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International Energy Module of the National Energy Modeling System: Model Documentation 2018

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Update Information

This edition of the *International Energy Module (IEM) of the National Energy Modeling System: Model Documentation 2018* reflects the following changes made to the IEM in 2018 relative to the 2016 version of the module

- Provision of exogenous assumptions for crude oil exported from the United States
- Provision of supply curves for all petroleum products imported into the United States
- Provision of demand curves for all petroleum products exported from the United States
- Provision of expected domestic crude oil production, net imports of petroleum products, and total crude oil processed by U.S. refineries
- Elimination of special supply curves of European gasoline imported in the United States
- Changes in the structure of intallin.xml input file to accommodate new data and faster exchanges of information within NEMS
- New approach in modeling interactions between the United States and the rest of the world petroleum markets in light of increasing domestic crude oil production
- Modeling the limits for sulfur content of marine fuel oil used on ships over the 2020-2025 period according to the International Maritime Organization (IMO) convention
- Improved dynamic reaction to the uncertainty of future oil prices for petroleum products, Organization of the Petroleum Exporting Countries (OPEC) investment and production decisions, non-OPEC petroleum liquid fuels supply, and supplies of other liquid fuels

1. Introduction

Purpose of the report

This report documents the objectives, analytical approach, and development of the National Energy Modeling System (NEMS) International Energy Module (IEM). It catalogues and describes the model assumptions; computational methodology; parameter estimation techniques; and model source code that are used 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 International Energy Module (IEM), working in conjunction with the Liquid Fuels Marketing Module (LFMM), simulates the interaction between U.S. and global petroleum markets. It uses assumptions of economic growth and expectations of future U.S. and world crude-like liquids production and consumption to estimate the effects of changes in U.S. liquid fuels markets on the international petroleum market. For each year of the projection period, the IEM projects the Brent crude oil price, provides supply curves for world crude-like liquids and each foreign-imported crude type, includes exogenous assumptions on U.S. crude oil exports, provides petroleum products demand curves for refinery region 9 (Maritime Canada and Caribbean region, see Figure 1), provides petroleum products import supply curves and export demand curves, and generates a worldwide oil supply-demand balance with regional detail.

Model archival citation

This documentation refers to the NEMS International Energy Module as archived for the *Annual Energy Outlook 2018 (AEO2018)*.

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Organization of this report

Chapter 2 of this report, “Model Purpose,” identifies the analytical issues the IEM addresses, 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 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 NEMS 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 focus of EIA. 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 oil price (BRENT). Changes in the oil price are computed in response to
    - The difference between projected U.S. total crude-like liquids production and the expected U.S. total crude-like liquids production at the current oil price (estimated using the current oil price and the exogenous U.S. total crude-like liquids supply curve for each year)
    - The difference between projected U.S. total crude-like liquids consumption and the expected U.S. total crude-like liquids consumption at the current oil price (estimated using the current oil price and the exogenous U.S. total crude-like liquids demand curve)
- The IEM projects international crude oil market conditions, including consumption, price, and supply availability, as well as the effects of the U.S. petroleum market on the world market.
- Provision of supply curves for foreign crude types imported in the United States(see Figure 2)
- Provision of exogenous assumptions for crude oil exported from the United States
- Provision of supply curves for petroleum products imported in the United States
- Provision of demand curves for petroleum products exported from the United States
- Provision of demand curves for petroleum products in refinery region 9 (see Figure 1)

Figure 1. Map of the U.S. refinery (LFMM) regions

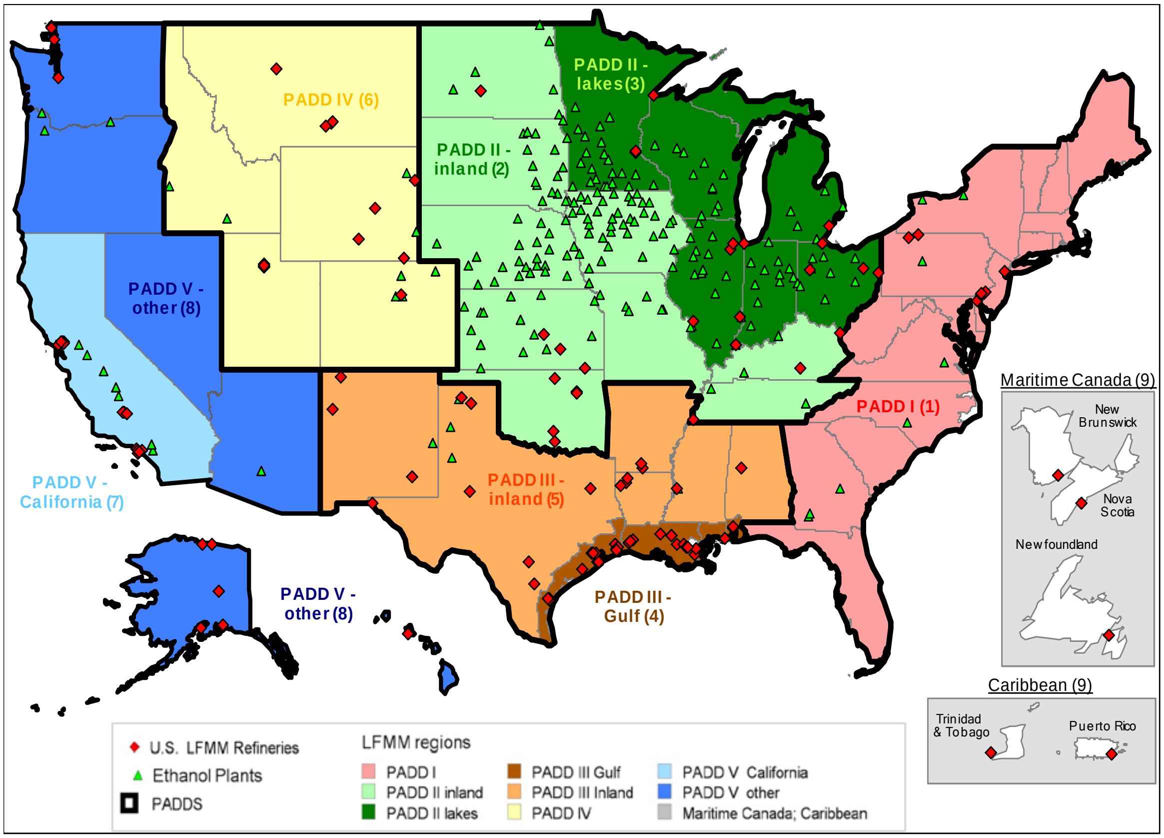
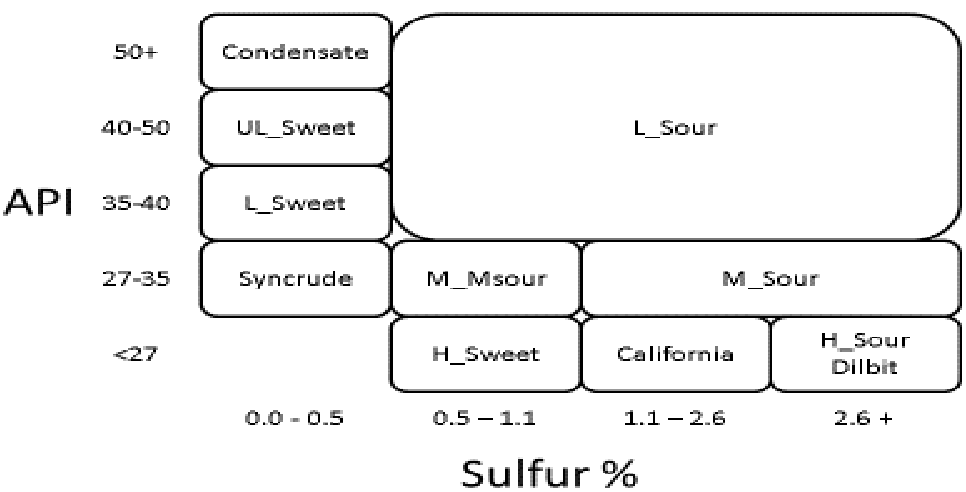


Figure 2. IEM crude types



Model inputs and outputs

Inputs

The primary inputs to the IEM include expected global crude-like liquids supply and demand curves; oil prices (Brent); crude types price differentials; world supply shares of each crude type; expected U.S. domestic crude production; net imports of petroleum products imported in the U.S.; petroleum products demand curves in Caribbean and Maritime Canada (Refinery Region 9); petroleum products import supply curves; petroleum products export demand curves; and exogenous assumptions on crude oil exported from the United States. 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
Crude oil prices (Brent)	Exogenous values included in input file intallin.xml
Expected U.S. crude-like liquids supply by year	Exogenous values included in input file intallin.xml
Expected world crude-like liquids supply and demand curves by year	Exogenous values included in input file intallin.xml
Expected supply curves, by year, for all foreign crude types	Exogenous values included in input file intallin.xml
GDP Deflators	Macroeconomic Activity Module
U.S. crude-like liquids production by year	OGSM
World crude-like liquids production and consumption by year	LFMM
U.S. crude oil imports by crude type and year	LFMM
U.S. petroleum product imports/exports	Exogenous and endogenous values included in input file intallin.xml
Petroleum products demand curves in the Caribbean and Maritime Canada (refinery region 9)	Exogenous and endogenous values included in input file intallin.xml
Crude oil types price differentials	Exogenous values included in input file intallin.xml

Outputs

The primary outputs of the IEM are projected oil prices (Brent, modified to reflect the effects of projected U.S. supply and demand pressures), updated world crude supply curves, updated imports/exports petroleum product curves, Non-U.S. crude-like liquids demand quantities, and supply curves for all foreign crudes. Chapter 4, Model Structure – key computational equations, explains in detail how the modified output Brent price differ from the input Brent price. Table 2 summarizes these outputs.

Table 2. IEM model outputs

Model Outputs	Destination
Computed world oil price	LFMM
World crude-like liquids supply and demand curves	LFMM
Supply curves for petroleum products imported in the U.S.	LFMM
Demand curves for petroleum products exported from U.S	LFMM
Supply curves, by year, for all foreign crude types	LFMM
Non-U.S. crude-like liquids demands	LFMM

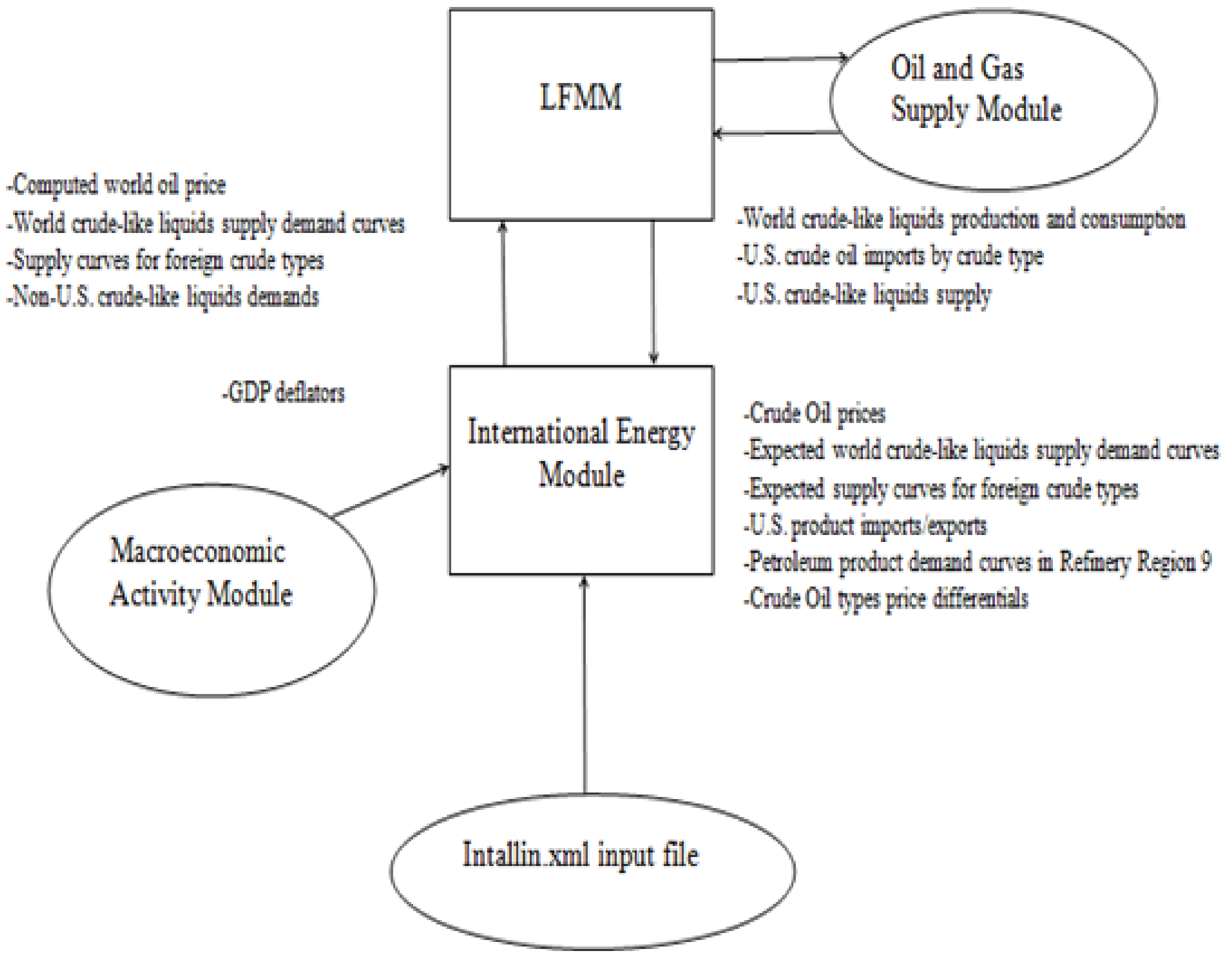
Relationship of the International Energy Module to other NEMS modules

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. and world projected production and consumption quantities of crude-like liquids. The information it provides includes world crude-like liquids supply curves, a computed oil price, U.S. imports supply curves of petroleum products, and U.S. exports demand curves of petroleum products. It should be noted, however, that the present focus of the IEM is on the international oil and petroleum product market. Any interactions between the U.S. and foreign regions in fuels other than oil or petroleum products (for example, coal trade) are modeled in the particular NEMS module that deals with that fuel.

For U.S. crude-like liquids production and consumption in any year of the projection period, the IEM uses production projections generated by the Oil and Gas Supply Module (OGSM) and provided through the LFMM (see Figure 3).

U.S. and world expected crude-like liquids supply and demand curves, for any year in the projection period, are exogenously provided through data included in the input file intallin.xml, as described in Appendix A, “Input Data and Variable Descriptions.”

Figure 3. 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 crude-like liquids supply and demand, by year, to model the interaction of U.S. and international oil markets. The IEM employs an equilibrium algorithm to calculate the oil price. Based on U.S. crude-like liquids production and consumption and other input data, the IEM computes a revised oil price that reflects the effects of projected U.S. supply and demand pressures.

IEM, as a module of AEO2018, considers a number of factors related to the uncertainty of future oil prices, including changes in worldwide demand for petroleum products, Organization of the Petroleum Exporting Countries (OPEC) investment and production decisions, non-OPEC petroleum liquid fuels supply, and supplies of other liquid fuels. IEM also has a representation of the International Maritime Organization (IMO) convention that limits the sulfur content of marine fuel oil used on ships over the 2020-2025 period.

Fundamental assumptions

For the *AEO2018*, 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 AEO2017 and the International Energy Outlook 2017. Appendix A contains a full sample of the IEM input data assumptions. The following data series are input into the IEM for each year between 2008 and 2050:

1. Global Total Crude-Like Liquids Supply Curves
2. Global Total Crude-Like Liquids Demand Curves
3. Imported crude oil types price differentials
4. Import/Export curves of petroleum products in the United States
5. World Supply and Demand, Including Conventional and Unconventional Liquids

For each year of the projection period (2008 through 2050), all supply and demand curves are expressed as functions

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

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. All values for quantities are expressed in units of one thousand barrels per day, and prices are expressed in real 2017 dollars per barrel.

Global total crude-like liquids supply curves

These curves are built exogenously with data from the Oil and Gas Supply Module, Generate World Oil Balances (GWOB)[1] , and previous runs of NEMS. For these supply curves, the values of the elasticities in each year between 2008 and 2050 are assumed to be in a 0.25 – 1.50 interval.

Global total crude-like liquids demand curves and U.S. total crude-like liquids demand curves

For each year of period 2008 to 2050, these curves are constructed in the same format as the supply curves:

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

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 the coordinates of a point on the curve. Values for P, the expected world oil prices, are provided by AEO2016 Assumptions document. Values for Q are assumed based upon previous NEMS and GWOB model runs.

Demand elasticities (ε) are calculated on an annual basis from 2008 through 2050 using past projections of prices and world liquids supply and demand from the *AEO2017*. For each year of the projection period, elasticities are computed using an optimization algorithm.

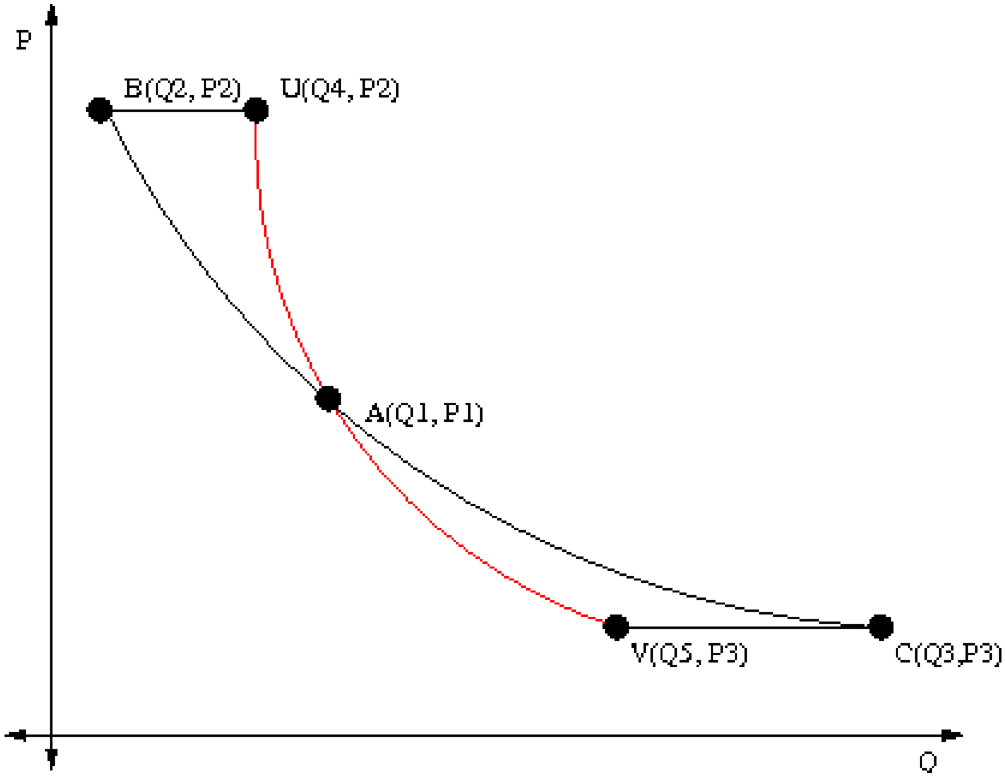
AEO2018 results are used as follows (see Figure 4):

$\mathrm{P1}$ – Oil price in Reference case scenario
$\mathrm{Q1}$ – Global total crude-like liquids demand in Reference case scenario
$\mathrm{P2}$ – Oil price in High Oil Price case scenario
$\mathrm{Q2}$ – Global total crude-like liquids demand in High Oil Price case scenario
$\mathrm{P3}$ – Oil price in Low Oil Price Case Scenario
$\mathrm{Q3}$ – Global total crude-like liquids demand in Low Oil Price case scenario

Points A ($\mathrm{Q1}$, $\mathrm{P1}$), B ($\mathrm{Q2}$, $\mathrm{P2}$), C ($\mathrm{Q3}$, $\mathrm{P3}$) are plotted as is shown in Figure 4, as are points U ($\mathrm{Q4}$, $\mathrm{P2}$) and V ($\mathrm{Q5}$, $\mathrm{P3}$). 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.

[1] GWOB is a spreadsheet-based application used to create a "bottom up" projection of world liquids supply—based on current production capacity, planned future additions to capacity, resource data, geopolitical constraints, and prices—and is used to generate conventional crude oil production cases. The scenarios (oil price cases) are developed through an iterative process of examining demand levels at given prices and considering the price and income sensitivity on both the demand and supply sides of the equation. Projections of conventional liquids production for 2010 through 2016 are based on analysis of investment and development trends around the globe. Data from EIA's Short-Term Energy Outlook are integrated to ensure consistency between short- and long-term modeling efforts. Projections of unconventional liquids production are based on exogenous analysis

Figure 4. Global total petroleum liquids demand curve



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

$$\frac{Q4}{Q1} = \left(\frac{P2}{P1}\right)^{\varepsilon}, \textit{ therefore } Q4 = Q1\left(\frac{P2}{P1}\right)^{\varepsilon}$$

$$\frac{Q5}{Q1} = \left(\frac{P3}{P1}\right)^{\varepsilon}, \textit{ therefore } Q5 = Q1\left(\frac{P3}{P1}\right)^{\varepsilon}$$

$$BU = |Q2 - Q4| = \left|Q2 - Q1\left(\frac{P2}{P1}\right)^{\varepsilon}\right| - \textit{length of segment } BU$$

$$VC = |Q3 - Q5| = \left|Q3 - Q1\left(\frac{P3}{P1}\right)^{\varepsilon}\right| - \textit{length of segment } VC$$

$$\textit{Let } F(\varepsilon) = BU + VC = \left|Q2 - Q1\left(\frac{P2}{P1}\right)^{\varepsilon}\right| + \left|Q3 - Q1\left(\frac{P3}{P1}\right)^{\varepsilon}\right|$$

Find $\varepsilon_0 < 0$ such that the sum of lengths of segments BU and VC has a minimum value:

$$F(\varepsilon_0) = \min_{\varepsilon<0} F(\varepsilon)$$

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 also be found. In the 2008 year case, ε_0 = -0.11.

Import crude oil types price differentials

Characteristics of all NEMS crude types are illustrated in Figure 2.

Light sweet (Brent) crude price path, over the projection period (2017 - 2050), is an exogenous assumption in NEMS. Based on analyst judgment, historical price correlation between Brent and heavy sour crudes (Maya), and historical price differentials, IEM makes an exogenous assumption for the price path of heavy sour crude type over the projection period.

For any year in the projection period, the projected price path for all other crude types will be a function of Brent crude price and heavy sour crude price.

Following is a description of the algorithm used to compute medium sour crude type price path over the projection period. Figure 5 is an illustration of this process:

- $P1$ – Brent price in 2020
- $P2$ – Heavy Sour price in 2020
- For each year define following ratio:

  $$r = \frac{AB}{BC} = \frac{(P2-P)}{(P1-P)} \qquad \text{(a)}$$

  AB and AC are the lengths of the corresponding line segments

  equivalent with,

  $$P = \frac{(P2-rP1)}{(1-r)} \qquad \text{(b)}$$

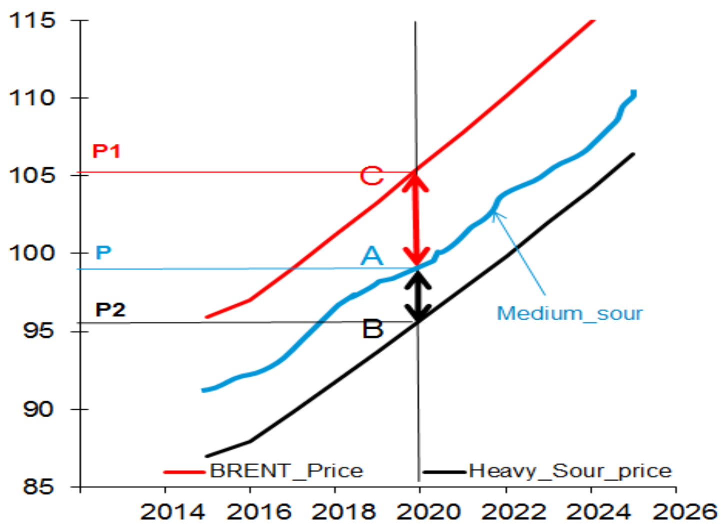
- Historical values for the ratio r average -1.10 for 2000-2017 period
- Average value for ratio r is used for each year of the projection period

In a similar way, average values for the ratio r are computed for other crude types. The list below shows these values for the ratio r for other crude types.

Crude type	r–Historical Values
Light Sour	-6.00
Medium M Sour	-2.00
Medium Soar	-1.10
Heavy Sweet	-0.40
California	0.12
Syncrude	-1.50
Dibit/Synbit	0.55
Ultra-Light Sweet	-10.00
Condensate	-8.00

Figure 5. Medium Sour crude price

2017 $ per barrel



Imports/Exports of petroleum products in the United States

The list of petroleum products modeled in IEM and LFMM is available in Table 1 in Appendix A. The International Energy Module and LFMM approach to petroleum product imports and exports has three parts:

1. First, the Caribbean and Maritime Canada are included as a separate refinery region. In most ways this refinery region is treated like the domestic refinery regions, except that product flows from this region to domestic markets are reported as product imports. For each petroleum product and for each year of the projected period, IEM builds isoelastic demand curves:
   $Q = \alpha P^{\varepsilon}$

   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 the coordinates of a point on the curve.
2. Second, the remaining product imports and exports values are represented as a projected set of dynamic supply and demand curves for each year of the projection period.

All quantities are represented in thousands barrels per day and all input prices are in 2017 dollars.

In order for data to be "linear programming ready" (LP ready), all isoelastic supply curves are approximated by incremental step curves. This means that step one is the quantity available at the lowest price, step two is the incremental amount available at the next higher price, etc. All IEM supply curves have 14 incremental steps. Prices considered on each of these steps are computed based on the initial value P (price) of the specified isoelastic supply curve and on the following breakpoints of P: 20%, 60%, 80%, 90%, 95%, 97%, 98.5%, 101.5%, 103%, 105%, 110%, 120%, 140%, and 180%.

AEO2018 projects an increase in domestic crude oil production, especially for lighter crudes. This aspect will lead to very dynamic interactions between U.S. and the rest of the world petroleum markets. U.S. refineries need to function at their optimal parameters, therefore the need for new exogenous assumptions on crude oil quality price differentials and petroleum products imports and exports. In order to implement some of these assumptions for AEO2018, foreign heavy crude oil import supply curves are modified toward a heavier slate of crude oil imports in the United States compared to previous years. IEM achieves this goal by proportionally increasing each step of these initial isoelastic curves.

Petroleum product export demand curves are approximated by step curves in a similar way.

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 intbalance.xml input file. Each oil price case has its own version of this file. The supply portion is divided into conventional and unconventional production. Appendix B 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 2017* for each oil price case. Likewise, because the U.S. consumption of liquids is a dynamic value (and an output from NEMS), data on 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 2017* for each oil price case.

4. Model Structure

Structural overview

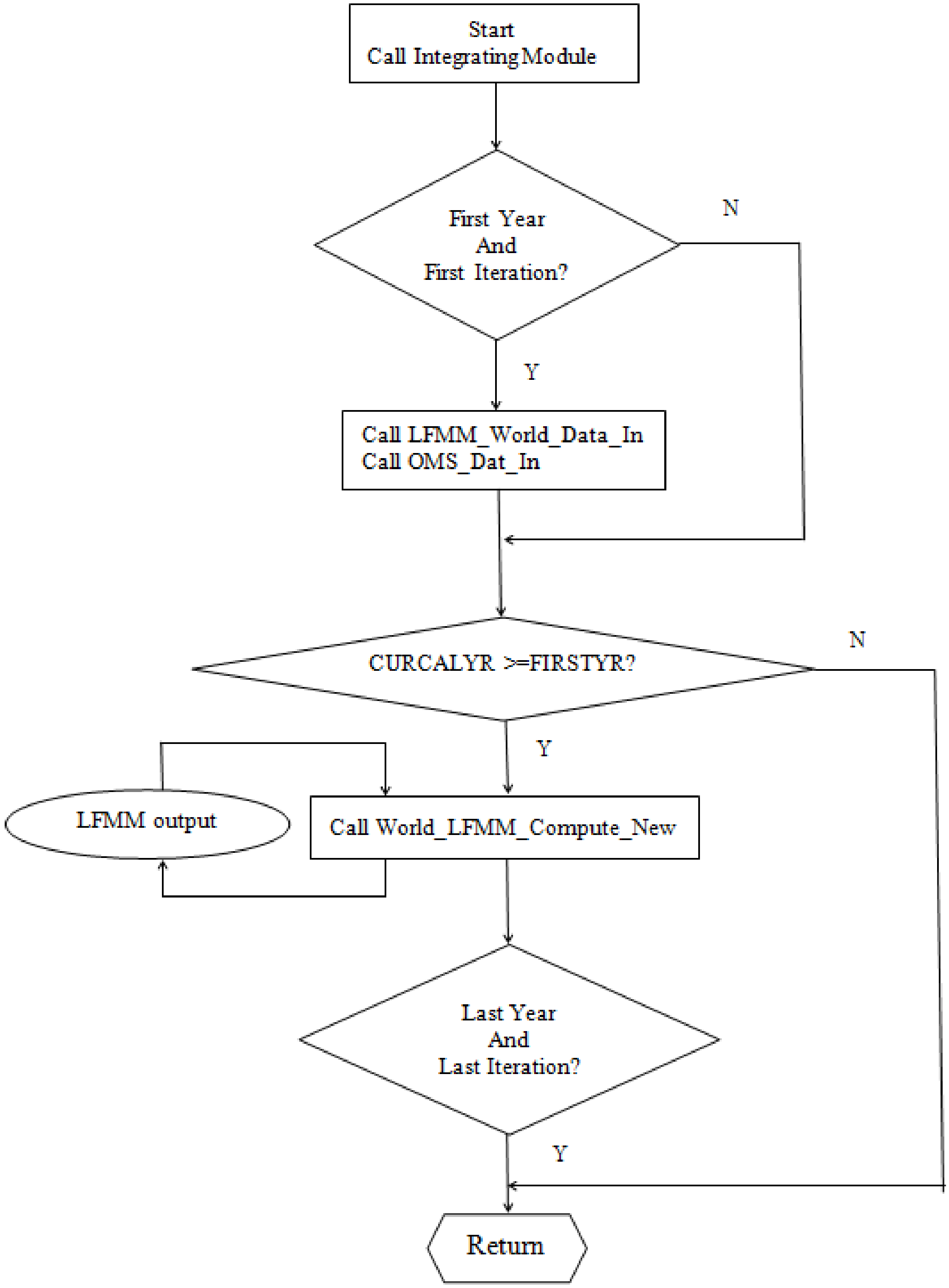
One of the main purposes of the NEMS IEM is to re-estimate oil prices to reflect the effects of U.S. supply and demand pressures. It also provides a supply curve for world crude-like liquids, supply curves for each of the ten foreign imported crude types, supply curves for imported petroleum products, demand curves for exported petroleum products, and petroleum products demand curves for refinery region 9 (Maritime Canada and Caribbean region, see Figure 1); and it generates a worldwide liquids supply-demand balance with regional detail. The IEM provides this data for each year of the projection period. The IEM calculates the oil prices based on differences between U.S. total crude-like consumption and production and the expected U.S. total crude-like liquids consumption and production at the input oil price. All of this must be achieved by modeling an equilibrium in world oil markets. Supply import curves are isoelastic curves, and points on the curves are adjusted as other NEMS modules (specifically the LFMM, 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 6. A call from the NEMS Integrating Module to the IEM initiates importation of the supporting information needed to complete the projection calculations for world liquids markets. A substantial amount of support information for the IEM is calculated exogenously. Various techniques, as explained in Chapter 3, are used to estimate the coefficients and elasticities that are applied within the IEM. The results are saved in the intallin.xml input file, and are read into the IEM.

The main IEM routine queries the current calendar year (CURCALYR) variable to make sure it is a projection year. If it is a projection year, the World_Compute_New subroutine is executed. LFMM_World_Data_In subroutine imports data for world crude-like liquids supply and demand curves, supply curves for each of the ten foreign-imported crude types, U.S. projections of petroleum liquids production, as well as data on petroleum products imported/exported in the United States from the intallin.xml input file. Next, OMS_Dat_In subroutine is executed to import global and U.S. projections of liquids production and consumption from the intbalance.xml input file.

Once the necessary data has been imported, the World_LFMM_Compute_New subroutine is executed (Figure 6). The first step of this subroutine is to re-estimate the oil price. Next, the model builds all supply and demand curves mentioned above. The model also reads the crude imports in the United States by crude type, refinery region and year (values that are computed in the LFMM). Next, to balance projected worldwide crude demand, this subroutine computes non-U.S. crude demands (see Appendix B for a detailed description).

Figure 6. Flowchart for Main IEM Routine



Key computations and equations

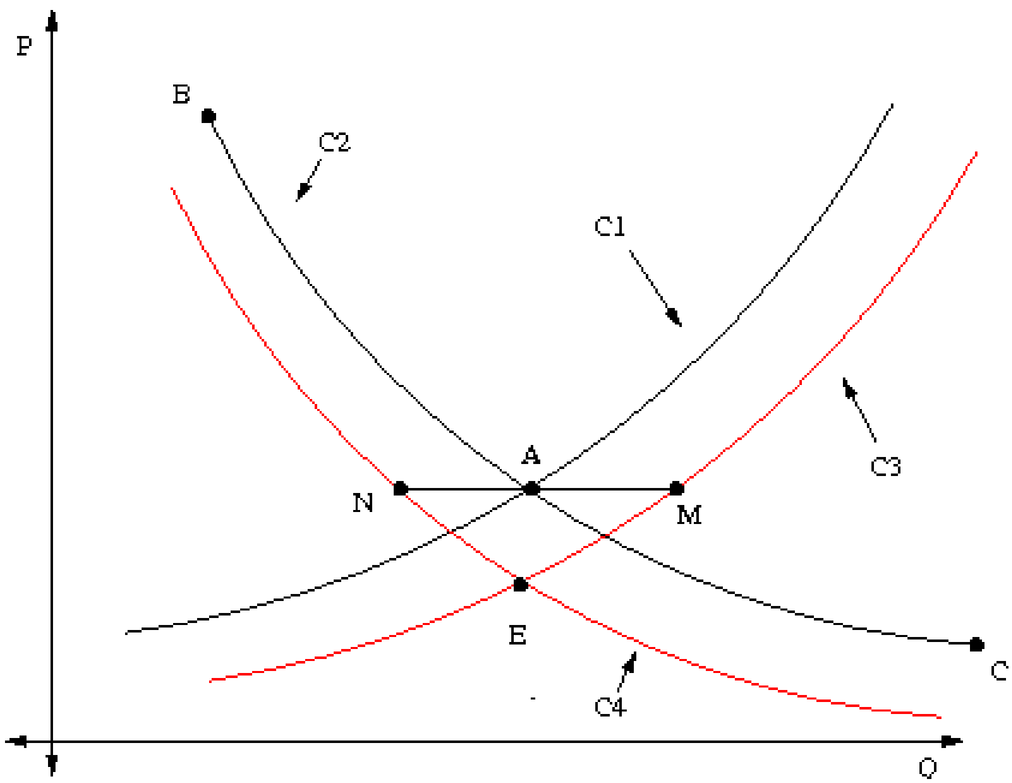
This section provides detailed solution algorithms arranged by sequential subroutine as executed in the NEMS International Energy Module. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the details considered by the full forms of the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

Recalculating world oil prices and U.S. crude oil and product import/export curves

This section explains the algorithm the IEM uses to compute oil prices. The oil price, it is important to note, is assumed to be the price of imported low sulfur light crude (BRENT).

All computations performed in the IEM start with year 2017. The IEM reads the input files (intallin.xml, intbalance.xml), 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 7.

Figure 7. Algorithm used to recalculate oil prices in the IEM



For each year of the forecasted period, the IEM uses the following methodology to revise the oil price. 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 chapter, Model Rationale.

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 ΔQ_d between U.S. petroleum products consumption (from the LFMM) and expected petroleum products demand Q_0 at the current crude price P_0 . Point N is the translation of point A along the horizontal axis with vector value of ΔQ_d. Therefore, the coordinates of point N are: $(P_0, Q_0 + \Delta Q_d)$. The new demand curve for world petroleum products will be the curve C4 that passes through point N. It is isoelastic, with the 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 ΔQ_s between U.S. petroleum products production (from the LFMM) 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, the coordinates of point M are: $(P_0, Q_0 + \Delta Q_d)$. 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.

The 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.

$$Q_0 + \Delta Q_S = \alpha(P_0)^{\varepsilon_s}$$

$$Q^* = \alpha(P_0)^{\varepsilon_s}$$

$$\text{Therefore, } Q^* = (Q_0 + \Delta Q_s)\left(\frac{P^*}{P_0}\right)^{\varepsilon_s} \text{ (i)}$$

$$(Q_0 + \Delta Q_d) = \beta(P_0)^{\varepsilon_d}$$

$$Q^* = \beta(P^*)^{\varepsilon_d}$$

where α and β are corresponding constants of the isoelastic supply and demand curve equations

$$\text{Therefore, } Q^* = (Q_0 + \Delta Q_d)\left(\frac{P^*}{P_0}\right)^{\varepsilon_d} \text{ (ii)}$$

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

$$\frac{Q_0 + \Delta Q_d}{Q_0 + \Delta Q_s} = \left(\frac{P^*}{P_0}\right)^{(\varepsilon_s - \varepsilon_d)} \quad \text{(iii)}$$

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

$$P^* = P_0 e^{\left(\frac{ln\left(\frac{Q_0 + \Delta Q_s}{Q_0 + \Delta Q_d}\right)}{(\varepsilon_s - \varepsilon_d)}\right)}$$

Also,

$$Q^* = (Q_0 + \Delta Q_s)\left(\frac{P^*}{P_0}\right)^{\varepsilon_s}$$

These computations are performed for each year from 2017 through 2050, until the convergence test is met.

Appendix A. Input Data and Variable Descriptions

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

Classification: Input variable

Worksheet: Total_Crude

P_Total_Crude_Init(CRSTEP,1990:1989+MNXYR) and	
Q_Total_Crude_Init(CRSTEP,1990:1989+MNXYR):	Initial global crude liquids supply curve
P_Init (1989+MNXYR):	Initial Brent price path
Q_Init (1989+MNXYR):	Initial global crude supply
S_E (1989+MNXYR):	Supply curves elasticity
D_E (1989+MNXYR):	Demand curves elasticity
P_Heavy_Sour(1989+MNXYR):	Heavy Sour crude type price
P_hs_Ratio(1989+MNXYR):	Heavy Sour/BRENT price ratio
BP(CRSTEP+1):	Supply and demand curves breakpoints

Worksheet: Crude_Supply_Inc_Domestic

Q_Domestic_Crude_ REF(1990:1989+MNXYR):	Expected domestic crude production

Worksheet: Crude_Supply_Inc_Foreign

Cr_Type_Coeff(MNCRUD,1989+MNXYR):	Crude Type coefficients
Cr_Type_Share(MNCRUD,1989+MNXYR):	Crude Type shares
BRENT_p(1989+MNXYR):	BRENT price path
WTI_p(1989+MNXYR):	WTI price path
Q_CRUDE_TO_CAN (MNUMPR,MNCRUD,MNXYRS)	Expected exogenous crude exports to Canada

Worksheet: C_MC_Prod_Demand

C_MC_P(MNPROD,1989+MNXYR):	Product demand curves price RefReg9
C_MC_Q(MNPROD,1989+MNXYR):	Product demand curves quantity

Worksheet: Imports_Exports

Petroleum product imports quantities IMP_Q (MNPROD, 1990:1989+MNXYR)
Petroleum product imports prices IMP_P (MNPROD, 1990:1989+MNXYR)
Petroleum product export quantities EXP_Q (MNPROD, 1990:1989+MNXYR)
Petroleum product exports prices EXP_P (MNPROD, 1990:1989+MNXYR)

Worksheet: Price_Cases_Data

Q_Non_USDemand_Base (1989+MNXYR): Non-U.S. crude demand for price case

Classification: Calculated variable

P_EQL(1989+MNXYR): Oil price at equilibrium
Q_EQL(1989+MNXYR): Global oil demand at equilibrium
S_*Diff(1989+MNXYR)*: Change in crude supply at equilibrium
D_*Diff(1989+MNXYR)*: Change in crude demand at equilibrium
P_Crude(MNCRUD, 1989+MNXYR): Foreign crude type price at equilibrium
Q_Crude(MNCRUD, 1989+MNXYR): Crude type quantity at equilibrium
LFMM_Purchase_Foreign_Crude(MNCRUD,1989+MNXYR): Crude type imports in the U.S
P_Non_US_Demand((MNCRUD,11,MNXYRS): Non-U.S. crude oil price by crude
Q_Non_US_Demand((MNCRUD,11,MNXYRS): Non-U.S. demand crude oil by crude
P_Total_Crude(CRSTEP,1990:MNXYRS): Price steps for world crude-like liquids
Q_Total_Crude(CRSTEP,1990:MNXYRS): Quantity steps for world crude liquids
P_Foreignl_Crude(MNCRUD,1,CISTEP,MNXYRS): Price steps for foreign crude supply
Q_Foreignl_Crude(MNCRUD,1,CISTEP,MNXYRS): Quantity steps for foreign crude supply
P_NON_US_DEMAND(MNCRUD,1,1,MNXYRS): Price steps for non-U.S. crude demand
Q_NON_US_DEMAND(MNCRUD,1,1,MNXYRS): Quantity steps for non-U.S. crude demand
P_C_MC_DEMAND(MCSTEP,MNXYRS,MNPROD): Price steps for region 9 petroleum product demands
Q_C_MC_DEMAND(MCSTEP,MNXYRS,MNPROD): Quantity steps for region 9 petroleum product demands

Classification: Input variables from NEMS

GLBCRDDMD(MNUMYR): LFMM view of global crude demand
MC_JPGDP*(MNUMYR)*: Chained price index-GDP
OGCRDPRD*(MNUMOR,MNCRUD,MNUMYR):* Crude production by region and type
Q_Crude_Imports*(MNUMOR,MNCRUD,MNXYRS):* Crude imports by region and type

Table 3. Petroleum products modeled in IEM

INDEX	GROUP	CODE
1	Asphalt	ASPHout
2	Aviation Gasoline	AVGout
3	CARBOB	CARBOBout
4	CARB DSU	CARBDSUout
5	Conventional Gasoline	CFGout
6	Low Sulfur Distillate	DSLout
7	Ultra-Low Sulfur Distillate	DSUout
8	Low Sulfur Residual Fuel	RL – N6H
9	Lubes	LUBout
10	Number 2 Heating Oil	N2Hout
11	High Sulfur Fuel Oil	N6Bout
12	Low Sulfur Fuel Oil	N6Iout
13	Petrochemical Feedstock	PCFout
14	Reformulated Gasoline	RFGout
15	Conventional Blendstock for Oxygenate Blending	CBOB
16	Reformulated Blendstock for Oxygenate Blending	RBOB
17	Methanol	Met
18	Atmospheric Resid-Medium Sulfur	AR3
19	Virgin Gas Oil-Medium Sulfur	GO3
20	Medium Naphtha-Medium Sulfur	MN3

Appendix B. Computer Code Description

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

SUBROUTINE: LFMM_World_Data_In

Description: LFMM_World_Data_In subroutine imports data for world crude-like liquids supply and demand curves, supply curves for each of the eight foreign imported crude types, U.S. projections of petroleum liquids production, as well as data on petroleum products imported/exported to or from the United States from the intallin.xml input file. Specifically, this subroutine reads and stores the following information from intallin.xml input file.

Source: intallin.xml input file

Worksheet: Total_Crude

P_Total_Crude_Init(CRSTEP,1990:1989+MNXYR)
Q_Total_Crude_Init(CRSTEP,1990:1989+MNXYR)
Step price and quantity values for expected global crude-like liquids supply curve
P_Init (1989+MNXYR) - Brent price path over the projection period
P_Init (1989+MNXYR) - Expected global crude-like liquids supply
S_E (1989+MNXYR) - Supply curves elasticity
D_E (1989+MNXYR) - Demand curves elasticity
P_Heavy_Sour(1989+MNXYR) - Heavy Sour crude type price
BP(CRSTEP+1) – Supply and demand curves breakpoints

Source: intallin.xml input file

Worksheet: Crude_Supply_Inc_Domestic

Q_Domestic_Crude_ REF (1990:1989+MNXYR) – Expected domestic crude production by year

Source: intallin.xml input file

Worksheet: Crude_Supply_Inc_Foreign
Cr_Type_Coeff(MNCRUD,1989+MNXYR) - Crude Type coefficients
Cr_Type_Share(MNCRUD,1989+MNXYR) - Crude Type shares
BRENT_p(1989+MNXYR) - BRENT price path
WTI_p(1989+MNXYR) - WTI price path
Q_CRUDE_TO_CAN (MNUMPR,MNCRUD,MNXYRS) - Expected exogenous crude exports to Canada

Source: intallin.xml input file

Source: intallin.xml input file

Worksheet: C_MC_Prod_Demand

C_MC_P(MNPROD,1989+MNXYR)

C_MC_Q(MNPROD,1989+MNXYR) - Step price and quantity values for expected petroleum product demands in refinery region 9

Source: intallin.xml input file

Worksheet: Imports_Exports

IMP_Q (MNPROD, 1990:1989+MNXYR)	Petroleum product imports quantities
IMP_P (MNPROD, 1990:1989+MNXYR)	Petroleum product imports prices
EXP_Q (MNPROD, 1990:1989+MNXYR)	Petroleum product exports quantities
EXP_P (MNPROD, 1990:1989+MNXYR)	Petroleum product exports prices

Source: intallin.xml input file

Worksheet: Price_Cases_Data

Q_Non_USDemand_Base (1989+MNXYR) - Non-U.S. crude demand for price case

SUBROUTINE: WORLD_LFMM_COMPUTE_NEW

Description: WORLD_LFMM_COMPUTE_NEW is the main subroutine of the International Energy Module. Most of the IEM computations are performed here, based on the data that is already made available by LFMM_World_Data_In subroutine or by other NEMS modules.

Equations

First, the U.S. actual domestic crude production is calculated as:

$$rActualCrudeProd = \sum \left(\frac{1000.0}{365.0}\right)(OGCRDPRD(MNCRUD, MNUMOR, 1989 + CURIYR)_{MNCRUD,MNUMOR}$$

where

OGCRDPRD(MNUMOR,MNCRUD,MNUMYR): *Crude production by supply region, crude type and year*.

Therefore, the changes in supply and demand are:

S_Diff = rActualCrudeProd – Q_Domestic_Crude_Ref

D_Diff = GLBCRDDMD(CURIYR) – Q_Init(1989+CURIYR)

where

GLBCRDDMD: Actual global oil demand
Q_Domestic_Crude_Ref: Expected domestic oil production
Q_Init: Expected global oil demand

New oil price (Brent) and new global oil supply, as explained in Key Computations and Equations Section, will be given by following formulas:

$$P\_Eql(1989 + CURIYR) = P\_Init(1989 + CURIYR)e^{\left(\left(\left(\frac{log\left(\frac{Q\_Init(1989+CURIYR)+ S\_Diff(1989+CURIYR)}{Q\_Init(1989+CURIYR)+D\_Diff(1989+CURIYR))}\right)}{D\_E(1989+CURIYR) - S\_E(1989+CURIYR)}\right)\right)\right)}$$

and,

$$Q\_Eql(1989 + CURIYR) = (Q\_Init(1989 + CURIYR) + S\_Diff(1989 + CURIYR)) \left(\frac{P\_Eql(1989+CURIYR)}{P\_Init(1989+CURIYR)}\right)^{S\_E(1989+CURIYR)}$$

where

P_Eql: Oil price at equilibrium in current year
Q_Eql: Oil quantity at equilibrium in current year
P_Init: Initial oil price in current year
Q_Init: Initial global oil supply in current year
D_Diff: Change in oil demand at equilibrium
S_E: Oil supply elasticity
D_E: Oil demand elasticity

If at least one of variables S_Diff and D_Diff is not null, then this subroutine will rebuild global crude supply curve around new center point $(P, Q) = (P\_Eql, Q\_Eql)$. The new supply curve will be also an incremental 14 steps supply curve.

do t = 1, CRSTEP

$$P\_Start = P\_Eql(1989 + CURIYR)(1 + BP(t))$$
$$P\_End = P\_Eql(1989 + CURIYR)(1 + BP(t + 1))$$

$$Q\_Start = Q\_Eql(1989 + CURIYR)\left(\frac{P\_Start}{P_{Eql(1989+CURIYR)}}\right)^{S\_E(1989+CURIYR)}$$

$$Q\_End = Q\_Eql(1989 + CURIYR)\left(\frac{P\_End}{P_{Eql(1989+CURIYR)}}\right)^{S\_E(1989+CURIYR)}$$

$$P\_Total\_Crude(t, 1989 + CURIYR) = \frac{P_{Start} + P\_end}{2}$$

$$Q\_Total\_Crude(t, 1989 + CURIYR) = Q\_End - Q\_Start$$

end do

Next, all step prices will be transformed from 2015 dollars to 1987 dollars.

do t = 1, CRSTEP

$$P\_Total\_Crude(t, 1989 + CURIYR) = \frac{P\_Total\_Crude(t, 1989 + CURIYR)}{MC\_JPGDP(25)}$$

end do

where

P_Start:	Starting price
P_End:	Ending price
Q_Start:	Starting quantity
Q_End:	Ending quantity
P_Total_Crude:	Oil price by step and year
Q_Total_Crude:	Step length by step and year
MC_JPGDP:	Chained price index – GDP by year

In order to comply with LFMM methods, this subroutine will build supply curves beyond 2040 (last year of projection period). All these supply curves will be identical with the 2040 supply curve.

do t=LASTYR+1, MNXYR

do iSt = 1, CRSTEP

$$P\_Total\_Crude(iSt, 1989 + t) = P\_Total\_Crude(iSt, 1989 + LASTYR)$$
$$Q\_Total\_Crude(iSt, 1989 + t) = Q\_Total\_Crude(iSt, 1989 + LASTYR)$$

end do
end do

Observation: The above method to build incremental supply (or demand) curves around a given central point (P, Q), with exogenously specified breakpoints BP and supply (or demand) elasticity, will be used a few more times by this subroutine.

Next, this subroutine builds incremental foreign crude supply curves.

Prices, by crude type, for the center of these curves, are computed using *Cr_Type_Coeff* variable, as detailed in Chapter 3, Fundamental Assumptions.

$$P_{Crude(c,1989+CURIYR)} = \frac{(P\_Crude(6{,}1989+CURIYR) - (Cr\_Type\_Coeff(c{,}1989+CURIYR))(P\_Crude(1{,}1989+CURIYR))}{1 - Cr\_Type\_Coeff(c{,}1989+CURIYR)}$$

Quantities, by crude type, for the center of these curves are computed by subtracting domestic production from the corresponding global quantity, using *Cr_Type_Share* variable.

$$\begin{aligned} QCrude(c, 1989 + CURIYR) \\ &= \big(QEql(1989 + CURIYR)\big)\big(CrTypeShare(c, 1989 + CURIYR)\big) \\ &- (sum(OGCRDPRD(:, c, CURIYR), 1) - OGCRDPRD(13, c, CURIYR))\left(\frac{1000.0}{365.0}\right) \end{aligned}$$

Based on the above observation, the subroutine builds incremental supply curves around central points $(P, Q) = (P\_Crude(c, 1989 + CURIYR), Q\_Crude\ (c, 1989 + CURIYR))$. Step prices and quantities of these supply curves are saved in *P_Foreign_Crude* and *Q_Foreign_Crude* variables.

Next, this subroutine computes non-U.S. crude demand by crude type. Quantities and prices are saved in Q_Non_US_Demand and P_Non_US_Demand variables. Non-U.S. crude demand quantity is computed by subtracting the crude imports in the United States from the foreign crude supply, by crude type. Non-U.S. crude demand prices will be equal to foreign crude prices (*P_Crude*).

Q_Non_US_Demand(c, Max_Crude_Source, Max_NonUS_Demand_Steps,1989+CURIYR) = Q_Crude(c,1989+CURIYR)-LFMM_PurchaseForeign_Crude(c,1989+CURIYR)

where LFMM_PurchaseForeign_Crude represents the sum of all imports in the United States, by crude type. These imports are saved in the global variable Q_Crude_Imports, and are computed by LFMM.

Petroleum product import supply curves are built using the same algorithm, around central points $(P, Q) = (IMP\_P(MNPROD, 1990{:}\,1989 + CURIYR), IMP\_Q(MNPROD, 1990{:}\,1989 + CURIYR))$

Petroleum product export demand curves are built using the same algorithm, around central points $(P, Q) = (EXP\_P(MNPROD, 1990{:}\,1989 + CURIYR), EXP\_Q(MNPROD, 1990{:}\,1989 + CURIYR))$

Petroleum product demands in refinery region 9 are built in a similar way, around central points $(P, Q) = (C\_MC\_P(iPr, 1989 + CURIYR), C\_MC\_Q(iPr, 1989 + CURIYR))$

where

IMP_P: Expected import price by product and year
IMP_Q: Expected import quantity by product and year
EXP_P: Expected export price by product and year
EXP_Q: Expected export quantity by product and year
C_MC_P: Expected price in Refinery Region 9 by product and year
Q_MC_Q: Expected demand in Refinery Region 9 by product and year

SUBROUTINE: OMS_DAT_IN

Description: This subroutine is used to read and transfer data to the NEMS integrating module, with the purpose of generating a worldwide liquids supply-balance report with regional detail. Specifically, data is read from the intbalance.xml input file and contains information on production and consumption of petroleum and non-petroleum liquids for the following global regions:

OPEC: Middle East, North Africa, West Africa, South America

Non-OPEC OECD: United States, Canada, Mexico and Chile, OECD Europe, Japan, Australia and New Zealand

Non-OPEC Non-OECD: Russia, China, Middle East, Africa, Brazil, Other Central and South America, Other Europe and Eurasia

Appendix C. References

U.S. Energy Information Administration, International Energy Statistics (www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm)

United States Geological Survey (USGS) World Petroleum Assessment of 2012

Bloomberg, L.P., www.bloomberg.com/energy.

BP Statistical Review of World Energy 2011 (London, UK, June 2012).

International Energy Agency, *IEA Statistics*: Oil Information 2010 (Paris, France, 2012).

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, supply, and the impact of changes in the U.S. petroleum market on world markets. It is used to recalculate oil prices in response to changes in U.S. crude-like liquids production and consumption. In addition, the IEM provides supply curves of crude oil imported to the United States for each of the eight foreign crude types considered (see Figure 2). Finally, the IEM provides U.S. import supply curves and export demand curves for petroleum products and petroleum product demand curves in refinery region 9. The model employs a general equilibrium algorithm to calculate the 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.

Purpose of the model:

As a component of the National Energy Modeling System, the NEMS IEM achieves following tasks: compute updated oil price (Brent), build supply curves for foreign crude types imported in the United States, build supply/demand curves for import/export of petroleum products in the United States, build demand curves for petroleum product demand in refinery region 9, make exogenous assumptions on crude oil exports to Canada and generate a report on world liquids production/consumption.

Most recent model update:

June 2018

Part of another model?

National Energy Modeling System (NEMS)

Model interfaces:

The IEM receives inputs from other NEMS models, including the NEMS Liquid Fuels Marketing Module (LFMM), and NEMS Macroeconomic Activity Module. The Generate World Oil Balance application is also a source of input to the IEM. Outputs are provided to the NEMS Integrating Module and LFMM.

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Documentation:

U.S. Energy Information Administration, U.S. Department of Energy, Model Documentation 2018 Report: International Energy Module (IEM) of the National Energy Modeling System, DOE/EIA-M071 (2018) (Washington, D.C., June 2018).

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 2016, DOE/EIA-0383 (2018). 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/aeo2018.zip).

Energy system described:

U.S. import supply curves for eight foreign crude oil types; imports/exports of petroleum products in each of the 9 refinery regions; petroleum product demands curves in refinery region 9.

Coverage:

- Geographic: Nine refinery regions, United States, and global (by region or country)
- Time Unit/Frequency: Annual through 2050
- Products: Oil prices; U.S. import supply curves for eight generic crude oil grades; U.S. crude oil imports; U.S. import/export curves for 20 petroleum products by refinery region; worldwide liquids supply-demand balance report
- Economic Sectors: Not applicable
- 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: see Table 1

Non-DOE input sources:

- None

DOE input sources:

NEMS

- 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 Application (GWOB) provided by EIA

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

Input data files: intallin.xml, intbalance.xml

Computing environment:

- Hardware Used: HP Proliant Multiprocessor Server

- Operating System: Windows Server 2012, 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: 44 seconds for a 1990-2050 run in non-iterating NEMS mode
- Special Features: None

Independent expert reviews conducted:

None

Status of evaluation efforts by sponsor:

None