GPA;” the particulars for this and for the tolerance levels for the specific fuels and prices are a user choice. Third, in each iteration, the models in WEPS+ are run for all years over the modeling horizon. This makes it much easier to code the models, make the models more independent, and allow them to be run as independent executables. This means that the convergence checking is done for all of the years (or for some subset).