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International Energy Module of the National Energy Modeling System: Model Documentation 2008

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Update Information

This edition of the *International Energy Module of the National Energy Modeling System: Model Documentation 2008* reflects changes made to the module for the *Annual Energy Outlook 2008*. These changes include:

- The International Energy Module (IEM) has been modified to use exogenous global and U.S. petroleum liquids[1] supply and demand curves, with one curve for each year from 2008 through 2030. The global curves are isoelastic curves fit to previous results from the Energy Information Administration's (EIA's) *International Energy Outlook 2007*. The U.S. curves are isoelastic curves fit to previous results from the National Energy Modeling System (NEMS).

- A new feedback algorithm for world oil price (WOP) has been implemented to estimate the effects of changes in U.S. petroleum liquids production and consumption on the WOP. Based on the difference between U.S. total petroleum liquids production (consumption) and the expected U.S. total liquids production (consumption) at the current WOP, curves for global petroleum liquids supply (demand) shift in each year. Using the shifted curves, a new WOP is calculated in each year.

- The IEM uses an exogenous oil supply model, Generate World Oil Balances (GWOB) to provide annual production detail at the regional/country level for conventional and unconventional liquids.

- Interaction between the IEM and the Petroleum Market Module (PMM) has been updated. This update enables new functionality which projects changes in the WOP and the prices of crude oils and petroleum products imported into the United States.

- The IEM also determines new quantities for oil production in the Middle East OPEC region, along with a report of crude oil and light and heavy refined products quantities imported into the United States by country of origin.

- The content of the NEMS input file (omsinput.txt) has been changed to reflect the new functionality in the IEM. Supply and demand curves for the United States and the world now have a different format. New data include: refinery utilization factors, linear regressions coefficients, percentages of crude oils and petroleum products imported in the United States by region, and correlation coefficients between oil types by Petroleum Administration for Defense District (PADD).

- To facilitate information exchange between the IEM and NEMS, the global structure includes new variables.

[1]In this document, "petroleum liquids" includes crude oils, lease condensate, shale oil, bitumen, extra heavy oils, natural gas plant liquids, and refinery gain.

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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach, and development of the International Energy Module (IEM) of the National Energy Modeling System (NEMS). The report 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 and other scenarios.

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

Model Summary

The NEMS International Energy Module is a calculation tool. It uses assumptions of economic growth and expectations of future annual U.S. and world petroleum liquids production and consumption to model the interaction of U.S. and international liquids markets. It projects international oil conditions, including demand, price and supply, and the impact of changes in the U.S. petroleum market on world markets. It is an instrument to recalculate world oil prices in response to changes in U.S. petroleum liquids production and consumption. In addition, the IEM provides supply curves of crude oil imported to the United States in each of the five Petroleum Allocation for Defense Districts (PADD) for five generic crude oil grades: low sulfur light, high sulfur light, medium sulfur heavy, high sulfur heavy, and high sulfur very heavy. Finally, the IEM provides U.S. import supply curves for as many as 18 petroleum products[2] by PADD. The model employs a general equilibrium algorithm to calculate the world oil price, and generates U.S. crude oil and petroleum product supply curves based on a series of simple and logarithmic linear regression equations that have been developed exogenously and are used as IEM model input. U.S. petroleum product import quantities are calculated by region or country for crude oil and light and heavy refined products based on a sharing algorithm that applies the share of the total each region is assumed to supply.

[2] The 18 petroleum products are: Motor Gasoline, Reformulated Motor Gasoline, Liquefied Petroleum Gases, Kerosene-Jet Fuel, Distillate, Low Sulfur Distillate, Ultra Low Sulfur Distillate, Low Sulfur Residual Fuel, High Sulfur Residual Fuel, Petrochemical Feedstocks, Other, Methanol, Conventional Blendstock for Oxygenate Blending (CBOB), Reformulated Blendstock for Oxygenate Blending (RBOB), MTBE, Unfinished Oils – Residual Fuel, Unfinished Oils – Naphtha, and Unfinished Oils – Heavy Gas Oil.

Model Archival Citation

This documentation refers to the NEMS International Energy Module as archived for the *Annual Energy Outlook 2008 (AEO2008)*.

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Organization of This Report

Chapter 2 of this report, "Model Purpose," identifies the analytical issues the IEM is intended to address, the general types of activities and relationships it embodies, its primary inputs and outputs, and its interactions with other NEMS modules. Chapter 3 describes in greater detail the rationale behind the model design, the modeling approach chosen for each IEM component, and the assumptions used in the model development process, citing theoretical or empirical evidence supporting 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, and the outputs of most relevance to the NEMS system. A table referencing the equation(s) in which each variable appears is also provided in Appendix A. 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.

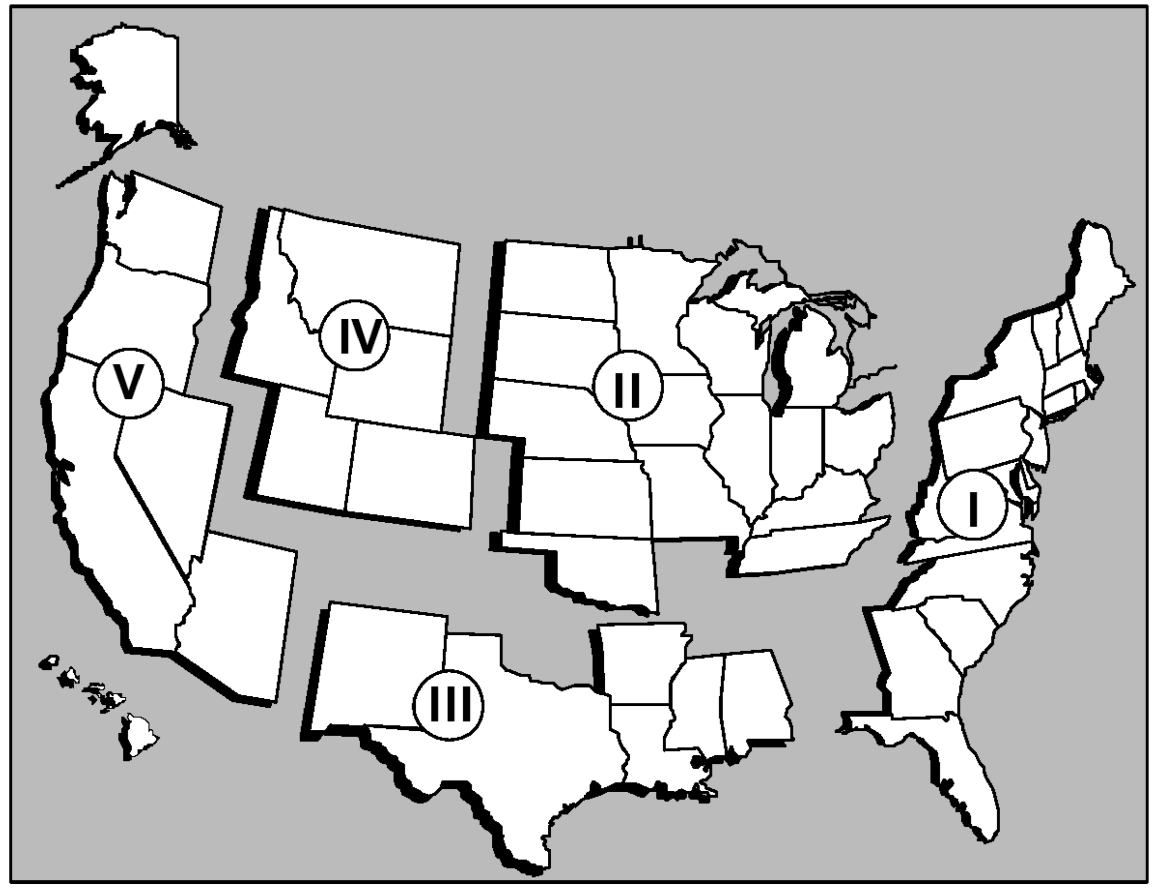
2. Model Purpose

Model Objectives

Understanding the interactive effects of changes in the U.S. and world energy markets has always been a key EIA focus. The IEM was incorporated into NEMS in order to enhance the capabilities of NEMS in addressing the interaction of the global and U.S. oil markets. Components of the IEM accomplish the following:

- Calculation of the world oil price (WOP), which is defined as the price of light, low sulfur crude oil delivered to Cushing, Oklahoma (PADD2). Changes in the WOP are computed in response to:
    - The difference between U.S. total petroleum liquids production and the expected U.S. total petroleum liquids production at the current WOP (which is estimated using the current WOP and the exogenous U.S. total petroleum liquids supply curve for each year).
    - The difference between U.S. total petroleum liquids consumption and the expected U.S. total petroleum liquids consumption at the current WOP (estimated using the current WOP and the exogenous U.S. total petroleum liquids demand curve).
- Provision of supply curves for five generic grades of crude oil for import to the United States in each of the five PADDs (Figure 1). The IEM forecasts international crude oil market conditions, including demand, price and supply, and the effects of changes in the U.S. petroleum market on the world market.
- Provision of supply curves for U.S. imports of 18 petroleum products in each of the five PADDs. The supply curves reflect conditions in the world liquids market, including refinery capacity, refinery utilization factors in different regions of the world, and transportation costs.

Figure 1. Map of the U.S. Petroleum Allocation for Defense Districts



Model Inputs and Outputs

Inputs

The primary inputs to the IEM include expected U.S. and global petroleum liquids production and consumption; elasticities associated with petroleum liquids demand and supply curves; world oil prices; refinery utilization factors; and linear regression coefficients for independent variables used in computing petroleum product prices. Additional detail on model inputs is provided in Appendix A. The major inputs are summarized in Table 1.

Table 1. IEM Model Inputs

Model Inputs	Source
Projected U.S. petroleum liquids consumption and production by year	Petroleum Market Module
Projected U.S. crude oil and petroleum product import quantities	Petroleum Market Module
Expected U.S. and world petroleum liquids supply and demand by year	Exogenous values included in input file Omsecon.txt
Elasticities for U.S. and world petroleum liquids demand curves by year	Exogenous values included in input file Omsecon.txt
Elasticities for U.S. and world petroleum liquids supply curves by year	Assumed isoelastic supply curves using exogenous elasticities in input file Omsecon.txt
Expected world oil price by year	Exogenous values included in input file Omsecon.txt
Crude oil quality (e.g., sulfur content) multipliers for each oil type; PADD independent	Exogenous values included in input file Omsecon.txt
Location multipliers by PADD for all oils	Exogenous values included in input file Omsecon.txt
Global regional refinery utilization factors	Exogenous values included in input file Omsecon.txt
Linear regression coefficients for independent variables used in the process of computing petroleum product prices	Exogenous values included in input file Omsecon.txt
Shares of total U.S. crude oil and light and heavy refined product import supplies by region	Exogenous values, included in input file Omsecon.txt
GDP Deflators	Macroeconomic Activity Module

Outputs

The primary outputs of the IEM are world import supply curves and regional supply quantities and U.S. import quantities by source. Table 2 summarizes these outputs.

Table 2. IEM Model Outputs

Model Outputs	Destination
World crude oil and petroleum product import supply curves	Petroleum Market Module
World liquids supply and distribution by region	Petroleum Market Module
U.S. crude and petroleum product import quantities by source	Petroleum Market Module

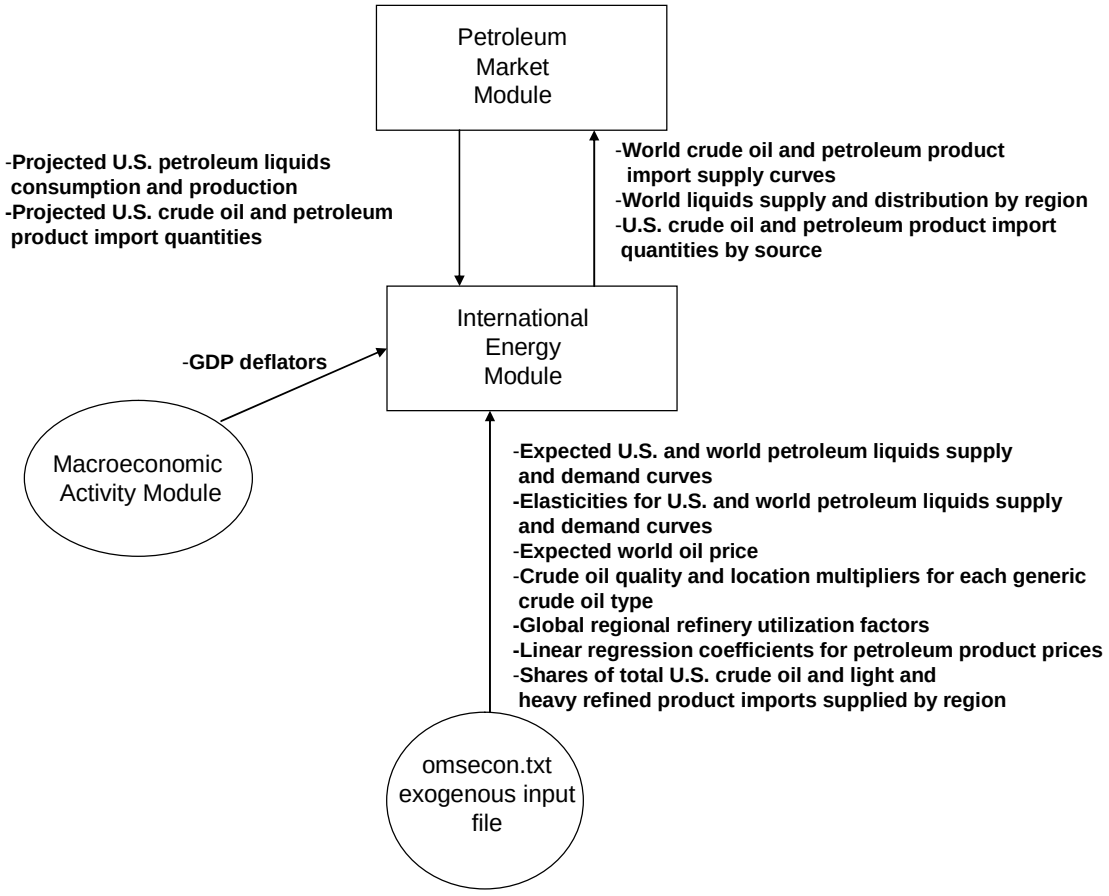
Relationship of the International Energy Module to Other NEMS Modules

The IEM uses information from other NEMS components; it also provides information to other NEMS components. The information it uses is primarily about annual U.S. projected production and consumption quantities. The information it provides is connected to crude oil and petroleum products prices and sources. It should be noted, however, that the present focus of the IEM is on the international oil market. Any interactions between the U.S. and foreign regions in fuels other than oil (e.g. the coal trade) are modeled in the particular NEMS module that deals with that fuel.

For U.S. petroleum liquids production and consumption in any year of the projection period, the IEM uses production projections generated by the Oil and Gas Supply Module and consumption projections from the end-use demand modules (Figure 2).

Supply and demand curves for U.S. and world expected petroleum liquids, for any year in the forecast period, are exogenously provided through data included in the input file omsecon.txt, as described in Appendix A, "Input Data and Variable Descriptions."

Figure 2. IEM Relationship to Other NEMS Modules



3. Model Rationale

Theoretical Approach

The NEMS International Energy Module is a calculation tool that uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids supply and demand, by year, to model the interaction of U.S. and international oil markets. The IEM employs a general equilibrium algorithm to calculate the world oil price. The module also uses coefficients from a set of exogenous, linear regression equations to estimate crude oil and petroleum product import supply curves for five generic crude oil types and up to 18 petroleum products by PADD.

The IEM helps to ensure that world liquids markets are in equilibrium. To do that, it tracks the initial world oil price path assumption as well as expected U.S. oil production and consumption quantities. It then calculates the world oil price required to bring world liquids markets into back into balance when U.S. oil production and/or consumption deviate from what is expected at the reference world oil price.

The IEM also determines U.S. petroleum import supply curves for five generic crude oil grades and 18 petroleum product streams, and passes this information to the Petroleum Market Module. Once the NEMS reaches convergence, the IEM produces data on total U.S. imports of crude oil and light and heavy refined products by country or region. Simple and logarithmic linear regressions are used to project supply curves for petroleum products imported in the U.S, and then to convey the results to the NEMS Integrating Module for use in the final NEMS reports.

Fundamental Assumptions

For the AEO2008, the IEM begins with basic assumptions about the liquids demand and supply curves for the United States and the world, based upon the results published in the AEO2007. Appendix A contains a full sample of the IEM input data file assumptions. The following data are input into the IEM:

1) Global Total Petroleum Liquids Demand Curves
2) U.S. Total Petroleum Liquids Demand Curves
3) Global Total Petroleum Liquids Supply Curves
4) U.S. Total Petroleum Liquids Supply Curves

For each year of the forecast period, all supply and demand curves are expressed as functions:

$$Q = \alpha P^{\varepsilon}$$

where P is the price, Q is the quantity, ε is the elasticity (assumed to be constant for each curve, but whose values may vary from year to year), and α is a constant that is determined by the coordinates of a point on the curve.

Global Total Petroleum Liquids Supply and US Total Petroleum Liquids Supply Curves. These curves are built exogenously with data from the Oil and Gas Supply Module of NEMS, the Generate World Oil Balances (GWOB) model developed to provide global liquids supplies by country and fuel type, and previous runs of NEMS. For both of these supply curves, the value of the elasticities in each year is assumed to be 0.25.

Global Total Petroleum Liquids Demand Curves and US Total Petroleum Liquids Demand Curves. For each year of period 2008-2030, these curves are constructed in the same format as the supply curves:

$$\mathbf{Q = \alpha P^{\varepsilon}}$$

where P is the price, Q is the quantity, ε is the elasticity assumed to be constant for each curve (but which can vary from year to year), and α is a constant that can be determined by knowing the coordinates of a point on the curve. Values for **P,** expected world oil prices, are provided by assumption. Values for **Q** are assumed based upon previous NEMS and GWOB model runs.

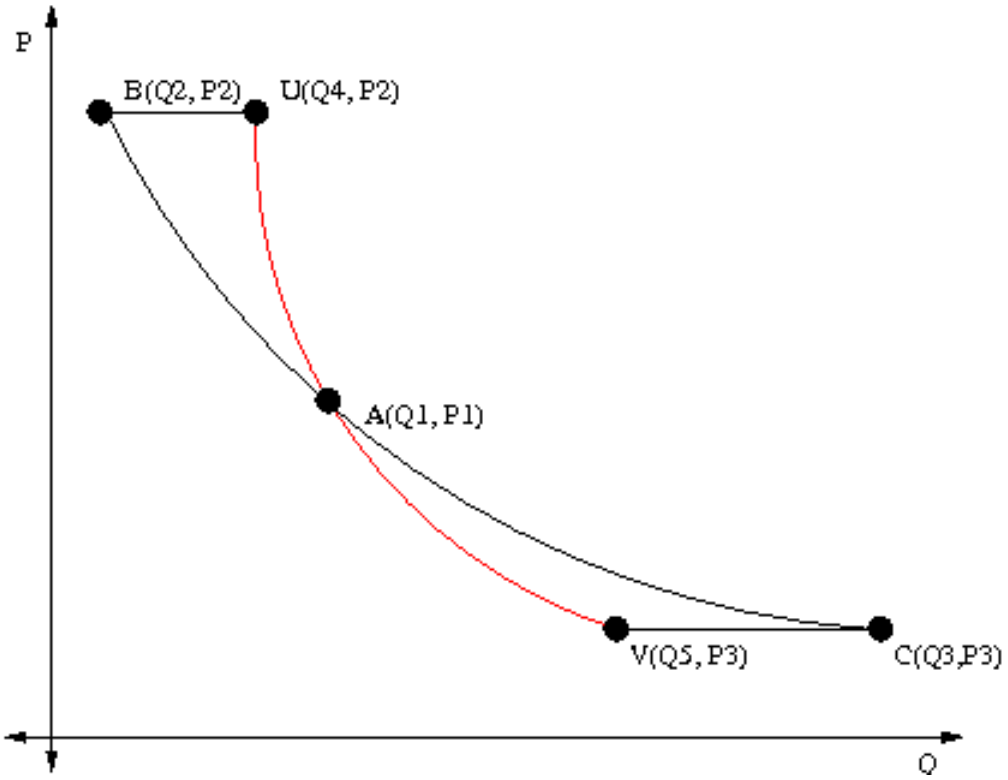
Demand elasticities (ε) were calculated on an annual basis from 2008 through 2030 using past projections of prices and world liquids supply and demand from the *Annual Energy Outlook* 2007. For each year of the forecasted period, elasticities are computed using an optimization algorithm.

That is, using results from the *AEO2007* as follows (see Figure 3):

P1 – World oil price in Reference Case Scenario
Q1 – Global total petroleum liquids demand in Reference Case Scenario
P2 – World oil price in High Oil Price Case Scenario
Q2 – Global total petroleum liquids demand in High Oil Price Case Scenario
P3 – World oil price in Low Oil Price Case Scenario
Q3 – Global total petroleum liquids demand in Low Oil Price Case Scenario

Points A (Q1, P1), B (Q2, P2), C (Q3, P3) are plotted as is shown in Figure 3, as are points U (Q4, P2) and V (Q5, P3). Curve BAC is then approximated using isoelastic curve UAV in such a way that the sum of the lengths of segments BU and VC has a minimum value.

Figure 3. Global Total Petroleum Liquids Demand Curve



$$Q4 = \alpha\,(P2)^{\varepsilon},\ Q5 = \alpha\,(P3)^{\varepsilon},\ Q1 = \alpha\,(P1)^{\varepsilon}$$

$$Q4/Q1 = (P2/P1)^{\varepsilon},\ \text{therefore}\ Q4 = Q1\,(P2/P1)^{\varepsilon}$$

$$Q5/Q1 = (P3/P1)^{\varepsilon},\ \text{therefore}\ Q5 = Q1\,(P3/P1)^{\varepsilon}$$

$$BU = abs\,|Q2 - Q4| = abs\,|Q2 - Q1\,(P2/P1)^{\varepsilon}|$$

$$VC = abs\,|Q3 - Q5| = abs\,|Q3 - Q1\,(P3/P1)^{\varepsilon}|$$

$$Let\ F(\varepsilon) = BU + VC = abs\,|Q2 - Q1\,(P2/P1)^{\varepsilon}| + abs\,|Q3 - Q1\,(P3/P1)^{\varepsilon}|$$

To find $\varepsilon < 0$ such that the sum of lengths of segments BU and VC has a minimum value, such that:

$$Min_{\varepsilon<0}\,F(\varepsilon) = Min_{\varepsilon<0}\,(abs\,|Q2 - Q1\,(P2/P1)^{\varepsilon}| + abs\,|Q3 - Q1\,(P3/P1)^{\varepsilon}|)$$

This optimization problem can be solved using a wide range of tools. Thus, the value of this minimum can be found and, more importantly, the value of ε for which the minimum value of function F is achieved can be found as well. In this case, ε = -0.11. By applying this algorithm for each year of the projection period (2008-2030), all U.S. and global total petroleum liquids demand curves are well-defined.

Multipliers. The IEM requires several multipliers for computations that relate the prices of five types of generic crude oil to each PADD. The values of these multipliers are determined based on the analysis of historical data taken from multiple sources. It is important to observe that

because the world oil price is considered to be the price of low sulfur light (FLL) crude in PADD2, multipliers for FLL and PADD2 are equal to 1.

Natural Price Multipliers for each oil type; PADD independent

Oil Type	Multiplier
FLL	1.000000
FHL	0.908613
FMH	0.870551
FHH	0.750917
FHV	0.741574

Multipliers by PADD for all oils

PADD	Multiplier
PADD1	1.018017
PADD2	1.000000
PADD3	1.022254
PADD4	1.013028
PADD5	1.074380

Where FHL = high sulfur light crude, FMH = medium sulfur heavy crude, FHH = high sulfur heavy crude, and FHV = high sulfur very heavy crude.

Refinery Utilization Factors. The refinery utilization factors for different regions of the world were used in the process of computing prices for petroleum products. These values are used in the linear regressions that are described in the Model Structure section of this report with samples illustrated included in Appendix B. Therefore input data, including the values of regression coefficients by petroleum product and by PADD, are as follows:

Global Regional Refinery Utilization
Mean 1995 – 2005

Asia-Pac.	0.852928
Europe	0.787325
Japan	0.853428
OAP	0.895728
USA	0.905742
World	0.840266
RestWorld	0.823726

PADD1 Coefficients for independent variables

Constant	WTI_REAL	UTIL_USA	UTIL_ROW	C5
0.0	0.766	4.222	2.206	0.0
0.0	0.943	0.0	7.288	0.0
0.0	0.922	0.0	7.659	0.0
-19.437	-0.752	0.0	0.0	0.0

U.S. Liquids Imports Assumptions. The IEM makes a number of assumptions about U.S. imports of crude oil and light and heavy refined petroleum products by region or country. The initial run of the IEM includes assumed total U.S. crude oil imports (in million barrels per day) and the percent of U.S. light and heavy refined petroleum product imports, as follows:

Percentage of Total Crude OIL Imports by Region

	2004	2005	2006	2007	2008
Canada	0.156590684	0.157534247	0.157843137	0.160358566	0.160358566
Mexico	0.158572844	0.151663405	0.147058824	0.141434263	0.142430279

Percentage of Light Refined Products by Region

	2004	2005	2006	2007	2008
Canada	0.247191011	0.250000000	0.243781095	0.243654822	0.236453202
N.Europe	0.174157304	0.168367347	0.164179105	0.167512690	0.167487684

Percentage of Heavy Refined Products by Region

	2004	2005	2006	2007	2007
Canada	0.05882353	0.056910569	0.05	0.052083333	0.06
N.Europe	0.176470588	0.162601626	0.158333333	0.1875	0.17

4. Model Structure

Structural Overview

The NEMS IEM provides supply curves of five crudes and 18 petroleum products imported to the U.S. under alternative worldwide energy market conditions over the 2008-2030 time period. Alternative scenarios could include policy and regulatory initiatives, resource conditions (such as the declining quality of crude oil in world trade or the location of new refinery capacity), and economic growth paths (specifically low and high growth cases).

The main purpose of the IEM is to re-estimate world oil prices and U.S. crude and petroleum product import supply curves by PADD, and ultimately to provide a report on the quantity of U.S. liquids imports by region or country. All of this must be achieved by keeping world oil markets in balance. Supply import curves are isoelastic curves and points on the curve are adjusted as other NEMS modules (specifically the Petroleum Market Module, Oil & Gas Supply Module, various end-use demand modules, and the Integrating Module) provide information about the U.S. liquids projection.

The basic structure of the main IEM routine is illustrated in Figure 4. A call from the NEMS Integrating Module to the IEM initiates importation of supporting information that is needed to complete the projection calculations for world liquids markets. A substantial amount of support information for the IEM is calculated exogenously. Various techniques, including simple and logarithmic linear regressions, are used to estimate the coefficients and elasticities that are applied within the IEM. The results are saved in the omsecon.txt input file, and are read into the IEM. The IEM main routine or "world" runs the subroutine OMS_Dat_In to import world and U.S. projections of liquids production and consumption from the OMSInput.wk1 file. Next, the World_Data_In subroutine is executed to import U.S. and world total liquids supply and demand curves from the omsecon.txt file.

After the importation of the necessary data, the OMS_Sim subroutine is executed (Figure 5). The purpose of this routine is to recalculate the average world oil price based on the weighted average of five generic crude oil types. In the next step, the model calculates the total U.S. demand for liquids by summing up demand for the individual liquids products. Similarly, U.S. conventional and unconventional production totals are calculated by summing up individual product projections, plus adjusting for refinery processing gain and exports. Finally, the "call on OPEC" is computed by subtracting U.S. conventional supply, U.S. unconventional production, OPEC production, and a discrepancy factor from U.S. demand. Finally OPEC production is recalculated by adjusting for the "call on OPEC" amount.

If the NEMS run is in its final iteration year, the World_Oil_Report subroutine is executed (Figure 6). This subroutine calculates U.S. crude oil import quantities, U.S. light refined product import quantities, and U.S. heavy refined product import quantities. In each case, calculations for total U.S. imports of crude and the appropriate product imports for light and refined products are based on PMM output. In the next step, the quantities imported from each region in the model are calculated. These calculations are based on input from the omsecon.txt file and the regional shares calculated exogenously to the IEM.

The main IEM routine then queries the current calendar year (CURCALYR) variable to ascertain that it is a projection year (in the case of the AEO2008, greater than or equal to 2008). If it is, the World_Compute subroutine is executed (Figure 7). In World_Compute, the total world oil prices are recalculated, along with U.S. import prices for each crude type and each product type based on the latest supply and demand estimates projections from the NEMS PMM.

Once again, the main IEM routine checks to see if the current calendar year is greater than or equal to 2008. If it is, the World_Curves subroutine is executed (Figure 8). World_Curves is a simple subroutine that takes a GDP-deflator to convert the prices from 2005 dollars into 1987 dollars for use in the NEMS PMM. Finally, price and quantity points on the import supply curves are all set to the corresponding price and quantities previously calculated by crude type and product type.

Flow Diagrams

Figure 4. Flowchart for Main IEM Routine

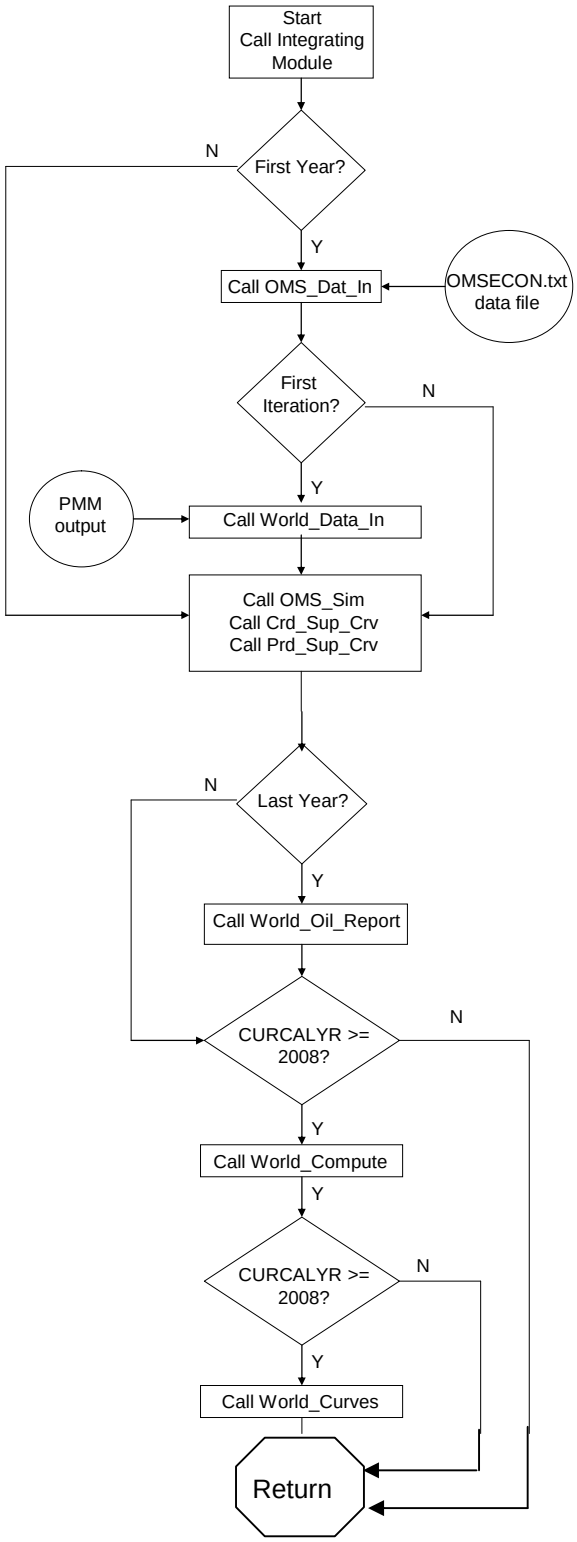


Figure 5. Flowchart for OMS_Sim Subroutine: Adjusts OPEC Supply to Balance World Oil Supply and Demand Based on U.S. Projections

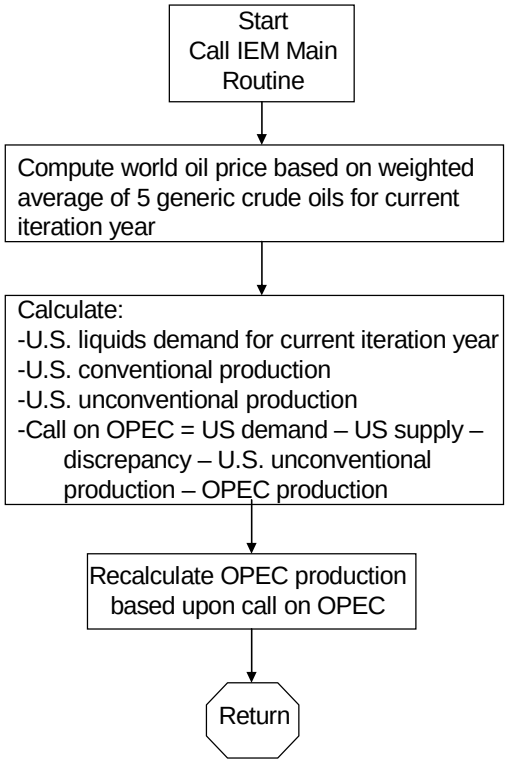


Figure 6. Flowchart for World_Oil_Report Subroutine: Calculates U.S. imports of crude oil and light and heavy refined products

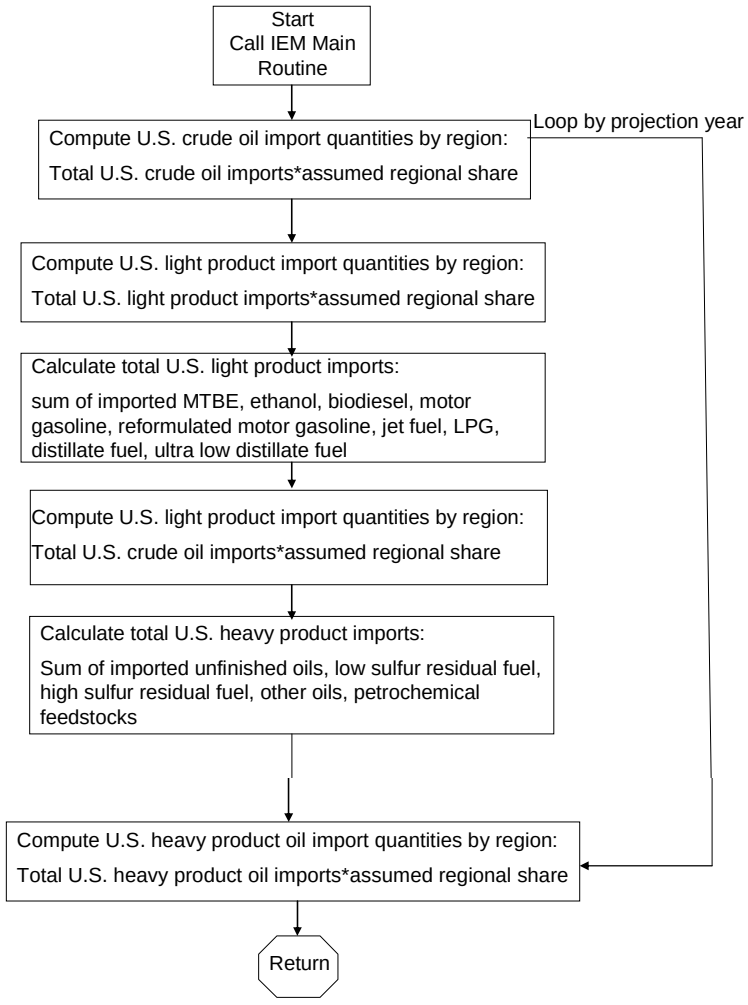


Figure 7. Flowchart for World_Compute Subroutine: Recalculates World Oil Prices Based on New Supply and Demand Estimates

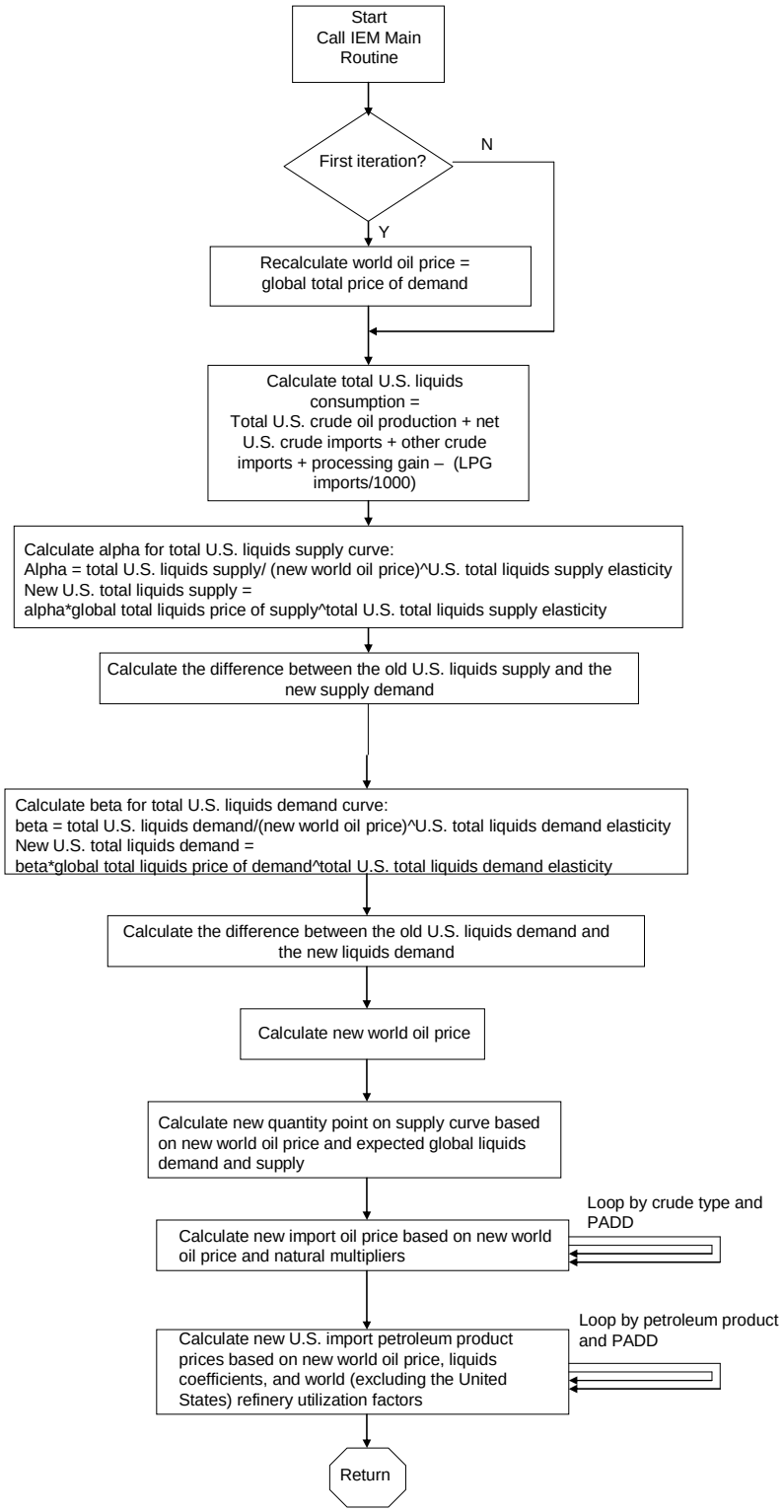
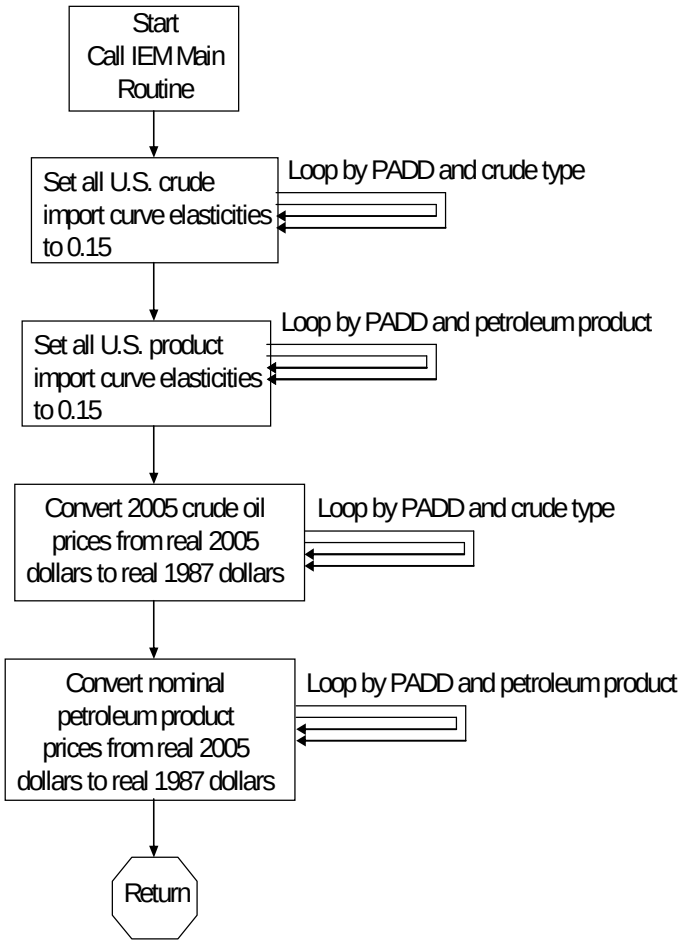


Figure 8. Flowchart for World_Curves Subroutine: Converts 2005 Dollars per Barrel to Real 1987 Dollars per Barrel



Key Computations and Equations

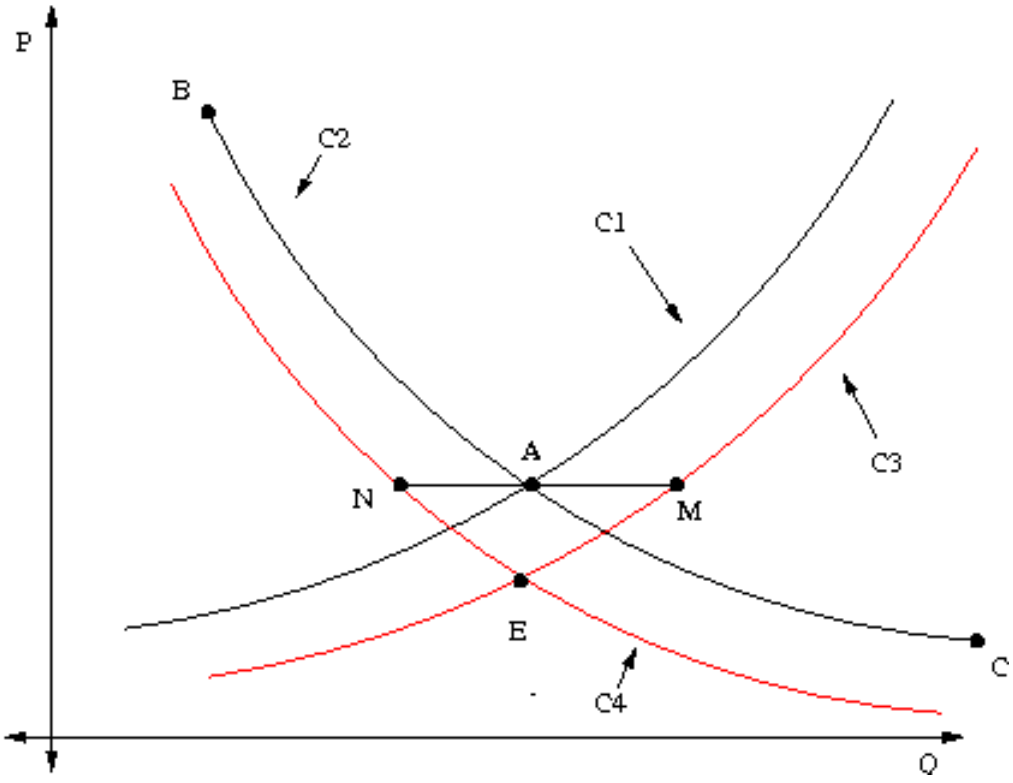
This section provides detailed solution algorithms arranged by sequential subroutine as executed in the NEMS International Energy Module. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the details considered by the full forms of the equations provided in Appendix B.

Recalculating World Oil Prices and U.S. Crude Oil and Product Import Supply Curves

This section explains the algorithm the IEM uses to compute world oil prices (WOP). The WOP, it is important to note, is assumed to be the price of low sulfur light crude (FLL) delivered at Cushing, Oklahoma, in PADD2.

All computations performed in the IEM start with year 2008. The IEM reads the input file (omsecon.txt), and all data and assumptions described in the Model Assumptions section of this report are stored and ready to be accessed for future computations. A visual representation of the algorithm is presented in Figure 4.

Figure 9. Algorithm Used to Recalculate World Oil Prices in the IEM



For each year of the forecasted period, the IEM uses the following methodology to compute the WOP. Let C1 and C2 be the expected world supply and demand curves of petroleum products. These curves are built according to the rules explained in the previous section – Structural Overview.

Let (P_0, Q_0) be the coordinates of equilibrium point A, based on the expected supply and demand curves C1 and C2.

Under a specific scenario, the change in the world petroleum products demand will be determined by the difference ΔQd between U.S. petroleum products consumption (from the PMM) and expected petroleum products demand Q_0 at the current WOP P_0. Point N is the translation of point A along horizontal axis with vector value of ΔQd. Therefore, coordinates of point N are: (P_0, Q_0 + ΔQd). The new demand curve for world petroleum products will be the curve C4 that passes through point N. It is isoelastic, with same elasticity as the initial demand curve C2.

Observation: the new demand curve C4 is not the translation of initial demand curve C2.

In a similar way, under a specific scenario, the change in the world petroleum products supply will be determined by the difference ΔQs between U.S. petroleum products production (from the PMM) and expected petroleum products supply Q_0 at the current WOP P_0. Point M is the translation of point A along horizontal axis with vector value of ΔQs. Therefore, coordinates of point M are: (P_0, Q_0 + ΔQs). The new supply curve for world petroleum products will be the curve C3 that passes through point M. It is isoelastic, with same elasticity as the initial supply curve C1.

Observation: the new supply curve C3 is not the translation of initial demand curve C1.

New equilibrium point E, at the intersection of the new supply and demand curves, will have coordinates (P*, Q*), where P* is the new WOP and Q* is the new total petroleum liquids quantity corresponding to point E.

The following method is used to compute P* and Q*.

ε_s and ε_d will be the symbols used for supply and demand elasticities of expected supply and demand curves.

$$Q_0 + \Delta Qs = \alpha\,(P_0)\ **\varepsilon_s$$
$$Q^* = \alpha\,(P^*)\ **\varepsilon_s$$

$$\text{Therefore } Q^* = (Q_0 + \Delta Qs)\,(P^*/P_0)\ **\varepsilon_s \qquad \text{(i)}$$

$$Q_0 + \Delta Qd = \beta\,(P_0)\ **\ \varepsilon_d$$
$$Q^* = \beta\,(P^*)\ **\ \varepsilon_d$$

$$\text{Therefore } Q^* = (Q_0 + \Delta Qd)\,(P^*/P_0)\ **\ \varepsilon_d \qquad \text{(ii)}$$

From relations (i) and (ii) we conclude that

$$(Q_0 + \Delta Qd) / (Q_0 + \Delta Qs) = (P^*/P_0)\ **\ (\varepsilon_s - \varepsilon_d) \quad \text{(iii)}$$

Relation (iii) is an equation that must be solved for P*. Its solution is given by the following expression:

$$P^* = P_0 e^{**} (\ln ((Q_0 + \Delta Qs) / (Q_0 + \Delta Qd)) / (\varepsilon_d - \varepsilon_s))$$

Also,

$$Q^* = (Q_0 + \Delta Qs) (P^*/ P_0)^{**} \varepsilon_s$$

These computations are performed for each year from 2008 through 2030, until the convergence test is met.

Imported Petroleum Products in the United States

This section explains the procedure used to compute prices for imported petroleum products in the United States. Concrete examples are illustrated in Appendix B.

Linear regression in simple or logarithmic form was used to compute the differential between World Oil Price and a specific petroleum product price. In each case, the independent variables were chosen in such a way that they provide a logical explanation and a better fit for historical data. Independent variables considered for these linear regressions are: world oil price (WOP) and regional refinery utilization factors for Asia-Pacific, Europe, Japan, U.S., and rest of world (whole world without U.S.).

Multiple sources (*International Petroleum Monthly*, Energy Information Administration public website, *Bloomberg*, International Energy Agency, and *BP Review of World Energy*) were used to gather historical data on petroleum product prices imported in the U.S. The "least square method" was used for each linear regression. This activity was performed outside of the IEM and the appropriate coefficients were saved in the omsecon.txt input file as noted above.

The data input section of the omsecon.txt file used for computing petroleum product prices consists of a table with values for refinery utilization factors for different regions in the world. It also includes a series of tables, one for each PADD, that hold the values of the coefficients of independent variables of linear regression that are used to compute product prices. In this set of tables each line corresponds to a petroleum product in the same order as mentioned in Table 5. Some of these regressions are simple linear, and some are logarithmic linear.

Global Regional Refinery Utilization
Mean 1995 - 2005

Asia-Pac.	0.852928
Europe	0.787325
Japan	0.853428
OAP	0.895728
USA	0.905742
World	0.840266
RestWorld	0.823726

PADD1 Coefficients for independent variables

Constant	WTI_REAL	UTIL_USA	UTIL_ROW	C5
0.0	0.766	4.222	2.206	0.0
0.0	0.943	0.0	7.659	0.0
0.0	0.922	0.0	7.659	0.0
-19.437	-0.752	0.0	0.0	0.0

Example 1. Reformulated Blendstock for Oxygenate Blending (RBOB)

The simple linear regression performed in each year of the forecasted period for each PADD is based on world oil price and motor gasoline price as dependent variables. Therefore, the equation that provides the price for RBOB in PADD1 is:

*LiquidRBOB_P(1,W_I_YR) = NEW_WOP(W_I_YR) + (Liquid_Coeff(13,1,1) + Liquid_Coeff(13,2,1)*NEW_WOP(W_I_YR) + 0.451*cGal_LiquidMG_P(1,W_I_YR))*

Equivalent with:

*LiquidRBOB_P(1,W_I_YR) = NEW_WOP(W_I_YR) - 19.437 – 0.752 *NEW_WOP(W_I_YR) + 0.451*cGal_LiquidMG_P(1,W_I_YR))*

Example 2. Motor Gasoline

This is an example of linear regression in logarithmic form. Dependent variables considered are: world oil price, refinery utilization factor in the U.S., and refinery utilization factor in the rest of the world. The equation that provides the price for motor gasoline in PADD1 (used in the Example 1. above) is:

*LiquidMG_P(1, W_I_YR) = NEW_WOP(W_I_YR) + EXP(Liquid_Coeff(1,2,1)*LOG(NEW_WOP(W_I_YR)) + Liquid_Coeff(1,3,1)*LOG(Util_USA) + Liquid_Coeff(1,4,1)*LOG(Util_Rest_of_World))*

Equivalent with:

*LiquidMG_P(1, W_I_YR) = NEW_WOP(W_I_YR) + EXP(0.766*LOG(NEW_WOP(W_I_YR)) + 4.222*LOG(Util_USA) + 2.206*LOG(Util_Rest_of_World))*

Example 3. Low Sulfur Distillate

This is a linear regression in logarithmic form. Dependent variables are: world oil price and refinery utilization factor in the rest of the world. The equation that provides the price for low sulfur distillate in PADD1 is:

LiquidDL_P(1, W_I_YR) = NEW_WOP(W_I_YR) +
*EXP(Liquid_Coeff(6, 2, 1)*LOG(NEW_WOP(W_I_YR)) +*
*Liquid_Coeff(6, 4, 1)*LOG(Util_Rest_of_World))*

Equivalent with:

LiquidDL_P(1, W_I_YR) = NEW_WOP(W_I_YR) +
*EXP(0.922*LOG(NEW_WOP(W_I_YR)) + 7.659*LOG(Util_Rest_of_World))*

World Supply and Demand, Including Conventional and Unconventional Liquids

NEMS also provides an international petroleum supply and disposition summary table. Exogenous data used to build this report is contained in omsinput.wk1 file. Each oil price case has its own version of this file. The supply portion of this report is divided into conventional and unconventional production. Table 2.2, Section A lists all regions considered in this report.

Because U.S. production of conventional liquids is a dynamic value (and an output from NEMS), the OPEC Middle East region is considered the "swing producer." For this reason, the total world production reflects the corresponding value from the International Energy Outlook 2007 for each oil price case. Likewise, because the U.S. consumption of liquids is a dynamic value (and an output from NEMS), all other world regions have been proportionally updated so that the total world liquids consumption corresponds to the values reported in the International Energy Outlook 2007 for each oil price case.

Appendix A. Input Data and Variable Descriptions

The following variables represent data input from omsecon.txt file.

Classification: Input variable.

GTL_P_Demand(MX_W_YR): Global petroleum liquids demand prices
GTL_Q_Demand(MX_W_YR): Global petroleum liquids demand quantities
GTL_DElasticity(MX_W_YR): Global petroleum liquids demand elasticities
USTL_P_Demand(MX_W_YR): U.S. petroleum liquids demand prices
USTL_Q_Demand(MX_W_YR): U.S. petroleum liquids demand quantities
USTL_DElasticity(MX_W_YR): U.S. petroleum liquids demand elasticities
GTL_P_Supply(MX_W_YR): Global petroleum liquids supply prices
GTL_Q_Supply(MX_W_YR): Global petroleum liquids supply quantities
GTL_SElasticity(MX_W_YR): Global petroleum liquids supply elasticities
USTL_P_Supply(MX_W_YR): U.S. petroleum liquids supply prices
USTL_Q_Supply(MX_W_YR): U.S. petroleum liquids supply quantities
USTL_SElasticity(MX_W_YR): U.S. petroleum liquids supply elasticities

The following arrays hold the new prices for oils and liquids (relative to NEW_WOP) by PADD and year:

Classification: Calculated variable.

OilCLL_P(6,MX_W_YR),
OilCMH_P(6,MX_W_YR),
OilCHL_P(6,MX_W_YR),
OilCHH_P(6,MX_W_YR),
OilCHV_P(6,MX_W_YR),
LiquidMG_P(6,MX_W_YR),
LiquidRG_P(6,MX_W_YR),
LiquidLG_P(6,MX_W_YR),
LiquidJF_P(6,MX_W_YR),
LiquidDS_P(6,MX_W_YR),
LiquidDL_P(6,MX_W_YR),
LiquidDU_P(6,MX_W_YR),
LiquidRL_P(6,MX_W_YR),
LiquidRH_P(6,MX_W_YR),
LiquidPF_P(6,MX_W_YR),
LiquidOT_P(6,MX_W_YR),
LiquidUFARB_P(6,MX_W_YR),
LiquidUFNPP_P(6,MX_W_YR),
LiquidUFHGM_P(6,MX_W_YR),
LiquidME_P(6,MX_W_YR),
LiquidCBOB_P(6,MX_W_YR),

LiquidMT_P(6,MX_W_YR),
LiquidRBOB_P(6,MX_W_YR).

U.S. total petroleum liquid production and consumption for 2008-2030 and expected U.S. total petroleum liquid production and consumption for current year:

Classification: Input from PMM

USTL_Production (MX_W_YR),
USTL_Consumption (MX_W_YR)

Classification: Calculated variable

expected_USTL_S, expected_USTL_D.

Current quantities imported in the U.S. for each liquid by type, PADD and year:

Classification: Input from PMM

OilCLL(6,MX_W_YR,2),
OilCMH(6,MX_W_YR,2),
OilCHL(6,MX_W_YR,2),
OilCHH(6,MX_W_YR,2),
OilCHV(6,MX_W_YR,2),
LiquidMG(6,MX_W_YR,2),
LiquidRG(6,MX_W_YR,2),
LiquidLG(6,MX_W_YR,2),
LiquidJF(6,MX_W_YR,2),
LiquidDS(6,MX_W_YR,2),
LiquidDL(6,MX_W_YR,2),
LiquidDU(6,MX_W_YR,2),
LiquidRL(6,MX_W_YR,2),
LiquidRH(6,MX_W_YR,2),
LiquidPF(6,MX_W_YR,2),
LiquidOT(6,MX_W_YR,2),
LiquidUFARB(6,MX_W_YR,2),
LiquidUFNPP(6,MX_W_YR,2),
LiquidUFHGM(6,MX_W_YR,2),
LiquidME(6,MX_W_YR,2),
LiquidCBOB(6,MX_W_YR,2),
LiquidMT(6,MX_W_YR,2),
LiquidRBOB(6,MX_W_YR,2).

Multipliers, from WTI to each oil type (U.S. generic):

Classification: Input variable

Nat_PMPI_FLL,
Nat_PMPI_FHL,
Nat_PMPI_FMH,
Nat_PMPI_FHH,
Nat_PMPI_FHV.

Multipliers, from each oil type (U.S. generic) to oil type by PADD:

Classification: Input variable

OIL_PADD1_PM,
OIL_PADD2_PM,
OIL_PADD3_PM,
OIL_PADD4_PM,
OIL_PADD5_PM.

Global regional refinery utilization:

Classification: Input variable

Util_Asia_Pacific,
Util_Europe,
Util_Japan,
Util_OAP,
Util_USA,
Util_World, *Util_Rest_of_World*.

Percentages, by source, of crude oils and light and heavy refinery products imported in the U.S.:

Classification: Input variable

IOCanadaPct(MX_W_YR2),
IOMexicoPct(MX_W_YR2),
IONorthSeaPct(MX_W_YR2),
IOOPECPct(MX_W_YR2),
IOOPLatinAmericaPct(MX_W_YR2),
IOOPNorthAfricaPct(MX_W_YR2),
IOOPWestAfricaPct(MX_W_YR2),
IOOPIndonesiaPct(MX_W_YR2),
IOOPPersianGulfPct(MX_W_YR2),
IOOtherMiddleEastPct(MX_W_YR2),
IOOtherLatinAmericaPct(MX_W_YR2),

IOOtherAfricaPct(MX_W_YR2),
IOOtherAsiaPct(MX_W_YR2),
ILPCanadaPct(MX_W_YR2),
ILPNorthEuropePct(MX_W_YR2),
ILPSouthEuropePct(MX_W_YR2),
ILPOPECPct(MX_W_YR2),
ILPOPAmericasPct(MX_W_YR2),
ILPOPNoAfricaPct(MX_W_YR2),
ILPOPWestAfricaPct(MX_W_YR2),
ILPOPIndonesiaPct(MX_W_YR2),
ILPOPPersianGulfPct(MX_W_YR2),
ILPCaribbeanPct(MX_W_YR2),
ILPAsiaPct(MX_W_YR2),
ILPOtherPct(MX_W_YR2),
IHPCanadaPct(MX_W_YR2),
IHPNorthEuropePct(MX_W_YR2),
IHPSouthEuropePct(MX_W_YR2),
IHPOPECPct(MX_W_YR2),
IHPOPAmericasPct(MX_W_YR2),
IHPOPNoAfricaPct(MX_W_YR2),
IHPOPWestAfricaPct(MX_W_YR2),
IHPOPIndonesiaPct(MX_W_YR2),
IHPOPPersianGulfPct(MX_W_YR2),
IHPCaribbeanPct(MX_W_YR2),
IHPAsiaPct(MX_W_YR2),
IHPOtherPct(MX_W_YR2).

Quantities of crudes, light and heavy refinery products imported in the U.S.:

Classification: Computed variable

ICOCANADA (MNUMYR),
ICOMEXICO(MNUMYR),
ICONORTHSEA(MNUMYR),
ICOOPAMERICAS(MNUMYR),
ICOOPWESTAFRICA(MNUMYR),
ICOOPINDONESIA(MNUMYR),
ICOOPPERSIANGULF(MNUMYR),
ICOOTHERMIDEAST(MNUMYR),
ICOOTHERAMERICAS(MNUMYR),
ICOOTHERAFRICA(MNUMYR),
ICOOTHERASIA (MNUMYR),
ICOTOTAL(MNUMYR),
IHPCANADA(MNUMYR),
IHPNORTHEUROPE(MNUMYR),
IHPSOUTHEUROPE (MNUMYR),
IHPOPEC(MNUMYR),

IHPOPAMERICAS (MNUMYR),
IHPOPNOAFRICA(MNUMYR),
IHPOPWESTAFRICA (MNUMYR),
IHPOPPERSIANGULF (MNUMYR),
IHPASIA(MNUMYR),
IHPOTHER(MNUMYR),
ILPNORTHEUROPE(MNUMYR),
ILPSOUTHEUROPE (MNUMYR),
ILPOPEC(MNUMYR),
ILPOPNOAFRICA(MNUMYR),
ILPOPWESTAFRICA (MNUMYR),
ILPOPINDONESIA(MNUMYR),
ILPOPPERSIANGULF(MNUMYR),
ILPCARIBBEAN(MNUMYR),
ILPASIA (MNUMYR),
ILPOTHER(MNUMYR),
ILPTOTAL (MNUMYR).

Supply curves for imported crudes and petroleum products in the U.S.:

Classification: Computed variable

CRDICURVES (5, MNUMPR, 3, MNUMYR),
PRDICURVES (18, MNUMPR, 3, MNUMYR).

Table 3. IEM Regional Representation of U.S. Imports

Crude Oil	Light Refined Products	Heavy Refined Products
Canada	Canada	Canada
Mexico	Northern Europe	Northern Europe
North Sea	Southern Europe	Southern Europe
OPEC	OPEC	OPEC
Latin America	Latin America	Latin America
North Africa	North Africa	North Africa
West Africa	West Africa	West Africa
Indonesia	Indonesia	Indonesia
Persian Gulf	Persian Gulf	Persian Gulf

Crude Oil	Light Refined Products	Heavy Refined Products
Other Middle East	Caribbean Basin	Caribbean Basin
Other Latin America	Asian Exporters	Asian Exporters
Other Africa	Other	Other
Other Asia		

Table 4. Crude Oil Categories for IEM Import Supply Curves

GROUP	CODE	SULFUR CONTENT	API GRAVITY
Low Sulfur Light	FLL	0 – 0.2 0.2 – 0.5	25 – 66 32 - 66
Medium Sulfur Heavy	FMH	0.2 – 1.1	21 - 32
High Sulfur Light	FHL	0.5 – 1.1 1.1 – 1.3 1.3 – 1.99	32 – 56 30 – 56 35 - 56
High Sulfur Heavy	FHH	1.3 – 1.99	21 - 35
High Sulfur Very Heavy	FHV	>2.7	<21

Table 5. Petroleum Products Categories for IEM Import Supply Curves

INDEX	GROUP	CODE
1	Motor Gasoline	MG - TRG
2	Reformulated Motor Gasoline	RG - RFG
3	Liquefied Petroleum Gases	LG - LPG
4	Jet Fuel	JF - JTA
5	Distillate	DS – N2H
6	Low Sulfur Distillate	DL - DSL
7	Ultra Low Sulfur Distillate	DU - DSU
8	Low Sulfur Residual Fuel	RL – N6H
9	High Sulfur Residual Fuel	RH – N6I
10	Petrochemical Feedstocks	PF - PCF
11	Other	OT - OTH
12	Methanol	ME - MET
13	Reformulated Blendstock for Oxygenate Blending (RBOB)	XG - SSR
14	MTBE	MT - MTB
15	Unfinished Oils – Residual Fuel	NA - ARB
16	Unfinished Oils - Naphtha	NA - NPP
17	Unfinished Oils – Heavy Gas Oil	NA - HGM
18	Conventional Blendstock for Oxygenate Blending (CBOB)	CB - SSE

Appendix B. Mathematical Description

This section provides the formulas and associated mathematical descriptions which represent the detailed solution algorithms. The section is arranged by sequential submodule as executed in the NEMS International Energy Module.

SUBROUTINE: OMS_SIM

Description: The OMS_Sim subroutine is first used to re-compute the world oil price paths based on a weighted average of the five generic crude oil types as estimated in the NEMS PMM. It is then used to calculate revised OPEC production numbers for the current iteration based on the latest demand and supply estimates for the United States. The associated sequence of equations begins with the re-estimation of the average world oil price:

Equations:

$$\underline{\textit{World oil price} = \frac{\sum(\textit{U.S. imports of crude}_i \times \textit{U.S. price of imported crude}_i)}{\sum(\textit{U.S. imports of crude}_i)}}$$

where,

i = low sulfur light, medium sulfur heavy, high sulfur light, high sulfur heavy, high sulfur very heavy. U.S. imports for the various crude oils are aggregated across PADD before the formula is applied.

Next, OMS_Sim calculates total U.S. demand for liquids:

$$\textit{Total U.S. liquids demand} = \textit{SPR\_Fill} + \Sigma(\textit{U.S. product demand}_c)$$

where,

c = motor gasoline; jet fuel; distillate fuel; low sulfur residual fuel; high sulfur residual; kerosene; petrochemical feedstocks; LPG; petroleum coke; asphalt and road oil; still gas; and other. U.S. demand for the various product demands are aggregated across the U.S. Census Division before the formula is applied. Demand is calculated in units of million barrels per day.

After total U.S. demand is projected, conventional and unconventional production is calculated:

Total U.S. conventional production = total U.S. domestic crude production +

total U.S. NGL production + other U.S. input to refineries + refinery processing gain

– U.S. domestic ethanol production – crude production (EOR) + (liquid hydrogen for transportation/ conversion factor for crude oil production)

Conventional production is measured in units of million barrels per day.

Total U.S. unconventional production = production of corn ethanol +

production of cellulosic ethanol + Σ biodiesel$_x$ + Alaskan GTL production +

CTL production + biomass-to-liquids production + crude production (EOR)

where,

x = white grease, yellow grease, and seed oil.

Finally, the call on OPEC is computed:

Call_on_OPEC = Total U.S. domestic demand –

Total U.S. domestic conventional supply – Discrepancy –

Total U.S. domestic unconventional supply –OPEC production

OPEC Production = OPEC production + Call_on_OPEC

SUBROUTINE: WORLD_OIL_REPORT

Description: In World_Oil_Report subroutine, the U.S. import quantities of crude oil and light and heavy refined products are computed by region or country based on output from the NEMS PMM. The routine calculates the country/regional quantities by applying shares estimated exogenously to total U.S. imports of the three petroleum forms for each projection year.

Equations:

U.S. Crude Oil Imports from Region r =

*Share of total crude oil imports from region r * Total U.S. crude oil imports*

where,

r = Canada, Mexico, North Sea, OPEC, Latin American OPEC, North African OPEC, West African OPEC, Indonesia (OPEC), Persian Gulf OPEC, other (non-OPEC) Middle East, other (non-OPEC) Latin America, other (non-OPEC) Africa, and other (non-OPEC) Asia.

The subroutine then computes the total imported light refined petroleum products:

Total U.S. light refined product imports =

U.S. blending component imports + MTBE imports + ethanol imports + biodiesel imports +

(motor gasoline imports + reformulated gasoline imports + jet fuel imports +

LPG imports + distillate fuel oil imports + ultra low sulfur distillate fuel imports)/1000

The next step is to compute the quantity imported by region by applying shares to total U.S. light refined products over the projection period. The shares are exogenously determined for each region.

U.S. light refined product imports from region r =

*Share of total light refined product imports from region r **

Total U.S. light refined product imports

where,

r = Canada, Mexico, Northern Europe, Southern Europe, OPEC, Latin American OPEC, North African OPEC, West African OPEC, Indonesia (OPEC), Persian Gulf OPEC, Caribbean, Asia, and other.

Finally, the subroutine computes the total imported heavy refined products:

Total U.S. heavy refined product imports =

U.S. total unfinished crude oil imports +

(low sulfur residual fuel imports + high sulfur residual fuel imports +

other imports + petroleum feedstocks imports)/1000

The next step is to compute the quantity imported by region by applying shares to total U.S. heavy refined products over the projection period. The shares are exogenously determined for each region.

U.S. heavy refined product imports from region r =

*Share of total heavy refined product imports from region r **

Total U.S. heavy refined product imports

where,

r = Canada, Northern Europe, Southern Europe, OPEC, Latin American OPEC, North African OPEC, West African OPEC, Indonesia (OPEC), Persian Gulf OPEC, Caribbean, Asia, and other.

SUBROUTINE: WORLD_COMPUTE

Description: In this subroutine, the total world oil prices are recalculated, along with U.S. import prices for each crude type and each product type based on the latest supply and demand estimates projections from the NEMS PMM. If this is the first iteration of the model run, the world oil price is defined as the global total liquids price of demand.

Next, total U.S. liquids consumption is calculated as:

Equations:

Total U.S. liquids consumption = U.S. crude oil production from the lower 48 states +

U.S. net crude oil imports + U.S. other crude oil imports + refinery processing gain +

U.S. net product imports – U.S. LPG imports/1000

The variable "alpha" is used to recalculate new U.S. total liquids supplies. Alpha is calculated as:

$$Alpha = \frac{Total\ U.S.\ liquids\ supply}{New\ world\ oil\ price^{U.S.\ Total\ liquids\ supply\ elasticity}}$$

Then U.S. total liquids supply is re-estimated as:

$$E[total\ U.S.\ liquids\ supply] = alpha * global\ total\ liquids\ price\ of\ supply^{U.S.\ Total\ liquids\ supply\ elasticity}$$

Compute the difference between the original U.S. liquids supply and the newly calculated total U.S. liquids supply.

Supply_Difference = U.S. total liquids supply –E[total U.S. liquids supply]

The variable "beta" is used to recalculate new U.S. total liquids demand.

$$Beta = \frac{Total\ U.S.\ liquids\ demand}{(new\ world\ oil\ price)^{U.S.\ Total\ liquids\ demand\ elasticity}}$$

Then U.S. total liquids demand is re-estimated as:

$$E[total\ U.S.\ liquids\ demand] = beta*(global\ total\ liquids\ price\ of\ demand)^{U.S.\ Total\ liquids\ demand\ elasticity}$$

Compute the difference between the original U.S. liquids demand and the newly calculated total U.S. liquids demand.

Demand_Difference =

U.S. total liquids demand –E[total U.S. liquids demand]

Calculate the new world oil price based on the supply and demand differences.

*New world oil price = (global total liquids price of supply)*e^{j}*

where j =

log { ((global liquids demand quantity + supply_diff)/(global liquids demand quantity + demand_diff)) / (global elasticity of demand – global elasticity of supply) }

Compute the new quantity point on the import supply curve to achieve equilibrium:

*New quantity point = (global liquids demand quantity + demand_difference)**

(new world oil price/global liquids supply price)$^{global\ liquids\ demand\ elasticity}$

Finally, U.S. liquids import prices are computed for each of the generic crude types and by PADD. Import prices are also computed for each of the petroleum products by PADD. For the five generic crude types, the price is computed using exogenously specified price multipliers:

*Import price$_{c,p}$ = new world oil price*natural price multiplier $_{c,p}$*

where,

c = crude type (low sulfur light, medium sulfur heavy, high sulfur light, high sulfur heavy, high sulfur very heavy) and p = PADD (1-5).

Simple linear regressions are used to calculate the by-product import prices by PADD:

$$\textit{Product price motor gasoline} = \textit{new world oil price} + e^{\textit{liquid coefficient\_2*log(new world oil price)}} + \textit{liquid coefficient\_3*log(U.S. refinery utilization factor)} + \textit{liquid coefficient\_4*log(rest of world refinery utilization factor)}$$

$$\textit{Product price RBOB} = \textit{new world oil price} + \textit{liquid coefficient\_1} + \textit{liquid coefficient\_2*new world oil price} + 0.451*\textit{product price of motor gasoline in cents per gallon}$$

$$\textit{Product price LPG} = \textit{new world oil price} + \textit{liquid coefficient\_1} + \textit{liquid coefficient\_2*new world oil price} + 2.172*\textit{price of natural gas}$$

$$\textit{Product price low sulfur distillate} = \textit{new world oil price} + e^{\textit{liquid coefficient\_2*log(new world oil price)}} + \textit{liquid coefficient\_4*log(rest of world refinery utilization factor)}$$

$$\textit{Product price ultra low sulfur distillate} = 1.024*\textit{product price distillate}$$

$$\textit{Product price jet fuel} = \textit{new world oil price} + e^{\textit{liquid coefficient\_2*log(new world oil price)}} + \textit{liquid coefficient\_4*log(rest of world refinery utilization factor)}$$

Product price low sulfur residual fuel =
price of low sulfur light crude oil –
130.15 + 185.33(U.S. refinery utilization factor) –*
*52.77*rest of world refinery utilization factor*

*Product price CBOB = 0.99*price of motor gasoline*

*Product price high sulfur residual fuel = 0.9*product price low sulfur residual fuel*

SUBROUTINE: WORLD_CURVES

Description: The World_Curves subroutine is used to convert the prices from 2005 dollars per barrel to real 1987 dollars per barrel for pass-back to the NEMS PMM. The U.S. import price series for the five generic crude oil types and 18 petroleum products are converted to 1987 dollars by PADD.

Equations: The crude import price curves are calculated as:

$Crude\ import\ curve\ price_{c,p} = crude\ oil\ price_c / conversion\ factor$

where,

c = crude type ((low sulfur light, medium sulfur heavy, high sulfur light, high sulfur heavy, high sulfur very heavy) and p = PADD (1-5).

Product prices are similarly converted:

$Product\ import\ curve\ price_{r,p} = product\ price_r / conversion\ factor$

where,

r = product type (Motor Gasoline, Reformulated Motor Gasoline, Liquefied Petroleum Gases, Kerosene-Jet Fuel, Distillate, Low Sulfur Distillate, Ultra Low Sulfur Distillate, Low Sulfur Residual Fuel, High Sulfur Residual Fuel, Petrochemical Feedstocks, Other, Methanol, Conventional Blendstock for Oxygenate Blending (CBOB), Reformulated Blendstock for Oxygenate Blending (RBOB), MTBE, Unfinished Oils – Residual Fuel, Unfinished Oils – Naphtha, and Unfinished Oils – Heavy Gas Oil) and p = PADD (1-5).

Quantity points on the import supply curves are all set to the corresponding quantity previously calculated for crude type and product type.

Appendix C. References

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

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

BP Statistical Review of World Energy 2007 (London, UK, June 2007).

International Energy Agency, *IEA Statistics: Oil Information 2008* (Paris, France, 2008).

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

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

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

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

Appendix D. Model Abstract

Introduction

This section gives a brief summary of the International Energy Module and its role within the National Energy Modeling System. Specific information on the following topics is provided:

- Model Name
- Model Acronym
- Description
- Purpose of the Model
- Most Recent Update
- Part of Another Model
- Model Interfaces
- Official Model Representative
- Documentation
- Archive Media and Manuals
- Energy System Described
- Coverage
- Modeling Features
- Model Inputs
- Non-DOE Input Sources
- DOE Input Sources
- Computing Environment
- Independent Expert Review Conducted
- Status of Evaluation Efforts by Sponsor

Model Name:

International Energy Module

Model Acronym:

IEM

Description:

The NEMS International Energy Module is a calculation tool that uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids production and consumption by year to model the interaction of U.S. and international liquids markets. The IEM projects

international oil conditions, including demand, price and supply, and the impact of changes in the U.S. petroleum market on world markets. The IEM is used to recalculate world oil prices in response to changes in U.S. petroleum liquids production and consumption. In addition, the IEM provides supply curves of crude oil imported to the United States in each of the five Petroleum Allocation for Defense Districts (PADD) for five generic crude oil grades: low sulfur light, high sulfur light, medium sulfur heavy, high sulfur heavy, and high sulfur very heavy. Finally, the IEM provides U.S. import supply curves for as many as 18 petroleum products[3] by PADD. The model employs a general equilibrium algorithm to calculate the world oil price, and generates U.S. crude oil and petroleum product supply curves based on a series of simple and logarithmic linear regression equations that are developed exogenously and used as IEM model input. U.S. petroleum product import quantities are calculated by region or country for crude oil and light and heavy refined products based on a sharing algorithm that applies the share of the total each region is assumed to supply.

Purpose of the Model:

As a component of the National Energy Modeling System, the NEMS IEM calculates:

- The world oil price (WOP), which is defined as the price of light, low sulfur crude oil delivered to Cushing, Oklahoma (PADD2). Changes in the WOP are computed in response to:
    - The difference between U.S. total petroleum liquids production and the expected U.S. total petroleum liquids production at the current WOP (estimated using the current WOP and the exogenous U.S. total petroleum liquids supply curve for each year).
    - The difference between U.S. total petroleum liquids consumption and the expected U.S. total petroleum liquids consumption at the current WOP (estimated using the current WOP and the exogenous U.S. total petroleum liquids demand curve).
- Supply curves for five generic grades of crude oil for import to the United States in each of the five PADDs (Figure 1). The IEM forecasts international crude oil market conditions, including demand, price and supply, and the effects of changes in the U.S. petroleum market on the world market.
- Supply curves for U.S. imports of 18 petroleum products in each of the five PADDs. The supply curves reflect conditions in the world liquids market, including refinery capacity, refinery utilization factors in different regions of the world, and transportation costs.
- Total U.S. imports of crude oil and light and heavy refined petroleum products by country or region.

[3] The 18 petroleum products are: Motor Gasoline, Reformulated Motor Gasoline, Liquefied Petroleum Gases, Kerosene-Jet Fuel, Distillate, Low Sulfur Distillate, Ultra Low Sulfur Distillate, Low Sulfur Residual Fuel, High Sulfur Residual Fuel, Petrochemical Feedstocks, Other, Methanol, Conventional Blendstock for Oxygenate Blending (CBOB), Reformulated Blendstock for Oxygenate Blending (RBOB), MTBE, Unfinished Oils – Residual Fuel, Unfinished Oils – Naphtha, and Unfinished Oils – Heavy Gas Oil.

Most Recent Model Update:

December 2007.

Part of Another Model?

National Energy Modeling System (NEMS)

Model Interfaces:

The IEM receives inputs from other NEMS models, including the NEMS Petroleum Market Module, and NEMS Macroeconomic Activity Module. The Generate World Oil Balance Model is also a source of input to the IEM. Outputs are provided to the NEMS Integrating Module and the NEMS Petroleum Market Module.

Official Model Representative:

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Documentation:

Energy Information Administration, U.S. Department of Energy, *Model Documentation 2008 Report: International Energy Module (IEM) of the National Energy Modeling System,* DOE/EIA-M071(2008) (Washington, D.C., July 2009).

Archive Media and Installation Manual(s):

The IEM, as part of the NEMS system, has been archived for the reference case published in the *Annual Energy Outlook 2008*, DOE/EIA-0581 (2008). The NEMS archive contains all of the nonproprietary modules of NEMS as used in the reference case. The NEMS archive is available on an as-is basis (ftp://eia.doe.gov/pub/oiaf/aeo/aeo2008.zip).

Energy System Described:

U.S. import supply curves for five generic crude oil types; U.S. import supply curves for as many as 18 petroleum products; and U.S. crude oil and light and heavy refined product import quantities by region or country for each year.

Coverage:

- Geographic: Five Petroleum Area Defense Districts (PADD), United States, and global (by region or country).
- Time Unit/Frequency: Annual through 2030
- Products: world oil prices, U.S. import supply curves for five generic crude oil grades by PADD, U.S. import supply curves for eighteen petroleum products by PADD, Total U.S. crude oil and light and heavy refined petroleum product import quantities by country and region.
- Economic Sectors: Not applicable.

Modeling Features:

- Model Structure: The NEMS International Energy Module is a calculation tool that uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids production and consumption, by year, to model the interaction of U.S. and international liquids markets. The IEM projects international oil market conditions, including demand, price and supply, and the impact of changes in the U.S. petroleum market on world markets.
- Modeling Technique: The model employs a general equilibrium algorithm to calculate the world oil price, and generates U.S. crude oil and petroleum product supply curves based on a series of simple and logarithmic linear regression equations that are developed exogenously and used as IEM model input.
- Special Features: The computational techniques used in the IEM enable it to accommodate a wide range of scenarios and policy analyses including but not limited to demand-side, supply-side, tax credits, and macro scenarios.

Model Inputs:

- Expected U.S. and world petroleum liquids supply and demand curves by year
- Elasticities for U.S. and world petroleum liquids supply and demand curves by year
- Expected world oil prices by year
- Crude oil quality (e.g., gravity, sulfur content) multipliers for each oil type; PADD independent
- Location multipliers for each generic crude oil type by PADD
- Global regional refinery utilization factors by region/country
- Linear regression coefficients for petroleum product prices
- Shares of total U.S. crude oil and light and heavy refined product imports supplied by region
- GDP deflators

- Projected U.S. petroleum liquids consumption and production
- Projected U.S. crude oil and petroleum product import quantities

Non-DOE Input Sources:

- None

DOE Input Sources:

NEMS Petroleum Market Module

- U.S. petroleum liquids production and consumption by year
- U.S. petroleum liquids supply and demand by year
- U.S. crude oil imports
- U.S. product imports
- GDP deflators

Generate World Oil Balance Model

- Total liquids supply and distribution by region by year by year

Input file omsecon.txt

- Expected U.S. petroleum liquids supply and demand curves by year
- Expected world petroleum liquids supply and demand curves by year
- Oil type price multipliers, PADD independent
- PADD multipliers
- Refinery Utilization Factors by region/country

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 1990-2030 run in non-iterating NEMS mode
- Special Features: None.

Independent Expert Reviews Conducted:

None.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E. Data Quality

Introduction

The NEMS International Energy Module develops projections of world oil prices; of supply curves for five grades of oils and 18 products for imports in the U.S.; and of U.S. imports by source of oil and light and heavy 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

- AEO2007 and IEO2007 – Final results from these publications are used to compute yearly elasticities for world and U.S. demand curves of petroleum products.

- Generate World Oil Balances (GWOB) – This exogenous oil supply module is used in International Energy Module to provide annual regional/country level production detail for conventional and unconventional liquids.

- *International Petroleum Monthly*, Energy Information Administration public website, Bloomberg database, International Energy Agency database, *BP Review of World Energy*, FACTS Global Energy publications, STEO results – All these sources of information were used to gather historical data used in linear regressions to forecast oils and petroleum product prices, to compute refinery utilization factors and to build a report for imports of oil, light and heavy petroleum products imports in the U.S. by source.

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. production and consumption of petroleum liquids range, prices, elasticities checks based on previous values, responses and on knowledge of industry.

- Consistency checks.

- Technical edits to detect and correct errors, extreme variability.