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Contents

Tables

Figures

Update Information

This edition of the *International Energy Module of the National Energy Modeling System: Model Documentation 2013* reflects that substantive modeling changes were made to the International Energy Module (IEM) in 2013 relative to the 2012 version of the module

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 utilized to generate projections in the reference and side cases, as well as other scenarios.

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

Model summary

The Liquid Fuels Marketing Module (LFMM) International Energy Module (IEM) 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 computes Brent and WTI prices, provides a supply curve of world crude-like liquids, supply curves for each foreign-imported crude types, supply curves for motor gasoline imported from Europe, petroleum products demand curves for refinery region 9 (Maritime Canada and Caribbean region, see Figure 1) and generates a worldwide oil supply-demand balance with regional detail. The IEM also provides, for each year of the projection period, endogenous and exogenous assumptions for petroleum products for import and export in the United States.

Model archival citation

This documentation refers to the NEMS International Energy Module as archived for the *Annual Energy Outlook 2013 (AEO2013)*.

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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 EIA focus. The IEM was incorporated into NEMS in order to enhance the capabilities of NEMS in addressing the interaction of the global and U.S. oil markets. Components of the IEM accomplish the following:

- Calculation of the 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).
- Calculation of the WTI price, which is defined as the price of light, low sulfur crude oil delivered to Cushing, Oklahoma
- Provision of supply curves for foreign crude types imported in the U.S.A.(see Figure 2)
- Provision of supply curves for European gasoline imported in the U.S.A.
- Provision of demand curves for petroleum products in refinery region 9 (see Figure 1)
- Provision of other petroleum products imported/exported in the U.S.A.
- 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.

Figure 1. Map of the U.S. refinery regions

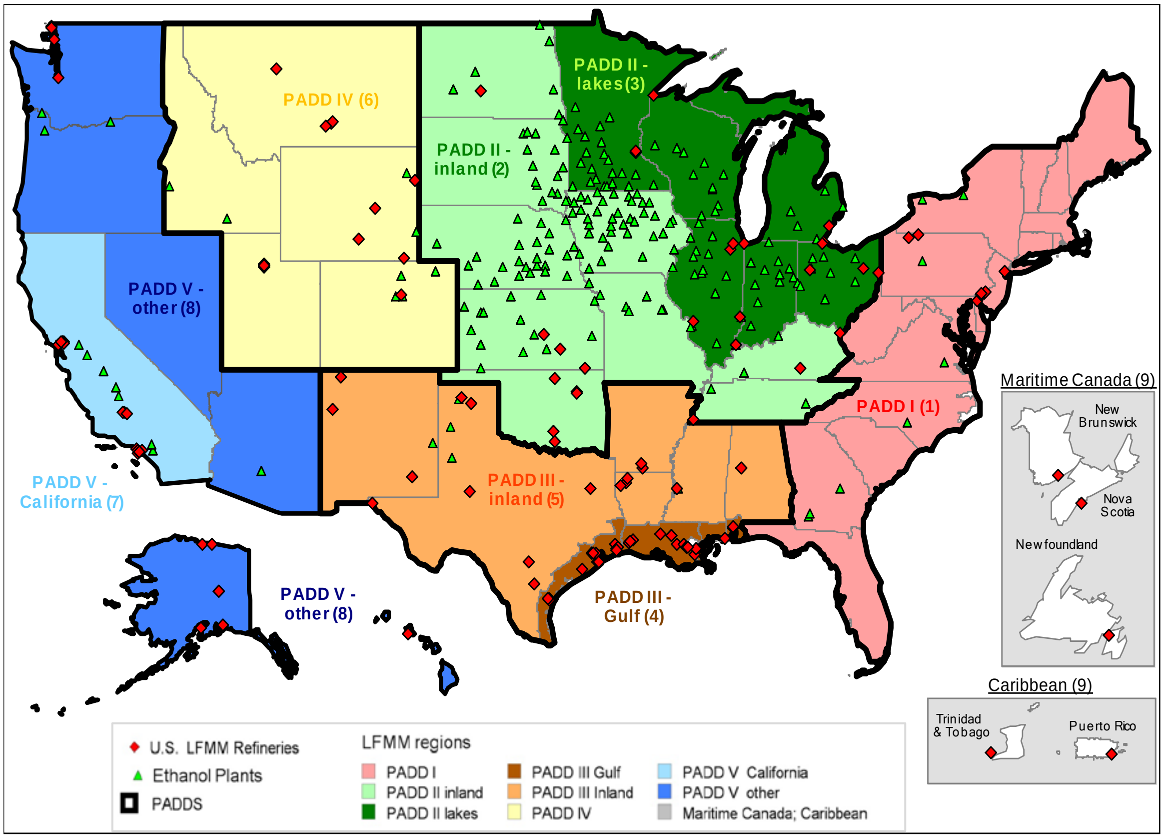
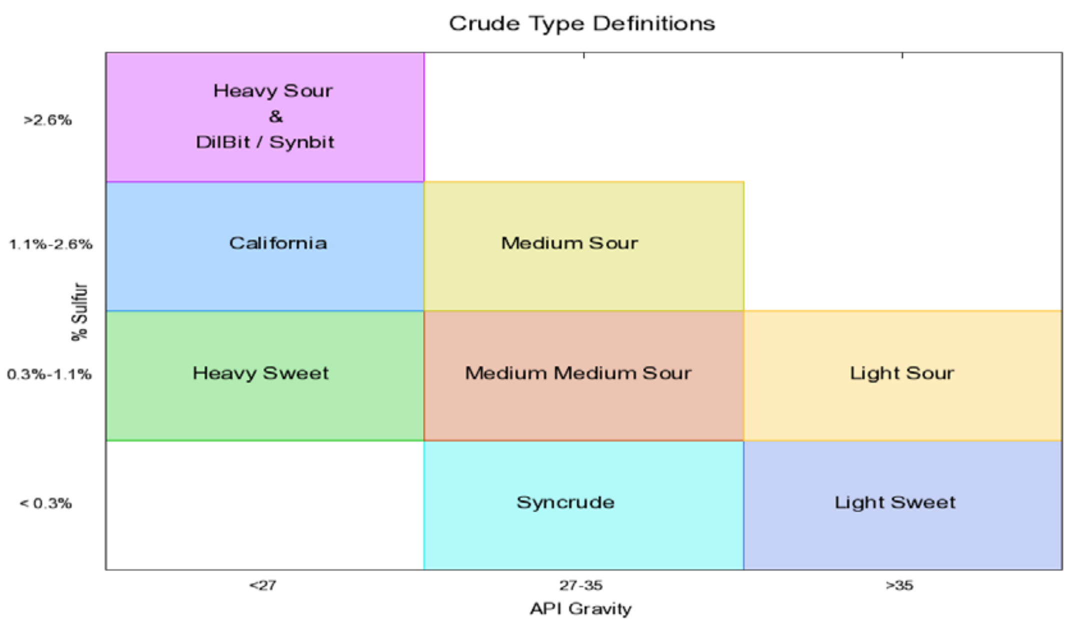


Figure 2. IEM crude types



Model inputs and outputs

Inputs

The primary inputs to the IEM include expected global crude-like liquids supply and demand curves; oil prices (Brent and WTI); crude types price differentials; world supply shares of each crude type; expected U.S. domestic crude production; Non-U.S. crude-like liquids demands for the three price cases; European gasoline supply curves for import in the United States; petroleum products demands curves in Caribbean and Maritime Canada (Refinery Region 9); other petroleum products imported/exported in 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 and WTI)	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 oil prices (Brent and WTI), world crude supply curves, Non-U.S. crude-like liquids demand quantities, and supply curves for all foreign crudes. 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, by year, for all foreign crude types	LFMM
Non-U.S. crude-like liquids demands	LFMM

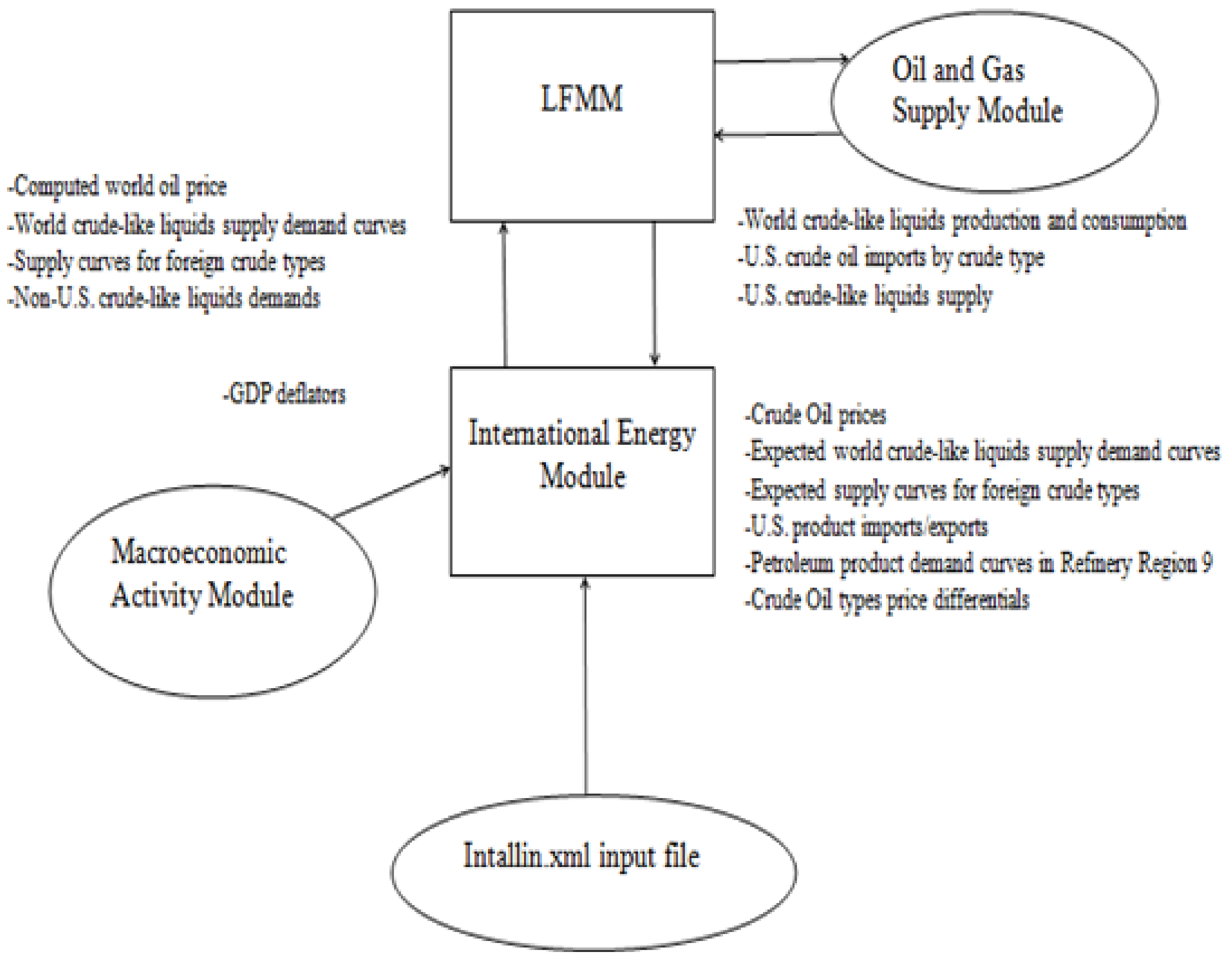
Relationship of the International Energy Module to other NEMS modules

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, and U.S. imports of petroleum products. It should be noted, however, that the present focus of the IEM is on the international oil market. Any interactions between the U.S. and foreign regions in fuels other than oil (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 new oil price.

Fundamental assumptions

For the *AEO2013*, 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 AEO2012 and the International Energy Outlook 2013. 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 2040:

1. Global Total Crude-Like Liquids Supply Curves
2. Global Total Crude-Like Liquids Demand Curves
3. Import crude oil types price differentials
4. Imports/Exports 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 2040), 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 2011 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 value of the elasticities in each year between 2008 and 2040 is assumed to be 0.25.

[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 2015 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

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

For each year of period 2008 to 2040, 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 by assumption. Values for **Q** are assumed based upon previous NEMS and GWOB model runs.

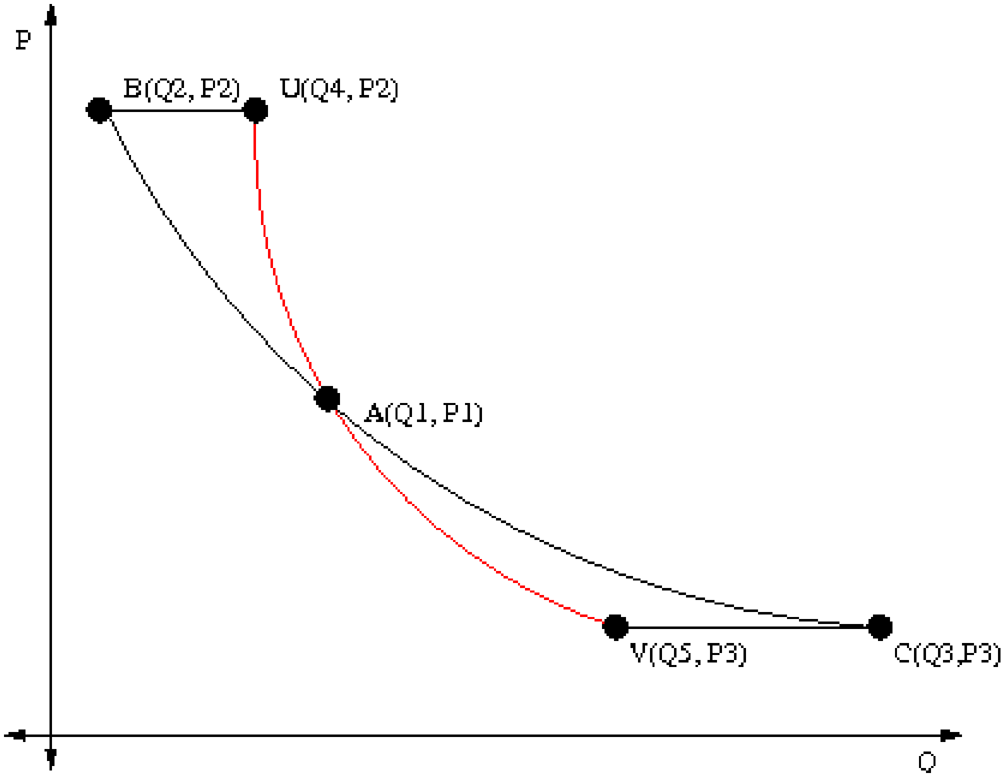
Demand elasticities (ε) are calculated on an annual basis from 2008 through 2040 using past projections of prices and world liquids supply and demand from the *AEO2012*. For each year of the projection period, elasticities are computed using an optimization algorithm.

That is, using results from the AEO2012 as follows (see Figure 4):

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

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

Figure 4. Global total petroleum liquids demand curve



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

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

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

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

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

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

Find ε < 0 such that the sum of lengths of segments BU and VC has a minimum value and so that:

$$Min\ \varepsilon < 0\ F(\varepsilon) \text{ or } Min\ \varepsilon < 0\ (abs\ |Q2 - Q1\ (P2/P1)^{\varepsilon}| + abs\ |Q3 - Q1\ (P3/P1)^{\varepsilon}|)$$

This optimization problem can be solved using a wide range of tools. Thus, the value of this minimum can be found and, more importantly, the value of ε for which the minimum value of function F is achieved can also be found. In 2008 year case, ε = -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 (2012-2040), is an exogenous assumption in NEMS. Based on analyst judgment, historical price correlation between BRENT and heavy sour crudes (MAYA), as well as on 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 = AB / AC = (P2-P) / (P1-P) (a)

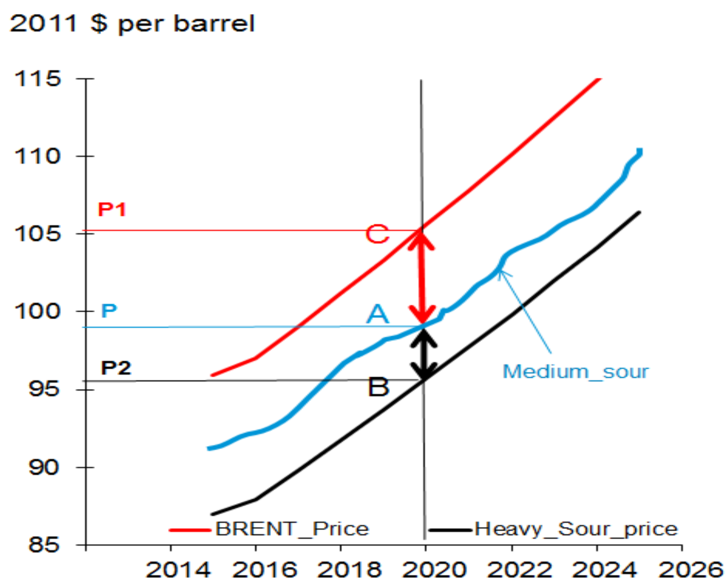
  equivalent with

  P = (P2-r*P1) / (1 – r) (b)
- Historical values for ratio r average -1.10
- Average value for ratio r is used for each year of the projection period

In a similar way, average values for ratio r are computed for other crude types. List below shows these values for 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	-3.50
Dibit/Synbit	0.20

Figure 5. Medium Sour crude price



Imports/Exports of petroleum products in the United States

The list of petroleum products modeled in IEM and LFMM is available in Table 1, Appendix A. 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 will be treated like the domestic refinery regions, except that product flows from this region to domestic markets will be reported as product imports. For each petroleum product and for each year of the projected period, IEM builds isoelastic demand curves:
   $\mathbf{Q = \alpha P^{\varepsilon}}$
   where P is the price, Q is the quantity, ε is the elasticity assumed to be constant for each curve (but which can vary from year to year), and α is a constant that can be determined by the coordinates of a point on the curve.
2. Second, IEM builds, for each year of projected period, a supply curve for European gasoline available for import in the United States. The reason for treating European gasoline imports separately from other product imports and exports is that historically these imports are a significant source of gasoline supply on the U.S. East Coast.
   As above, these supply curves will be isoelastic:
   $\mathbf{Q = \alpha P^{\varepsilon}}$
   where P is the price, Q is the quantity, ε is the elasticity assumed to be constant for each curve (but which can vary from year to year), and α is a constant that can be determined by the coordinates of a point on the curve.
3. Third, the remaining product imports and exports values are represented as a projected set of fix requirements for each year of the projected period.

All quantities are represented in thousands barrels per day and all input prices are in 2011 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 specified 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%.

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 of this report 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 2013* for each oil price case. Likewise, because the U.S. consumption of liquids is a dynamic value (and an output from NEMS), all other world regions have been proportionally updated so that the total world liquids consumption corresponds responds to the values reported in the *International Energy Outlook 2013* for each oil price case.

4. Model Structure

Structural overview

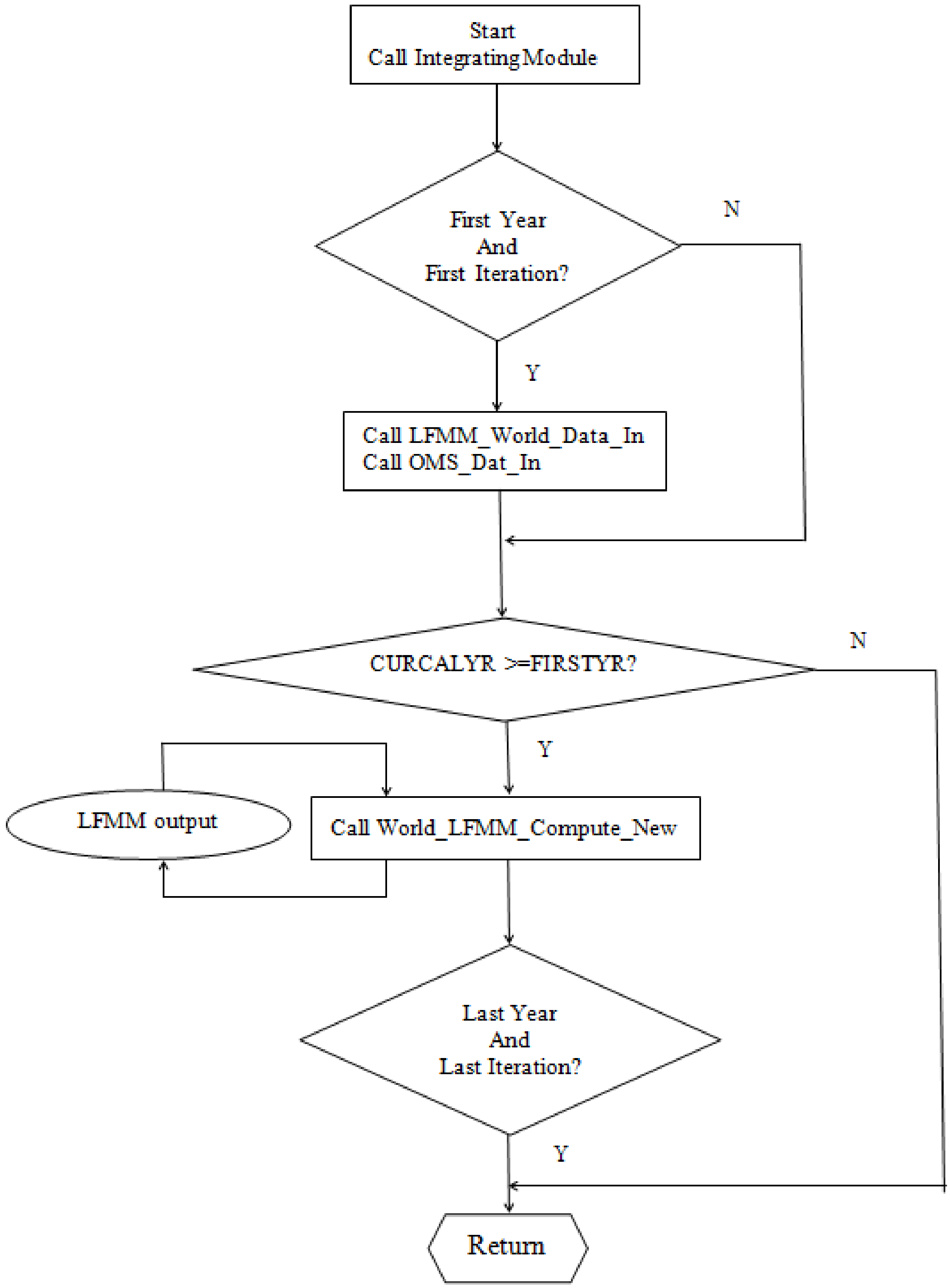
The main purpose of the NEMS IEM is to re-estimate oil prices. It also provides a supply curve of world crude-like liquids, supply curves for each of the eight foreign imported crude types, supply curves for motor gasoline imported from Europe, petroleum products demand curves for refinery region 9 (Maritime Canada and Caribbean region, see Figure 1) and generates a worldwide liquids supply-demand balance with regional detail. The IEM also makes available, for each year of the projection period, endogenous and exogenous assumptions for petroleum products for import and export in the United States. 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 current oil price. All of this must be achieved by keeping world oil markets in balance. Supply import curves are isoelastic curves, and points on the curve are adjusted as other NEMS modules (specifically the 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, including simple and logarithmic linear regressions, are used to estimate the coefficients and elasticities that are applied within the IEM. The results are saved in the intallin.xml input file, and are read into the IEM.

The main IEM routine or world queries the current calendar year (CURCALYR) variable to make sure it is a projection year (in the case of the *AEO2013*, greater than or equal to 2011). 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 eight 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 LFMM. Next, to balance worldwide crude demand, this subroutine computes non-U.S. crude demands (see Appendix B for detailed description).

Figure 6. Flowchart for Main IEM Routine



Key computations and equations

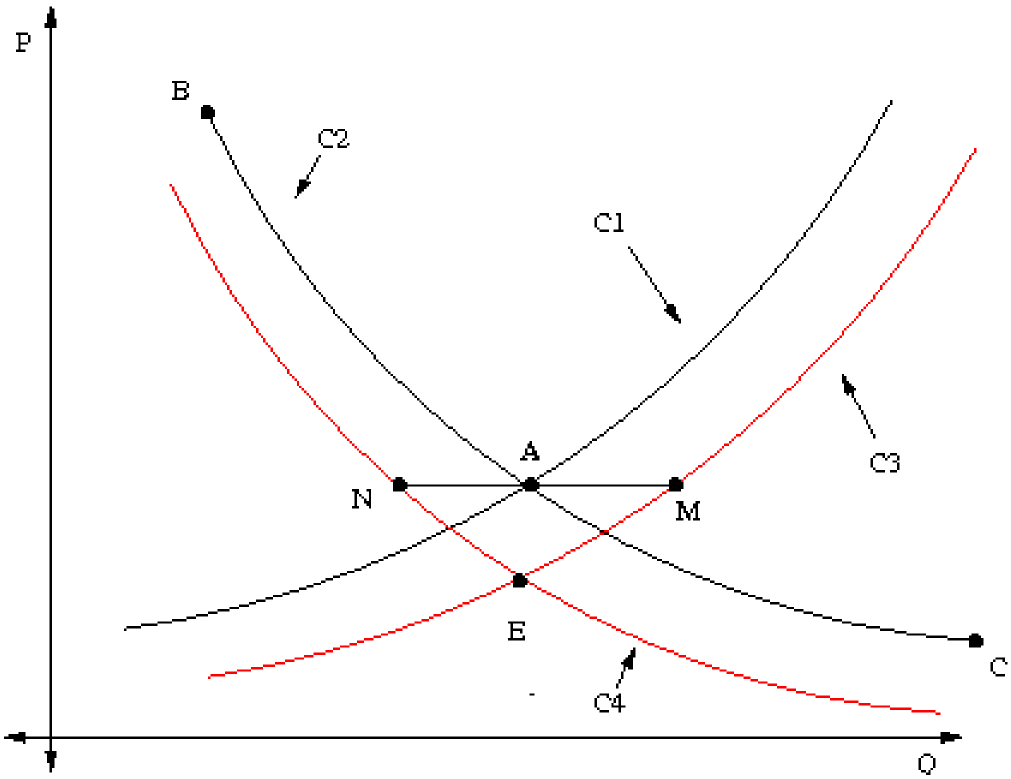
This section provides detailed solution algorithms arranged by sequential subroutine as executed in the NEMS International Energy Module. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the details considered by the full forms of the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

Recalculating world oil prices and U.S. crude oil and product import supply 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 2011. 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 compute 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 section – Structural Overview.

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

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

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

In a similar way, under a specific scenario, the change in the world petroleum products supply will be determined by the difference ΔQs between U.S. petroleum products production (from the 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, coordinates of point M are: (P_0, Q_0 + ΔQs). The new supply curve for world petroleum products will be the curve C3 that passes through point M. It is isoelastic, with same elasticity as the initial supply curve C1.

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

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

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

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

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

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

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

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

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

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

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

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

Also,

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

These computations are performed for each year from 2011 through 2040, 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_Production(MNCRUD,MNUMOR,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

Worksheet: EU_MG_Imports

P_EU_Gas(1989+MNXYR):	Imports Europe gasoline price
Q_*EU_Gas(1989+MNXYR)*:	Imports Europe gasoline quantity

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: Exp_Imp_Prod

Q_IMPORT_PRODUCT (MNPROD,REFREG,MNXYRS): *Q_EXPORT_PRODUCT (MNPROD,REFREG,MNXYRS)*:Other imports/exports quantities

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_PrchaseForeign_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-like
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 prod. demand
Q_C_MC_DEMAND(MCSTEP,MNXYRS,MNPROD):	Quantity steps for region 9 prod.
demand P_*EUROPE_GAS(EUSTEP,MNXYRS):*	Price steps for Europe gasoline supply
Q_*EUROPE_GAS(EUSTEP,MNXYRS):*	Quantity steps for Europe gasoline supply

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. Mathematical 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 in 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_Production(MNCRUD,MNUMOR,1990:1989+MNXYR) – Expected domestic crude production by crude type and refinery region

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

Source: intallin.xml input file

Worksheet: EU_MG_Imports

P_EU_Gas(1989+MNXYR) - Expected imported Europe gasoline price
Q_EU_Gas(1989+MNXYR) - Expected imported Europe gasoline quantity

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: Exp_Imp_Prod

Q_IMPORT_PRODUCT(MNPROD,REFREG,MNXYRS)

Q_EXPORT_PRODUCT(MNPROD,REFREG,MNXYRS) – Other petroleum product imports/exports by product and refinery region

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. expected and actual domestic crude production is calculated as:

$$Dom\_Crud\_Prod = \Sigma(Q\_Domestic\_Crude\_Production(MNCRUD,MNUMOR,1989+CURIYR)_{MNCRUD,MNUMOR})$$

$$rActualCrudeProd = \Sigma(OGCRDPRD(MNCRUD,MNUMOR,1989+CURIYR)_{MNCRUD,MNUMOR})*(1000.0/365.0)$$

Therefore, the change in supply is:

$$S\_Diff = Dom\_Crud\_Prod - rActualCrudeProd$$

In a similar way, the change in global crude demand is:

$$D\_Diff = GLBCRDDMD(CURIYR) - Q\_Init(1989+CURIYR)$$

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

$$P\_Eql(1989+CURIYR) = P\_Init(1989+CURIYR)*EXP(LOG((Q\_Init(1989+CURIYR)+S\_Diff(1989+CURIYR))/(Q\_Init(1989+CURIYR)+D\_Diff(1989+CURIYR)))/(D\_E(1989+CURIYR) - S\_E(1989+CURIYR)))$$

$$Q\_Eql(1989+CURIYR) = (Q\_Init(1989+CURIYR)+S\_Diff(1989+CURIYR))*(P\_Eql(1989+CURIYR)/P\_Init(1989+CURIYR))**S\_E(1989+CURIYR)$$

WTI prices will be computed based on the exogenous assumptions on price differentials between WTI and BRENT.

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)*(P_Start/P_Eql(1989+CURIYR))**S_E(1989+CURIYR)
Q_End   = Q_Eql(1989+CURIYR)*(P_End/P_Eql(1989+CURIYR))**S_E(1989+CURIYR)

 P_Total_Crude(t, 1989+CURIYR) = (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 2011 dollars to 1987 dollars.

```
do t = 1, CRSTEP

  P_Total_Crude(t, 1989+CURIYR) = P_Total_Crude(t, 1989+CURIYR)/MC_JPGDP(22)

end do
```

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) = (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.

*Q_Crude(c,1989+CURIYR) = Q_Eql(1989+CURIYR)*Cr_Type_Share(c,1989+CURIYR)- (sum(OGCRDPRD(:,c,CURIYR), 1)-OGCRDPRD(13,c,CURIYR))*(1000.0/365.0)*

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.

Gasoline import supply curves from Europe are built using same algorithm, around central points (P, Q) = (P_EU_Gas(1989+CURIYR), Q_EU_Gas(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))

SUBROUTINE: OMS_DAT_IN

Description: This subroutine is used to read and transfer data to NEMS integrating module, with the purpose of generating a worldwide liquids supply-balance report with regional detail. Specifically, data is read from 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)

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

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

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Appendix D. Model Abstract

Introduction

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

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

Model name:

International Energy Module

Model acronym:

IEM

Description:

The NEMS International Energy Module is a calculation tool that uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids production and consumption, by year, to model the interaction of U.S. and international liquids markets. The IEM projects international oil conditions, including demand, price and supply, and the impact of changes in the U.S. petroleum market on world markets. 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 for European gasoline, petroleum product demand curves in refinery region 9, and other exports and imports of petroleum products in each of the 9 refinery regions. 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:

- Calculation of the oil price (BRENT). Changes in the oil price are computed in response to:
  - O 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).
  - o 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).
- Calculation of the WTI price, which is defined as the price of light, low sulfur crude oil delivered to Cushing, Oklahoma
- Provision of supply curves for each foreign crude type imported in the U.S.A.(see Figure 2)
- Provision of supply curves for European gasoline imported in the U.S.A.
- Provision of demand curves for petroleum products in refinery region 9 (see Figure 1)
- Provision of other petroleum products imported/exported in the U.S.A.
- 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.

Most recent model update:

November 2012.

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 2013 Report: International Energy Module (IEM) of the National Energy Modeling System, DOE/EIA-M071 (2012) (Washington, D.C., February 2012).

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 2013, DOE/EIA-0383 (2012). 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/aeo2013.zip).

Energy system described:

U.S. import supply curves for eight foreign crude oil types; U.S. import supply curves of European gasoline; other 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 2040
- 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

Modeling features:

- Model Structure: The NEMS International Energy Module is a calculation tool that uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids production and consumption, by year, to model the interaction of U.S. and international liquids markets. The IEM projects international oil market conditions, including demand, price and supply, and the impact of changes in the U.S. petroleum market on world markets.

- Modeling Technique: The model employs a general equilibrium algorithm to calculate the oil price, and generates U.S. crude oil and petroleum product supply curves based on a series of simple and logarithmic linear regression equations that are developed exogenously and used as IEM model input.
- Special Features: The computational techniques used in the IEM enable it to accommodate a wide range of scenarios and policy analyses including but not limited to demand-side, supply-side, tax credits, and macro scenarios.

Model inputs: 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

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

Input data files: intallin.xml, intbalance.xml

Computing environment:

- Hardware Used: HP Proliant Multiprocessor Server
- Operating System: Windows Server 2003, Standard Edition with MKS Toolkit UNIX emulation
- Language/Software Used: Intel Visual Fortran, Version 9
- Memory Requirement: 4,000K
- Storage Requirement: 126.5 Megabytes
- Estimated Run Time: 32 seconds for a 1990-2040 run in non-iterating NEMS mode
- Special Features: None

Independent expert reviews conducted:

None

Status of evaluation efforts by sponsor:

None