

Refinery Model of the World Energy Projection System Plus: Model Documentation

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1. Introduction

Purpose of This Report

This report documents the objectives, analytical approach, and development of the World Energy Projection System Plus (WEPS+) Refinery Model. It catalogues and describes the model assumptions; computational methodology; parameter estimation techniques; and model source code that are utilized to generate projections in the reference and side cases, as well as other scenarios.

The document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, it meets the legal requirement of the U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 93-275, section 57.b.1*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements as future projects.

Model Summary

The WEPS+ Refinery Model is a calculation tool. It uses the projected light, low sulfur crude oil price (a proxy for West Texas Intermediate—WTI—crude) and other input information to model global refined product markets. The WEPS+ Refinery Model computes wholesale and retail refined product pricing in key global refining centers and the 16 *International Energy Outlook 2010 (IEO2010)* regions.

Model Archival Citation

This documentation refers to the WEPS+ Refinery Model.

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Organization of This Report

Chapter 2 of this report, “Model Purpose,” identifies the analytical issues the WEPS+ Refinery Model, and addresses the general types of activities and relationships it embodies, its primary inputs and outputs, and its interactions with other WEPS+ modules. Chapter 3 describes in greater detail the rationale behind the model design, the modeling approach chosen for the Refinery Model, and the assumptions used in the model development process, citing theoretical or empirical evidence to support those choices. Chapter 4 details the model structure, using graphics and text to illustrate model flows and key computations.

The Appendices to this report provide supporting documentation for the input data and parameter files. Appendix A lists and defines the input data used to generate parameter estimates and endogenous projections, along with the outputs of most relevance to the WEPS+ system. Appendix B contains a mathematical description of the computational algorithms, including the complete set of model equations and variable transformations. Appendix C is a bibliography of reference materials used in the development process. Appendix D provides the model abstract and Appendix E discusses data quality and estimation methods.

2. Model Purpose

Model Objectives

Understanding the interactive effects of changes in U.S. and world energy markets has always been a key EIA focus. The Refinery Model was incorporated into WEPS+ in order to enhance the capabilities of WEPS+ to address the interaction of the global and U.S. oil markets. The main objective of the Refinery Model is to further enhance the EIA's long term pricing capabilities. The model is divided into two parts. Part 1 is a simple aggregation of liquids demands from the WEPS+ demand and transformation models. Part 2 is used to calculate refined product prices based on world crude oil prices provided by the Petroleum Model.

Components of the WEPS+ Refinery Model accomplish the following:

- Refinery Model 1: Calculation of world crude demand delivered to refineries in order to meet the aggregated product demand in the transportation, industrial, residential, commercial, electric power, and district heat sectors. The computed world crude demands are used by the Petroleum Model.
- Refinery Model 2: Calculation of reasonable, long-term equilibrium-type refined product pricing for the three primary global refining centers: the U.S. Gulf Coast (USGC), Northwest Europe (N.W.E.), and Singapore.
 - The Refinery Model utilizes the projected WTI price at Cushing, Oklahoma as the basis for marker crude oil prices in the USGC, Brent projected crude prices in N.W.E., and Dubai projected crude prices in Singapore.
 - The model also uses projected light to heavy product differentials and the expected marginal refining configuration in each of the three refining centers as bases for the respective refined product pricing calculations.
 - Refined product pricing guidelines for the three global refining centers have also been established to ensure that relative product pricing among the three centers is in agreement with projected global trade patterns.
- Refinery Model 2: Calculation of refined product pricing for the 16 *IEO2010* regions.
 - The Refinery Model uses a set of established global pricing guidelines to relate pricing in the three global refining centers to pricing in the *IEO2010* regions.
 - The global pricing guidelines are based on the projected transportation linkages between the three global refining centers and each of the 16 regions.
 - The transportation costs used for these linkages are reasonable representations of the relative shipping costs between the refining centers and the regions.

Model Inputs and Outputs

Because Refinery Model 1 performs a simple aggregation of output data from other WEPS+ components, it is not explicitly documented. The remainder of this documentation focuses on the computations performed in Refinery Model 2 and will refer to it as the “Refinery Model.”

Inputs

The primary inputs to the WEPS+ Refinery Model are as follows:

- For the calculation of refined product pricing for the three global refining centers, inputs include the projected WTI price; the corresponding marker crude price in the three centers; the marker crude product yields in the marginal refining configuration for the three centers; the heavy fuel oil to crude oil discount, which sets the light to heavy refined product differential environment; expected variable and fixed refining operating costs; a capital recovery cost factor; light product pricing deltas to a primary light product; and the liquefied-petroleum-gas (LPG)-to-crude-oil discount.
- For the calculation of wholesale refined product pricing in the 16 *IEO2010* regions, inputs include the transportation cost differentials from the three global refining centers to the 16 regions.
- For the calculation of the retail refined product pricing in the 16 *IEO2010* regions, inputs include the multipliers that are used to compute retail product prices by sector based on the wholesale product prices.

The major inputs are summarized in Table 1. Additional detail on model inputs is provided in Appendix A.

Table 1. Refinery Model Inputs

Model Inputs	Source
To Determine Long Term, Equilibrium Pricing in the Three Global Refining Centers	
Expected WTI Marker Crude price	Exogenous values from WEPS+
Expected Corresponding Marker Crude prices in the three Global Refining Centers	Determined via adjustment constants derived from linear regressions.
Marker Crude yields in the appropriate Marginal Refining Configuration	Constants provided to the Refinery Model Source: Refinery2.xml
Expected Heavy Fuel Oil to Marker Crude discount for the three Global Refining Centers	Constants provided to the Refinery Model Source: Refinery2.xml
Expected LPG to Marker Crude discount for the three Global Refining Centers	Constants provided to the Refinery Model Source: Refinery2.xml
Expected Variable and Fixed Operating Costs and Capital Recovery Factor for the three Global Refining Centers	Constants provided to the Refinery Model Source: Refinery2.xml
Light Product Pricing Delta to the Primary Light Product	Constant provided to the Refinery Model Source: Refinery2.xml
Heat content for Refined Petroleum Products	Constants provided to the Refinery Model Source: Refinery2.xml
Multipliers, by region and sector, used to compute retail prices for Refined Petroleum Products	Constants provided to the Refinery Model Source: Refinery2.xml
To Determine Long Term, Equilibrium Pricing in the 16 IEO Regions	
Transportation Cost Differentials from three Global Refining Centers to the 16 IEO Regions and between Regions	Constants provided to the Refinery Model Source: Refinery2.xml

Outputs

The primary outputs of the WEPS+ Refinery Model are projected long-term, equilibrium-type refined product pricing for the three global refining centers and the 16 *IEO2010* regions. Table 2 summarizes these outputs.

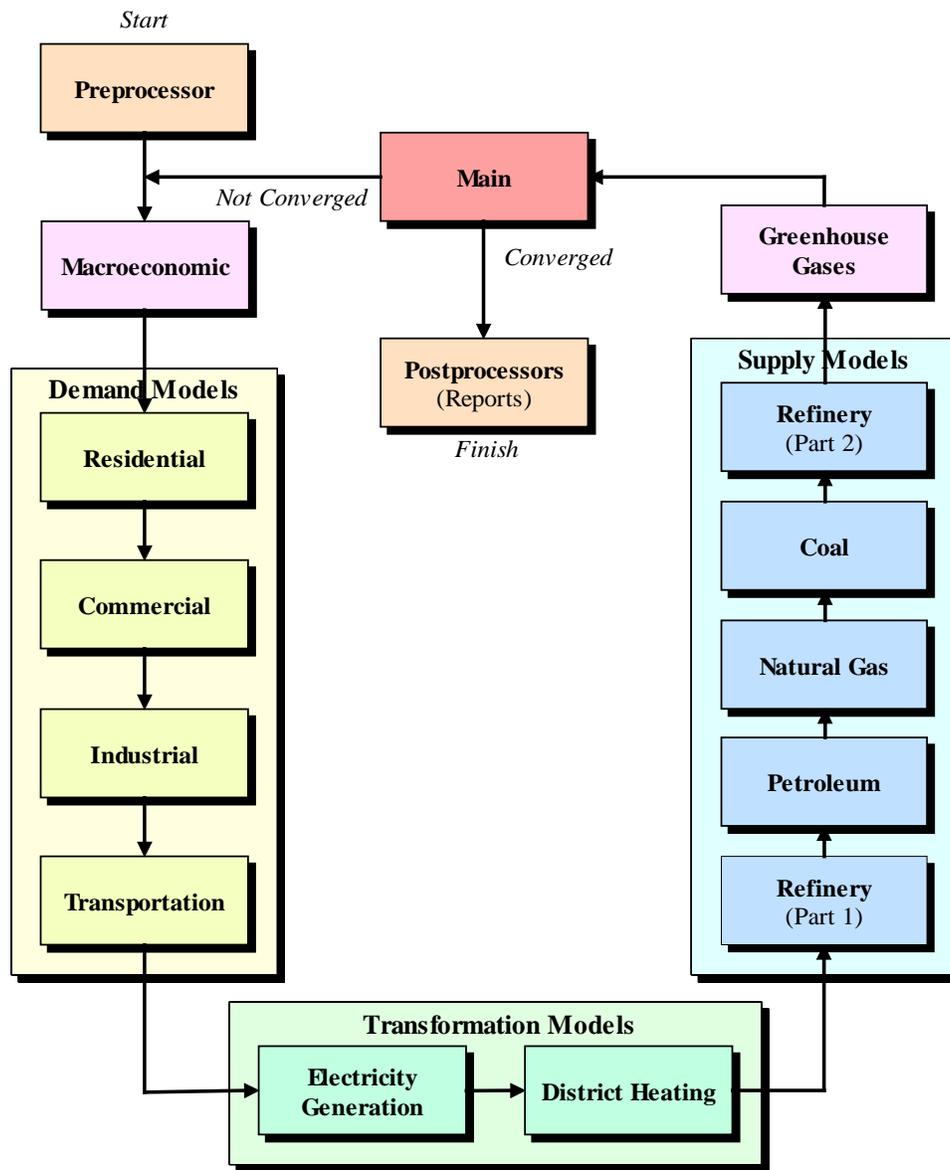
Table 2. WEPS+ Model Outputs

Model Outputs	Destination
Computed Wholesale Refined Product Prices for three Global Refining Centers	Reporting
Computed Wholesale Refined Product Prices for the 16 WEPS+ Regions	Reporting
Computed Retail Refined Product Prices for the 16 WEPS+ Regions	Demand, transformation, and supply models

Relationship of the Refinery Model to the other WEPS+ Models

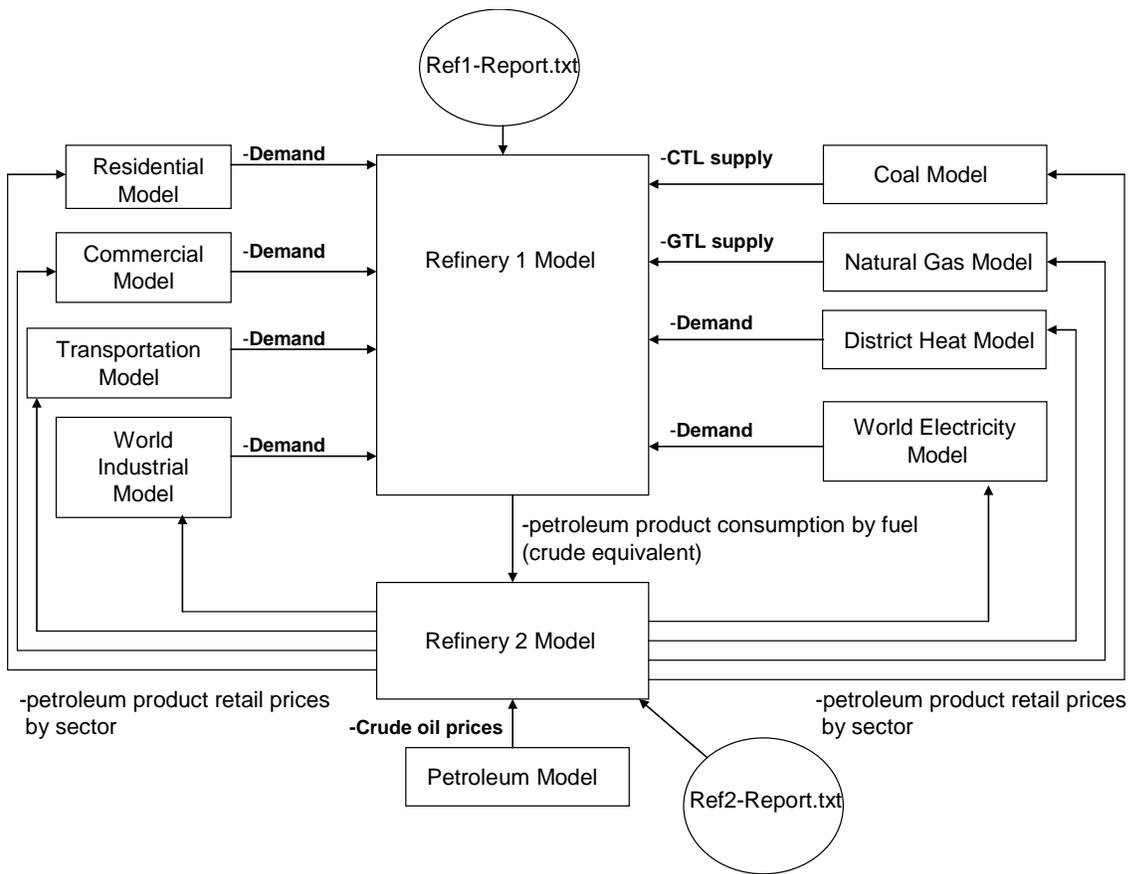
The Refinery Model uses information from other WEPS+ components (Figure 1). It also provides information to and receives information from other WEPS+ components. The information it uses is primarily the projected WTI crude price. The information it provides includes refined product pricing for the three global refining centers and the 16 *IEO2010* regions. The Refinery Model focus is on the international oil and refined products markets.

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



Through the system, the Refinery Model receives liquids consumption of fuel by end use, coal-to-liquids production, gas-to-liquids production, and crude oil prices from the demand, transformation, and supply models of WEPS+ (Figure 2). In turn, the Refinery Model provides retail petroleum product liquids prices, through the system, back to the demand, transformation, and supply models.

Figure 2. Relationship Between the Refinery Model and Other WEPS+ Models



3. Model Rationale

Theoretical Approach

The WEPS+ Refinery Model is a calculation tool. It uses projected WTI crude oil prices and other input information to model global refined product markets. The Refinery Model computes long-term, equilibrium refined product pricing in key global refining centers and the 16 *IEO2010* regions. The underlying logic and approach used in the Refinery Model acts to yield internally consistent price sets for both crude oil and refined products.

Fundamental Assumptions

The WEPS+ Refinery Model utilizes the concept of light product price setting for a given refining center based on three fundamental pricing drivers:

- Marker Crude Oil Price
- Refining Marginal, or Price Setting, Configuration
- Light-to-Heavy Refined Product Price Differential

This light product price setting concept is widely used in the global refining and marketing industry by operating companies, industry consultants and other market participants.

For the marker crude oil price, the model uses the following crude oil prices for the three primary global refining centers:

- WTI - United States Gulf Coast (USGC)
- Brent - Northwest Europe (N.W.E.)
- Dubai - Singapore

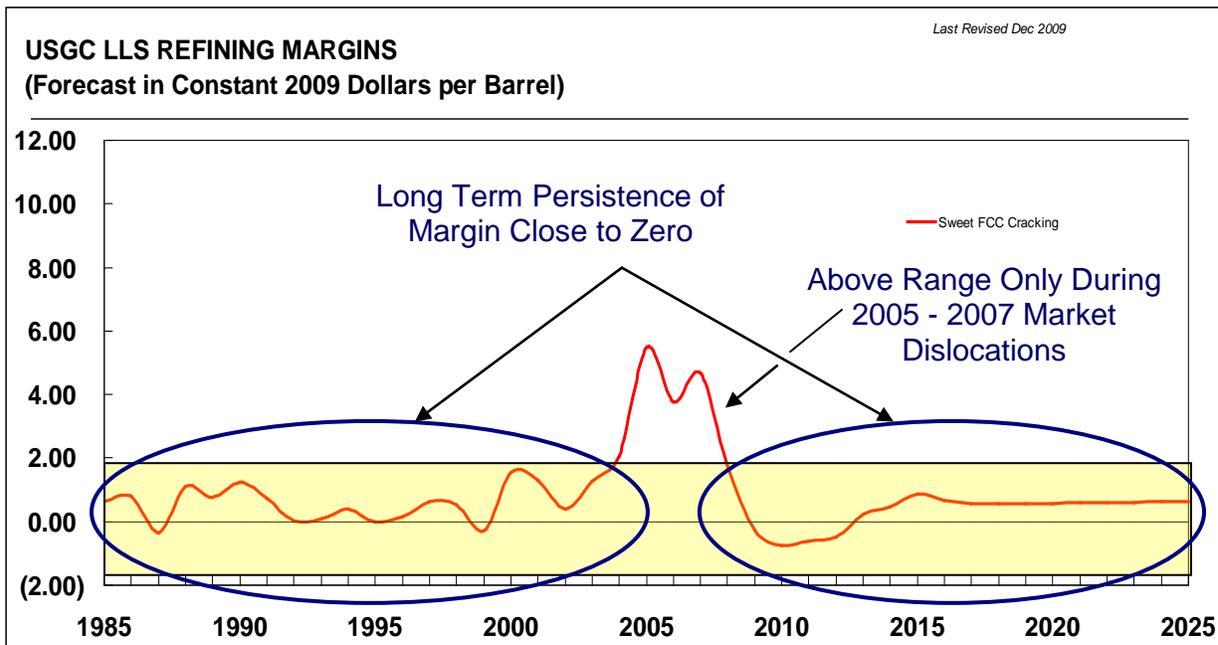
The model imports the WTI price and then estimates the Brent and Dubai marker crude oil prices by adjusting the WTI price to account for that reflect location and quality differences. The adjustment factors are computed by linear regressions, as described in Section 4.

For the refining marginal type, the model uses the following refining configurations as the appropriate refining price setting modes:

- Catalytic Cracking USGC, N.W.E.
- Hydroskimming Singapore

These marginal refining configurations were determined based on historical data and expected future marginal capacity refining modes. In addition, the marginal refining configuration for a given global refining center generally persists for an extended time period as seen in Figure 3 for the Louisiana Light Crude (LLS) refining margins. The persistence of low margins for a typical catalytic cracking refinery in the U.S. Gulf Coast supports validity of the marginal refinery approach used in the Refinery Model. These marginal configurations act to set the refined product yield patterns for the respective crude oils in the three refining centers.

Figure 3. Long Term Persistence of Marginal Refining Configuration for a Given Global Refining Center



Source: Purvin and Gertz (GPMO – Dec 09)

For the light-to-heavy refined product differential, the expected long term equilibrium differential environment is projected to be relatively narrow. In other words, the differential is expected to be wide enough to support reasonable incremental refining margins, but not so wide as to reflect non-equilibrium differentials that are periodically seen in refining markets and which then promote additional bottoms upgrading refining capacity additions.

Key Assumptions

The key assumptions that underlie the marginal refinery light product price setting model in the Refinery Model are as follows:

- Prices respond to long-term commodity supply/demand concepts and typical refining reality, including

- Liquid, normally functioning spot markets for crude oil and refined products, with transportation-based links to other markets
- Sufficient global refining capacity to meet refined product demand
- Refiners acting in a rational, profit-maximizing manner, thereby processing crude oil up to the point of essentially zero margin operation
- This method does not attempt to predict pricing under short-term market dislocations that yield extraordinary crude oil and/or refined product imbalances and non-equilibrium pricing
- Even with the presence of short-term market dislocations, the method is still valid for long-term, equilibrium price projections, because market participants will act to address short-term disturbances
 - A seven-year horizon is currently used to reach equilibrium-type pricing. This assumption is based on the two waves of new refining capacity additions in India, China and the Middle East during this period.

4. Model Structure

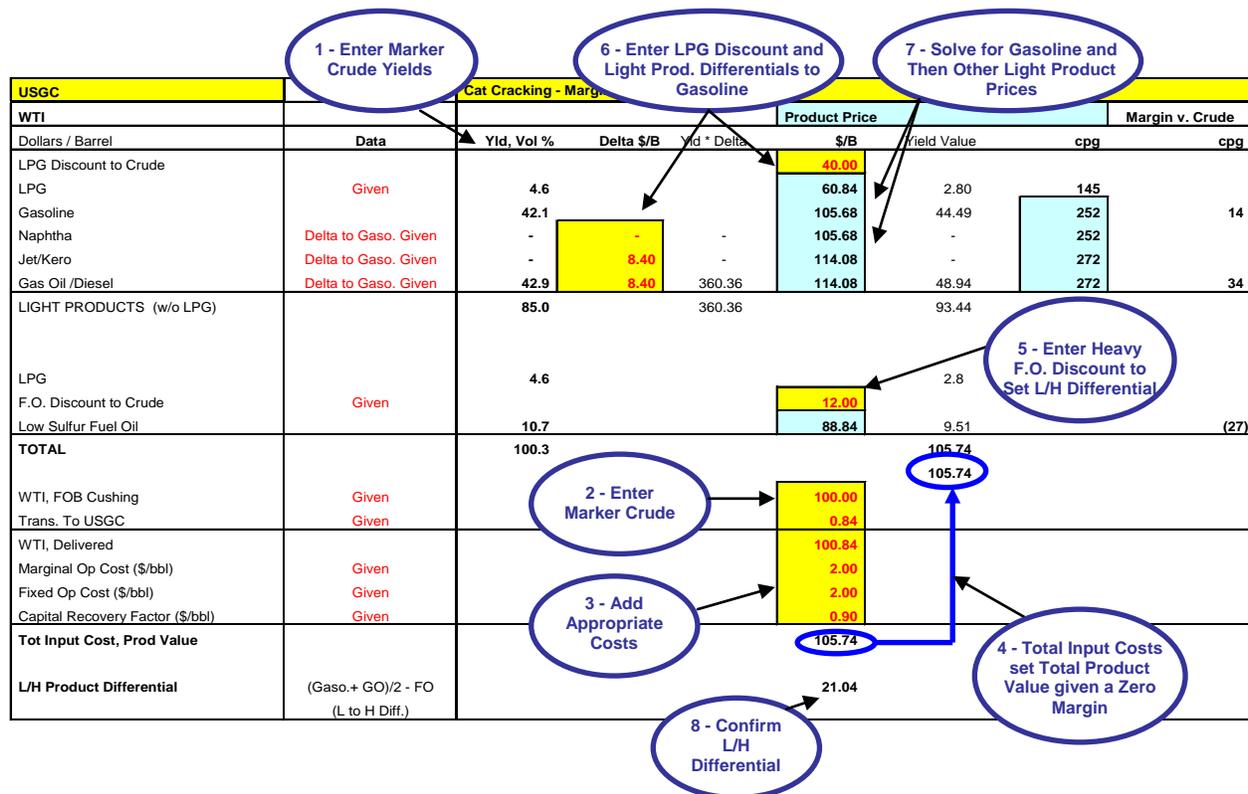
Structural Overview

The main purpose of the Refinery Model is to project long-term, equilibrium refined product prices in key global refining centers and the 16 *IEO2010* regions. It uses the projected WTI crude oil prices and other input information to model global refined product markets. The underlying logic and approach used in the Refinery Model acts to yield internally consistent price sets for both crude oil and refined products.

Refined Product Pricing – Three Global Refining Centers

The Refinery Model first computes the long-term, equilibrium refined product prices in the three Global Refining Centers: the USGC, North West Europe and Singapore. Figure 4 shows an example of the model's structure and the logic flow used to determine the refined product prices in one of the Global Refining Centers, the U.S. Gulf Coast. The eight steps illustrated in the figure are described in detail below.

Figure 4. Example Refining Center Refined Product Determination – USGC



Step 1. The product yields for the marker crude in the marginal refining configuration are entered in the Refinery Model. For this example, the USGC marker crude is WTI and the marginal refining configuration is catalytic cracking.

- The yield data specify the slate of products produced by processing a barrel of WTI in a refinery where the last (or marginal) barrel is consumed
- A catalytic cracking (cat cracking) refinery configuration is one in which the crude oil and its intermediate products are processed through the following primary refinery processes in order to produce final products:
 - Atmospheric and Vacuum Crude Distillation
 - Reforming
 - Catalytic Cracking
 - Alkylation
 - Hydrotreating
 - Final Product Blending
- In this example, the primary products are
 - Liquefied petroleum gas (LPG)
 - Gasoline and Naphtha
 - Diesel and Kerosene
 - Low Sulfur Heavy Fuel Oil

Step 2. The marker crude price is entered. In the case of the USGC, this is the WTI price set at Cushing, Oklahoma.

Step 3. Reasonable additional costs per barrel of crude oil are added to the marker crude price in order to arrive at the refiner's total cost, including

- Transportation cost from Cushing, Oklahoma to the USGC
- Marginal, or Variable, Operating Cost
- Fixed Operating Cost
- Long Term Capital Recovery Factor
 - The capital recovery factor represents the relatively small overall return realized by refining assets across time.

- The factor does not reflect the return for individual investments in specific upgrading capacity that a given refiner may have made.
- Rather, the factor reflects the overall modest returns refiners have realized from the entirety of their investments across time.

Once the necessary data have been imported, the Refinery Model sums up the marker crude price and the refining costs to yield the total input cost to process a barrel of crude into refined products in the particular marginal, or price setting, configuration.

Step 4. The Refinery Model sets the total input cost equal to the total product value. This can be done because the marginal refining configuration is, in fact, the price setting configuration.

In the price setting configuration, the model sets the total product value equal to the total input cost, including fixed and capital return factors, i.e., the model assumes a zero profit margin.

Step 5. The heavy fuel oil (F.O.) discount to crude is entered in the Refinery Model. This discount is used to calculate the light to heavy product differential.

Step 6. The LPG discount to crude oil is entered and the relative light product differentials to Gasoline are entered. These are the final inputs to the Refinery Model.

Step 7. The Refinery Model solves for the Gasoline/Naphtha price and following that, the Diesel/Kerosene price.

Step 8. As a final confirmation step, the Refinery Model calculates the Light to Heavy Product Differential to ensure that it is in the expected range. The Light to Heavy Product Differential is projected to be relatively narrow in the long term.

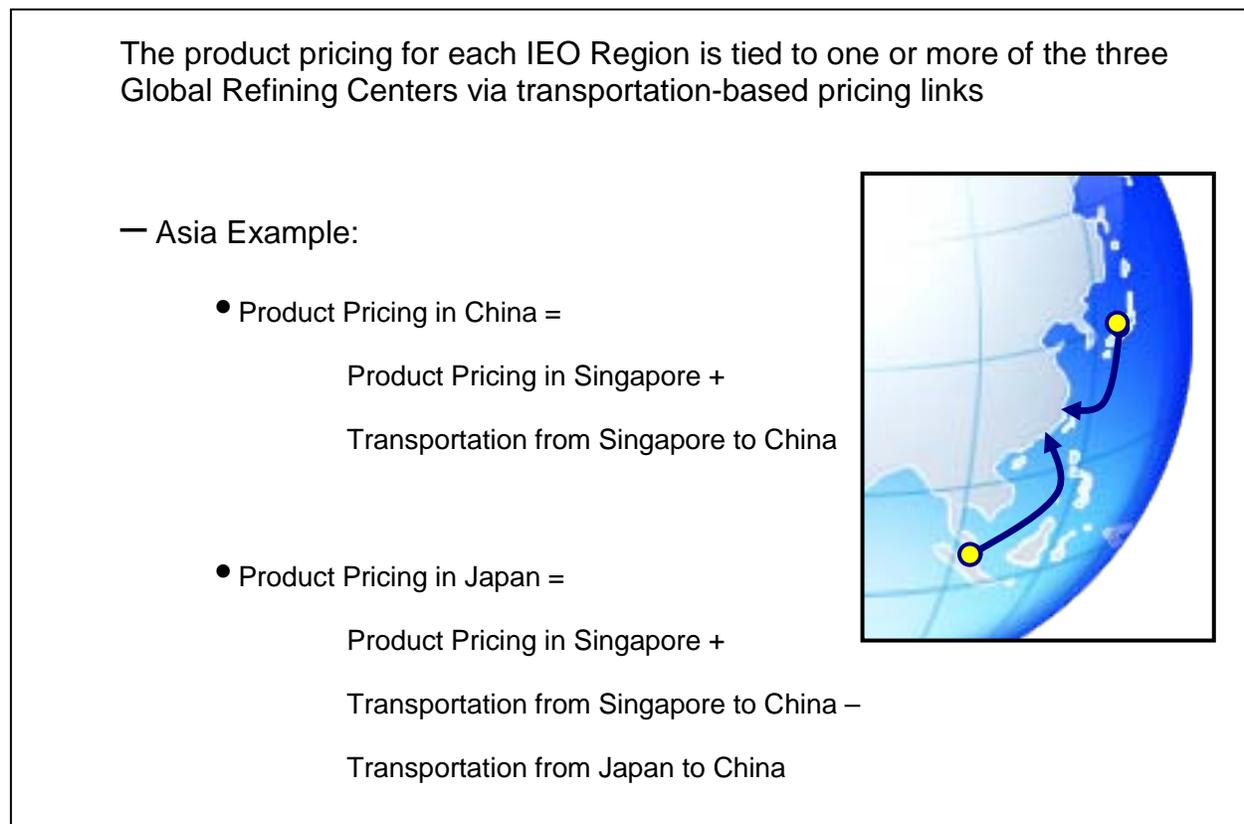
The differential is expected to be wide enough to support reasonable incremental refining margins but not so wide as to reflect non-equilibrium differentials that are periodically seen in refining markets and which promote additional bottoms upgrading refining capacity additions.

The Refinery Model determines the refined product prices for the other two global refining centers (Singapore and North West Europe) using a methodology similar to the one described above for the U.S. Gulf Coast.

Refined Product Pricing – 16 IEO Regions

Once the Refinery Model determines the refined product prices for the USGC, N.W.E. and Singapore, it calculates the long-term equilibrium product wholesale prices for each of the 16 *IEO2010* regions. The primary inputs are the relative transportation cost differentials from the appropriate refining center(s) to the WEPS+ regions (Figure 5).

Figure 5. Example Refined Wholesale Product Price Determination for two of the 16 IEO Regions



As seen in the Figure 5 example, the refined product price in China is tied to the price in the Singapore Global Refining Center via the estimated transportation cost from Singapore to China. In addition, Japan is tied to Singapore via the projected trading patterns for that region. As a refined product exporter to China, Japan’s refined product pricing is linked to Singapore pricing through its export trade to China. The transportation costs used for the *IEO2010* regions are reasonable representations of the projected costs, with the primary focus on their relative values to one another across the global refined product trading network.

Key Computations and Equations

This section provides detailed solution algorithms arranged in order of execution by the Refinery Model. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the details considered by the full forms of the equations provided in Appendix B.

Refined Product Wholesale Pricing – Three Global Refining Centers

This section explains the algorithm the Refinery Model uses to compute refined product pricing in the three Global Refining Centers. The crude price basis for these calculations begins with the projected WTI price at Cushing, Oklahoma, in **Petroleum Administration for Defense District**

2 (PADD2). A description of the methodology used to compute the long term, equilibrium refined product prices for each of the three Global Refining Centers follows.

Let TIC be the expected Total Input Cost (in dollars per barrel) for a USGC refinery in a cat cracking marginal configuration.

$$TIC = WTI (FOB Cushing) + Transportation Cost to the USGC + \\ Marginal Operating Cost + Fixed Operating Cost + Capital Recovery Factor$$

In the price setting (marginal) configuration, the model sets the total product value equal to the total input cost, including fixed and capital return factors.

Let TPV be the expected Total Product Value for the USGC refinery. From relationship noted above:

$$TPV = TIC$$

Therefore the total product value is known, based on input data.

By definition, the total product value equals the sum of refined product yields multiplied by their respective prices:

$$TPV = LPG Yield * LPG Price + \\ Gasoline Yield * Gasoline Price + Naphta Yield * Naphta Price + \\ Diesel Yield * Diesel Price + Kerosene Yield * Kerosene Price + \\ Low Sulfur Fuel Oil(LSFO) Yield * LSFO Price$$

The model imports the LPG price and LSFO price, in terms of the WTI crude cost, and estimates the combined gasoline and naphtha price and the combined diesel and kerosene price.

Based on historical information and the projected long term pricing relationship between gasoline and naphtha and diesel and kerosene, a reasonable price premium may be estimated for diesel and kerosene above gasoline and naphtha. The diesel and kerosene price is computed by adding the estimated premium to the gasoline and naphtha price:

$$Diesel Price = Gasoline Price + Diesel Premium above Gasoline Price \\ Kerosene Price = Gasoline Price + Kerosene Premium above Gasoline Price$$

The total product value equation can be rewritten as

$$TPV = LPG Yield * LPG Price + \\ Gasoline Yield * Gasoline Price + Naphta Yield * Naphta Price +$$

$$\begin{aligned}
 & Diesel\ Yield * (Gasoline\ Price + Diesel\ Premium\ above\ Gasoline\ Price) + \\
 & Kerosene\ Yield * (Gasoline\ Price + Kerosene\ Premium\ above\ Gasoline\ Price) + \\
 & Low\ Sulfur\ Fuel\ Oil\ Yield * LSFO\ Price
 \end{aligned}$$

Because all of the variables are known except for the combined gasoline and naphtha price, the equation can be explicitly solved for that single variable. Once the combined gasoline and naphtha price is determined, the combined diesel and kerosene price is calculated. As a final check, the refined product light to heavy differential (LHPD) is calculated:

$$LHPD = (Gasoline\ Price + Naphta\ Price + Diesel\ Price + Kerosene\ Price) / 4 - LSFO\ Price$$

The overall result is a set of long term, equilibrium crude oil and refined product wholesale prices that are internally consistent and based on reasonable assumptions and projections about the refined products market in the USGC. The calculations are similar for the North West Europe and Singapore global refining centers.

Refined Product Wholesale and Retail Pricing – 16 IEO2010 regions

After the Refinery Model determines the refined product pricing for the USGC, N.W.E. and Singapore, the model calculates the long-term equilibrium product pricing for each of the WEPS+ regions:

- | | | |
|----|-------|-------------------------------|
| 1 | - USA | - United States |
| 2 | - CAN | - Canada |
| 3 | - MEX | - Mexico |
| 4 | - EUR | - OECD Europe |
| 5 | - JPN | - Japan |
| 6 | - ANZ | - Australia and New Zealand |
| 7 | - SKO | - South Korea |
| 8 | - RUS | - Russia |
| 9 | - URA | - Non-OECD Europe and Eurasia |
| 10 | - CHI | - China |
| 11 | - IND | - India |
| 12 | - OAS | - Other Asia |
| 13 | - MID | - Middle East |

- 14 - AFR - Africa
- 15 - BRZ - Brazil
- 16 - CSA - Central and South America (excluding Brazil)

The following are examples of the formulas relating regional wholesale prices to prices in one of the three global refining centers, in this case the USGC.

PP = Petroleum Products

P = Price

T = Transportation Cost

- 1 - USA $P (PP,USA) = P (PP,USGC)$
- 2 - CAN $P (PP,CAN) = P (PP,USGC) - T (CAN \text{ to } USGC)$
- 3 - MEX $P (PP,MEX) = P (PP,USGC) + T (USGC \text{ to } MEX)$

In the example shown above for Canada, the long term, equilibrium refined product price is generally lower than the U.S. price (as represented by USGC price). This is because Canada is generally a refined product exporter to the United States.

On a more detailed sub-regional basis, the precise transportation linkages are more complex than those shown above. Canada, for example, is typically a refined product exporter into the U.S. Midwest and U.S. Northeast sub-regions. For the *IEO2010*, however, the goal was to project the overall refined product trade and resultant pricing patterns for the 16 WEPS+ regions without adding another layer of sub-regional complexity.

For Mexico, the long term, equilibrium refined product price is generally higher than the U.S. price, because Mexico is generally a refined product importer from the United States.

The rest of the formulas relating regional wholesale prices to prices in one of the three global refining centers are enumerated below.

- EUR $P (PP,EUR) = P (PP,EUR/NWE)$
- JPN $P (PP,JPN) = P (PP,SING) + T (SING \text{ to } CHI) - T (JPN \text{ to } CHI)$
- ANZ $P (PP,ANZ) = P (PP,SING) - T (SING \text{ to } ANZ)$
- SKO $P (PP,SKO) = P (PP,SING) + T (SING \text{ to } CHI) - T (SKO \text{ to } CHI)$
- RUS $P (PP,RUS) = P (PP,SING) - T (RUS \text{ to } EUR)$

- *URA* $P (PP,URA) = P (PP,EUR) - T (RUS \text{ to } EUR) + T (RUS \text{ to } URA)$
- *CHI* $P (PP,CHI) = P (PP,SING) + T (SING \text{ to } CHI)$
- *IND* $P (PP,IND) = P (PP,SING) - T (IND \text{ to } SING)$
- *OAS* $P (PP,OAS) = P (PP,SING) + T (SING \text{ to } CHI)$
- *MID*
 - $P (DS,JF,KS, MID) = AVERAGE(P (DS,JF,KS, EUR) - T (MID \text{ to } CHI)$
and $P (DS,JF,KS, SING) - T (MID \text{ to } SING))$
 - $P (MG, MID) = P (MG, SING) + T (SING \text{ to } MID)$
 - $P (RS, MID) = P (RS, SING) - T (MID \text{ to } SING)$
- *AFR*
 - $P (DS,JF,KS, AFR) = P (DS,JF,KS, MID) + T (MID \text{ to } AFR)$
 - $P (MG, AFR) = P (MG, SING) + T (SING \text{ to } AFR)$
 - $P (RS, AFR) = P (RS, USGC) - T (AFR \text{ to } USGC)$
- *BRZ* $P (PP, BRZ) = P (PP, USGC) - T (BRZ \text{ to } USGC)$
- *CSA* $P (PP, CSA) = AVERAGE (P (PP, USGC) + T (USGC \text{ to } CSA)$
and $P (PP, USGC) - T (CSA \text{ to } USGC))$

OBS. *AVERAGE* has the meaning of the arithmetic average.

Wholesale prices for ethanol (ET) are computed by applying an adjustment to motor gasoline (MG) prices. There is a 14% percent premium, relative to the MG price, for the first 10% of a barrel of ET. For the remaining 90% of a barrel of ET, the price is computed based on the heat content of ET relative to that of MG. Wholesale prices for other biofuels (OB) are computed based on the heat content of the OB relative to that of diesel (DS).

Retail prices for petroleum products in each of the 16 WEPS+ regions, and for each sector, are computed based on the wholesale prices by applying factors computed exogenously based on the historical data. Sectors considered in the model are as follows: industrial, commercial, residential, transportation, electric power, and district heating. The complete list of petroleum products considered in each sector is available in Appendix A.

Appendix A. Input Data and Variable Descriptions

The following variables represent data input from the restart file.

Classification: Input variables from demand, transformation, and supply models.

$QHDSRS(r,y)$:	Historical distillate fuel consumption in the residential sector by region and year (years 1980 through 2007)
$QHKRSR(r,y)$:	Historical kerosene consumption in the residential sector by region and year (years 1980 through 2007)
$QHLGRS(r,y)$:	Historical liquefied petroleum gas consumption in the residential sector by region and year (years 1980 through 2007)
$QHMGCM(r,y)$:	Historical motor gasoline consumption in the commercial sector by region and year (years 1980 through 2007)
$QHDSCM(r,y)$:	Historical distillate fuel consumption in the commercial sector by region and year (years 1980 through 2007)
$QHKSCM(r,y)$:	Historical kerosene consumption in the commercial sector by region and year (years 1980 through 2007)
$QHRSCM(r,y)$:	Historical residual fuel consumption in the commercial sector by region and year (years 1980 through 2007)
$QHLGCM(r,y)$:	Historical liquefied petroleum gas consumption in the commercial sector by region and year (years 1980 through 2007)
$QHMGIN(r,y)$:	Historical motor gasoline consumption in the industrial sector by region and year (years 1980 through 2007)
$QHDSIN(r,y)$:	Historical distillate fuel consumption in the industrial sector by region and year (years 1980 through 2007)
$QHRSIN(r,y)$:	Historical residual fuel consumption in the industrial sector by region and year (years 1980 through 2007)
$QHKSIN(r,y)$:	Historical kerosene consumption in the industrial sector by region and year (years 1980 through 2007)
$QHLGIN(r,y)$:	Historical liquefied petroleum gas consumption in the industrial sector by region and year (years 1980 through 2007)
$QHPCIN(r,y)$:	Historical petroleum coke consumption in the industrial sector by region and year (years 1980 through 2007)

<i>QHSPIN(r,y):</i>	Historical sequestered petroleum fuel consumption in the industrial sector by region and year (years 1980 through 2007)
<i>QHOPIN(r,y):</i>	Historical other petroleum consumption in the industrial sector by region and year (years 1980 through 2007)
<i>QHMGTR(r,y):</i>	Historical motor gasoline consumption in the transportation sector by region and year (years 2005 through 2007)
<i>QHDSTR(r,y):</i>	Historical distillate (diesel) fuel consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHRSTR(r,y):</i>	Historical residual fuel consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHLGTR(r,y):</i>	Historical liquefied petroleum gas consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHJFTR(r,y):</i>	Historical jet fuel consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHSPTR(r,y):</i>	Historical sequestered petroleum fuel consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHOPTR(r,y):</i>	Historical other petroleum consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHETTR(r,y):</i>	Historical ethanol (E85) consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHOBTR(r,y):</i>	Historical biofuels (excluding ethanol) consumption in the transportation sector by region and year (years 1980 through 2007)
<i>QHDSPG(r,y):</i>	Historical utility consumption of distillate (in trillion Btu) by region and year (years 1980 through 2007)
<i>QHRSPG(r,y):</i>	Historical utility consumption of residual (in trillion Btu) by region and year (years 1980 through 2007)
<i>QHSDH(r,y):</i>	Historical distillate fuel consumption in the district heat sector by region and year (years 1980 through 2007)

$QHRSDH(r,y):$	Historical residual fuel consumption in the district heat sector by region and year (years 1980 through 2007)
$QDSRS(r,y):$	Consumption of residential distillate fuel by region and year
$QKSRS(r,y):$	Consumption of residential kerosene by region and year
$QLGRS(r,y):$	Consumption of residential liquefied petroleum gas by region and year
$QMGCM(r,y):$	Consumption of commercial sector motor gasoline by region and year
$QDSCM(r,y):$	Consumption of commercial sector distillate fuel by region and year
$QRSCM(r,y):$	Consumption of commercial sector residual fuel by region and year
$QKSCM(r,y):$	Consumption of commercial sector kerosene by region and year
$QLGCM(r,y):$	Consumption of commercial sector liquefied petroleum gas by region and year
$QMGIN(r,y):$	Motor gasoline consumption in the industrial sector by region and year
$QDSIN(r,y):$	Distillate fuel consumption in the industrial sector by region and year
$QRSIN(r,y):$	Residual fuel consumption in the industrial sector by region and year
$QKSIN(r,y):$	Kerosene consumption in the industrial sector by region and year
$QLGIN(r,y):$	Consumption of industrial sector liquefied petroleum gas by region and year
$QPCIN(r,y):$	Petroleum coke consumption in the industrial sector by region and year
$QSPIN(r,y):$	Sequestered petroleum fuel consumption in the industrial sector by region and year
$QOPIN(r,y):$	Other petroleum consumption in the industrial sector by region and year

$QMGTR(r,y)$:	Motor gasoline consumption in the transportation sector by region and year
$QDSTR(r,y)$:	Distillate fuel consumption in the transportation sector by region and year
$QRSTR(r,y)$:	Residual fuel consumption in the transportation sector by region and year
$QLGTR(r,y)$:	Liquefied petroleum gas consumption in the transportation sector by region and year
$QJFTR(r,y)$:	Jet fuel consumption in the transportation sector by region and year
$QSPTR(r,y)$:	Sequestered petroleum fuel consumption in the transportation sector by region and year
$QOPTR(r,y)$:	Other petroleum consumption in the transportation sector by region and year
$QETTR(r,y)$:	Ethanol (E85) consumption in the transportation sector by region and year
$QOBTR(r,y)$:	Biofuels (excluding ethanol) consumption in the transportation sector by region and year
$QDSPG(r,y)$:	Distillate fuel consumption in the electric power sector by region and year
$QRSPG(r,y)$:	Residual fuel consumption in the electric power sector by region and year
$QDSDH(r,y)$:	Consumption of distillate fuel used for district heat generation by region and year (2008 through 2035)
$QRSDH(r,y)$:	Consumption of residual fuel used for district heat generation by region and year (2008 through 2035)
$QGTLProd(r,y)$:	Quantity of gas-to-liquids fuel produced by region and year (2001 through 2035)
$QGTLPProd(r,y)$:	Quantity of coal-to-liquids fuel produced by region and year (2001 through 2035)
$QBTLProd(r,y)$:	Quantity of biofuels-to-liquids fuel produced by region and year (2001 through 2035)

The following variables represent data input from Refinery2.xml file.

Classification: Input variable.

<i>LMYr</i>	Last model forecast year
<i>LHYr</i>	Last model historical year
<i>ICrude_Type(ty)</i>	Type of crude oil (1 = WTI, 2 = Brent, 3 = Dubai)
<i>IPrice_Center(c)</i>	Price center (1 = USGC, 2 = N.W.E., 3 = Singapore)
<i>IRef_Type(rt)</i>	Refining type (1 = catalytic cracking, 2 = hydroskimming)
<i>IDifferential(d)</i>	Type of price differential (1 = narrow, 2 = wide)
<i>IReg(r)</i>	Region indicator (1= United States, 2= Canada, 3 = Mexico, 4 = OECD Europe, 5 = Japan, 6 = Australia/New Zealand, 7 = South Korea, 8 = Russia, 9 = Other non-OECD Europe and Eurasia, 10 = China, 11 = India, 12 = Other non-OECD Asia, 13 = Middle East, 14 = Africa, 15 = Brazil, and 16 = Other Central and South America)
<i>TrCost(r1,r2)</i>	Transportation costs between each of the <i>IEO2010</i> regions
<i>RCVar(c,x,2001;pFYr)</i>	Real pricing projections for each center (c – potential for 5, but only 3 are currently used); x is: 1-Transportation Cost, 2-Marginal Op. Cost, 3-Fixed Op. Cost, 4-Capital Recovery, 5-LG_Y, 6-MG_Y, 7-NA_Y, 8-JF_KS_Y, 9-DS_Y, 10-RS_Y (Yields), 11-LG_P (Price), 12-RS_D, 13-NA_D, 14-JF_KS_D, 15-DS_D (Discounts)—potential for 20 variables, but currently only 15 are used
<i>rLHeatContent(20)</i>	Heat content for 15 liquids in million Btu per barrel; there is space for 20 different products, but only 12 liquids are currently used (MG, DS, RS, KS, LG, JF, PC, SP, OP, ET OB, NA)
<i>tr(rte)</i>	Transportation costs by route for two miscellaneous U.S. routes: tr(1) = T(USGC to USEC); tr(2) = T(EUR to USEC); where USEC = U.S. East Coast

Classification: Computed variable.

<i>rCenterProductPrice(15,c,y)</i>	Wholesale crude product prices by product, center and year
<i>rCenterProductYieldValue(15,c,y)</i>	Yields wholesale product prices value by product, center and year
<i>rRegionProductPrice(15,r,y)</i>	Wholesale crude product prices by product, region and year

coeffPrSect(r,24)

Coefficients to compute retail prices by sector based on wholesale product prices in each region. First dimension is region, second dimension is as follows: 1-PDSCM, 2-PDSDH, 3-PDSIN, 4-PDSPG, 5-PDSRS, 6-PDSTR, 7-PJFTR, 8-PKSCM, 9-PKSIN, 10-PKSRS, 11-PLGCM, 12-PLGIN, 13-PLGRS, 14-PLGTR, 15-PMGCM, 16-PMGIN, 17-PMGTR, 18-POPIN, 19-POPTR, 20-PRSCM, 21-PRSDH, 22-PRSIN, 23-PRSPG, 24-PRSTR

****Retail Crude Product Prices by region and sectors are stored in following WEPS+ variables

!Prices for Residential Sector

<i>PDSRS(pReg,2001:pFYr)</i>	Distillate
<i>PKSRS(pReg,2001:pFYr)</i>	Kerosene
<i>PLGRS(pReg,2001:pFYr)</i>	Liquefied petroleum gas

!Prices for Commercial Sector

<i>PMGCM(pReg,2001:pFYr)</i>	Motor gasoline
<i>PDSCM(pReg,2001:pFYr)</i>	Distillate
<i>PRSCM(pReg,2001:pFYr)</i>	Residual
<i>PKSCM(pReg,2001:pFYr)</i>	Kerosene
<i>PLGCM(pReg,2001:pFYr)</i>	Liquefied petroleum gas

!Prices for Industrial Sector

<i>PMGIN(pReg,2001:pFYr)</i>	Motor gasoline
<i>PDSIN(pReg,2001:pFYr)</i>	Distillate
<i>PRSIN(pReg,2001:pFYr)</i>	Residual
<i>PKSIN(pReg,2001:pFYr)</i>	Kerosene
<i>PLGIN(pReg,2001:pFYr)</i>	Liquefied petroleum gas
<i>POPIN(pReg,2001:pFYr)</i>	Other petroleum

!Prices for Transportation Sector

<i>PMGTR(pReg,2001:pFYr)</i>	Motor gasoline
<i>PDSTR(pReg,2001:pFYr)</i>	Distillate
<i>PRSTR(pReg,2001:pFYr)</i>	Residual
<i>PLGTR(pReg,2001:pFYr)</i>	Liquefied petroleum gas
<i>PJFTR(pReg,2001:pFYr)</i>	Jet fuel
<i>POPTR(pReg,2001:pFYr)</i>	Other petroleum

!Prices for Electric Power Sector

<i>PDSPG(pReg,2001:pFYr)</i>	Distillate
<i>PRSPG(pReg,2001:pFYr)</i>	Residual

!Prices for District Heating Sector

<i>PDSDH(pReg,2001:pFYr)</i>	Distillate
<i>PRSDH(pReg,2001:pFYr)</i>	Residual

Table 3 includes a list of the liquid products considered in WEPS+ Refinery Model together with their identification number and heat rate.

Table 3. Heat Rates

Refined Product	LiquidID	Million BTU per barrel
Motor Gasoline	1	5.208
Distillate	2	5.838
Residual	3	6.287
Kerosene	4	5.670
LPG	5	3.822
Jet Fuel	6	5.460
Petroleum Coke	7	6.024
Sequestered Petroleum	8	5.800
Other Petroleum	9	5.800
Ethanol	10	3.539
Biodiesel	11	5.500
Naphtha	12	5.208

Appendix B. Mathematical Description

This section provides the formulas and associated mathematical descriptions that represent the detailed solution algorithms. The section is arranged by sequential submodule as executed in the WEPS+ Refinery Module.

SUBROUTINE: Refinery2_Main

Description: The Refinery2_Main subroutine is the central subroutine of the Refinery Module. This subroutine first reads, from FileCntl.txt file, the values for the last historical data year (LHYr) and for the last year in the forecast (LMYr). Following this, by calling ReadInputData subroutine, the input data file Refinery2.xml is opened, all necessary input data is read and stored in the appropriate variables (See Appendix A) and then Refinery2.xml file is closed. Next, a sequence of subroutines are being called in the following order: ComputeCenterPrices, ComputeRegionPrices, CheckPriceCenterRules, ComputeRegionSectorPrices. The role of each of these subroutines is illustrated below.

SUBROUTINE: ReadInputData

Description: The ReadInputData subroutine is responsible for reading all required input data from Refinery2.xml file. After Refinery2.xml file is opened, following variables will receive their values: *ICrude_Type*, *IPrice_Center*, *IRef_Type*, *IDifferential*, *IReg*, *TrCost*, *RCVar*, *rLHeatContent*, *tr*, *coeffPrSect*. See Appendix A for a complete description of these variables. At the end of this process the Refinery2.xml input file is closed.

SUBROUTINE: ComputeCenterPrices

Description: The ComputeCenterPrices subroutine computes wholesale crude product prices in each of the three centers: United States Gulf Coast, Northwest Europe and Singapore. These prices are stored in *rCenterProductPrice* variable. The entire process is described in detail in Refined Product Wholesale Pricing – **Three Global Refining Centers** section of this documentation. These prices are logged to the Ref2-Report.txt output report file.

SUBROUTINE: ComputeRegionPrices

Description: The ComputeRegionPrices subroutine computes wholesale crude product prices in each of the 16 world regions considered in WEPS+ Refinery Model. It uses the wholesale crude product prices in each of the three centers computed by the ComputeCenterPrices subroutine, the assumptions made in connection with transportation costs between regions, and expert assumptions about the flows of specific products from one region to another. These prices are stored in *rRegionProductPrice* variable. The entire process is described in detail in **Refined Wholesale Product Pricing – 16 IEO2010 regions** section of this documentation. These prices are logged to the Ref2-Report.txt output report file.

SUBROUTINE: CheckPriceCenterRules

Description: The CheckPriceCenterRules subroutine checks for some logical rules to hold during the process of running this Refinery Model. Specifically, 2 rules are enforced.

Rule 1. Because EUR region exports MG to U.S.A. following rule is enforced: $P(MG, EUR) \leq P(MG, USGC) + T(USGC \text{ to USEC}) - T(EUR \text{ to USEC})$.

Rule 2. Because USGC region exports DS to EUR following rule is enforced: $P(DS, EUR) \geq P(DS, USGC) + T(USGC \text{ to EUR})$.

If any of these rules are not observed, a corresponding message is logged to the Ref2-Report.txt output report file.

SUBROUTINE: ComputeRegionSectorPrices

Description: The ComputeRegionSectorPrices subroutine computes retail crude product prices in each of the 16 regions by product, sector and year. These prices are computed based on wholesale crude product prices in each of the 16 regions of WEP+ Refinery Model by applying corresponding multipliers *coeffPrSect* read by ReadInputData subroutine from refinery2.xml input file. Final results are stored in variables described in Appendix A.

Appendix C. References

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Appendix D. Model Abstract

Introduction

Model Name:

Refinery Model

Model Acronym:

RM

Description:

The WEPS+ Refinery Model is a calculation tool. It uses the projected WTI crude oil price and other input information to model global refined product markets. The WEPS+ Refinery Model computes long term, equilibrium refined product pricing in the three global refining centers (the U.S. Gulf Coast, North West Europe and Singapore) and the 16 International Energy Outlook (IEO) regions.

The underlying logic and approach used in the Refinery Model acts to yield internally consistent price sets for both crude oil and refined products.

Purpose of the Model:

As a component of the WEPS+, the Refinery Model accomplishes the following:

- Calculation of reasonable, long-term equilibrium-type refined product pricing for the three primary global refining centers: the U.S. Gulf Coast (USGC), Northwest Europe (N.W.E.) and Singapore.
 - The Refinery Model utilizes the projected WTI price at Cushing, Oklahoma as the basis for marker crude oil prices in the USGC, N.W.E. and Singapore.
 - The RM also utilizes projected light to heavy product differentials and the expected marginal refining configuration in each of the three refining centers as bases for the respective refined product pricing calculations.
 - In addition, refined product pricing guidelines for the three global refining centers have been established to ensure that relative product pricing among the three centers is in agreement with projected global trade patterns.
- Calculation of refined product pricing for the International Energy Outlook regions.
 - The Refinery Model utilizes a set of global pricing guidelines that have been established to relate pricing in the three global refining centers to pricing in the IEO'S 16 regions.

- The set of global pricing guidelines are based on the projected transportation linkages between the three global refining centers and the 16 regions.
- The transportation costs utilized for these linkages are reasonable representations of the relative shipping costs between the refining centers and the regions.

Most Recent Model Update:

December 2009.

Part of Another Model?

WEPS+

Model Interfaces:

The Refinery Model uses information from other WEPS+ components; it also provides information to other WEPS+ components. The information it uses is primarily the projected WTI crude price. The information it provides includes refined product pricing for the three global refining centers and the 16 *IEO2010* regions, and alternative crude pricing for the EIA's five import crude types.

The expected WTI price for any year in the projection period is exogenously provided to the Refinery Model through data included in the input file

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Documentation:

U.S. Energy Information Administration, U.S. Department of Energy, *Refinery Model of the World Energy Projection System Plus: Model Documentation 2010 Report*, DOE/EIA-M084(2010) (Washington, D.C., September 2010).

Archive Media and Installation Manual(s):

The Refinery Model, as part of the WEPS+ system, has been archived for the Reference case published in the *International Energy Outlook 2010*, DOE/EIA-0484 (July 2010). The WEPS+ archive contains all of the nonproprietary modules of WEPS+ as used in the Reference case.

Energy System Described:

Refined product pricing for the three global refining centers (the U.S. Gulf Coast, North West Europe and Singapore) and the 16 *International Energy Outlook 2010 (IEO2010)* regions.

Coverage:

- Geographic: 16 *IEO2010* regions
- Time Unit/Frequency: Annual through 2035
- Products: Primary refined product pricing for 16 *IEO2010* regions
- Economic Sectors: Not applicable

Modeling Features:

- Model Structure: The WEPS+ Refinery Model is a calculation tool that uses the projected WTI crude oil price and other input information to model global refined product markets. The WEPS+ Refinery Model computes long term, equilibrium refined product pricing in the three global refining centers (the U.S. Gulf Coast, North West Europe and Singapore) and the 16 International Energy Outlook (IEO) regions.
- Modeling Technique: The Refinery Model utilizes the projected WTI price at Cushing, Oklahoma as the basis for marker crude oil prices in the USGC, N.W.E. and Singapore. It then utilizes projected light to heavy product differentials and the expected marginal refining configuration in each of the three refining centers as bases for the respective refined product pricing calculations. A set of global pricing guidelines relate pricing in the three global refining centers to pricing in the IEO'S 16 regions.
- Special Features: The underlying logic and approach used in the Refinery Model acts to yield internally consistent price sets for both crude oil and refined products.

Model Inputs:

- For calculation of refined product pricing for the three global refining centers, inputs include the projected WTI price; the corresponding marker crude price in the three centers; the marker crude product yields in the marginal refining configuration for the three centers; the heavy fuel oil to crude oil discount, which sets the light to heavy refined product differential environment; expected variable and fixed refining operating costs; a capital recovery cost factor; light product pricing deltas to a primary light product; and the LPG to crude oil discount.
- For calculation of the refined product pricing in the 16 *IEO2010* regions, inputs include the transportation cost differentials from the three global refining centers to the 16 regions.

Non-DOE Input Sources:

- IEA Data - Product Yields Used for computing wholesale product prices in each of the three price centers: U.S.G.C., N.W.E., and Singapore.

DOE Input Sources:

NEMS Petroleum Market Module

- NEMS crude types

Input file Refinery2.xml

- Refinery2.xml contains all input data necessary to run WEPS+ Refinery Module.

Computing Environment:

- Hardware Used: HP Proliant Multiprocessor Server
- Operating System: Windows Server 2003, Standard Edition with MKS Toolkit UNIX emulation
- Language/Software Used: Intel Visual Fortran, Version 9
- Memory Requirement: 4,000K
- Storage Requirement: 126.5 Megabytes
- Estimated Run Time: 32 seconds for a 1990-2035 run in non-iterating WEPS+ mode
- Special Features: None

Independent Expert Reviews Conducted:

None

Status of Evaluation Efforts by Sponsor:

None

Appendix E. Data Quality

Introduction

The WEPS+ Refinery Model uses the projected WTI crude oil price and other input information to model global refined product markets. The WEPS+ Refinery Model computes long-term, equilibrium refined product pricing in key global refining centers and the 16 *IEO2010* regions. The underlying logic and approach used in the Refinery Model acts to yield internally consistent price sets for both crude oil and refined products.

These projections are based upon the data elements as detailed in Appendix A of this report. The input data, parameter estimates, and module variables are described in Appendix A. The documentation details transformations, estimation methodologies, and resulting inputs required to implement the model algorithms in Chapter 4: Model Structure. The quality of the principal sources of input data is discussed in Appendix E. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Source of Input Data

- *AEO2010* – Final results from this publication are used to provide the expected WTI crude oil pricing for the projected time horizon. This information, along with the projected refining center marginal configuration and refined product light to heavy product differential forms the basis for the refined product and alternative crude oil pricing projections.
- IEA Data - Product Yields Used for computing wholesale product prices in each of the three price centers: U.S.G.C., N.W.E., and Singapore.

Data Quality Verification

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

- World and U.S. crude and petroleum product price checks based on previous values and projections and knowledge of the industry
- Consistency checks
- Technical edits to detect and correct errors, extreme variability