Independent Statistics & Analysis
U.S. Energy Information Administration

International Energy Module of the National Energy Modeling System: Model Documentation 2022

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Update Information

This edition of the *International Energy Module (IEM) of the National Energy Modeling System: Model Documentation 2022* reflects the following changes made to the IEM in 2022 relative to the 2020 version of the module:

- Added exogenous assumptions for crude oil exported from the United States
- Added supply curves for all petroleum products imported into the United States
- Added demand curves for all petroleum products exported from the United States
- Added expected domestic crude oil production, net imports of petroleum products, and total crude oil processed by U.S. refineries
- Changed the structure of the intallin.xml input file to accommodate new data and faster exchanges of information within the National Energy Modeling System
- Introduced a new approach in modeling interactions between U.S. petroleum markets and other petroleum markets around the world in light of increasing domestic crude oil production
- Improved modeling Syncrude crude oil imports from Canada
- Improved dynamic reaction to the uncertainty of future oil prices for petroleum products, investment and production decisions of the Organization of the Petroleum Exporting Countries (OPEC), 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's (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 case and side cases, as well as other scenarios.

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

Model summary

The IEM, working 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 oil type
- Includes exogenous assumptions on U.S. crude oil exports
- Provides petroleum products demand curves for refinery region 9 (Maritime Canada and Caribbean region) (Figure 1)
- Provides petroleum products import supply curves and export demand curves
- 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 2022 (AEO2022)*.

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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 appendixes 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

EIA has always focused on understanding the interactive effects of changes in U.S. and world energy markets. The IEM was incorporated into NEMS 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:

- Calculate 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)
- Project 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 petroleum market
- Provide supply curves for foreign crude oil types imported into the United States (Figure 2)
- Provide exogenous assumptions for crude oil exported from the United States
- Provide supply curves for petroleum products imported into the United States
- Provide demand curves for petroleum products exported from the United States
- Provide demand curves for petroleum products in refinery region 9 (Figure 1)

Figure 1. Map of the U.S. refinery regions, Liquid Fuels Marketing Module (LFMM)

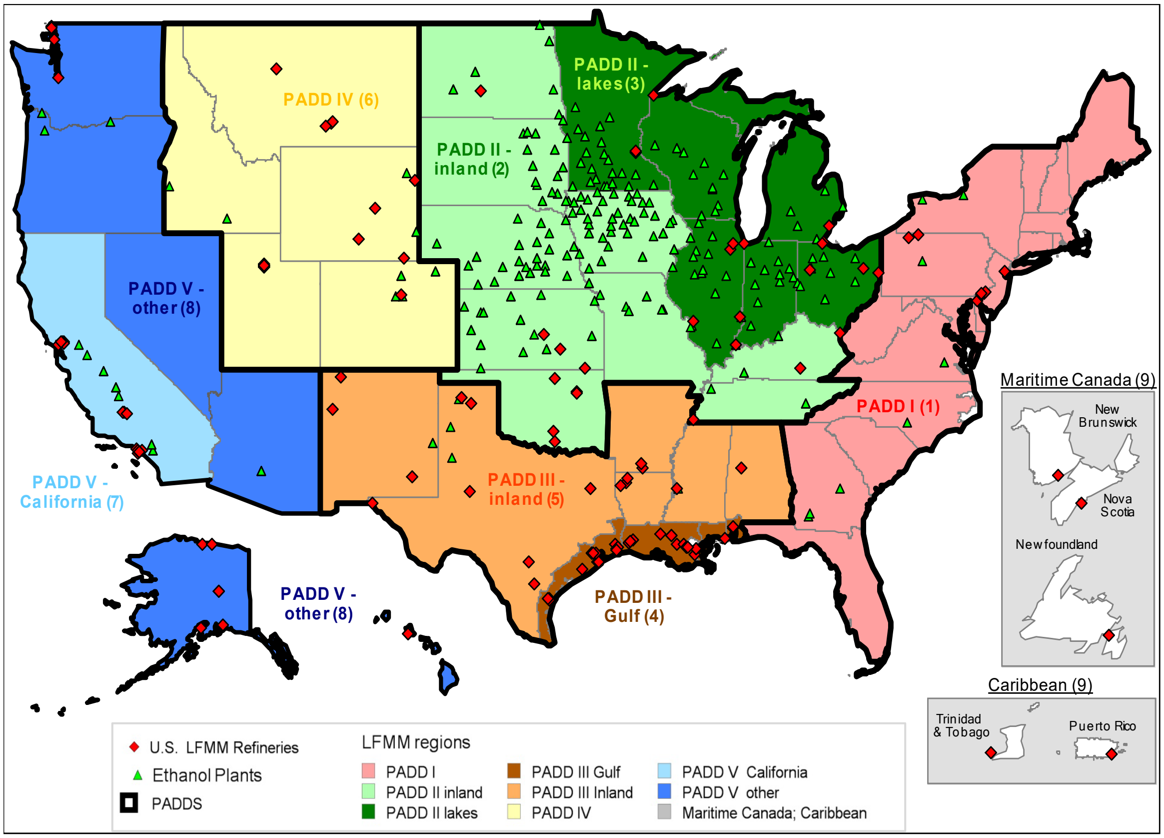
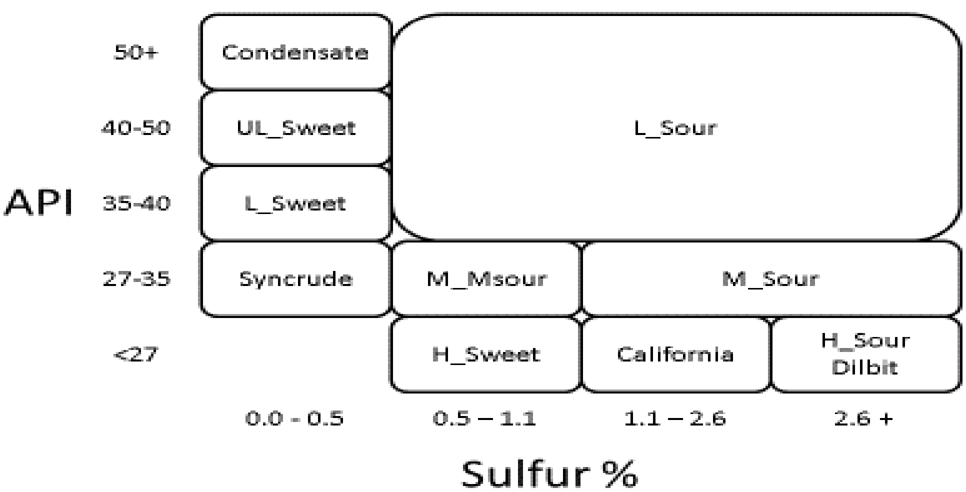


Figure 2. International Energy Module crude oil types



Model inputs and outputs

Inputs

The primary inputs to the IEM include:

- Expected global crude-like liquids supply and demand curves
- Crude oil prices (Brent)
- Crude oil types price differentials
- World supply shares of each crude oil type
- Projected U.S. domestic crude oil production
- Net imports of petroleum products imported into the United States
- Petroleum products demand curves in the Caribbean and Maritime Canada (refinery region 9)
- Petroleum products import supply curves
- Petroleum products export demand curves
- Exogenous assumptions on crude oil exported from the United States

Appendix A contains additional details on model inputs. The major inputs are summarized in Table 1.

Table 1. International Energy Module 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 oil types	Exogenous values included in input file intallin.xml
Gross domestic product deflators	Macroeconomic Activity Module
U.S. crude-like liquids production by year	Oil and Gas Supply Module
World crude-like liquids production and consumption by year	Liquid Fuels Marketing Module
U.S. crude oil imports by crude oil type and year	Liquid Fuels Marketing Module
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 oil supply curves, updated imports/exports petroleum product curves, non-U.S. crude-like liquids demand quantities, and supply curves for all foreign crude oils. Chapter 4, Model Structure—key computations and equations, explains in detail how the modified output Brent price differs from the input Brent price. Table 2 summarizes these outputs.

Table 2. International Energy Module model outputs

Model outputs	Destination
Computed world oil price	Liquid Fuels Marketing Module
World crude-like liquids supply and demand curves	Liquid Fuels Marketing Module
Supply curves for petroleum products imported into the United States	Liquid Fuels Marketing Module
Demand curves for petroleum products exported from the United States	Liquid Fuels Marketing Module
Supply curves, by year, for all foreign crude oil types	Liquid Fuels Marketing Module
Non-U.S. crude-like liquids demands	Liquid Fuels Marketing Module

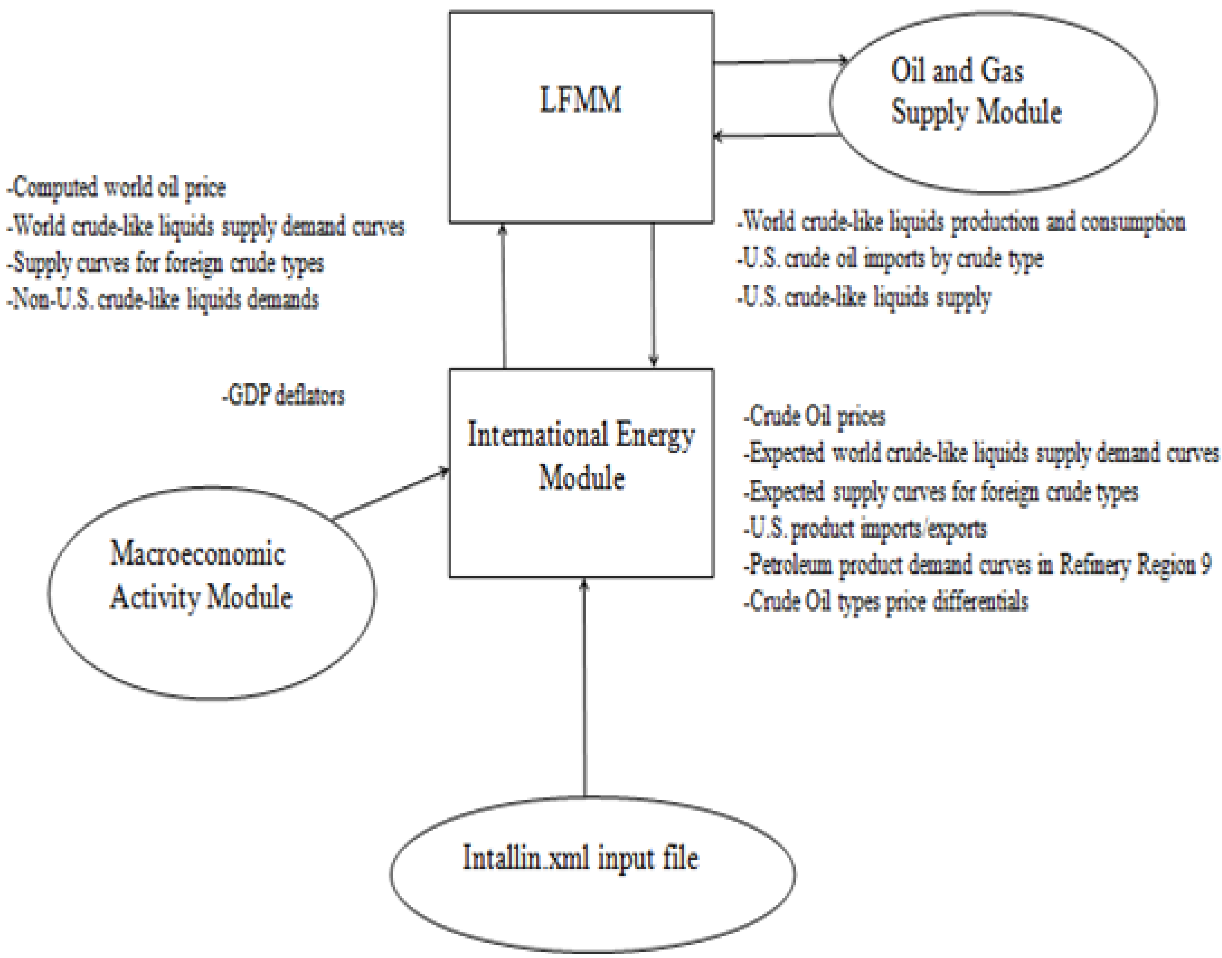
Relationship of the International Energy Module to other NEMS modules

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. 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. import supply curves of petroleum products, and U.S. export demand curves of petroleum products. The present focus of the IEM is on the international oil and petroleum product market. Any interactions between the United States 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 (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. International Energy Module's relationship to other modules in the National Energy Modeling System



3. Model Rationale

Theoretical approach

The NEMS IEM 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.

The IEM, as a module of AEO2022, considers a number of factors related to the uncertainty of future oil prices, including changes in worldwide demand for petroleum products, OPEC investment and production decisions, non-OPEC petroleum liquid fuels supply, and supplies of other liquid fuels.

Fundamental assumptions

For AEO2022, the IEM begins with basic assumptions about the liquid fuel demand and supply curves for the United States and the world, based on the results published in the AEO2021 and the *International Energy Outlook 2021*. 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 and export curves of petroleum products in the United States
5. World supply and demand, including conventional and unconventional liquid fuels

For each year of the historical and projection period (2008 through 2050), 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. All values for quantities are expressed in units of one thousand barrels per day, and prices are expressed in real 2021 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 from 2008 to 2050, these curves are constructed in the same format as the supply 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. Values for P, the expected world oil prices, are provided in the AEO2022 Assumptions document. Values for Q are assumed based on previous NEMS and GWOB model runs.

Demand elasticities

Demand elasticities (ε) are calculated on an annual basis from 2008 through 2050 using past projections of prices and world liquid fuel supply and demand from the AEO2021. For each year of the projection period, elasticities are computed using an optimization algorithm.

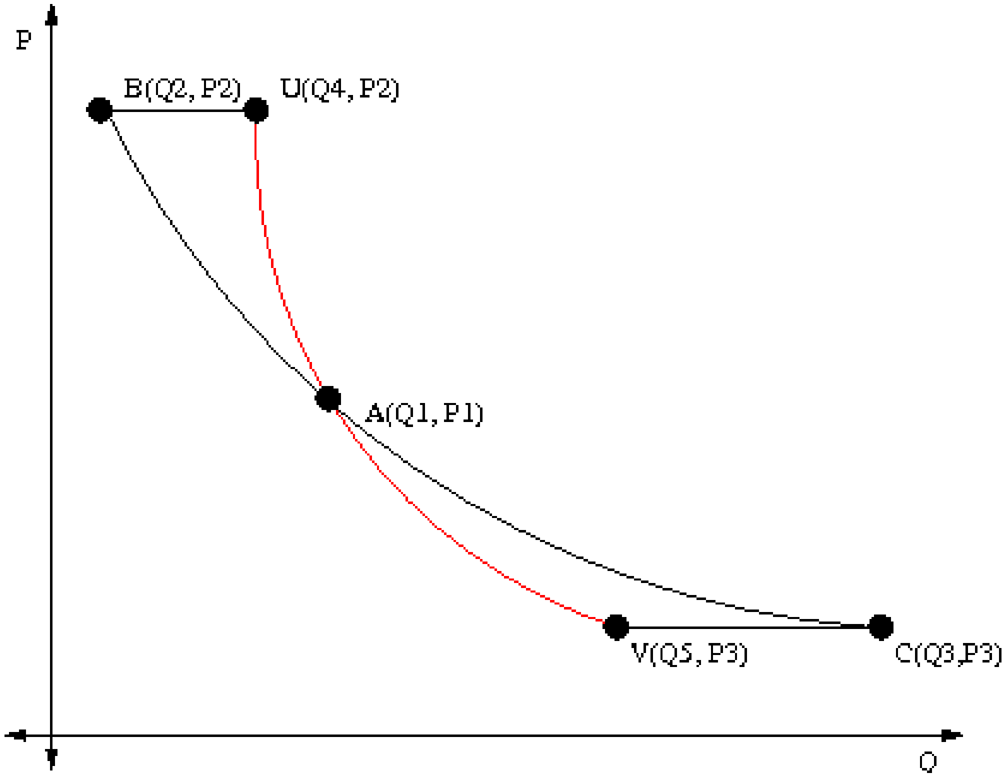
AEO2022 results are used as follows (Figure 4):

$P1$ – Oil price in Reference case
$Q1$ – Global total crude-like liquids demand in Reference case
$P2$ – Oil price in High Oil Price case
$Q2$ – Global total crude-like liquids demand in High Oil Price case
$P3$ – Oil price in Low Oil Price case
$Q3$ – Global total crude-like liquids demand in Low Oil Price case

Points A ($Q1$,$P1$), B ($Q2$,$P2$), and C ($Q3$, $P3$) are plotted as shown in Figure 4, 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.

[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. We develop the scenarios (oil price cases) 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. We base projections of conventional liquid fuels production for 2010 through 2020 on analysis of investment and development trends around the globe. We integrate data from our *Short-Term Energy Outlook* to ensure consistency between short-term 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 oil types are illustrated in Figure 2.

The light-sweet (Brent) crude oil price path during the projection period (2021–2050) is an exogenous assumption in NEMS. IEM makes an exogenous assumption for the price path of heavy-sour crude oil during the projection period based on analyst judgment, historical price correlation between Brent and heavy-sour crude oils (Maya), and historical price differentials.

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

The following is a description of the algorithm used to compute the medium-sour crude oil price path during 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 the 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,

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

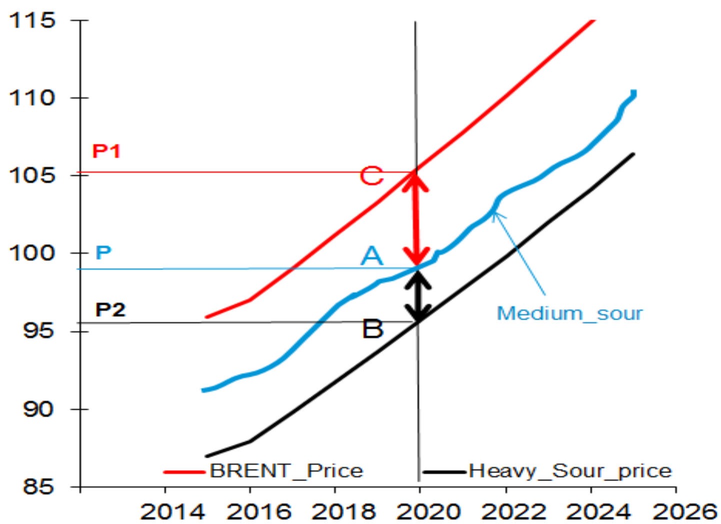
- Historical values for the ratio r average -1.10 for the 2000−2018 period
- Average value for ratio r is used for each year of the projection period

In a similar way, we compute average values for the ratio *r* for other crude oil types. The list below shows sample values for the ratio *r* for other crude oil types.

Crude oil type	***r*–historical values**
Light sour	-6.00
Medium Medium sour	-2.00
Medium sour	-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 oil price

2019$ per barrel



Imports and 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 IEM and LFMM approach to petroleum product imports and exports has two parts:

1. 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. 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 of barrels per day, and all input prices are in 2021 dollars.

For data to be *linear programming ready* (LP ready), all isoelastic supply curves are estimated by incremental step curves. In this process, 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. We compute the prices considered on each of these steps 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%.

AEO2022 projects an increase in domestic crude oil production, especially for lighter crude oils. This projection will lead to very dynamic interactions between U.S. petroleum markets and other petroleum markets around the world. U.S. refineries need to function at their optimal parameters, which creates a need for new exogenous assumptions on crude oil quality price differentials and petroleum product imports and exports. To implement some of these assumptions for AEO2022, we modified foreign heavy crude oil import supply curves toward a slate of heavier crude oil imports into the United States compared with previous years.

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

4. Model Structure

Structural overview

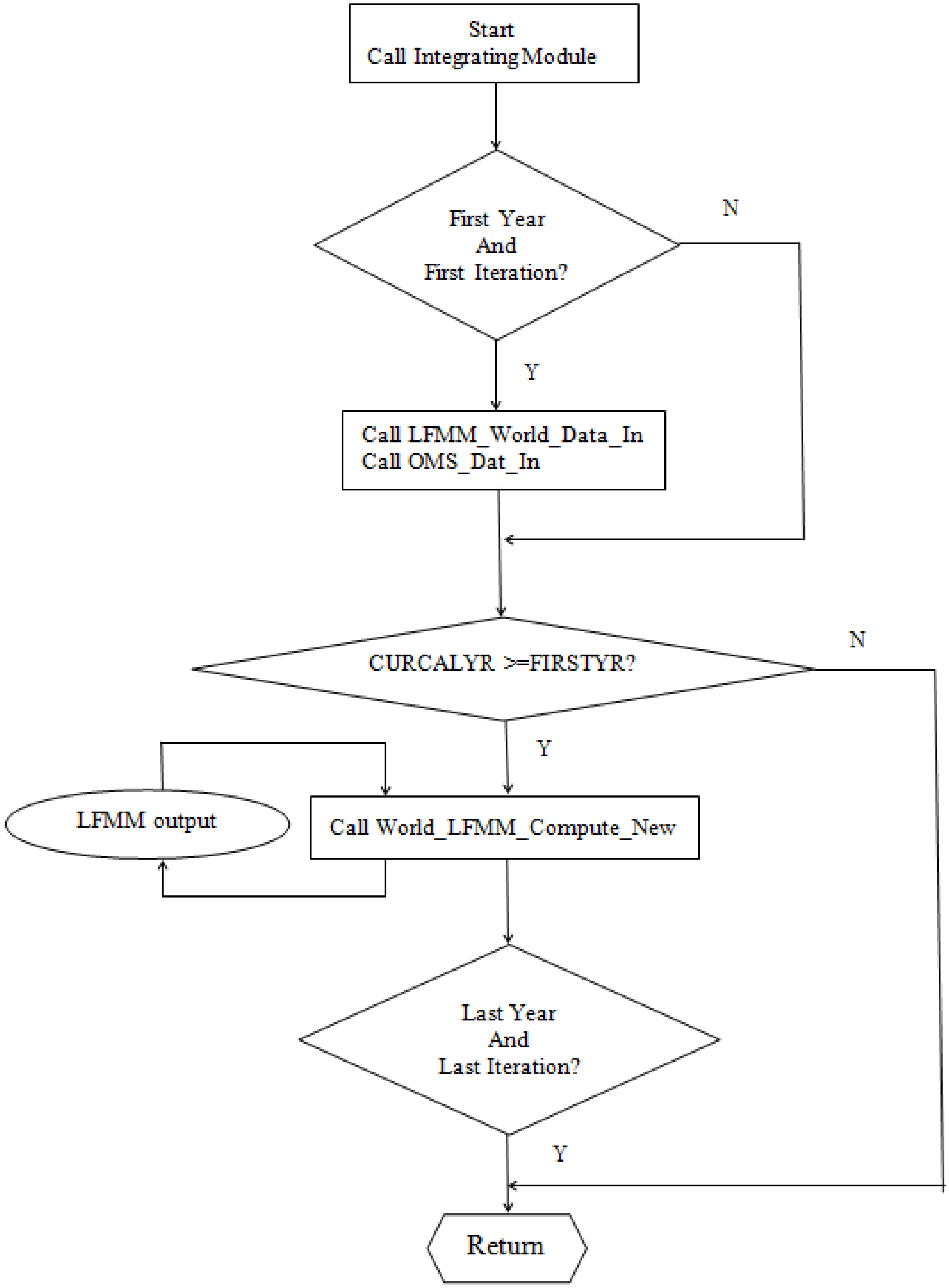
One of the main purposes of the NEMS IEM is to reestimate oil prices to reflect the effects of U.S. supply and demand pressures. It also provides a supply curve for world crude-like liquids, supply curves for each of the 10 foreign-imported crude oil types, supply curves for imported petroleum products, demand curves for exported petroleum products, and petroleum products demand curves for refinery region 9 (the Maritime Canada and Caribbean region) (Figure 1). It also 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 these factors must be accounted for 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 and Gas Supply Module, various end-use demand modules, and the Integrating Module) provide information about the U.S. liquid fuels 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 the import of the supporting information needed to complete the projection calculations for world liquid fuels markets. We calculate a substantial amount of support information for the IEM exogenously. We use various techniques, as explained in Chapter 3, 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. The LFMM_World_Data_In subroutine imports data for world crude-like liquids supply and demand curves, supply curves for each of the 10 foreign-imported crude oil types, U.S. projections of petroleum liquids production, as well as data on petroleum products imported and 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 liquid fuels production and consumption and provide information about the U.S. liquid fuels projection.

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

Figure 6. Flowchart for main International Energy Module routine



Key computations and equations

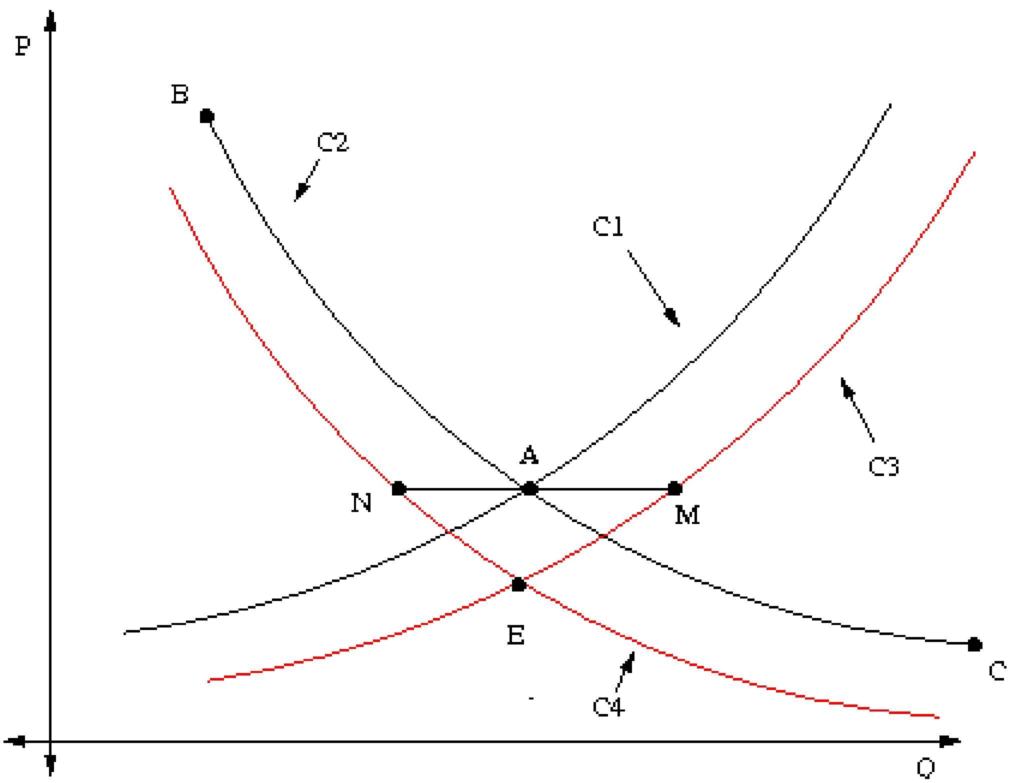
This section provides detailed solution algorithms arranged by sequential subroutine as executed in the NEMS IEM. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the details considered by the full forms of the equations provided in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

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

This section explains the algorithm the IEM uses to compute oil prices. The oil price is assumed to be the price of imported low-sulfur light crude oil (Brent).

All computations performed in the IEM start with year 2021. 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. Figure 7 is a visual representation of the algorithm.

Figure 7. Algorithm used to recalculate oil prices in the International Energy Module



For each year of the projection 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 oil 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 and has 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 and has the 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

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

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

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

Therefore, $Q^* = (Q_0 + \Delta Q_d)\left(\frac{P^*}{P_0}\right)^{\varepsilon_d}$ (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 2021 through 2050, until the convergence test is met.

Appendix A. Input Data and Variable Descriptions

The following variables represent data input from the 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-like liquids supply curve
P_Init (1989+MNXYR)	Initial Brent price path
Q_Init (1989+MNXYR)	Initial global crude oil supply
S_E (1989+MNXYR)	Supply curves elasticity
D_E (1989+MNXYR)	Demand curves elasticity
P_Heavy_Sour(1989+MNXYR)	Heavy-sour crude oil 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 oil production

Worksheet: Crude_Supply_Inc_Foreign

Cr_Type_Coeff(MNCRUD,1989+MNXYR)	Crude oil type coefficients
Cr_Type_Share(MNCRUD,1989+MNXYR)	Crude oil type shares
BRENT_p(1989+MNXYR)	Brent price path
WTI_p(1989+MNXYR)	West Texas Intermediate (WTI) price path
Q_CRUDE_TO_CAN (MNUMPR,MNCRUD,MNXYRS)	Expected exogenous crude oil exports to Canada

Worksheet: C_MC_Prod_Demand

C_MC_P(MNPROD,1989+MNXYR)	Product demand curves price for refinery region 9
C_MC_Q(MNPROD,1989+MNXYR)	Product demand curves quantity

Worksheet: Imports_Exports

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

Worksheet: Price_Cases_Data

Q_Non_USDemand_Base (1989+MNXYR)	Non-U.S. crude oil 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 oil supply at equilibrium
D_Diff(1989+MNXYR)	Change in crude oil demand at equilibrium
P_Crude(MNCRUD, 1989+MNXYR)	Foreign crude oil type price at equilibrium
Q_Crude(MNCRUD, 1989+MNXYR)	Crude oil type quantity at equilibrium
LFMM_Purchase_Foreign_Crude(MNCRUD,1989+MNXYR)	Crude oil type imports in the United States
P_Non_US_Demand((MNCRUD,11,MNXYRS)	Non-U.S. crude oil price by crude oil type
Q_Non_US_Demand((MNCRUD,11,MNXYRS)	Non-U.S. demand crude oil by crude oil type
P_Total_Crude(CRSTEP,1990:MNXYRS)	Price steps for world crude-like liquids
Q_Total_Crude(CRSTEP,1990:MNXYRS)	Quantity steps for world crude-like liquids
P_Foreignl_Crude(MNCRUD,1,CISTEP,MNXYRS)	Price steps for foreign crude oil supply
Q_Foreignl_Crude(MNCRUD,1,CISTEP,MNXYRS)	Quantity steps for foreign crude oil supply
P_NON_US_DEMAND(MNCRUD,1,1,MNXYRS)	Price steps for non-U.S. crude oil demand
Q_NON_US_DEMAND(MNCRUD,1,1,MNXYRS)	Quantity steps for non-U.S. crude oil demand
P_C_MC_DEMAND(MCSTEP,MNXYRS,MNPROD)	Price steps for region 9 petroleum product demand
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 oil demand
MC_JPGDP(MNUMYR)	Chained price index for gross domestic product (GDP)
OGCRDPRD(MNUMOR,MNCRUD,MNUMYR)	Crude oil production by region and type
Q_Crude_Imports(MNUMOR,MNCRUD,MNXYRS)	Crude oil imports by region and type

Table 3. Petroleum products modeled in International Energy Module

Index	Group	Code
1	Asphalt	ASPHout
2	Aviation gasoline	AVGout
3	California reformulated oxygenate blendstock	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 that represent the detailed solution algorithms. We arranged this section by sequential submodule as executed in the NEMS IEM.

Subroutine: LFMM_World_Data_In

The 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 oil types See Figure 2), U.S. projections of petroleum liquids production, as well as data on petroleum products imported and exported to or from the United States from the intallin.xml input file.

Specifically, this subroutine reads and stores the following information from the 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 during the projection period
Q_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 oil 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 oil production by year

Source: intallin.xml input file

Worksheet: Crude_Supply_Inc_Foreign

Cr_Type_Coeff(MNCRUD,1989+MNXYR)	Crude oil type coefficients
Cr_Type_Share(MNCRUD,1989+MNXYR)	Crude oil 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 oil exports to Canada

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 oil demand for price case

Subroutine: WORLD_LFMM_COMPUTE_NEW

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 are already made available by LFMM_World_Data_In subroutine or by other NEMS modules.

Equations

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

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

where

OGCRDPRD(MNUMOR,MNCRUD, $1989 + CURIYR$*)* = crude oil production by supply region, crude oil 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 the 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 the global crude oil supply curve around new center point $(P, Q) = (P\_Eql, Q\_Eql)$. The new supply curve will be also an incremental 14-step 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 changed 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

To comply with LFMM methods, this subroutine will build supply curves beyond 2050 (the final year of the 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 and supply (or demand) elasticity, will be used a few more times by this subroutine.

Next, this subroutine builds incremental foreign crude oil supply curves.

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

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

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

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

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 oil demand by crude oil type. Quantities and prices are saved in *Q_Non_US_Demand* and *P_Non_US_Demand* variables. Non-U.S. crude oil demand quantity is computed by subtracting the crude oil imports in the United States from the foreign crude oil supply, by crude oil type. Non-U.S. crude oil demand prices will be equal to foreign crude oil 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 oil 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

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

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

- Non-OPEC OECD (Organization for Economic Cooperation and Development): United States, Canada, Mexico and Chile, OECD Europe, Japan, and Australia and New Zealand
- Non-OPEC Non-OECD: Russia, China, Middle East, Africa, Brazil, Other Central and South America, and Other Europe and Eurasia

Appendix C. References

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

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

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

International Energy Agency, *IEA Statistics*: Oil Information 2020 (Paris, France, 2018).

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

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

U.S. Geological Survey (USGS), World Petroleum Assessment of 2012.

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

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

Appendix D. Model Abstract

Introduction

This section summarizes the IEM and its role within NEMS, specifically:

- Model name
- Model acronym
- Description
- Purpose of the model
- Most recent update
- Main model
- Model interfaces
- Official model representative
- Documentation
- Archive media and manuals
- Energy system description
- Coverage
- Modeling features
- Model inputs
- Input sources outside the U.S. Department of Energy (DOE)
- DOE input sources
- Independent expert reviews
- Status of evaluation efforts by sponsor

Model name

International Energy Module

Model acronym

IEM

Description

The NEMS IEM 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 liquid fuels 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 ten foreign crude oil types considered (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 it 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 are used as IEM model inputs.

Purpose of the model

As a component of NEMS, IEM:

- Computes the updated oil price (Brent)
- Builds supply curves for foreign crude oil types imported into the United States
- Builds supply and demand curves for import and export of petroleum products in the United States
- Builds demand curves for petroleum product demand in refinery region 9
- Makes exogenous assumptions on crude oil exports to Canada
- Generates a report on world liquid fuels production and consumption

Most recent model update

March 2020

Main model

The IEM is part of the 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. The IEM sends outputs to the NEMS Integrating Module and LFMM.

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Documentation

U.S. Energy Information Administration, U.S. Department of Energy, *Model Documentation 2020 Report: International Energy Module (IEM) of the National Energy Modeling System*, DOE/EIA-M071 (2020) (Washington, DC, January 2018).

Archive media and installation manuals

The IEM, as part of the NEMS system, has been archived for the Reference case published in the *Annual Energy Outlook 2022*. The NEMS archive contains all of the nonproprietary modules of NEMS as used in the Reference case.

Energy system description

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

Coverage

- Geographic: Nine U.S. and global refinery regions (by region or country)
- Time unit and frequency: Annual through 2050
- Products: Oil prices, U.S. import supply curves for ten generic crude oil grades, U.S. crude oil imports, U.S. import and export curves for 20 petroleum products by refinery region, and 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 demand-side, supply-side, tax credits, and Model inputs

Input sources outside the U.S. Department of Energy (DOE)

- 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. petroleum 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

Independent expert reviews

None

Status of evaluation efforts by sponsor

None