DOE/EIA-M084(2011)

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

August 12, 2011

U.S. Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

Contents

Tables

Figures

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 2011* (*IEO2011*) regions.

Model Archival Citation

This documentation refers to the WEPS+ Refinery Model.

Model Contact

Adrian Geagla
Office of Integrated Analysis and Forecasting
International, Economic, and Greenhouse Gases Division
Phone: (202) 586-2873
Email: adrian.geagla@eia.gov

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 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 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 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.
    - 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 *IEO2011* regions.
    - The Refinery Model utilizes a set of global pricing guidelines which have been established to relate pricing in the three global refining centers to pricing in the *IEO2011* regions.
    - The set of 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 utilized for these linkages are reasonable representations of the relative shipping costs between the refining centers and the regions.

- Refinery Model 2: Calculation of five crude type prices using Alternative Crude Valuation method which is based on the concept of indifference or parity pricing.
  - In a perfect market, the price differential between two crude types should be very close to the difference between their netbacks of the marginal refinery, which sets the price.
  - In a Global Refining Center refiners can select from a variety of crudes to fill out their marginal refining capacity.
  - Refiners will typically pay more for light sweet crudes vs. heavy sour crudes since the light sweet crudes yield a more highly valued product slate with less hydroprocessing than do heavy sour crudes.

Model Inputs and Outputs

Because Refinery Model 1 is a simple aggregation of output 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 "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 *IEO2011* 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 *IEO2011* 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 in Refinery Model 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
To Determine Long Term, Equilibrium Pricing for alternative crudes in the US Gulf Coast region	
Sulfur content for five crude types considered (%)	Constant provided to the Refinery Model Source: Refinery2.xml
Liquefied Gases yields for five crude types considered (%)	Constant provided to the Refinery Model Source: Refinery2.xml
Motor Gasoline/Naphta yields for five crude types considered (%)	Constant provided to the Refinery Model Source: Refinery2.xml
Distillate yields for five crude types considered (%)	Constant provided to the Refinery Model Source: Refinery2.xml
Residual yields for five crude types considered (%)	Constant provided to the Refinery Model Source: Refinery2.xml
Incremental High Sulfur Fuel Oil discount for five crude types considered ($ / % sulfur)	Constant provided to the Refinery Model Source: Refinery2.xml

Incremental sulfur Marginal Operational Cost for five crude types considered ($ / % sulfur)	Constant provided to the Refinery Model Source: Refinery2.xml
Fixed Operational Cost for five crude types considered ($/BBL)	Constant provided to the Refinery Model Source: Refinery2.xml
Capital Recovery Cost for five crude types considered ($/BBL)	Constant provided to the Refinery Model Source: Refinery2.xml
Transportation Cost to US Gulf Coast Region for five crude types considered ($/BBL)	Constant provided to the Refinery Model Source: Refinery2.xml
High Sulfur Fuel Oil Discount for Medium Sulfur Heavy crude type ($/BBL)	Constant 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 *IEO2011* regions. Table 2 summarizes these outputs.

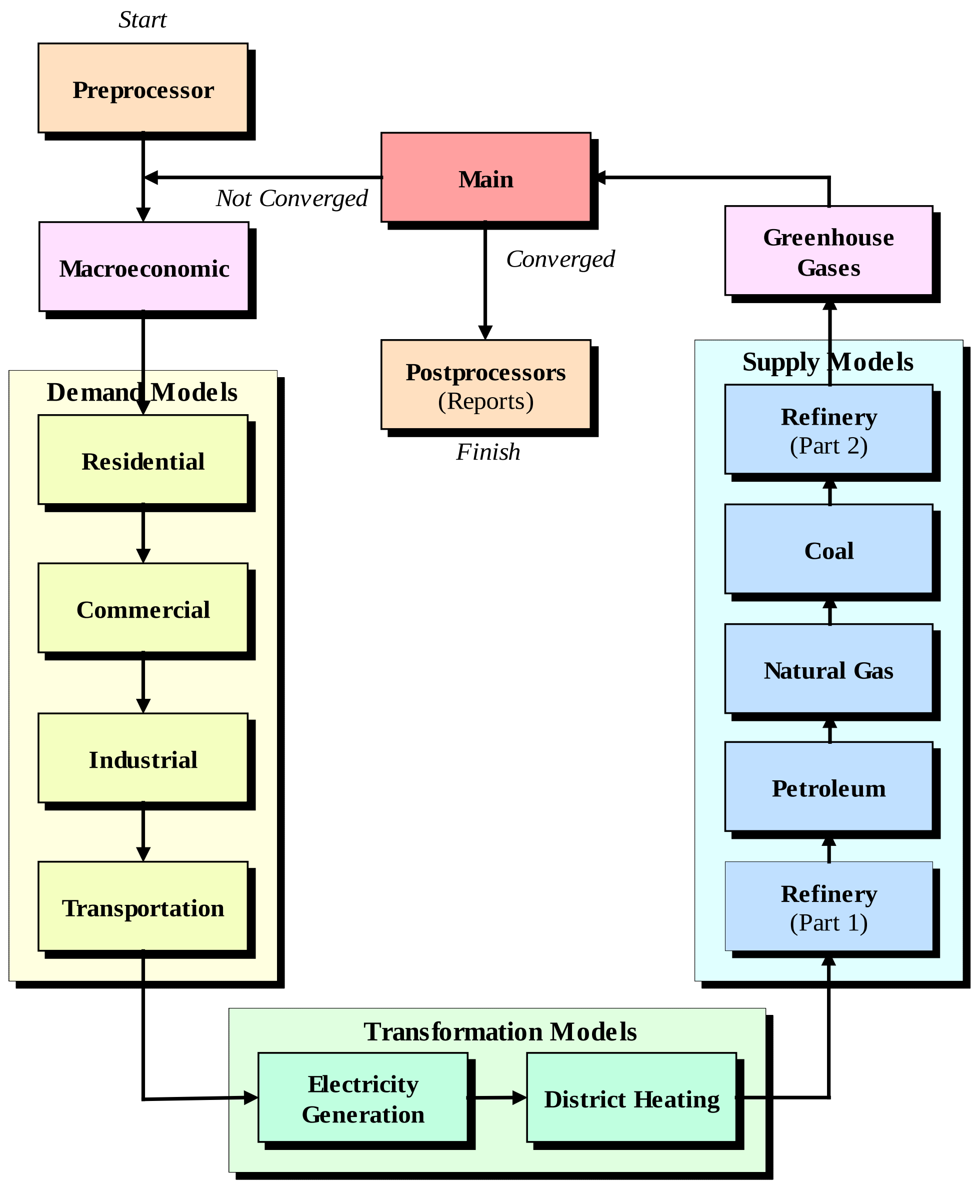
Table 2. WEPS+ Model Outputs

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
Computed Prices for five crude types for US Gulf Coast region	Reporting

Relationship of the Refinery Model to the other WEPS+ Models

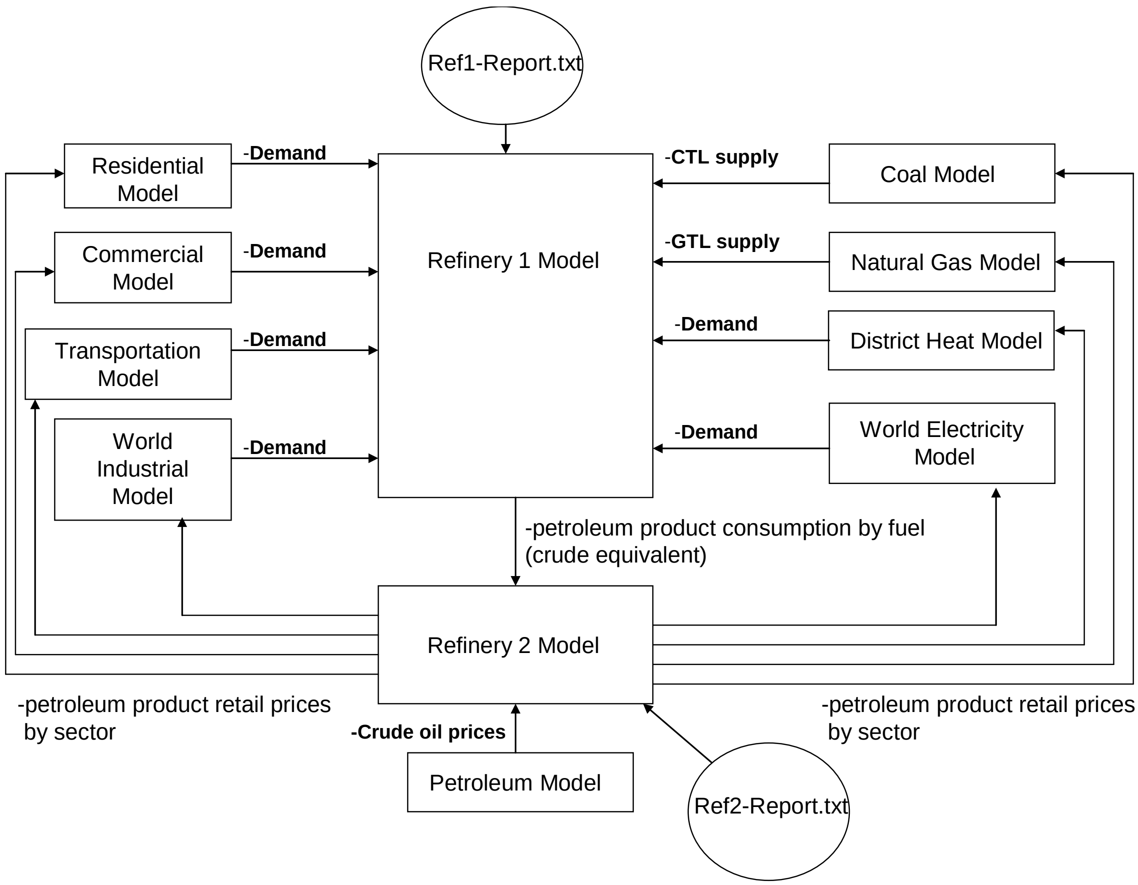
The Refinery Model uses information from other WEPS+ components (Figure 1). It also provides information to and receives information from other WEPS+ components. The information it uses is primarily the projected WTI crude price. The information it provides includes refined product pricing for the three global refining centers and the 16 *IEO2011* 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 *IEO2011* 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 following crude oils are utilized for the three primary global refining centers:

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

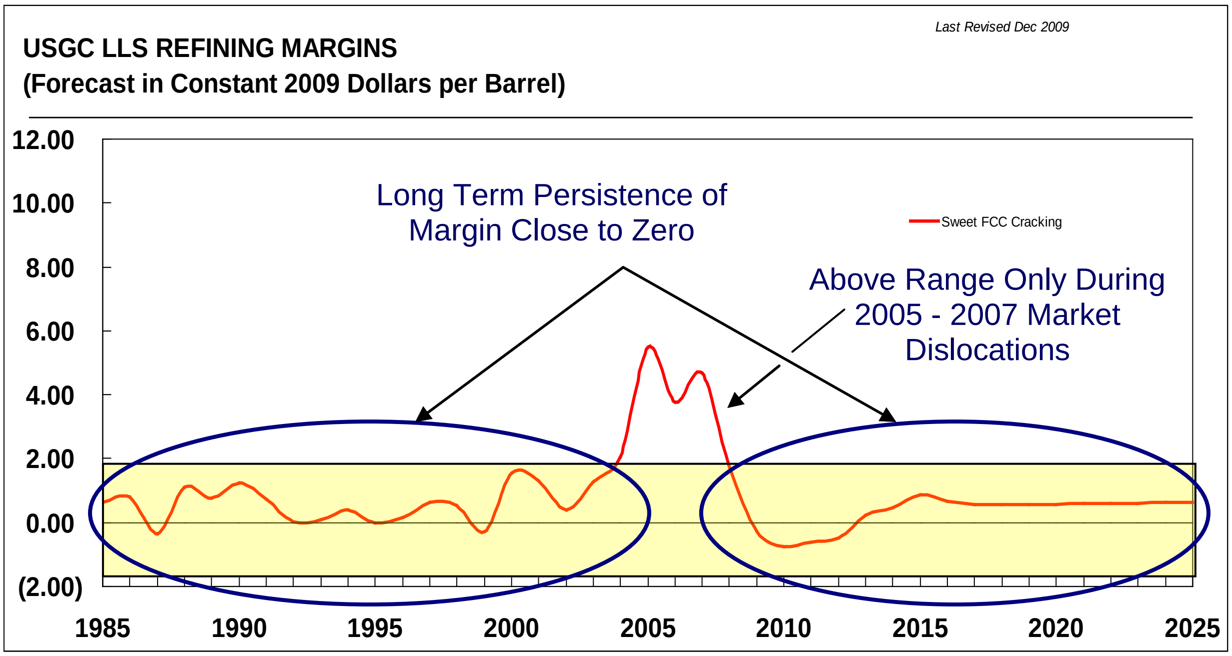
The WTI price is brought into the Refinery Model as an input value. The Brent and Dubai marker crude oil prices are set relative to the WTI price by taking into account representative differentials to WTI which reflect location and quality differences. They are computed using linear regressions method.

For the refining marginal configuration, the following configurations are utilized as the appropriate respective 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 which exemplifies 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.

For Alternative Crude Prices, we considered following five crude types:

1. Foreign Light Sulfur Light (FLL)
2. Foreign Medium Sulfur Heavy (FMH)
3. Foreign High Sulfur Light (FHL)
4. Foreign High Sulfur Heavy (FHH)
5. Foreign High Sulfur Very Heavy (FHV)

Key Assumptions

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

- Method adheres to basic, 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
- 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 pricing projections because market participants will act to address short-term disturbances
    - A seven-year horizon is currently utilized to reach equilibrium-type pricing. This assumption is based on the two waves of new refining capacity additions in India, China and Middle East during this period.

4. Model Structure

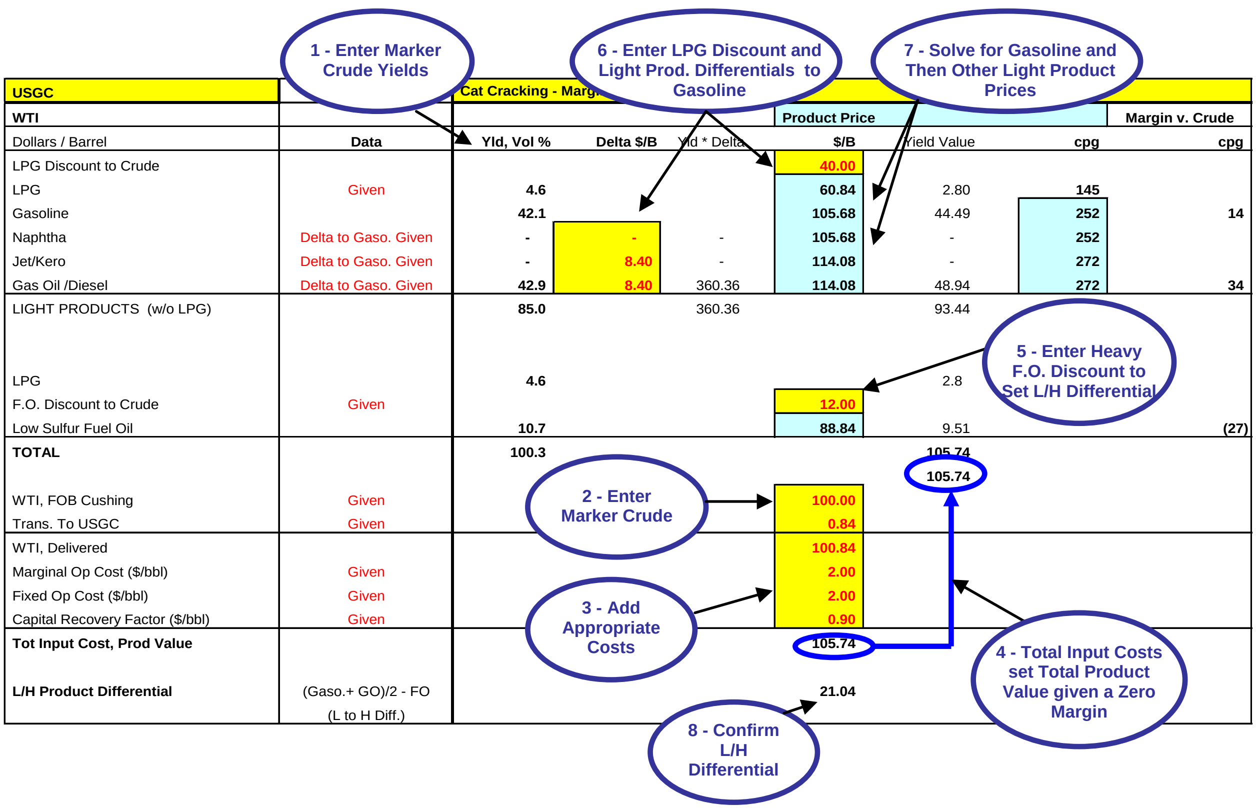
Structural Overview

The main purpose of the Refinery Model is to compute long-term, equilibrium refined product pricing in key global refining centers and the 16 *IEO2011* regions. It uses the projected WTI crude oil price 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 pricing in the three Global Refining Centers: the USGC, North West Europe and Singapore. An example of the model's structure and the logic flow used to determine the refined product pricing in one of the Global Refining Centers—the U.S. Gulf Coast—is illustrated in Figure 4.

Figure 4. Example Refining Center Refined Product Determination – USGC



USGC		Cat Cracking - Marg…						
WTI					Product Price			Margin v. Crude
Dollars / Barrel	Data	Yld, Vol %	Delta $/B	Yld * Delta	$/B	Yield Value	cpg	cpg
LPG Discount to Crude					40.00			
LPG	Given	4.6			60.84	2.80	145	
Gasoline		42.1			105.68	44.49	252	14
Naphtha	Delta to Gaso. Given	-	-	-	105.68	-	252	
Jet/Kero	Delta to Gaso. Given	-	8.40	-	114.08	-	272	
Gas Oil /Diesel	Delta to Gaso. Given	42.9	8.40	360.36	114.08	48.94	272	34
LIGHT PRODUCTS (w/o LPG)		85.0		360.36		93.44		
LPG		4.6				2.8		
F.O. Discount to Crude	Given				12.00			
Low Sulfur Fuel Oil		10.7			88.84	9.51		(27)
TOTAL		100.3				105.74		
						105.74		
WTI, FOB Cushing	Given				100.00			
Trans. To USGC	Given				0.84			
WTI, Delivered					100.84			
Marginal Op Cost ($/bbl)	Given				2.00			
Fixed Op Cost ($/bbl)	Given				2.00			
Capital Recovery Factor ($/bbl)	Given				0.90			
Tot Input Cost, Prod Value					105.74			
L/H Product Differential	(Gaso.+ GO)/2 - FO (L to H Diff.)				21.04			

In 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.

- In other words, the yield data represents the products produced by processing a barrel of WTI in a refinery where the last (or marginal) barrel is consumed and yields the given product slate.

- 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

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

In Step 3, reasonable additional costs, on a barrel of crude oil basis, are added to the marker crude price in order to arrive at the 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 has 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 marginal, or price setting, configuration.

In 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 total product value equals the total input cost, given a zero margin above variable, fixed and capital return factors included in the input cost.

In Step 5, the heavy fuel oil discount to crude is entered in the Refinery Model. This discount acts to define the light to heavy product differential environment.

In 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.

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

In 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 long term relatively narrow.

- 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.

The Refinery Model determines the refined product pricing for the other two global refining centers, Singapore and North West Europe, using a methodology similar to that used for the U.S. Gulf Coast.

Refined Product Pricing – 16 IEO Regions

Once the Refinery Model determines the refined product pricing for the USGC, N.W.E. and Singapore, the model then calculates the long-term equilibrium product wholesale pricing for each of the 16 *IEO2011* regions. The primary inputs are the relative transportation cost differentials from the appropriate refining center(s) to a region (Figure 5).

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

The product pricing for each IEO Region is tied to one or more of the three Global Refining Centers via transportation-based pricing links

– Asia Example:

- Product Pricing in China =

  Product Pricing in Singapore +

  Transportation from Singapore to China

- Product Pricing in Japan =

  Product Pricing in Singapore +

  Transportation from Singapore to China –

  Transportation from Japan to China

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 *IEO2011* 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 total product value equals the total input cost, given a zero margin above variable, fixed and capital return factors included in the input cost.

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.

The total product value equals the sum of refined product yields times their respective pricing, as follows:

*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 Yield * LSFO Price*

Based on input data that provides the LPG price and LSFO price in terms of the WTI crude cost, the only two prices left are 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 estimate for diesel and kerosene above gasoline and naphtha. Therefore, the diesel and kerosene price can be expressed in terms of the gasoline and naphtha price, as follows.

Diesel Price = Gasoline Price + Diesel Premium above Gasoline Price

Kerosene Price = Gasoline Price + Kerosene Premium above Gasoline Price

And the total product value equation can be expressed in the following manner

*TPV = LPG Yield * LPG Price +*

*Gasoline Yield * Gasoline Price + Naphta Yield * Naphta Price +*

*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*

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 that are based on reasonable assumptions and projections about the projected 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 *IEO2011* regions

After the Refinery Model determines the refined product pricing for the USGC, N.W.E. and Singapore, the model then calculates the long-term equilibrium product pricing for each of the *IEO2011* regions:

1 - USA - United States

2 - CAN - Canada

3 - MXC - Mexico/Chile

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 pricing to pricing 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 to USGC)*
3	*- MXC*	*P (PP,MEX) = P (PP,USGC) + T (USGC to MEX)*

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

- Of course, on a more detailed sub-regional basis, the precise transportation linkages are more complex than those shown above.
- For example, Canada is typically a refined product exporter into the U.S. Midwest and U.S. Northeast sub-regions.
- However, for the 16 IEO Regions, the goal was to present the overall refined product trade and resultant pricing patterns in a reasonable and straightforward manner, without adding another layer of sub-regional complexity.

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

It should also be noted that the calculated pricing is on an open market basis and does not include specific pricing adjustments within a given country.

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

- *EUR* *P (PP,EUR) = P (PP,EUR/NWE)*
- *JPN* *P (PP,JPN) = P (PP,SING) + T (SING to CHI) - T (JPN to CHI)*
- *ANZ* *P (PP,ANZ) = P (PP,SING) - T (SING to ANZ)*

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

  and P (PP, USGC) - T (CSA to USGC))

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

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

Alternative Crude Pricing

This section explains the algorithm the Refinery Model uses to compute prices, for every year in the forecasted period, in the USGC region for the following crude types:

1. Foreign Light Sulfur Light (FLL)
2. Foreign Medium Sulfur Heavy (FMH)
3. Foreign High Sulfur Light (FHL)
4. Foreign High Sulfur Heavy (FHH)
5. Foreign High Sulfur Very Heavy (FHV)

FLL price, by definition, is the price of WTI (FOB Cushing) in a USGC refinery in a cat cracking marginal configuration. Following are the formulas used to compute prices for five alternative crudes. All product prices used are for USGC region.

FLL Total Input Cost = WTI (FOB Cushing) +Transportation Cost to the USGC+

Marginal Operating Cost + Fixed Operating Cost + Capital Recovery Factor

*FMH Total Input Cost = LPG Yield * LPG Price + Gasoline Yield * Gasoline Price + Naphta Yield * Naphta Price + Diesel Yield * Diesel Price + Kerosene Yield * Kerosene Price + High Sulfur Fuel Oil Yield * High Sulfur Fuel Oil Price*

where

High Sulfur Fuel Oil Price = Low Sulfur Fuel Oil Price - High Sulfur Fuel Oil Discount for FMH crude type

FMH Price (USGC) = FMH Total Input Cost – Capital Recovery Cost – Fixed Op Cost – Marginal Op Cost

FMH (FOB) = FMH price (USGC) – Transport Cost to USGC

*FHL Total Input Cost = LPG Yield * LPG Price + Gasoline Yield * Gasoline Price + Naphta Yield * Naphta Price + Diesel Yield * Diesel Price + Kerosene Yield * Kerosene Price + High Sulfur Fuel Oil Yield * High Sulfur Fuel Oil Price*

where

High Sulfur Fuel Oil Price = Low Sulfur Fuel Oil Price - High Sulfur Fuel Oil Discount for FHL crude type

and

*High Sulfur Fuel Oil Discount for FHL crude type = High Sulfur Fuel Oil Discount for FMH crude type + (FHL Sufur Content – FMH Sulfur Content) * Incremental High Sulfur Fuel Oil Discount for FHL crude type*

FHL price (USGC) = FHL Total Input Cost – Capital Recovery Cost – Fixed Op Cost – Marginal Op Cost (FHL)

Where

*Marginal Op Cost (FHL) = Marginal Op Cost (FLL) + Incremental Cost for Alt. Crude Sulfur (FHL) * (FHL Sulfur Content – FLL Sulfur Content)*

FHL (FOB) = FHL Price (USGC) – Transport Cost to USGC

Prices for the other two alternative crudes, FHH and FHV, are computed in the same way as they were computed for FHL crude type.

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 2008)
QHKSRS(r,y):	Historical kerosene consumption in the residential sector by region and year (years 1980 through 2008)
QHLGRS(r,y):	Historical liquefied petroleum gas consumption in the residential sector by region and year (years 1980 through 2008)
QHMGCM(r,y):	Historical motor gasoline consumption in the commercial sector by region and year (years 1980 through 2008)
QHDSCM(r,y):	Historical distillate fuel consumption in the commercial sector by region and year (years 1980 through 2008)
QHKSCM(r,y):	Historical kerosene consumption in the commercial sector by region and year (years 1980 through 2008)
QHRSCM(r,y):	Historical residual fuel consumption in the commercial sector by region and year (years 1980 through 2008)
QHLGCM(r,y):	Historical liquefied petroleum gas consumption in the commercial sector by region and year (years 1980 through 2008)
QHMGIN(r,y):	Historical motor gasoline consumption in the industrial sector by region and year (years 1980 through 2008)
QHDSIN(r,y):	Historical distillate fuel consumption in the industrial sector by region and year (years 1980 through 2008)
QHRSIN(r,y):	Historical residual fuel consumption in the industrial sector by region and year (years 1980 through 2008)
QHKSIN(r,y):	Historical kerosene consumption in the industrial sector by region and year (years 1980 through 2008)
QHLGIN(r,y):	Historical liquefied petroleum gas consumption in the industrial sector by region and year (years 1980 through 2008)
QHPCIN(r,y):	Historical petroleum coke consumption in the industrial sector by region and year (years 1980 through 2008)
QHSPIN(r,y):	Historical sequestered petroleum fuel consumption in the industrial sector by region and year (years 1980 through 2008)
QHOPIN(r,y):	Historical other petroleum consumption in the industrial sector by region and year (years 1980 through 2008)
QHMGTR(r,y):	Historical motor gasoline consumption in the transportation sector by region and year (years 2005 through 2008)

QHDSTR(r,y):	Historical distillate (diesel) fuel consumption in the transportation sector by region and year (years 1980 through 2008)
QHRSTR(r,y):	Historical residual fuel consumption in the transportation sector by region and year (years 1980 through 2008)
QHLGTR(r,y):	Historical liquefied petroleum gas consumption in the transportation sector by region and year (years 1980 through 2008)
QHJFTR(r,y):	Historical jet fuel consumption in the transportation sector by region and year (years 1980 through 2008)
QHSPTR(r,y):	Historical sequestered petroleum fuel consumption in the transportation sector by region and year (years 1980 through 2008)
QHOPTR(r,y):	Historical other petroleum consumption in the transportation sector by region and year (years 1980 through 2008)
QHETTR(r,y):	Historical ethanol (E85) consumption in the transportation sector by region and year (years 1980 through 2008)
QHOBTR(r,y):	Historical biofuels (excluding ethanol) consumption in the transportation sector by region and year (years 1980 through 2008)
QHDSPG(r,y):	Historical utility consumption of distillate (in trillion Btu) by region and year (years 1980 through 2008)
QHRSPG(r,y):	Historical utility consumption of residual (in trillion Btu) by region and year (years 1980 through 2008)
QHDSDH(r,y):	Historical distillate fuel consumption in the district heat sector by region and year (years 1980 through 2008)
QHRSDH(r,y):	Historical residual fuel consumption in the district heat sector by region and year (years 1980 through 2008)
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 (2009 through 2035)
QRSDH(r,y):	Consumption of residual fuel used for district heat generation by region and year (2009 through 2035)
QGTLProd(r,y):	Quantity of gas-to-liquids fuel produced by region and year (2001 through 2035)
QGTLProd(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.

LMYr	Last model forecast year
LHYr	Last model historical year
ICrude_Type(ty)	Type of crude oil (1 = WTI, 2 = Brent, 3 = Dubai)
IPrice_Center(c)	Price center (1 = USGC, 2 = N.W.E., 3 = Singapore)
IRef_Type(rt)	Refining type (1 = catalytic cracking, 2 = hydroskimming)
IDifferential(d)	Type of price differential (1 = narrow, 2 = wide)
IReg(r)	Region indicator (1= United States, 2= Canada, 3 = Mexico/Chile, 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)
TrCost(r1,r2)	Transportation costs between each of the *IEO2011* regions
RCVar(c,x,2001;pFYr)	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
rLHeatContent(20)	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)

tr(rte)	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.

rCenterProductPrice(15,c,y)	Wholesale crude product prices by product, center and year
rCenterProductYieldValue(15,c,y)	Yields wholesale product prices value by product, center and year
rRegionProductPrice(15,r,y)	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
AltCrudeRCVar(10,20,2001:2050)	Coefficients to compute alternative crude prices. First dimension is crude type as follows: 1-FLL (WTI), 2-FMH, 3-FHL, 4-FHH, 5-FHV. Second dimension is as follows: 1-sulfur content, 2-LG yield, 3-Gas/Naphta yield, 4-DS yield, 5-FO yield, 6-Incremental HSFO discount ($/%sulfur), 7-Incremental sulfur Marg. Op. Cost ($/%sulfur), 8-Incremental TAN Marg. Op. Cost,9- Fixed Op. Cost ($/bbl), 10-Capital Recovery Factor ($/bbl), 11-Transportation to USGC ($/bbl)

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

!Prices for Residential Sector

PDSRS(pReg,2001:pFYr)	Distillate
PKSRS(pReg,2001:pFYr)	Kerosene
PLGRS(pReg,2001:pFYr)	Liquefied petroleum gas

!Prices for Commercial Sector

PMGCM(pReg,2001:pFYr)	Motor gasoline
PDSCM(pReg,2001:pFYr)	Distillate
PRSCM(pReg,2001:pFYr)	Residual

PKSCM(pReg,2001:pFYr)	Kerosene
PLGCM(pReg,2001:pFYr)	Liquefied petroleum gas

!Prices for Industrial Sector

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

!Prices for Transportation Sector

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

!Prices for Electric Power Sector

PDSPG(pReg,2001:pFYr)	Distillate
PRSPG(pReg,2001:pFYr)	Residual

!Prices for District Heating Sector

PDSDH(pReg,2001:pFYr)	Distillate
PRSDH(pReg,2001:pFYr)	Residual

Note: alternative crude prices for five crude types are stored in the variable:

rCrudeTypePriceFOB(10,2001:2050)

The first dimension is the crude type as noted above.

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	5.253
Distillate	2	5.825
Residual	3	6.287

Kerosene	4	5.670
LPG	5	3.553
Jet Fuel	6	5.670
Petroleum Coke	7	6.024
Sequestered Petroleum	8	5.800
Other Petroleum	9	5.800
Ethanol	10	3.563
Biodiesel	11	5.359
Naphtha	12	5.248

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 is first used to read, from FileCntl.txt file, the values for 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 is beeping 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 the "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 *IEO2011* 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) <= P (MG, USGC) + T (USGC to USEC) – T (EUR to USEC).

Rule 2. Because USGC region exports DS to EUR following rule is enforced: P (DS, EUR) >= P (DS, USGC) + T (USGC 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.

SUBROUTINE: ComputeAlternativaCrudePricingsubroutine

Description: The ComputeAlternativaCrudePricingsubroutine computes prices (FOB) for five alternative crudes: FLL, FMH, FHL, FHH, and FHV, based on the concept of indifference or parity pricing. In a perfect market, the price differential between two crude types should be very close to the difference between their netbacks of the marginal refinery, which sets the price.

Appendix C. References

Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (McGraw-Hill Book Company, NY: NY, 1967).

Bloomberg.com: Energy, Bloomberg News Service: Energy, web site www.bloomberg.com/energy.

BP Statistical Review of World Energy 2011 (London, UK, June 2011).

Energy Information Administration, *International Petroleum Monthly* (various editions), web site (www.eia.doe.gov/ipm).

Franklin J. Stermole and John M. Stermole, *Economic Evaluation and Investment Decision Methods: Eleventh Edition* (Investment Evaluations Corporation, Lockwood, CO, 2006).

International Energy Agency, *IEA Statistics: Oil Information 2010* (Paris, France, 2010).

International Energy Agency, *OMR Data: Refinery Product Yields for Marginal Refining Configurations* (Paris, France, 2009).

Purvin and Gertz, Inc., *GPMO (Global Petroleum Market Outlook) 2009 and Updates*

Walter Nicholson, *Microeconomic Theory: Basic Principles and Extensions* (Harcourt College Publishers, Fort Worth: Texas, 1972).

Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).

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:

March 2010.

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 *IEO2011* 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

Official Model Representative:

Adrian Geagla
U.S. Energy Information Administration
EI-81/Forrestal Building
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

telephone: (202) 586-2873
fax: (202) 586-3045
e-mail: adrian.geagla@eia..gov

Documentation:

U.S. Energy Information Administration, U.S. Department of Energy, *Refinery Model of the World Energy Projection System Plus: Model Documentation 2011 Report*, DOE/EIA-M084(2011) (Washington, D.C., August 2011).

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 2011,* DOE/EIA-0484 (August 2011). 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 2011* (*IEO2011*) regions.

Coverage:

- Geographic: 16 *IEO2011* regions
- Time Unit/Frequency: Annual through 2035
- Products: Primary refined product pricing for 16 *IEO2011* 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 *IEO2011* regions, inputs include the transportation cost differentials from the three global refining centers to the16 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 *IEO2011* 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

- *AEO2011* – 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