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World Energy Projection System Plus: Overview

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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 2017 (IEO2017)*. 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 *IEO2017*. The complete WEPS+ system contains three main sections:

- A common 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 *IEO2017*; 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

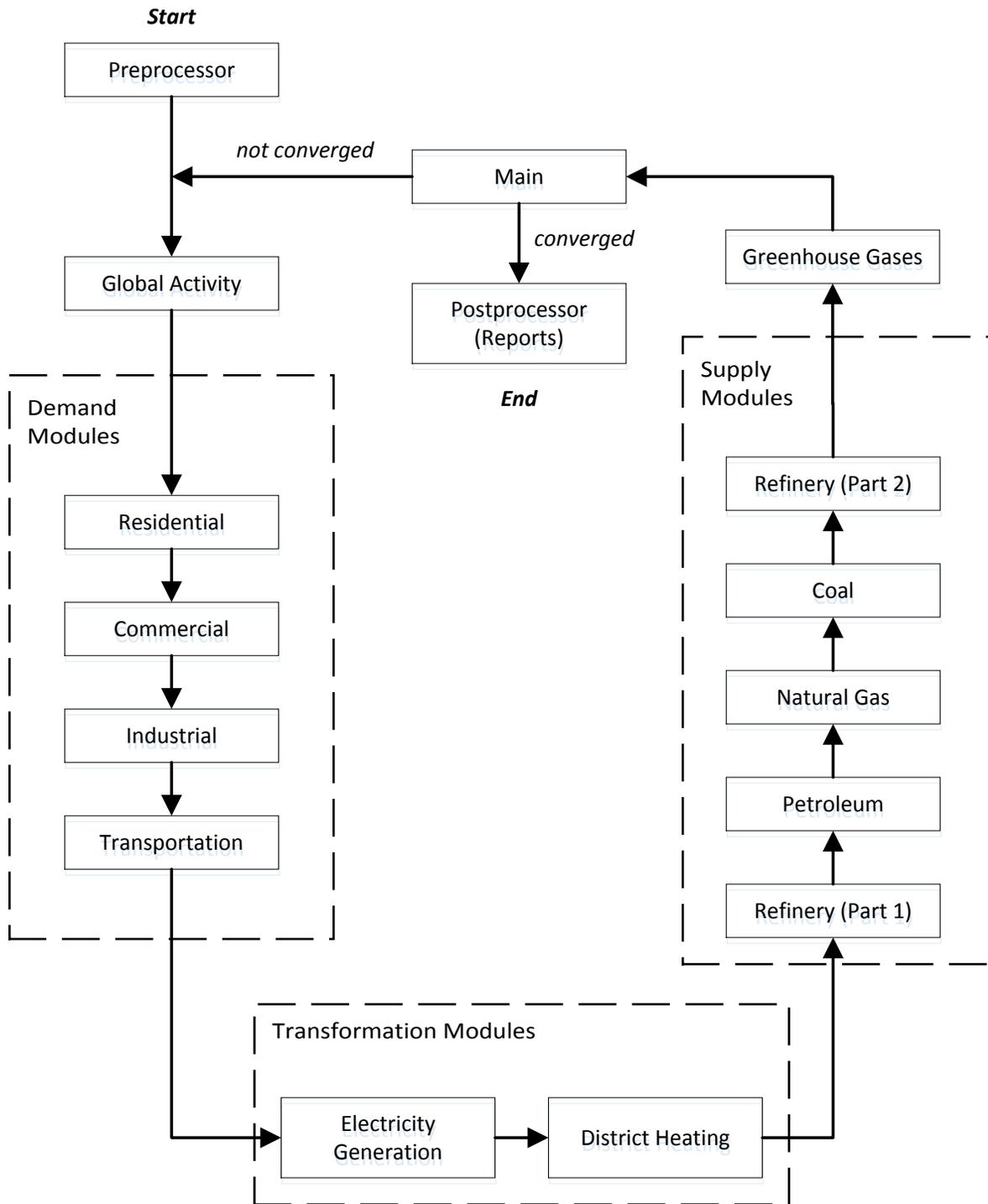
system also includes models that perform preprocessing and post-processing, including various final reporting programs. The current core set of models is outlined in Table 1.

Table 1: Core models

Type of Activity	WEPS+ Model
Demand Models	1. Global Activity Model
	2. Residential Model
	3. Commercial Model
	4. Industrial Model
	5. Transportation Model
Transformation Models	6. Electricity Model
	7. District Heat Model
	8. Petroleum Model
Supply Models	9. Natural Gas Model
	10. Coal Model
	11. Refinery (Part 1 & 2)
	12. Greenhouse Gas 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 common database (also known as the ‘restart file’) from a 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 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 Non-OECD Americas

The following report provides an overview of the various WEPS+ modules as used for the *IEO2017*.

System archival citation

This documentation refers to the World Energy Projection System Plus (WEPS+) Overview, as archived for the *International Energy Outlook 2017 (IEO2017)*.

WEPS+ source code for the most recent IEO is available at https://www.eia.gov/outlooks/ieo/ieowepsplus_sourcecode.php. Previous year's WEPS+ code is also available. For example, the WEPS+ source code for *IEO2016* can be downloaded from https://www.eia.gov/outlooks/archive/ieo16/ieowepsplus_sourcecode.php

System contact

Michael Cole
 U.S. Energy Information Administration
 U.S. Department of Energy
 1000 Independence Avenue, SW
 Washington, D.C. 20585
 Telephone: (202) 586-7209
 E-mail: Michael.Cole@eia.gov

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.

2. Common Database

There are several key historical data sources used for WEPS+:

- The U.S. Energy Information Administration’s (EIA) International Energy Statistics (IES) database (<https://www.eia.gov/beta/international/>) provides non-U.S. country-level consumption data for liquids, natural gas, coal, nuclear energy, and hydroelectric and other renewables consumed for electricity generation. IES also includes thermal, nuclear, hydroelectric, and other renewables (wind, biomass and waste, geothermal, and solar/tide/wave/fuel cell) electricity generation and installed generating capacity.
- 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 provides country-level consumption data for a wide variety of “flows” (sectors and users) and for a wide variety of “products” (detailed petroleum products, coal types, renewable sources, etc.). EIA uses these detailed data to derive the historical, end-use sector data used in WEPS+ demand models.
- Historical data and projections for the United States are extracted from the most recent EIA *Annual Energy Outlook (AEO2017 for IEO2017)*.

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 Industrial Model
- Provide mode-level detail for the Transportation Model
- Coordinate with capacity and generation data at various levels for the 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 common database, 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 common database. Each model, when it is executed, first reads the common database 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 database for use by the other models. 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 IEO 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 household income 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 income and price projections are available to the Residential Model from the WEPS+ Global Activity Model and supply models through the common database. The trend factor is meant to represent continuing impacts on energy use not directly represented in household income and prices, 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 common database. These values come from previous system iterations by the Global Activity Model and the various transformation and supply models. Residential Model inputs are summarized in Table 3.

Table 3. Residential model input data series

Residential Model Input	Source
Household income	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 common database 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 assumptions for gross output of the services sector, 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 service sector gross output and price projections are available to the Commercial Model from the WEPS+ Global Activity Model and the supply models through the common database. 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 common database. 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 output of the services sector	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 common database 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

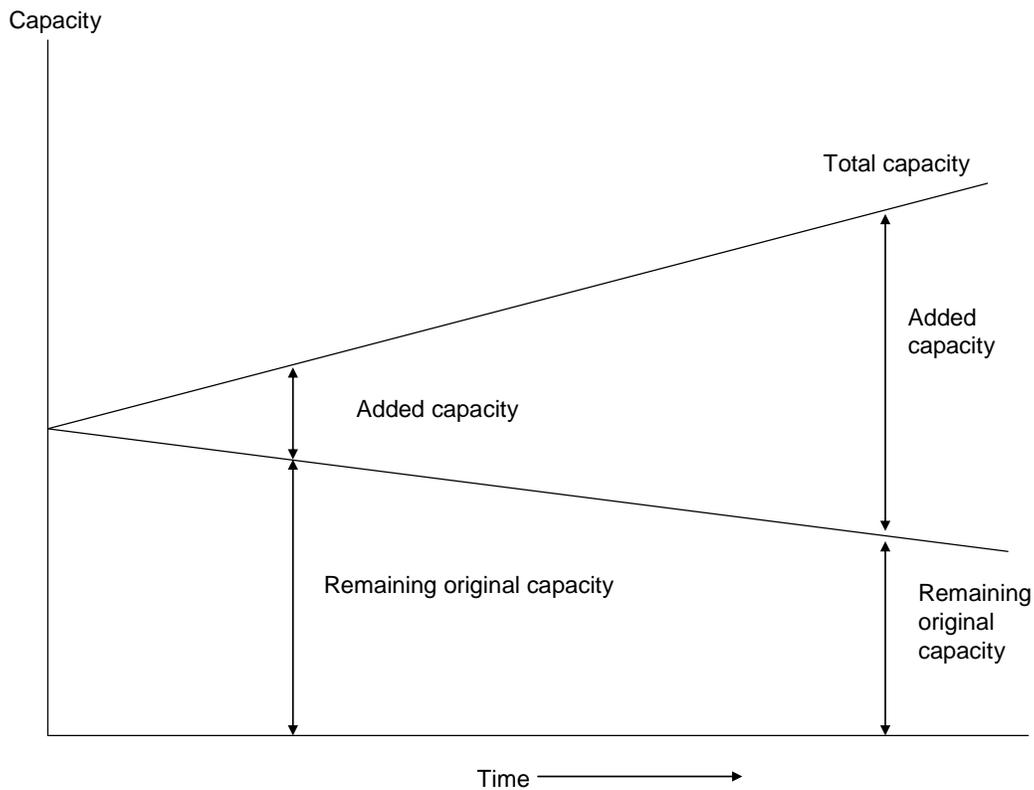
The WEPS+ Industrial Model projects the amount of energy that is directly consumed as a fuel or as a feedstock by industrial processes and activities. It includes both manufacturing industries and non-manufacturing industries such as construction, agriculture and mining. It projects industrial consumption 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 common database.

The Industrial Model projects energy consumption in multiple separate industries identified according to their energy consumption characteristics. The industries modeled include Paper, Basic Chemicals, Refineries, Iron and Steel, Motor Vehicles, and others. For a complete list, see the separate Industrial Model documentation.

The Industrial Model 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 2.

Figure 2. Stock/flow capacity adjustments over time

The Industrial Model reads macroeconomic and price projections from the common database. These values come from previous system iterations by the Global Activity Model and by various transformation and supply models. 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 common database for use by the other models. These outputs are summarized in Table 8.

Table 8. Industrial output data series

Industrial Model Output	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 bottom-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 common database. 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 common database 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
Sequestered 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 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.

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 common database. 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 common database. 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 Electricity Model projects consumption for a variety of energy sources and puts the projections into the common database 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 common database, 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 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 WEPS+ 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 common database. 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 common database 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
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 common database 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 common database (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 common database 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 common database 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.

The INGM¹ is used to estimate the details of natural gas production, imports, exports, LNG, and other supply components that are published in the IEO. 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 Natural Gas 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 Natural Gas 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 Natural Gas 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.

The key output of the Natural Gas 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 Natural Gas Model reads natural gas consumption projections from the common database. These values come from previous iterations by the various demand and transformation models. Natural Gas Model inputs are summarized in Table 18.

¹ A separate documentation report for the International Natural Gas Model (INGM) is available on 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 Natural Gas Model projects retail prices for the demand and transformation sectors and stores the results in the common database 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 wholesale prices and sectoral retail prices of coal in each region. The regional wholesale prices are based on an exogenous price path and a price elasticity term, which are 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 common database for subsequent use by the Petroleum Model.

The second part of the Refinery Model runs after the supply models, and projects wholesale and retail product prices. The Refinery Model is based on 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 on 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 common database to be used by the other models.

The Refinery Model reads petroleum consumption projections from the common database. 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
World oil price	Petroleum Model
Residential consumption of distillate, kerosene, and LPG	Residential Model
Commercial consumption of motor gasoline, distillate, residual, kerosene, and LPG	Commercial Model
Industrial consumption of motor gasoline, distillate, residual, kerosene, LPG, petroleum coke, sequestered petroleum, other petroleum, and crude oil	Industrial Model
Transportation consumption of motor gasoline, distillate, residual, LPG, jet fuel, sequestered petroleum, other petroleum, and crude oil	Transportation Model
Electricity generation consumption of distillate, residual, and crude oil	Electricity Model
District heat consumption of distillate, residual, and crude oil	District Heat Model

The Refinery Model projects retail prices for the demand and transformation sectors, and exports them to the common database 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 sector retail prices for distillate, kerosene, and LPG	Residential Model
Commercial sector retail prices for motor gasoline, distillate, residual, kerosene, and LPG	Commercial Model
Industrial sector retail prices for motor gasoline, distillate, residual, kerosene, and LPG	Industrial Model
Transportation sector retail prices for motor gasoline, distillate, residual, LPG, jet fuel, other petroleum, ethanol, and other biofuels	Transportation Model
Electricity sector generation retail prices for distillate and residual	Electricity Model
District heat sector retail prices for distillate and residual	District Heat Model

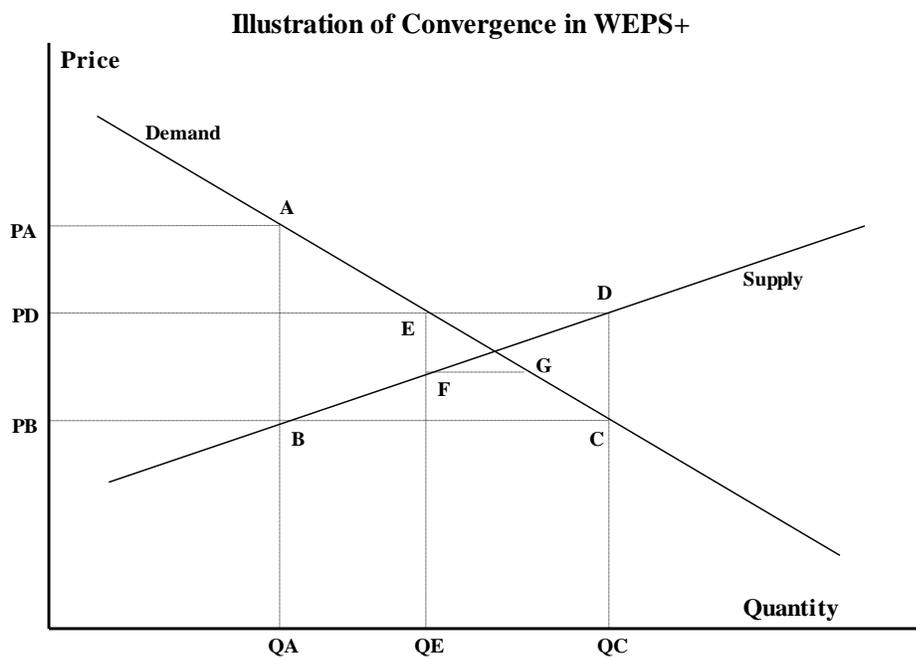
14. Greenhouse Gases Model

The Greenhouse Gases Model projects energy-related carbon dioxide emissions by taking all of the consumption projections of the other models from the common database 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 3, along with the discussion below, helps to explain the convergence process.

Figure 3. 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 common database that was created in a previous run (which ideally is a similar run to the current run). In Figure 3, 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 common database for subsequent use by the supply model.

Later in this first iteration, the supply model reads the QA level of demand from the common database 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 common database 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 common database (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 common database. 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 common database. 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 3, 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 common database 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 common database. 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 common database, is replaced in the common database 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).