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World Energy Projection System Plus Model Documentation 2010: World Industrial Model

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1. Introduction

Purpose of This Report

The World Industrial Model of the World Energy Projection System Plus (WEPS+) is an energy demand modeling system that projects industrial end-use sector energy consumption for 16 international regions. This report describes the version of the World Industrial Model (WIM) that was used to produce the industrial sector projections published in the *International Energy Outlook 2010* (*IEO2010*). WIM is one of 13 components of WEPS+ energy modeling system, but the industrial model can also be run as a separate, individual model. The WEPS+ is a modular system, consisting of separate energy models that are communicate and work together through the overall system model. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a 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 simultaneous convergence of consumption and price to simulate market equilibrium.

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

Model Summary

The World Industrial Model of the World Energy Projection System Plus (WEPS+) projects energy use in the manufacturing, agricultural, construction and mining sectors for 18 energy sources in each of the 16 WEPS+ regions on an annual basis to 2035. The model primarily employs a stock-flow accounting framework that uses exogenously-specified output of specific industries as a proxy for productive capacity. In WIM, old capacity is retired over time to make way for new capacity. This framework allows for the modeling of changes in energy efficiency over time. Exogenously-specified energy prices impact both the mechanisms of the stock-flow process and fuel switching over time.

Model Archival Citation

This documentation refers to the WEPS+ World Industrial Model, as archived for the *International Energy Outlook 2010* (*IEO2010*).

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Organization of This Report

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

2. Model Purpose

Model Objectives

The primary objective of the WIM is to generate annual projections of industrial energy use for 2008 through 2035 for each of the 16 WEPS+ international regions. Projections are further broken out by fuel type, industry, and capacity vintage. As an integral component of the WEPS+ system, WIM provides consumption inputs to the various transformation and supply models of WEPS+ and contributes to the simulation of the overall energy supply and demand balance. The consumption inputs are also used by the Greenhouse Gases Model to calculate energy-related carbon dioxide emissions.

As part of the WEPS+ system, WIM operates at the level of the 16 WEPS+ world regions (Table 1). These regions consist of countries and country groupings within the broad divide of the Organization of Economic Cooperation and Development (OECD) membership.

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

OECD Regions	Non-OECD Regions
1. United States	8. Russia
2. Canada	9. Non-OECD Europe and Eurasia
3. Mexico	10. China
4. OECD Europe	11. India
5. Japan	12. Other Non-OECD Asia
6. Australia/New Zealand	13. Middle East
7. South Korea	14. Africa
	15. Brazil
	16. Other Central and South America

Model Inputs and Outputs

Inputs

WIM uses macroeconomic and industrial price projections that are imported from the WEPS+ restart file. These inputs have been previously projected by the Macroeconomic Model and the transformation and supply models (Table 2).

Table 2. WEPS+ Models that Provide Input to the World Industrial Model

World Industrial Model Input	Source
Gross domestic product	Macroeconomic Model
Outputs of specific industries	Macroeconomic Model
Industrial motor gasoline retail price	Refinery Model
Industrial distillate retail price	Refinery Model
Industrial residual 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	World Electricity Model
Industrial district heat retail price	District Heat model

The data series listed in Table 3 are also imported into the World Industrial Model from the WIMInput-MASTER.xml file.

Table 3. Major Exogenous World Industrial Model Input Data Series

Source Input File	World Industrial Model Input
WIMInput-MASTER.xml	Capacity retirement rates by industry and region
	Capacity retirement rate elasticities by industry and region
	Relative Energy Intensity (REI) coefficients by industry and region
	Technology Possibility Curve (TPC) growth rates for existing and new capacity by industry and region
	Technology Possibility Curve (TPC) price elasticities for existing and new capacity by industry and region
	Fuel share growth rates for existing and new capacity by industry, fuel and region
	Fuel share switching fraction for existing and new capacity by industry, fuel and region
	Fuel share switching price elasticity for existing and new capacity by industry, fuel and region
	New/Relative fuel switching factor for added capacity by industry, fuel and region

Outputs

WIM projects annual energy consumption by fuel and region. Upon completion of a model run, the projections are exported into the WEPS+ restart file for use by other models (Table 4).

Table 4. WIM Model Output and the WEPS+ Models that Use Them

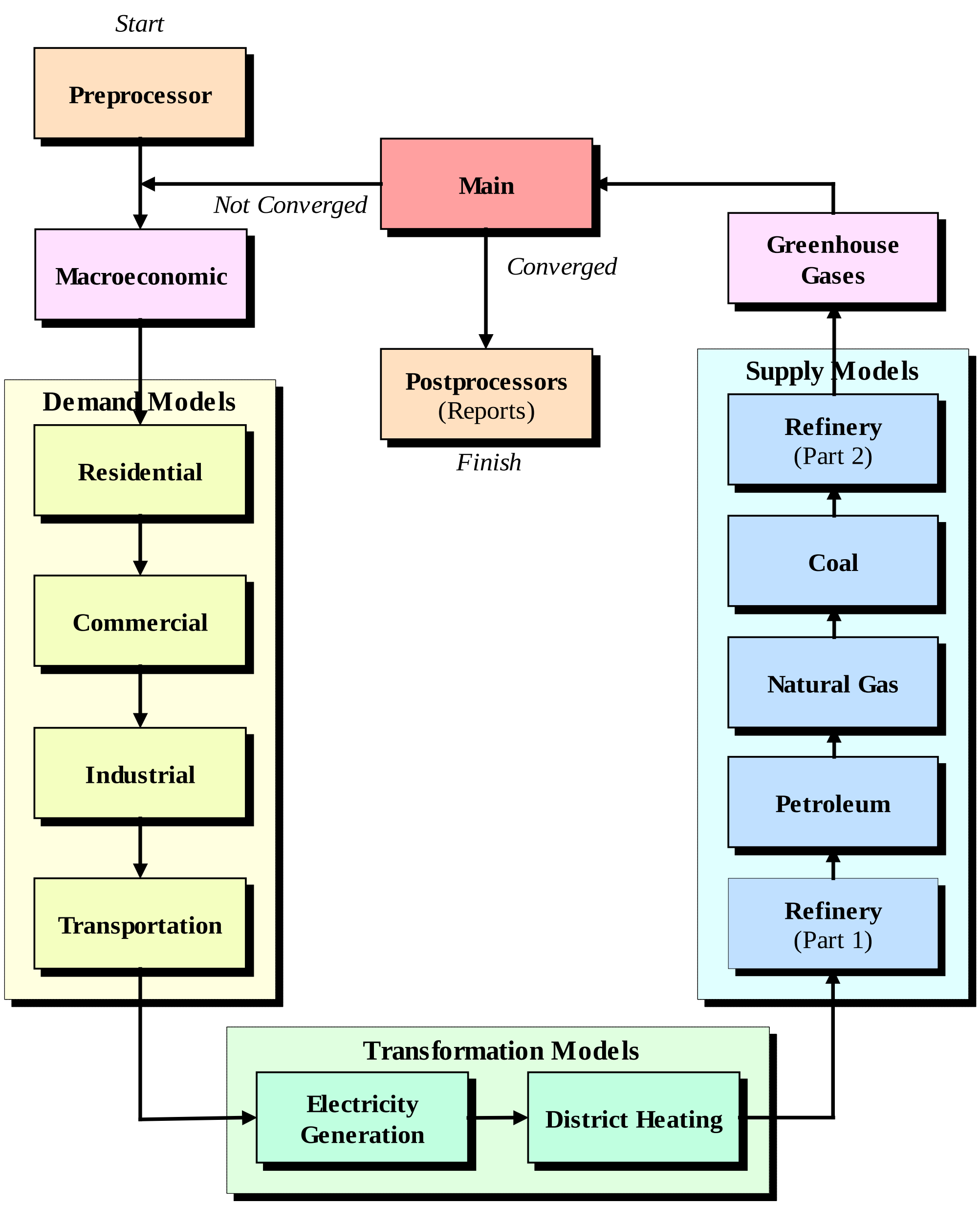
World Industrial Model Output	Destination
Motor gasoline consumption	Petroleum and Refinery Models
Distillate consumption	Petroleum and Refinery Models
Residual consumption	Petroleum and Refinery Models
Kerosene consumption	Petroleum and Refinery Models
LPG consumption	Petroleum and Refinery Models
Petroleum 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	World Electricity Model
Heat consumption	District Heat Model
Waste consumption	Reporting
Biomass consumption	Reporting

Geothermal consumption	Reporting
Solar consumption	Reporting
Other renewable consumption	Reporting

Relationship to Other Models

WIM is an integral component of the WEPS+ system and depends upon other models in the system for some of its key inputs. In turn, the WIM provides projections of energy consumption that other models in the system depend upon for their key inputs (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2010* report is available in a separate *Overview* documentation.

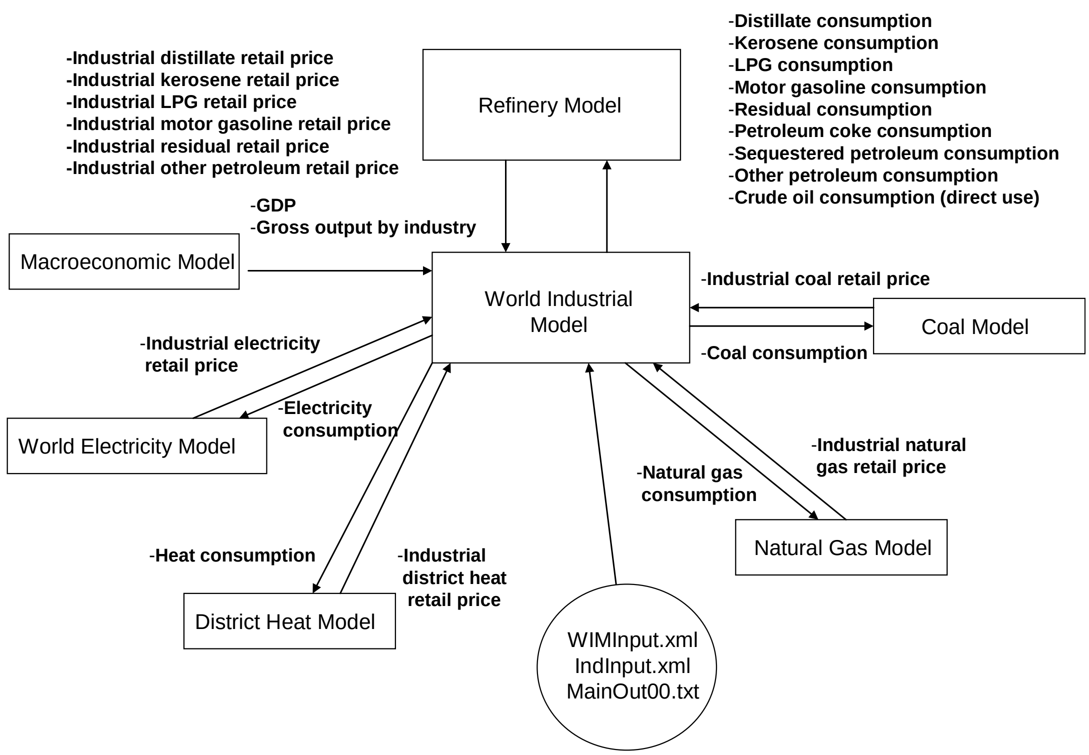
Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence



Through the system, WIM receives gross domestic product (GDP) projections and gross output projections for specific industries from the Macroeconomic Model and receives a variety of price projections from various supply and transformation models (Figure 2). In turn, WIM provides consumption projections through the system back to the supply and transformation models.

Although WIM is an integral part of the WEPS+ system, it can also be easily run as a standalone model. In standalone mode, WIM inputs macroeconomic and price projections from the WEPS+ system "restart" file as created in a previous full-system run.

Figure 2. The World Industrial Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical Approach

The World Industrial Model (WIM) projects energy use that is directly consumed as a fuel or as a feedstock by industrial processes and activities. WIM includes manufacturing industries along with non-manufacturing industries such as construction, agriculture, and mining. The model is used to project industrial consumption for 18 energy sources in each of the 16 WEPS regions to the year 2035. WIM is a structured, industry-level, stock/flow model that uses gross output from the Macroeconomic Model as its primary driver. The model also uses retail energy prices for 12 energy sources. These drivers are available to the World Industrial Model from the WEPS+ transformation and supply models through the shared restart file.

WIM projects energy consumption in eight separate industries that are considered energy intensive or distinctive with respect to energy consumption. The "all other" industry category contains the remaining industries, including the non-manufacturing sectors including of agriculture, construction, and mining. The list of the 8 industries is:

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

WIM uses a stock/flow approach. It is initialized with an existing stock of productive capacity for each industry, and that capacity consumes energy based upon its energy intensity. In each projection year, the model simulates the change in productive capacity for three vintage categories:

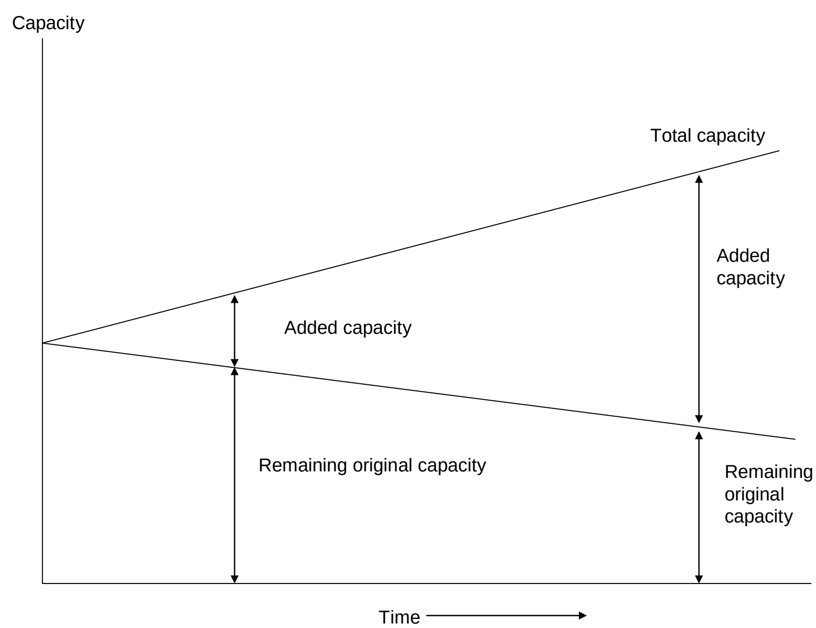
Original Existing Capacity. The model uses a retirement rate to determine how much of the original existing capacity remains (was not retired). The "original existing capacity" is simply the historical base year industrial capacity (the base year was 2007 for the *IEO2010*) which is based on industrial output. The base year industrial energy intensity is computed from the original existing capacity.

Previously Added Capacity. The model projects changes in energy intensity (largely due to "housekeeping") and changes in the fuel mix for the cumulative amount of previously added capacity. "Previously added capacity" is the amount of new capacity added up to the current model year.

New Capacity. In the current model year the model determines the amount of new capacity added by subtracting the previously available capacity (original plus previously added) from the total required capacity, given the projected 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. A new fuel mix for the new capacity is also determined.

Total energy consumption in each vintage category is computed as gross output multiplied by energy intensity. Consumption of each fuel in each vintage category is computed as total energy consumption multiplied by the vintage-category fuel share. As discussed below, these fuel shares can be fixed or allowed to vary depending on consumption trends and price changes. The overall total industry consumption by fuel is calculated as the sum of consumption over the vintage categories. This approach takes into account the growth in output by industry and the rate at which new, typically more efficient, capacity is added. Over time, in rapidly growing industries, the new 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. Illustration of Stock/Flow Industrial Capacity Changes Over Time



WIM requires a significant amount of initial data along with a number of projection coefficients. The data used to project industrial sector consumption is drawn from the International Energy Agency's *Energy Statistics and Balances of OECD and non-OECD Countries* and calibrated for consistency with historical international energy data available from the Energy Information Administration. The coefficients for the *IEO2010* were based on comparisons of existing industrial energy intensities among world regions, taking into account the efficiency discrepancies between the more industrialized regions and the developing regions. Analysts used these comparisons, along with expert judgment, to estimate parameters such as regional energy intensities, capacity retirement rates, rates of change intensity for remaining and added capacity, and fuel price elasticities.

Model Assumptions

WIM projects industrial energy consumption based upon numerous assumptions. The assumptions most critical to the projections include:

- Economic output is a suitable proxy for productive capacity, i.e., utilized capacity.[1]
- Energy intensity of economic output is assumed to be inversely related to energy efficiency.
- Energy efficiency of new productive capacity will be better than energy efficiency of old productive capacity.
- Energy efficiency of economic output improves over time.
- Energy prices impact the retirement rate of capital, the rate of efficiency change, and the choice of fuels.

[1] The model does not explicitly consider capacity utilization. However, if there is a decline in industrial output, followed by a subsequent increase, then the model will logically assume that the capacity "lost" during the downturn was just idled, and that this idled capacity is to brought back "on line" first before adding new (more energy effcienct) capacity when industrial output starts to ramp up again.

4. Model Structure

Structural Overview

The main purpose of the World Industrial Model is to project annual industrial sector energy consumption, by region and fuel type, for 2008 through 2035. The industrial energy consumption calculations incorporate inputs that reflect analysts' expectations of the state of technology in each region. Consumption is estimated for each of the 16 WEPS+ regions for 18 energy sources (motor gasoline, distillate fuel, residual fuel, kerosene, liquefied petroleum gas including feedstocks, petroleum coke, sequestered petroleum, other petroleum use including feedstocks, direct use crude oil, natural gas including feedstocks, coal including coking coal, electricity, heat, waste, biomass, geothermal, solar, and other renewables).

The basic structure of the World Industrial Model is illustrated in Figure 4. A call from the WEPS+ model interface to the WIM begins the import of information from the restart file and the other WEPS+ models needed to complete the projection calculations

Next, a call from the main Industrial Model initiates the Ind subroutine (Figure 5), which uses data from the WIMInput.xml file to complete its calculations. To read in this information, the Ind subroutine calls the ReadXML subroutine (Figure 6), which assigns values from the WIMInput.xml file to local variables in the model. This file contains analyst-developed inputs for switching fractions, price elasticities, technology possibility curve growth rates, and relative energy intensity coefficients.

After the ReadXML subroutine executes, the Ind subroutine begins to compute industrial capacity and consumption projections by industry, fuel, and region. First, GDP and industrial price indices are computed across the projection period, by region and fuel, and adjusted for a high world oil price case scenario. Next, an overall industrial quantity index is calculated as the product of the historical consumption of fuels and the GDP and industrial price indices using benchmark factors for each region and industry.

The main Industrial Model then calls the GetGO subroutine (Figure 7) read in macroeconomic data from an input file and compute the economic growth rate. After calculating the projected growth over the projection period, this subroutine relates overall economic growth of consumption to growth of GDP. It uses a dollar-to-physical-unit growth rate to convert dollars of output to industrial gross output, accounting for inflation and technological advancements over time. This information is then written into an output file. Next, the InitCalc subroutine is called to set up the initial gross outputs, consumption vintages, and intensity vintages. Finally, a weighted average price for each industry is calculated which is related to historical price indices.

The bulk of the calculations in the Ind subroutine are made in the CalcMan subroutine (Figure 8). CalcMan uses the data in the WIMInput.xml subroutine to estimate the amount of existing, added, new, and total capacities for each fuel, industry, and region. First, consumption growth for each fuel is calculated by region and industry using a formula that assumes a continuous growth rate. Then, a switching fraction and price elasticity determines how much fuel is switched because of price changes throughout the projection. The totals for each fuel are then calibrated to agree with the projected total fuel usage in each region and industry through 2035. Then, the AddUp subroutine is called to aggregate the quantities calculated in the previous subroutines and export reports. Several output files are generated and returned to the main World Industrial Model routine. After the Ind subroutine has executed, the WriteRestart subroutine is called to send the output from the WIM to the restart file that will be used in future iterations of WEPS+.

Flow Diagrams

Figure 4. Flowchart for the Industrial Model

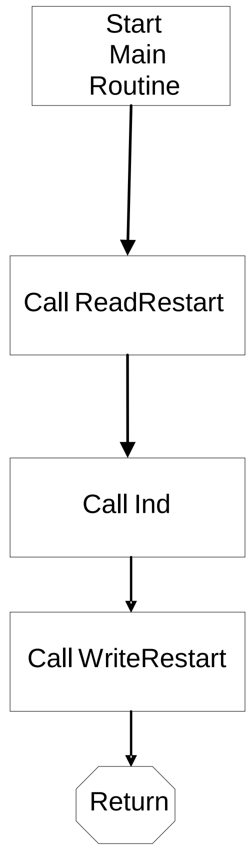
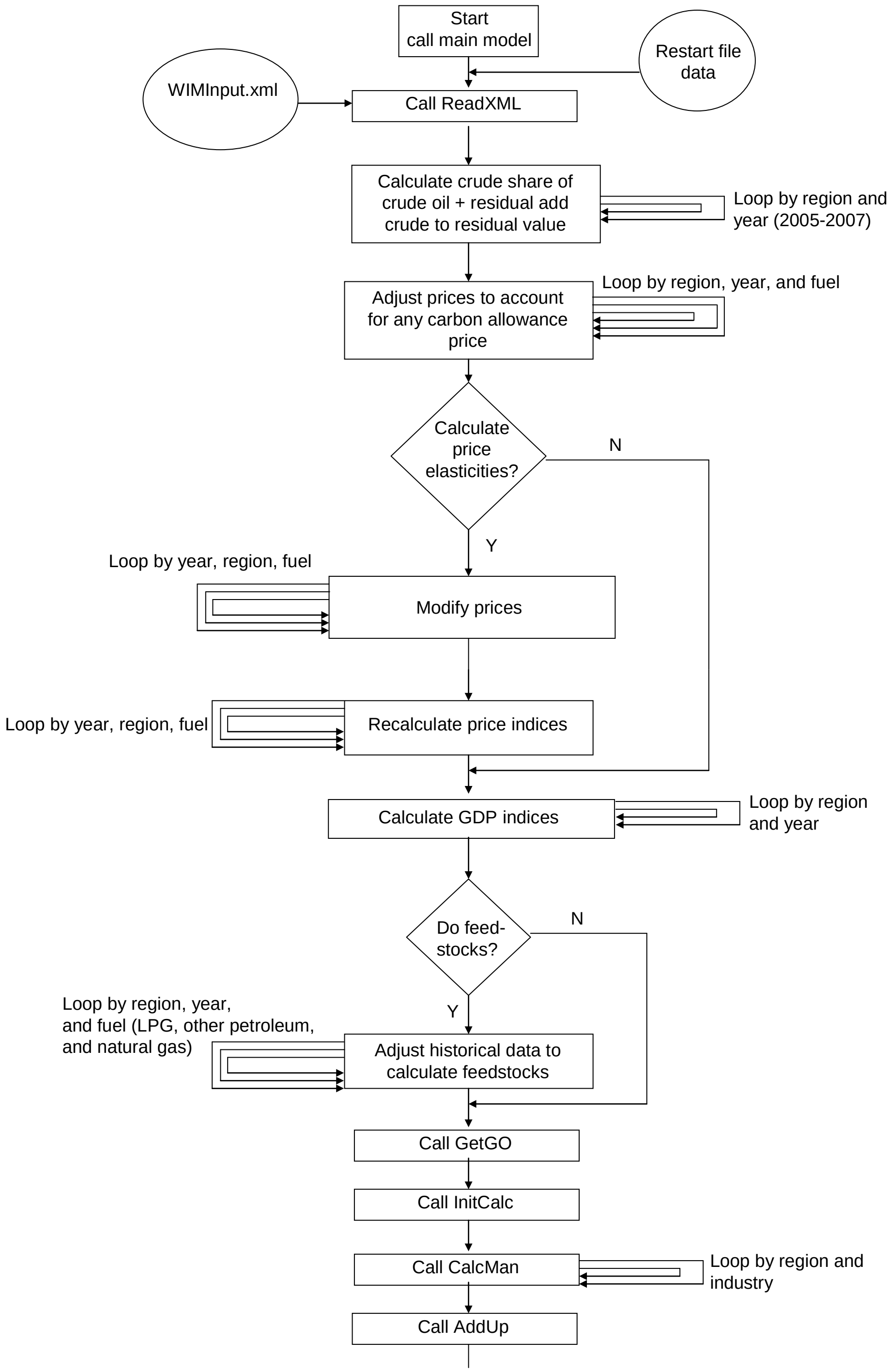


Figure 5. Flowchart for the Ind Subroutine



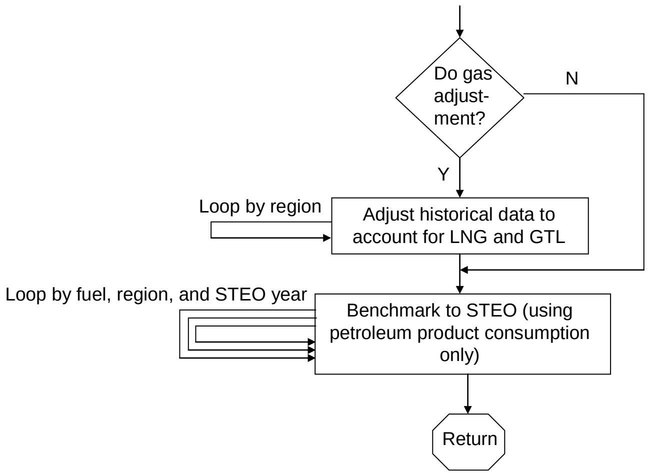

Do gas adjust-ment?
N
Y
Loop by region
Adjust historical data to account for LNG and GTL
Loop by fuel, region, and STEO year
Benchmark to STEO (using petroleum product consumption only)
Return

Figure 6. Flowchart for the ReadXML Subroutine

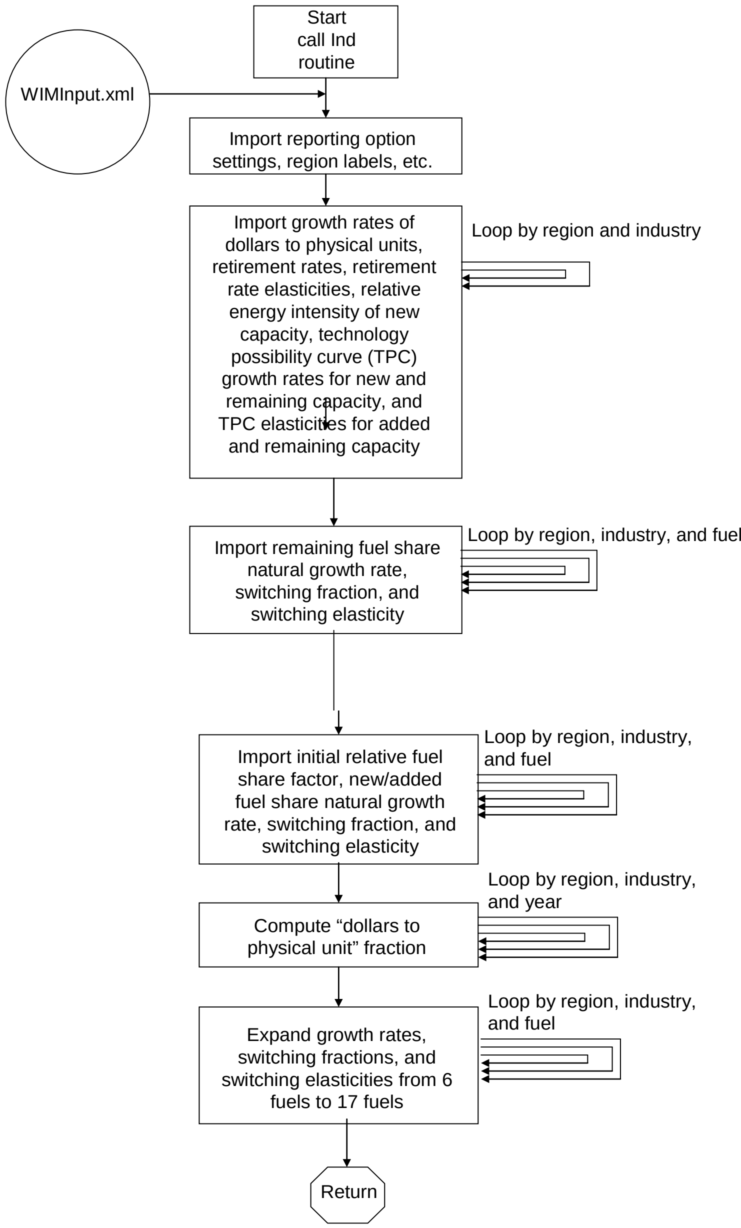


Figure 7. Flowchart for the GetGO Subroutine

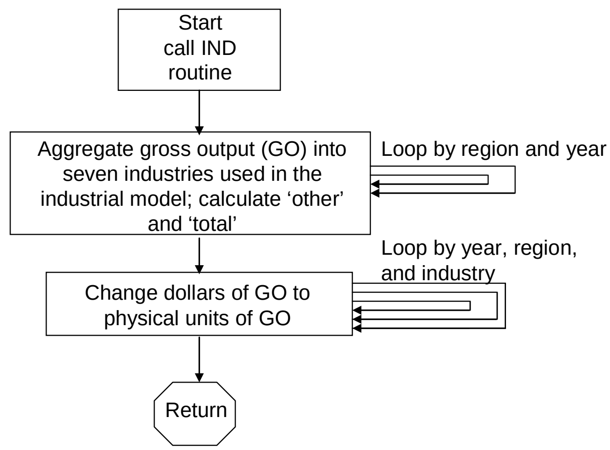
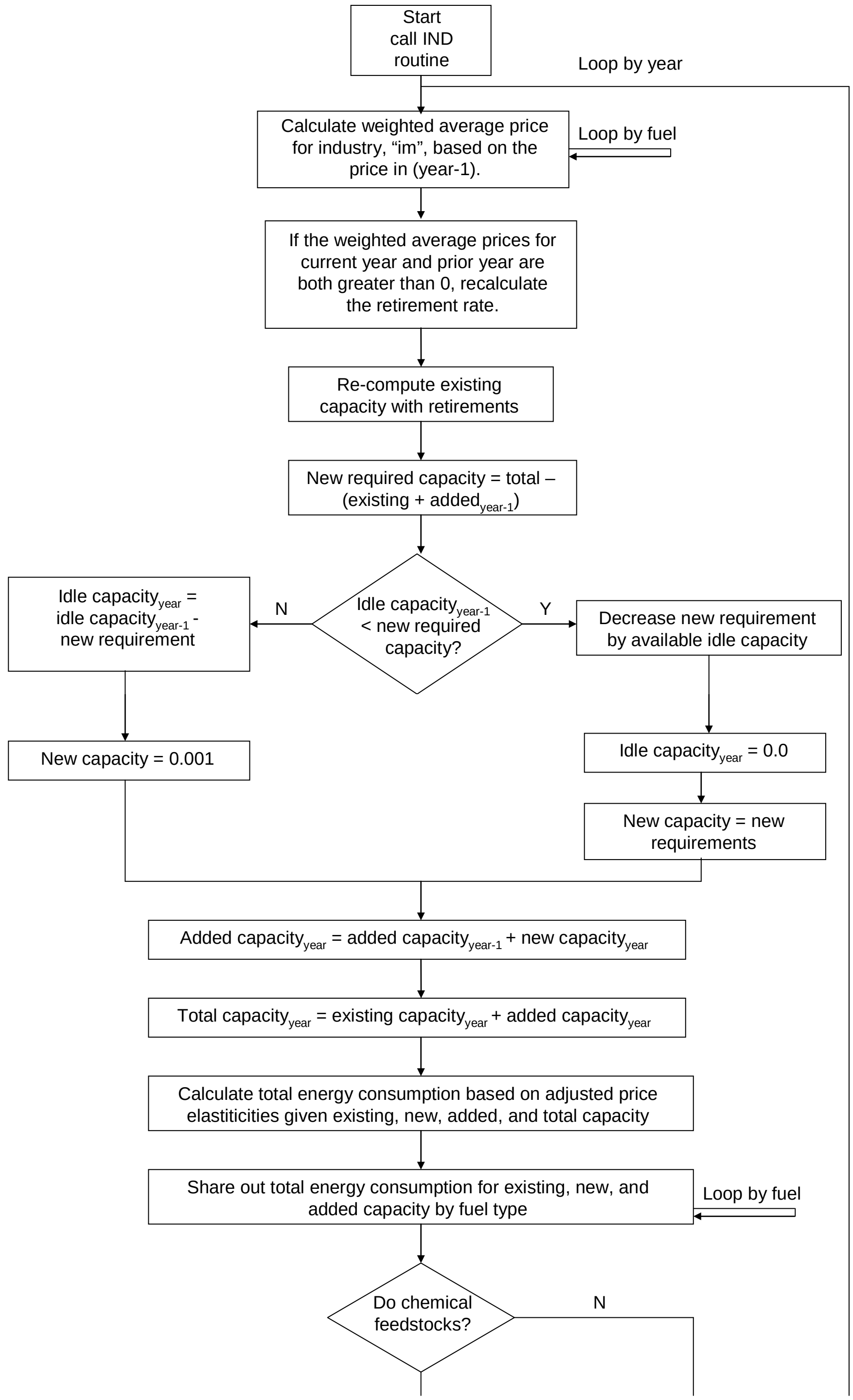
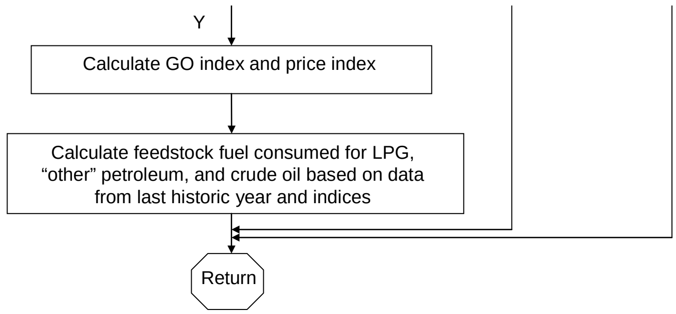


Figure 8. Flowchart for the CalcMan Subroutine





Key Computations

Gross Output

The baseline for the World Industrial Model projections consists of set of gross output projections in physical units (e.g., tons of steel) for specific industries through 2035 for each of the 16 regions from the restart file. These values are generated by the macroeconomic model for specific industries, some of which are aggregates of others. There are a total of 54 values for gross output along with one additional line item for the GDP. WIM further aggregates these totals to the eight industry categories that are used in the model:

- Food
- Paper
- Chemicals
- Refinery
- Iron and steel
- Non-ferrous metals
- Non-metallic minerals
- Other (other manufacturing along with agriculture, mining, and construction)

Vintaging of Gross Output as a Proxy for Capacity

WIM is a stock/flow model that keeps track of simple vintaging of the capacity for each industry and in each region. Since there is no direct measure of capacity or a measure of physical output, the model uses gross output as a proxy for capacity. WIM tracks four vintage categories:

Original Existing Capacity. In each year the model uses a retirement rate to determine how much of the original existing capacity is remaining (was not retired). It also forecasts changes in energy intensity (largely due to "housekeeping) and changes in the fuel mix.

Previously Added Capacity . For each year the model projects changes in energy intensity (largely due to "housekeeping) and changes in the fuel mix for the cumulative amount of previously added gross output.

New Capacity. For each year the model determines how much new capacity is added based upon what is available from the remaining original existing capacity plus the previously added capacity and what is required based on the growth in gross output for the industry. The model forecasts the energy intensity for this new capacity, which is generally much better than that for the overall stock.

Total Capacity. In each year, the total gross output is calculated based on the other three vintage categories.

To estimate change in output across the projection period the model adds new gross output, and subtracts output associated with existing capacity that is being retired. In WIM, gross output is exogenously specified. The "added gross output" is then computed as the sum of newly installed gross output and the amount of gross output added in the previous projection year. Finally, the existing/remaining gross output is added to the "added gross output" to calculate the projected "total gross output." The WIM does not have an exogenously supplied "new gross output" projection series. As a result, it is necessary to indirectly account for the new output for each projection year.

First, the model imports the estimated amount of total gross output, *TotGo(y)*, for each forecast year *y*. For each forecast year, the model adjusts the estimated existing/remaining gross output to account for retirement of capacity (again, gross output is as a proxy for capacity):

$$ExtGO(y) = ExtGO(y\text{-}1) * (1.0 - RetRate(y)),$$

where *ExtGO(y)* = existing gross output for year *y*, and

RetRate(y) = capacity retirement rate foryear *y*

The model then calculates the new gross output added in year *y* by subtracting the total gross output for year *y*-1 from the the total gross output for year *y*. The total gross output for year *y*-1 is estimated as the sum of the existing gross output for year *y* and the gross output added in year *y*-1: :

$$NewGO(y) = TotGO(y) - [\ ExtGO(y) + AddGO(y\text{-}1)\ ],$$

where *NewGO(y)* = new gross output for year *y*, and
AddGO(y-1) = gross output that was added in year *y*-1

Finally, the added gross output for the current projection year is calculated as the sum of the added gross output from the previous year plus the new gross output:

$$AddGO(y) = AddGO(y-1) + NewGO(y)$$

Retirement Rate Price Elasticity (Price Accelerator)

The model estimates a price elasticity for each industry in each region. The price elasticity uses the weighted average price for the specific industry in each region and reflects the extent to which the retirement rate changes in response to changes in overall price from year to year. The basic relationship is given by:

$$RetElas = \ln[\ RetRate(y) / RetRate(y-1)\ ] / \ln[\ IndPrice(y) / IndPrice(y-1)\ ]$$

Intensity and Consumption by Vintage

The industrial model projects the energy intensity (of consumption) for each stock/flow vintage of gross output for each industry and each region. Intensity is defined as the total amount of energy consumption for a specific industry in a specific region divided by the corresponding gross output. The intensity in each vintage category is the total consumption for that category divided by its gross output. The model estimates intensity in order to estimate consumption – it does not use consumption estimates to calculate intensity.

Initial Intensity for the Existing Vintage

The model begins with the total consumption and the initial total gross output for each industry and region in the most recent historical year for which data are available (currently 2007). It uses the historical consumption and output data to calculate the energy intensity in 2007 for each industry in each region. This is the starting point for the existing gross output that changes over the projection period.

$$ExtInt(x,2007,r) = ExtQty(x,2007,r) / ExtGO(x,2007,r)$$

where, for for industry x in year y and region r,

$ExtInt(x,y,r)$ = existing intensity of industrial demand;
$ExtQty(x,y,r)$ = existing quantity of energy consumed; and
$ExtGO(x,y,r)$ = existing gross output

Intensity and Consumption Forecast by Vintage

Over the course of the projection period, the model calculates the intensity for a new vintage by multiplying the previous measure of intensity by a Relative Energy Intensity (REI) coefficient. The REI coefficient, *REI(x)*, is exogenously-specified for each industry *x* and imported into the model for the initial projection year:

$$NewInt(x,2008,r) = ExtInt(x,2008,r) * REI(x)$$

where, for for industry *x* in year *y* and region *r*,

NewInt(x,y,r) = new measure of intensity, and
ExtInt(x,y,r) = the original measure of intensity

The energy intensity for the existing/remaining vintage changes over time as a result of upgrades, process changes, fuel substitution, and other reasons. For each industry and region, this process is represented by a coefficient that provides a growth rate trend factor, *ExtIntGR(x,r)*, that accounts for changes in the intensity over time for industry *x* in region *r*. Like the REI, the coefficients *ExtIntGR(x,r)* are exogenously-specified. The relationship for each industry *x* and in each region *r* in forecast year *y* is given by:

$$ExtInt(x,y,r) = ExtInt(x,y-1,r) * (1 + ExtIntGR(x,r))$$

Changing energy prices are one reason the vintage intensity may change over time. WIM models this process by a simple price elasticity. For each industry and region, a price elasticity of intensity relates a change in the intensity from the previous year to a change in the overall industry fuel price from the previous year. The trend factor (given above) is applied first and then a factor representing change in intensity is applied. The elasticity parameter is given by

$$ExtPElas = ln[ExtInt(x,y) / ExtInt(x,y)^*] / ln[IndPrice(x,y) / IndPricex,(y-1)],$$

where *ExtInt(x,y,r)* has already been adjusted to reflect trend growth. The projected consumption in the existing vintage for each industry *x* in each region *r* and year *y* is simply the previously calculated existing gross output times the existing intensity calculated above:

$$ExtQty(x,y,r) = ExtGO(x,y,r) * ExtInt(x,y,r)$$

The process described above is repeated for new capacity and added capacity. The intensity and consumption forecast for the overall total capacity are already determined through summing total energy use for added and existing capacity and dividing by total gross output:

$$TotQty(x,y,r) = ExtQty(x,y,r) + AddQty(x,y,r)$$

$$TotInt(x,y,r) = TotQty(x,y,r) / TotGO(x,y,r)$$

Consumption by Fuel and Vintage

The WIM first computes total energy consumption by industry and region for each of vintage category, as described above. Then it allocates the total consumption projections to the fuels used in the industrial sector. Although there are 17 fuel types represented in the WIM, the allocation algorithm is applied using six broad fuel categories. This is done to facilitate share specification. The share coefficients for these six fuel categories are later used for all of the subcategories. The six fuel categories are as follows:

- Petroleum (the sum of eight petroleum products)
- Natural Gas
- Coal
- Electricity
- District Heating
- Renewable (the sum of five renewable categories)

The ability to “switch” fuels is considered to be limited to amongst these 6 groups. The switching on one petroleum fuel for another (say diesel for gasoline) would in most cases not make sense given that a) they are priced nearly identically or b) it would be unlikely that one would put the investment effort into switching from a diesel, say, generator to one that runs on gasoline. The fuel sharing methodology is applied at the vintage category level, because, while the existing/remaining fuel shares are fairly fixed, the added fuel shares can differ as new capacity is installed.

Fuel Shares and Consumption for the Existing Vintage

The existing vintage fuel shares (*FuelShr*) are first set to their values in the initial projection year and then updated for subsequent years, based on trend patterns and the effects of price change. The trend factor (*FShrGR*) is implemented through user inputs (e.g., based on historical trends coupled with a realization of limited resources for some fuels) that provide a growth rate for each of the six fuels in each of the industries in each region. The growth rate is applied directly to the share for each fuel:

$$FuelShr(f,r,y,i) = FuelShr(f,r,y-1,i) * (1 + FShrGR(f,r,y,i)),$$

where x = fuel type, r = region, y = year, and i = industry.

As each individual share is updated, the sum of the shares may deviate from 1, making it necessary to renormalize the shares. The changes in shares may differ from the changes in actual consumption volume. For example, even though a fuel has a positive growth rate, its normalized share might decrease because other fuels have higher growth rates. Also, fuels with larger initial shares are rising from a larger base value, so minor changes in their shares may represent large consumption changes.

In addition to the trend, the fuel shares are affected by fuel substitution in response to changes in relative prices. In the input file, the user can designate a fraction, $FShrSw(f,r,y,i)$ of each fuel f, industry i and region r, that can be switched. That fraction of each fuel is then temporarily allocated to a separate switching group, each with a share of the total.

$$FuelSw(f,r,y,i) = FuelShr(f,r,y,i) * FShrSw(f,r,y,i)$$

In the input file, the user also designates a fuel share switching elasticity for each fuel that changes the share of the fuel based upon how the price of that fuel has changed from the previous year. The basic relationship is given by:

$$SwElas = \ln[FuelSw(f,r,y,i) / FuelSw(f,r,y-1,i)] / \ln[FuelPrc(f,r,y,i) / FuelPrc(f,r,y-1,i)]$$

Fuels which have lower prices in year y will be increased by this formula; those that have higher prices will suffer a decrease. Again, renormalization may be necessary as the fuel individual shares change. The switching group is then added back into the remaining part of the overall group and the overall shares and consumption for each fuel type are calculated by industry and region.

Initial Fuel Shares for the Added Vintage

As new capacity is installed for an industry, it is possible for fuel shares to vary because of changes in processes, product mix, and typical practices, among other things. The input file has initial “added fuel share factors” ($FShrFac(f,r,i)$), specified by industry i and region r. These factors are relative to existing fuel shares. Each added share is computed by multiplying the existing fuel share by a factor:

$$AddFuelShr(f,r,2008,i) = ExtFuelShr(f,r,2007,i) * FShrFac(f,r,i)$$

Again, shares may be renormalized to ensure consistency with the estimated totals.

Fuel Shares and Consumption for the Added Vintage

Like the fuel shares for existing capacity, the added fuel shares are initialized at the first projection year and then updated to account for trends and substitution due to changes in relative prices. The updates are computed by the same method described above for existing capacity, though the coefficients differ.

High World Oil Price Fuel Substitution

In the High Oil Price (HWOP) case, the level of petroleum consumption declines significantly. In the model formulation shown above, however, there are no cross-price elasticities so there is no fuel substitution. This was not considered a particular problem for the original Reference case because the model was “calibrated” through user judgment for each of the individual fuels. However, because high oil prices cause a lot of movement out of petroleum fuels, it was recognized that some of this change is a behavioral change in which less energy is consumed, but some change is a structural change where other fuels have been substituted for petroleum. A simple algorithm was built into the model to recognize this fuel substitution.

In the HWOP case, a portion of the decline in petroleum consumption from the level in the Reference case is replaced by an increase in other fuels. In order to determine how much petroleum consumption has declined from the Reference case, it is first necessary to read in some data that specify the level of petroleum consumption in the Reference case. These data are read in along with some other data that provide the fractional increment of the petroleum that will be replaced by other fuels. In the input file, the fractional increment is set to be 0.5 in all regions, meaning that 50 percent of the petroleum decrease in the HWOP case will be replaced by an increase in other fuels. The model achieves the substitution over the years 2010 to 2030, and modifies the fractional increment so that it starts at 0 in 2010 and ramps up to its full value in 2020, then remains the same to 2030, after which the model solves as it does in the Reference case.

Once the model determines how much petroleum requires a substitution, it allocates the amounts into natural gas, coal, and electricity based upon the current relative shares of each of these fuels. For example, if 100 trillion Btu requires a substitution, and the respective shares of natural gas, coal, and electricity are 0.4, 0.0, and 0.6, then natural gas will increase by 40 trillion Btu, coal will be unchanged, and electricity will increase by 60 trillion Btu.

STEO Calibration

The Energy Information Administration's *Short-Term Energy Outlook* (*STEO*) projects worldwide liquid fuels consumption to 2011. The regions in the *STEO* are somewhat more aggregate than in the WEPS+, and the consumption projections are for total petroleum with no sectoral or product differentiation. Nonetheless, the *IEO2010* projection must replicate these values in the *STEO* projection years. Outside of the World Industrial Model but within the WEPS+, the Main Model reads the *STEO* data in each iteration. Based upon the results from the current iteration, the Main Model shares the total petroleum consumption to some sub-regions and to all the detail in the end use sectors. The exception to this step is the electric power sector, where liquids-fired generation is not included. The reason for this exception is that electricity generation is a small liquids-consuming sector, and it is much more complicated in terms of its transformation of energy. Instead, the amount of liquids consumed in the electricity generation sector is subtracted from the total *STEO* liquids consumption. After that, the remaining amount of liquids consumption is allocated to the remaining sectors, based upon the remaining share of liquids consumption. These quantities are then exported to the restart file so that they are available to each of the WEPS+ models for calibration to *STEO*. It is worth noting that these sector shares are performed in the Main Model for each WEPS+ iteration so that the actual amounts adapt to the changing shares of sector consumption as the model moves towards the equilibrium solution.

The World Industrial Model reads the *STEO* petroleum allocations for the industrial sector from the restart file, and then determines calibration factors for each petroleum product in each region for each of the years from 2008 through 2011. These factors are simply the ratio of the *STEO* residential consumption allocation to the model's projection consumption in those years:
For each year 2008 through 2011:

$$STEOFac(r, y) = \frac{STEOQty(r, y)}{IQty(f = petroleum, r, y)}$$

Where: *STEOQty* is the *STEO* industrial consumption allocation
IQty(f=petroleum) is the model's total industrial sector petroleum consumption
STEOFac is the *STEO* calibration factor

$$QDSIN(r,y) = QDSIN'(r,y) * STEOFac(r,y)$$
$$QRSIN(r,y) = QRSIN'(r,y) * STEOFac(r,y)$$
$$QCDIN(r,y) = QCDIN'(r,y) * STEOFac(r,y)$$

Where: *QDSDH* is the industrial distillate consumption
QRSDH is the industrial residual consumption
QCDDH is the industrial crude (directly used) consumption

Because the amount of adjustment in 2011 can be significant, it is not appropriate to go directly back to the model consumption level in 2012 (there could be a disconnect). Instead, the 2011 *STEO* calibration factor is carried out over the next 10 years, gradually ramping back to 1.0 during that time. Therefore the transition from 2011 to 2021 is fairly smooth.

Appendix A. Model Abstract

Model Name:

World Industrial Model of the World Energy Projection System Plus

Model Acronym:

WIM

Model Description:

The World Industrial Model of the World Energy Projection System Plus (WEPS+) is a computer-based energy demand modeling system of the world industrial sector at a regional level. The WEPS+ World Industrial Model for the *IEO2010* projects energy use that is consumed in the manufacturing, agricultural, construction, and mining sectors. The model projects industrial sector consumption for 18 energy sources in each of the 16 WEPS+ regions on an annual basis to 2035.

Model Purpose:

As a component of the World Energy Projection System Plus (WEPS+) integrated modeling system, WIM generates long-term projections of industrial sector energy consumption. As part of the system, the model provides consumption inputs for a variety of the other WEPS+ models. The model provides a tool for analysis of international industrial energy use within the WEPS+ system and can be run independently as a standalone model.

Most Recent Model Update:

December 2009.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

WIM receives inputs from and provides outputs to a variety of other models in the WEPS+ system, through the common, shared interface file of the WEPS+.

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Documentation:

Energy Information Administration, U.S. Department of Energy, *World Industrial Model of the World Energy Projection System Plus: Model Documentation 2010*, DOE/EIA-M079(2010) (Washington, DC, December 2010).

Archive Information:

The model is archived as part of the World Energy Projection System Plus archive of the runs used to generate the *International Energy Outlook 2010*.

Energy System Described:

International industrial sector energy consumption.

Coverage:

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

Mode: total industrial sector energy consumption.

Time Unit/Frequency: Annual, 2008 through 2035.

Modeling Features:

The World Industrial Model projects energy use in the manufacturing, agricultural, construction and mining sectors for 18 energy sources in each of the sixteen WEPS+ regions on an annual basis to 2035. The model primarily employs a stock-flow accounting framework that uses exogenously-specified output of specific industries as a proxy for productive capacity. In WIM, old capacity is retired over time to make way for new capacity. This framework allows for the modeling of changes in energy efficiency over time. Exogenously-specified energy prices impact both the mechanisms of the stock-flow process and fuel switching over time.

DOE Input Sources:

Energy Information Administration, International Energy Statistics Database, web site www.eia.doe.gov/emeu/international (as of November 30, 2009).
Energy Information Administration, *Short Term Energy Outlook* (STEO), Washington, D.C., (January 2010 release).

Non-DOE Input Sources:

International Energy Agency (IEA), *Energy Balances of OECD Countries*, Paris, 2009.
International Energy Agency (IEA), *Energy Balances of Non-OECD Countries*, Paris, 2009.
IHS Global Insight, *World Overview, Third Quarter 2*009 (Lexington, MA, November 2009).
IHS Global Insight, *World Industry Service Forecast Tables: Sector Gross Sales by Regions and Countries* (Lexington, MA, Revised August 24, 2009).

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows XP (or other Windows OS).
Language/Software Used: Fortran 90/95 (Currently using Compaq Visual Fortran), not required at runtime.
Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 20MB storage.
Special Features: None.

Appendix B. Input Data and Variable Descriptions

The table below details the variables in WIM.

Variables	
ACLIN	carbon price increment to coal
ADSIN	carbon price increment to distillate
AELIN	carbon price increment to electricity
AFmInt	added since initial year intensity at fuel max detail level
AFmQty	added since initial year consumption at fuel max detail level.
AFQtyA	added fuel that is not switched
AFQtyB	added fuel that is switched
AFrInt	added since initial year intensity at fuel report detail level.
AFrQty	added since initial year consumption at fuel report detail level.
AFShr	added fuel share
AFSwitch	part of added fuel that can be switched
AFTotA	added fuel total a (fuel consumption that cannot be switched)
AFTotB	added fuel total b (fuel consumption that can be switched)
AGrOut	added since initial year real gross output
AHTIN	carbon price increment to heat
AKSIN	carbon price increment to kerosene
ALGIN	carbon price increment to LPG
AMGIN	carbon price increment to motor gasoline
ANGIN	carbon price increment to natural gas
AOPIN	carbon price increment to other petroleum
ARSIN	carbon price increment to residual
BenQty	benchmark quantity
Bfac	benchmark factor
Binc	benchmark increment
Bval	benchmark value
CalibDet	calibration detail
Ccoal	industrial coking coal consumption
CCRat	ratio of industrial coking coal consumption to total industrial use of coal
CrudeShr	share of petroleum used in each region that is crude oil
CurItr	current iteration
DFLabA	short labels for fuels for demand values
DFLabB	long labels for fuels for demand values
DFMap	maps each of the demands to fuel type
DoFeed	do feedstock calculation by fuel for chemicals industry
DoGO	domestic gross output
DoNGas	do natural gas
DoPElas	do price elasticity
DoPrice	domestic price
DoSTEO	do short term energy outlook
DSLabA	short labels for sectors for demand value
DSLabB	long labels for sectors for demand values
DSMap	maps each of the demands to sector
DtoPFrac	dollar to physical unit fraction
DtoPGR	dollar to physical unit growth rate

EffIdx	trend index
EFmInt	existing/remaining from initial year intensity at fuel max detail level.
EFmQty	existing/remaining from initial year consumption at fuel max detail level.
EFQtyA	existing fuel quantity A (fuel consumption that cannot be switched)
EFQtyB	existing fuel quantity B (fuel consumption that can be switched)
EFrInt	existing/remaining from initial year intensity at fuel report detail level.
EFrQty	existing/remaining from initial year consumption at fuel report detail level
EFShr	existing fuel share
EFSwitch	existing fuels that can be switched
EFTotA	existing fuel total A
EFTotB	existing fuel total B
EGrOut	existing/remaining from initial year real gross output
EGrOutA	copy of existing/remaining from initial year real gross output in case some of the “other” is idled.
f	fuel
FBMap	fuel type mapping function
FFmFeed	Projected consumption of feedstock in chemical sector at maximum fuel detail level
FLLab	stores labels for fuel types
FMYr	first model forecast year
FSLab	stores labels for fuel types
Fwrite	file write
GDP_PPP	GDP purchasing power parity
GDPElas	GDP elasticity
GDPI	GDP index
GDPLag	GDP lag
GOIdx	gross output index
GrRate	GDP growth rate
HFmFeed	historical feedstock consumption in chemicals at max fuel detail level
HFmQty	historical consumption at fuel max detail
HFrFeed	historical consumption in chemicals at reporting fuel detail level
HFrQty	historical consumption at fuel reporting detail
HQCoke	historical coking coal consumption in iron and steel
Hqty	historical quantity
HQtyOrg	historical quantity original
HSysQty	historical system quantity
IGrOut	idled capacity/gross output
ILLab	stores labels for industries
im	industry
IndGO	total gross output that is input into the model
InMacGO	dollars of output
InName	industry name
IPIdx	industrial price index
IQIdx	industrial quantity index
IQty	industrial quantity
ISLab	stores labels for industries
KeyList	search function
KeyList2	search function
LGFDRat	ratio of LPG feedstock consumption to total industrial consumption of LPG
LGFeed	industrial LPG feedstock consumption
LHYr	last historical year

LMYr	last model forecast year
Ncol	number of columns
NewPrc	new price
NewQty	new quantity
NewReq	new capacity required
NFmInt	new this year intensity at fuel max detail level.
NFmQty	new this year consumption at fuel max detail level.
NFrInt	new this year intensity at fuel report detail level.
NFrQty	new this year consumption at fuel report detail level.
NFsFac	new fuel share factor
NFsNGr	new fuel base growth rate
NFsSE1	new fuel switching elasticity
NFsSFr	new fuel share switching fraction
NGFDRat	ratio of natural gas feedstock to total industrial consumption of natural gas
NGFeed	industrial natural gas feedstock consumption
NGrOut	new this year real gross output
Nrow	number of rows
OPFDRat	ratio of other petroleum feedstock to total industrial use of sequestered petroleum
OPFeed	industrial other petroleum feedstock consumption
PCLIN	price of coal over forecast period
PDSIN	price of distillate fuel over forecast period
PEAFac	price elasticity adding factor
PELIN	price of electricity over forecast period
PERFac	price elasticity removal factor
PetHWOP	petroleum high world oil price
PFMap	maps each of the prices to fuel type
pFYr	potential forecast year
PHTIN	price of heat over forecast period
pHYr	history year
PKSIN	price of kerosene over forecast period
PLGIN	price of LPG over forecast period
PMGIN	price of gasoline over forecast period
PNGIN	price of natural gas over forecast period
POPIN	price of other petroleum over forecast period
PrcElas	price elasticity
PrcIdx	price index
PrcInd	price industrial
PrcLag	price lag
Preg	region
PRSIN	price of residual over forecast period
PSMap	maps each of the prices to sector
QCLCCIN	industrial coking coal consumption
QCLIN	quantity of coal consumed for industrial purposes
QHBMIN	quantity of industrial use of biomass
QHCDIN	quantity of industrial use of crude oil
QHCLIN	quantity of industrial use of coal including coking coal
QHDSIN	quantity of industrial use of distillate
QHELIN	quantity of industrial use of electricity
QHGTIN	quantity of industrial use of geothermal

QHHTIN	quantity of industrial use of heat
QHKSIN	quantity of industrial use of kerosene
QHLGIN	quantity of industrial use of LPG including feedstocks
QHMGIN	quantity of industrial use of motor gasoline
QHNGIN	quantity of industrial use of natural gas including feedstocks
QHOPIN	quantity of industrial use of other petroleum including feedstocks
QHORIN	quantity of industrial use of other renewables
QHPCIN	quantity of industrial use of petroleum coke
QHRSIN	quantity of industrial use of residual
QHSLIN	quantity of industrial use of solar
QHSPIN	quantity of industrial use of sequestered petroleum
QHWSIN	quantity of industrial use of waste
QLGFDIN	industrial LPG feedstock consumption
QLGIN	quantity of LPG consumed for industrial purposes
QNGFDIN	industrial natural gas feedstock consumption
QNGGLIN	industrial natural gas GTL fuel consumption
QNGIN	quantity of natural gas consumed for industrial purposes
QNGLGIN	industrial gas LNG fuel consumption
QOPFDIN	industrial other petroleum feedstock consumption
QOPIN	quantity of "other" petroleum consumed for industrial purposes
r	region
REINew	relative energy intensity for new capital
RetElas	retirement elasticity
RetRate	retirement rate
RFsNGr	remaining fuel share net growth
RFsSEl	removed fuel share switching elasticity
RFsSFr	removed fuel share switching fraction
RLabA	provides short names for each region
RLLab	stores labels for regions
rm	region
Sadj	steo adjuster
SCLab	labels for seven supply chain categories
SFLabA	short labels for "supply chain" energy sources in supply array
SFLabH	short labels for heat consumption
SFLabU	short labels for electricity consumption
Srat	steo ratio
Star	steo targets
SwIR	switch for industrial region
TFmInt	Total intensity at fuel max detail level.
TFmQty	Total consumption at fuel max detail level.
TFrInt	Total intensity at fuel report detail level.
TFrQty	Total consumption at fuel report detail level.
TGrOut	total real gross output
TmpGO	temporary gross output
TmpTot	temporary total
TPCAddElas	technology possibility curve adding elasticity
TPCNewGR	technology possibility curve new growth rate
TPCRemElas	technology possibility curve removal elasticity
TPCRemGR	technology possibility curve removal growth rate

Tqty	total quantity
Trend	trend
TrendGr	trend growth rate
WAPrc	weighted average price
WOPCase	world oil price case
XPrc	industrial price
y	year
ZBMIN	quantity of biomass consumption over forecast period
ZCDIN	quantity of industrial consumption of crude oil over forecast period
ZCLCCIN	industrial coking coal consumption
ZCLIN	quantity of coal consumed for industrial purposes over forecast period
ZDSIN	quantity of industrial consumption of distillate over forecast period
ZELIN	quantity of electricity consumption over forecast period
ZGTIN	quantity of geothermal consumption over forecast period
ZHTIN	quantity of heat consumption over forecast period
ZKSIN	quantity of industrial consumption of kerosene over forecast period
ZLGFDIN	industrial coal gasification
ZLGIN	quantity of industrial consumption of LPG over forecast period
ZMGIN	quantity of industrial consumption of motor gasoline over forecast period
ZNGFDIN	industrial natural gas feedstock consumption
ZNGIN	quantity of industial consumption of natural gas over forecast period
ZNGLPIN	industrial natural gas lease and plant consumption
ZOPFDIN	industrial other petroleum feedstock consumption
ZOPIN	quantity of industrial consumption of other petroleum over forecast period
ZORIN	quantity of industrial consumption of other renewables over forecast period
ZPCIN	quantity of industrial consumption of petroleum coke over forecast period
ZRSIN	quantity of industrial consumption of residual over forecast period
ZSLIN	quantity of industrial consumption of solar over forecast period
ZSPIN	quanity of industrial consumption of sequestered petroleum over forecast period
ZWSIN	quantity of waste consumption over forecast period

Appendix C. References

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2. Energy Information Administration, *Model Documentation Report: Industrial Sector Demand Model of the National Energy Modeling System*, (Washington, DC, May 2010)

3. International Energy Agency, *Energy Statistics and Balances of OECD Countries,* web site www.iea.org (subscription site).

4. International Energy Agency, *Energy Statistics and Balances of Non-OECD Countries*, web site www.iea.org (subscription site).

5. International Energy Agency, *Energy Prices and Taxes* (Paris, France, quarterly: various issues).

6. International Energy Agency, *Energy Technology Perspectives: Strategies and Scenarios to 2050*, (Paris, France 2008).

7. International Energy Agency, *World Energy Outlook 2009 Edition* (Paris, France, November 2009).

8. IHS Global Insight, *World Industry Service Forecast Tables: Sector Gross Sales by Regions and Countries* (Lexington, MA, Revised August 24, 2009).

Appendix D. Data Quality

Introduction

For 16 regions of the world, WIM projects world industrial use of fuels (including motor gasoline, distillate fuel, residual fuel, kerosene, liquefied petroleum gas including feedstocks, petroleum coke, sequestered petroleum, other petroleum use including feedstocks, direct use crude oil, natural gas including feedstocks, coal including coking coal, electricity, heat, waste, biomass, geothermal, solar, and other renewables). The WIM projections are computed from the data elements listed in Appendix B. Chapter 4 (Model Structure) details the WIM estimation methods and the inputs required to implement the model algorithms. Here the principal sources of input data are described and information is provided, where available, about the quality of the imported parameter estimates.

Source and Quality of Input Data

Source of Input Data

- *STEO* – Short-term liquid fuel consumption from 2005 to 2011 are provided by region from EIA's *Short-Term Energy Outlook.* The *IEO2010* results are benchmarked to the STEO results from the January 2010 edition of the report.

- *International Statistics Database* – The Energy Information Administration provides historical data on international energy consumption by fuel type from 1980 through 2008. These data are used as the historical basis for all regional projections that appear in the *IEO2010*. While the numbers are continuously updated, WEPS+ used a "snap shot" of the database as it existed on November 30, 2009 as the source of its international data.

- *International Energy Agency* – The by-end-use-sector, by-product historical data are available from the OECD and non-OECD balances and statistics database by country on the subscription site www.iea.org. These data are benchmarked to the historical aggregate energy consumption data provided in the Energy Information Administration's international statistical data base.

- *NEMS* – Many of the assumptions about price and economic elasticities are based in large part on those included in the National Energy Modeling System for the United States. Expert judgment has, in some cases, been used to alter assumptions based on analyst knowledge about specific regions in the WEPS+ model.

Data Quality Verification

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

- Checks of projected values for world and U.S. industrial consumption of fuels, retail prices, and elasticities, based on historical data, previous projections, responses, knowledge of regional economics, and technical knowledge

- Consistency checks
- Technical edits to detect extreme values or variability and correct errors