Independent Statistics & Analysis
U.S. Energy Information Administration

Liquid Fuels Market Module of the National Energy Modeling System: Model Documentation 2018

July 2018

Independent Statistics & Analysis
www.eia.gov

U.S. Department of Energy
Washington, DC 20585

This report was prepared by the U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy. By law, EIA's data, analyses, and forecasts are independent of approval by any other officer or employee of the United States Government. The views in this report therefore should not be construed as representing those of the Department of Energy or other federal agencies.

Update Information

This edition of the Liquid Fuels Market Module (LFMM) of the National Energy Modeling System: Model Documentation 2018 reflects changes made to the module over the past two years for the *Annual Energy Outlook 2018*. These changes include:

- Extended the projection year from 2040 to 2050 (NEMS assumption)
- Modified E15 penetration potential to begin slowly in 2017 and grow to a maximum of 50% by 2050
- Revised motor gasoline octane projections (trending slightly higher)
- Revised RFS levels for historical and near-term years, per EPA decision (through 2017)
- Revised RFS levels over the projection period
- Changed first build year to 2024 for biomass-based liquids production and GTL units
- Changed first build year to 2027 for coal-to-liquid units
- Combined the constraint to restrict growth rate of GTL and CTL, since construction of these technologies compete for similar economic and natural resources
- Updated data defining crude and product transportation network, transport costs, and transport capacity, for both domestic and import/export links
- Modified seed oil supply curve data with soyoil data from Polysys (NEMS renewable fuels module)
- Revised the AB-32 coverage factor for jet fuel
- Revised coproduct pricing for gas oil
- Revised historical biodiesel import quantities
- Revised yield on heavy crude for better representation of the heavier crudes
- Correction to federal fuel tax for motor gasoline
- Updated refinery and non-refinery existing and planned capacity data, and refinery cogeneration data
- Updated data used to estimate state mandated ultra-low sulfur heating oil
- Updated other historical data for prices and volumes

Contents

Update Information ii
Acronyms and Abbreviations viii
Introduction 1
Purpose of this report 1
Model summary 1
Model archival citation 1
Organization of this report 1
Model Purpose 2
Model objectives 2
Relationship to other models 3
Model Rationale 5
Theoretical approach 5
Fundamental assumptions 6
Model Structure 7
Main subroutines (refine.f, lfshell.gms) 7
LP Preprocessing (lf_nem.gms, lfprep.gms) 9
LP Formulation (lfmodel.gms) 9
LP Post-Processing (lfreport.gms) 10
Appendix A. Data and Outputs 11
Variables and definitions 11
Data sources 11
Data tables 15
Appendix B. Mathematical Description of Model 20
Notation 23
Objective Function 27
Crude-related constraints 29
Product imports and exports 30
Brazil ethanol trade flow 31
Ethanol Flows 32
Refinery Input Streams (non-crude) 32
Miscellaneous Constraints 33

Policy Constraints 36
Appendix C. Bibliography 37
Appendix D. Model Abstract 44
Model name 44
Model acronym 44
Description 44
Purpose of the model 44
Most recent model update 44
Part of another model? 45
Model interfaces 45
Official model representative 45
Documentation 45
Archive media and installation manual 45
Energy system described 45
Coverage 45
Modeling features 47
Non-DOE input sources 47
DOE input sources 47
Independent expert reviews conducted 48
Status of evaluation efforts by sponsor 48
Appendix E. Data Quality 49
EIA Survey Forms 49
Quality of distribution cost data 51
Quality of tax data 52
Critical variables 53
Appendix F. Estimation Methodologies 54
Refinery investment recovery thresholds 54
Refinery unit fixed operating costs 64
Natural gas plant liquids 67
Estimation of distribution costs 67
Data-Reading Programs 68
Estimation of taxes 71

Gasoline specifications 72
Estimation of gasoline market shares 72
Diesel specifications 72
Estimation of diesel market shares 73
Estimation of regional conversion coefficients 75
Product pipeline capacities and tariffs 76
Cogeneration methodology 77
Refinery cogeneration 77
Non-petroleum feedstock supplies 77
E85 Infrastructure representation 79
Renewable Fuels Standard (EISA 2007) Representation 79
California Low Carbon Fuel Standard (LCFS) representation 82
Appendix G. Historical Data Processing 86
Processing data for LFMM history file 86
Processing other historical data 94

Tables

Table A-1. Btu/bbl for gases lighter than propane 13
Table A-2. Btu/bbl for other streams 14
Table A-3. GAMS files used to make LFMinset.GDX 15
Table A-4. Excel files used to make LFMINPUT.GDX 17

Table B-1. Specification-blended intermediate products 21
Table B-2. Recipe-blended (finished) products 21
Table B-3. Crude-related constraints 29
Table B-4. Product import/export constraints 30
Table B-5. Brazil ethanol constraints 31
Table B-6. Ethanol flow constraints 32
Table B-7. Refinery input stream constraints 32
Table B-8. Miscellaneous constraints 33
Table B-9. Policy constraints 36

Table E-1. Sources of markup inputs 52

Table F-1. Location multipliers for refinery construction 56
Table F-2. State and federal corporate income tax rates 60
Table F-3. Location multipliers for refinery operating labor 66
Table F-4. Capital-related fixed operating cost multipliers 67
Table F-5. Data series from federal tax table (CSeds_Fedtax) 69
Table F-6. Data identification codes 70
Table F-7. Gasoline specification 72
Table F-8. EPA diesel fuel sulfur Limits 73
Table F-9. Screenshot of spreadsheet for estimation of diesel market shares 74
Table F-10. Distillate consumption distribution 75
Table F-11. States and start years for ultra-low sulfur heating oil ..... **Error! Bookmark not defined.**
Table F-12. LFMM product pipeline capacity and tariff data represented in AEO2018**Error! Bookmark not defined.**
Table F-14. Available virgin feedstock (soybean oil, cotton seed oil, sunflower oil, canola oil), 1000 b/d ..... **Error! Bookmark not defined.**
Table F-15. Lag year factors for relating soyoil price to corn price ..... **Error! Bookmark not defined.**
Table F-16. EISA2007 RFS schedule 80
Table F-17. RFS schedule implemented in AEO2018 81
Table F-18. California LCFS carbon intensity targets 83
Table F-19. Sample carbon intensities 83

Table G-1. Park list sample 87

Figures

Figure B-1. Flow chart of stream flows 20

Figure G-1. Database linkages for historical data processing 86

Acronyms and Abbreviations

AEO	EIA Annual Energy Outlook
AFPM	American Fuel & Petrochemical Manufacturers
API	American Petroleum Institute
ASTM	Formerly known as the American Society for Testing and Materials
bbl	Barrel
bbl/cd	Barrels Per Calendar Day
Btu	British thermal unit
CARB	California Air Resources Board
CBTL	Coal-Biomass-To-Liquids (converting coal-biomass mix to diesel-grade blending streams)
CD	Census Division
CHP	Combined Heat and Power
Cn	Represents a hydrocarbon stream containing n atoms of carbon, i.e., C1 is methane, C2 is ethane, C3 is propane, C4 is butane, etc.
CTL	Coal-To-Liquids (converting coal to diesel-grade blending streams)
DOE	U.S. Department of Energy
E85	Gasoline blend of 85 percent ethanol and 15 percent conventional gasoline (The annual average of ethanol content in E85 is 74%, when factoring in cold start need in winter)
EIA	U.S. Energy Information Administration
EISA2007	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
FREC	U.S. Federal Energy Regulatory Commission
FOE	Fuel Oil Equivalent
GTL	Gas-To-Liquids (converting natural gas to diesel-grade blending streams)
IEO	EIA International Energy Outlook
IEM	International Energy Model
ISBL	Inside the battery limit
KWh	Kilowatt-hour
LCFS	Low Carbon Fuel Standard
LFMM	Liquid Fuels Market Module
LP	Linear Programming
LPG	Liquefied Petroleum Gas
Mbbl/cd	Thousand Barrels Per Calendar Day
MBtu	Thousand British Thermal Units
MMbbl/cd	Million Barrels Per Calendar Day
MMBtu	Million British Thermal Units
MTBE	Methyl Tertiary Butyl Ether
MW	Megawatts, electric generation capacity
MWh	Megawatt-hour
NACOD	North American Crude Oil Distribution
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NGL	Natural Gas Liquid
NGPL	Natural Gas Plant Liquid
NPC	National Petroleum Council
NPRA	National Petrochemical and Refiners Association, now known as the American Fuel & Petrochemical Manufacturers (AFPM)

OGSM	Oil and Gas Supply Module
ORNL	Oak Ridge National Laboratory
OVC	Other Variable Costs
PADD	Petroleum Administration for Defense District
PCF	Petrochemical Feed
PMM	Petroleum Market Model
ppm	Parts Per Million
PSA	Petroleum Supply Annual
RFG	Reformulated Gasoline
RFS	Renewable Fuels Standard
RVP	Reid Vapor Pressure
RYM	Refinery Yield Model (EIA)
SCF	Standard Cubic Feet
SPR	Strategic Petroleum Reserve
STEO	Short-Term Energy Outlook
TRG	Conventional Gasoline
ULSD	Ultra-Low Sulfur Diesel

Introduction

Purpose of this report

The purpose of this report is to define the objectives of the Liquid Fuels Market Module (LFMM), describe its basic approach, and provide details on how it works. This report is intended as a reference document for model analysts and users. It is also intended as a tool for model evaluation and improvement. Documentation of the model is in accordance with EIA's legal obligation to provide adequate documentation in support of its models (Public Law 94-385, section 57.b.2). An overview of the LFMM and its major assumptions can also be found in two related documents: *Annual Energy Outlook 2018 (Appendix E)*, and *Assumptions to the Annual Energy Outlook 2018*. This volume documents the version of the LFMM used for the *Annual Energy Outlook 2018* (AEO2018) and supersedes all previous versions of the LFMM documentation.

Model summary

The LFMM models petroleum refining activities, the marketing of petroleum products to consumption regions, the distribution of natural gas liquids from natural gas processing plants, and the production of renewable fuels (including ethanol, biodiesel, and cellulosic biofuels) and non-petroleum fossil fuels (including coal- and gas-to-liquids). The LFMM projects domestic petroleum product prices and input supply quantities for meeting petroleum product demands by supply source, fuel, and region. These input supplies include domestic and imported crude oil; alcohols, biodiesel, and other biofuels; domestic natural gas plant liquids; petroleum product imports; and unfinished oil imports. In addition, the LFMM estimates domestic refinery capacity expansion and fuel consumption. Product prices are estimated at the Census Division (CD) level; much of the liquid fuels production activity information is at the level of Petroleum Administration for Defense Districts (PADDs) and sub-PADDs.

Model archival citation

The LFMM is archived as part of the National Energy Modeling System (NEMS) for AEO2018. The model contact is:

James Preciado
Energy Information Administration
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585
(202) 586-8769

Organization of this report

The remainder of this report is organized in the following chapters: Model Purpose; Model Rationale; Model Structure; Appendix A, Data and Outputs; Appendix B, Mathematical Description of Model; Appendix C, Bibliography; Appendix D, Model Abstract; Appendix E, Data Quality; Appendix F, Estimation Methodologies; and, Appendix G, Historical Data Processing.

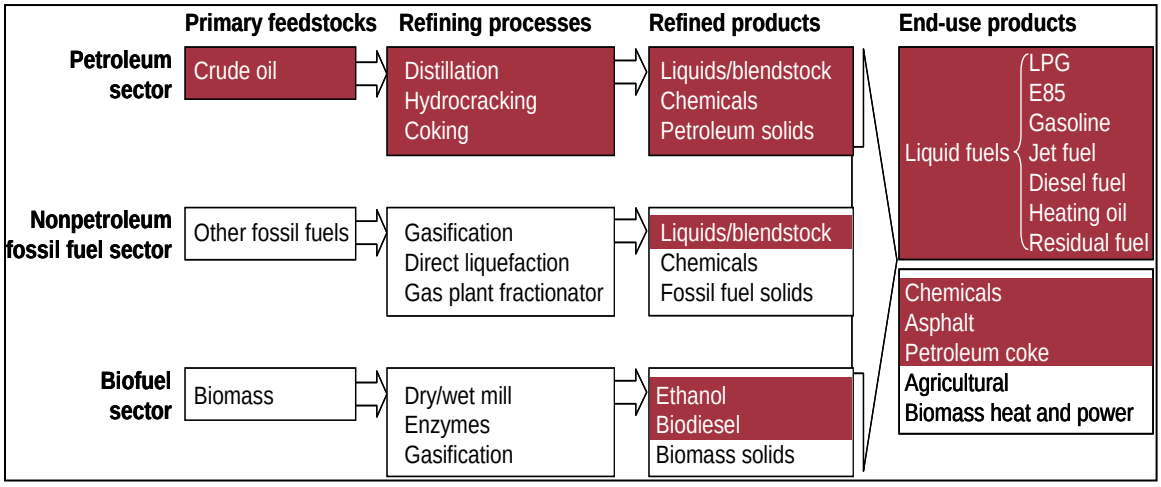
Model Purpose

Model objectives

The Liquid Fuels Market Module (LFMM) models production and marketing of liquid fuels, including petroleum products and non-petroleum liquid fuels. The purpose of the LFMM is to project liquid fuel prices, production activities, and movements of petroleum into and out of the United States and among domestic regions. In addition, the LFMM estimates capacity expansion and fuel consumption in the liquid fuels production industry. The LFMM is also used to analyze a wide variety of issues and policies related to petroleum fuels and non-petroleum liquid fuels in order to foster a better understanding of the liquid fuels industry, and the effects of certain policies and regulations.

The production processes and physical flows represented in LFMM are shown in the figure below.

Figure 1. Liquid fuels production industry, with LFMM highlighted in red



The LFMM simulates the operation of petroleum refineries and non-petroleum liquid fuels production plants in the United States, with a simple representation of the international refinery market used to provide competing crude oil[1] and product import and export prices and quantities. The U.S. component includes the supply and transportation of crude oil to refineries, regional processing of these raw materials into petroleum products, and the distribution of petroleum products to meet regional demands. The U.S. component also represents the marketing and distribution of the fractionated natural gas liquids from natural gas processing plants, the production of distillate and naphtha blending streams from natural gas (gas-to-liquids, GTL), coal (coal-to-liquids, CTL), and biomass (biomass-to-liquids, BTL), and the processing of renewable fuel feedstock (corn, biomass, seed oils, fats and greases) into alcohol and biomass-based diesel liquid blends. The essential outputs of this model are domestic liquid fuels product prices, a petroleum supply/demand balance, demands for refinery fuel use, and capacity expansion decisions.

Inputs to the LFMM:

[1] The International Energy Module (IEM) provides price and quantity representation for foreign crude supplies.

- domestic petroleum product demands
- international petroleum product import/export curves
- domestic crude oil production levels (9 crude types, including average California)
- international crude oil supply curves (10 crude types, excluding California, including Canadian syncrude and dilbit) and import/export links
- costs of energy inputs such as natural gas and electricity
- costs and available quantities of feedstocks (biomass, corn, etc.) used to produce blending components such as ethanol and biodiesel
- yield coefficients for crude oil distillation and other processing units
- existing and planned process unit capacities
- investment costs for capacity expansion
- capacities and tariffs for pipeline and other transportation modes
- product specifications
- policy requirements (including RFS, LCFS, etc.)

From these inputs, the LFMM produces:

- a slate of domestic prices for petroleum products
- regional domestic crude prices
- the quantity of crude oil processed at domestic refineries
- imports and exports of crude oil and petroleum products
- estimates of other refinery inputs and processing gain
- domestic capacity expansion for petroleum refineries and biorefineries
- refinery fuel consumption

The LFMM is used to represent the liquid fuels production and marketing sector in projections published in the Annual Energy Outlook. The model is also used for analysis of a wide variety of related issues. The LFMM is able to project the impact on refinery operations and on the marginal costs of refined products associated with changes in: demands for various kinds of petroleum products; crude oil prices; refinery processing unit capacities; petroleum product specifications; energy policies and regulations; and taxes, tariffs, and subsidies.

Relationship to other models

The LFMM represents the liquid fuels production and marketing sector within the National Energy Modeling System (NEMS). The LFMM projects petroleum product prices, crude and product import and export levels, and supplies/production of alternative fuels. These projections are generated as part of a NEMS supply/demand/price equilibrium solution. The LFMM does not examine inventories or inventory changes between projection years.

Several other models in NEMS provide inputs to the LFMM. These inputs are listed below.

- Demands for petroleum products are provided by the Residential Demand, Commercial Demand, Industrial Demand, Transportation Demand, and Electricity Market Modules. The demands include motor gasoline, E85, jet fuel, kerosene, heating oil, ultra-low sulfur diesel,

CARB diesel, low- and high-sulfur residual fuel, liquefied petroleum gases (LPG), petrochemical feedstocks, petroleum coke, and other petroleum products.

- Benchmark crude price is provided by the International Energy Module (IEM). The IEM provides a benchmark crude oil supply curve for Brent crude, as well as for 9 other crude types. Prices for the other crude types are computed in the LFMM based on the import/export decision levels for each crude type.
- Domestic crude oil production levels are provided by the Oil and Gas Supply Module (OGSM). The crude oil is categorized into the same types represented for the import supply curves (excluding Canadian dilbit and syncrude), plus an average California crude.
- Natural gas liquids, which are among the non-crude inputs to refineries, are also estimated by OGSM from domestic natural gas production levels and characteristics.
- Coal supply information (prices and quantities on supply curves, coal type, transportation network, emissions, and consumption for electricity generation and other needs) used for feedstock to produce CTL and CBTL are provided by the Coal Market Module (CMM).
- Natural gas and electricity prices are provided by the Natural Gas Market Module (NGMM) and the Electricity Market Module (EMM), respectively. The LFMM estimates the refinery consumption of these energy sources.
- Certain macroeconomic parameters are provided by the Macroeconomic Activity Module (MAM). The Baa average corporate bond rate is used for the cost of debt calculation, and the 10-year Treasury note rate is used for the cost of equity calculation. Both rates are used in estimating the capital-related financial charges for refinery and liquid fuels process unit investments. Discount rates are also provided by the MAM.
- Cellulosic and soy bean oil feedstock prices and quantities are provided by the Renewable Fuels Module (RFM).
- The logit function and other parameters used to estimate the ratio of E85 to motor gasoline usage for flex fuel vehicles (FFV) are provided by the Transportation Demand Module (TDM).

The LFMM also provides information to other NEMS modules:

- Prices of petroleum products are passed to the Residential Demand, Commercial Demand, Industrial Demand, Transportation Demand, Electricity Market, and Natural Gas Market Modules. The prices are used to estimate end-use demands for the various fuels.
- Supply balance quantities, including crude oil refinery inputs, non-crude refinery inputs, and processing gain, are provided for reporting purposes.
- Capacity expansion and utilization rates at petroleum refinery and biorefinery plants are determined mainly for reporting purposes.
- Fuel consumption at refineries. This information is passed to the Industrial Demand Module (IDM) for inclusion in the industrial sector totals. In addition, refinery combined heat and power (CHP) capacity and generation levels are sent to the IDM and EMM.
- Cellulosic biomass consumption is sent to the Renewable Fuels Module.

Model Rationale

Theoretical approach

The National Energy Modeling System (NEMS) is a general energy-economy equilibrium model that solves for quantities and prices of fuels delivered regionally to end-use sectors. The solution algorithm (Gauss-Seidel) is an iterative procedure used to achieve convergence between prices and quantities for each fuel in each region. For example, the various demand modules use the petroleum product prices from the LFMM to estimate product demands. The LFMM then takes the petroleum product demands as given, and estimates petroleum product prices. When successive solutions of energy quantities demanded and delivered prices are within a pre-specified percentage difference (convergence tolerance), the NEMS solution is declared converged. If the computed prices have not converged, new demand quantities are computed, passed to the LFMM, and the cycle is repeated. This process continues until a converged solution is found. See the description of the NEMS integrating module for a more complete description of the iterative process and convergence tests.

Within the LFMM, a linear program (LP) is used to represent domestic liquid fuels production, distribution, and marketing operations. The model includes eight U.S. regions based on PADDs (Petroleum Administration for Defense Districts) and sub-PADDs, and one international region representing petroleum refining activity in eastern Canada and the Caribbean. A transportation network model represents transport of domestic crude oils to the refining regions and products from the refining regions to the end-use Census Division (CD) demand regions. Changes in one refining region can affect operations in other refining regions because each demand region can be supplied by more than one refining region (if the transportation connections exist). Additional supply and demand for crude and product from and to the international market are represented by import and export curves which connect the international markets to the domestic transportation network described above.

An optimal solution is found by minimizing net total cost while simultaneously meeting regional demands and various constraints. The model estimates revenues from prices and product sales in the previous NEMS iteration, and projects costs incurred from the purchase and processing of raw materials and the transportation of finished products to the market. The liquid fuels production activities are constrained by material balance requirements on feedstocks and intermediate streams, product specifications, processing and transportation capacities, demand, and policy requirements. Economic forces also govern the decision to import (export) crude oil or refined products into (out of) the U.S. regions.

Fundamental assumptions

The LFMM assumes that the liquid fuels production and marketing industry is competitive. The market will move toward lower-cost refiners (producers) who have access to crude oil (or non-petroleum feedstocks) and markets. The selection of feedstocks, process utilization, renewable fuel blends, and logistics will adjust to minimize the overall cost of supplying the market with petroleum products. If petroleum product demand is unusually high in one region, the price will increase, driving down demand and providing economic incentives for bringing supplies in from other regions, thus restoring the supply/demand balance. Because the LFMM is an annual model, it cannot be used to analyze short-term petroleum market issues related to supplies, demands, or prices.

Model Structure

During each NEMS iterative solution (each iteration, each model year), product demand quantities, crude and product import and export curve data, and other data provided by the other NEMS demand and supply modules are used to update the LFMM linear program (LP) matrix. Once an optimal solution is obtained from the updated LP, marginal crude and petroleum product prices and other material balance information are extracted. Post-processing takes place on the domestic crude and petroleum product prices and refinery input and output volumes; system variables are updated; and, reports are produced. The modification and optimization of the LFMM LP matrix are accomplished within a GAMS program using the Xpress solver. Appendix B describes the formulation of the LP representation in the LFMM.

The LFMM program code is a mix of Fortran and GAMS. The model begins operation when NEMS calls the Fortran subroutine REFINE – the main controlling subroutine for the LFMM. Through subroutine calls and a call to the main GAMS program lfshell.gms, the LFMM code initializes variables, reads data, updates and solves the LP, retrieves and processes results, and generates report variables. Each major routine and its functions are described below.

Main subroutines (refine.f, lfshell.gms)

The LFMM includes Fortran subroutines and GAMS programs. The Fortran subroutines are in the file refine.f: REFINE, RFHIST1, PMM_NEXTDATA, WRITE_INIT_GDX, WRITE_GDX, READ_GDX, and E85_Demand_Curve. The Fortran subroutine REFINE calls the GAMS program lfshell.gms, which subsequently calls other GAMS programs to read and prepare data, set up and solve the LP, and extract results for reporting to other NEMS modules.

Subroutine REFINE

REFINE is the main entry point into the LFMM from the rest of NEMS. It calls subroutines RFHIST1 (which in turn calls subroutine PMM_NEXTDATA), Write_INIT_GDX, Write_GDX, E85_Demand_Curve, lfshell.gms, and Read_GDX.

Subroutines RFHIST1 and PMM_NEXTDATA

RFHIST1 reads the text file rfhist.txt, which contains historical and STEO-year data on crude imports, production capacity of petroleum refineries and non-petroleum liquid fuels plants, capacity utilization, product imports and exports, product demands, refinery gain, HGL imports and exports, etc.

RFHIST1 calls PMM_NEXTDATA to iterate through the rfhist.txt file.

Subroutine WRITE_INIT_GDX

Writes relevant NEMS variables (available the first model year the LFMM is called) to a GAMS GDX data file: NEM_TO_LFMM_INIT.gdx. This GDX file is used for debugging purposes.

Subroutine WRITE_GDX

Writes relevant NEMS variables (every model year and iteration, beginning with the LFMM start year, 2010) to NEM_TO_LFMM1.gdx, a GAMS GDX file which is later read by lf_nem.gms.

Subroutine READ_GDX

Reads LFMM LP results from LFMM_to_NEMS.gdx, a GAMS GDX file created by lfreport.gms that includes LFMM model results for other NEMS models and NEMS reports.

Subroutine E85_Demand_Curve

Sets up an E85 demand curve to speed up convergence between LFMM and TRAN. The curve is written to E85.gdx, a GAMS GDX file which is later read by lfprep.gms.

Lfshell.gms

Lfshell.gms is the main entry point to the GAMS portion of the LFMM, called by Fortran subroutine REFINE.

- Call lf_nem.gms to read NEM_TO_LFMM1.gdx
- Call lfprep.gms to read input data files lfminput.gdx, lfminset.gdx, lfinvest.gdx and to prepare data to define the LP matrix
- Call lfmodel.gms to set up the LP model (decision variables, objective function, constraints)
- Set capacity expansion parameters (fixed costs, learning, etc.)
- NPV (net present value) calculations to put all data on a consistent (nominal) year basis
- LCFS: create LCFS carbon factors ready to be incorporated into the LP
- RFS: read expected demand for motor fuels, which is an input to the calculated RVO used to implement RFS requirements for each year.
- Set up supply curves for crude, imported sugarcane ethanol, various feedstocks (corn, soyoil, etc.)
- Restrict capacity expansion for alternative fuel processes (celluloisic ethanol, etc.) before a specified year
- Solve LP
- Call lfreport.gms to write LP results to LFMM_TO_NEMS.gdx

LP Preprocessing (lf_nem.gms, lfprep.gms)

lf_nem.gms

Reads NEM_TO_LFMM1.gdx (created in refine.f), which contains all the data defined by other NEMS models that are needed to build the LP matrix (includes, product demands, feedstock costs and supply curve data, energy conversion factors, etc.).

lfprep.gms

- Read lfminset.gdx, which defines many of the sets used by the LFMM GAMS code
- Read lfminput.gdx, a GDX data file created by reading in various Excel (xlsx) data files
- Read lfinvest.gdx, a GDX data file created from process unit investment and learning data stored in lfinvestment.xlsx
- Create mapping sets that mediate between NEMS regions and LFMM regions
- Initialize LP parameters based on NEMS variables read from NEM_TO_LFMM1.gdx
- Set up supply curves for corn, soyoil, and other non-crude feedstocks
- Define “waiver costs” for RFS and LCFS to ensure that the LP does not become infeasible

LP Formulation (lfmodel.gms)

Lfmodel.gms specifies the LP decision variables, the constraints, and the objective function that represents the operations of liquid fuel production facilities in the U.S., transport of liquids between supply and demand regions, and imports/exports of liquid fuels in the U.S. The LP finds the minimum cost of satisfying the set of liquid fuel demands given by the NEMS demand modules, subject to

build/operate constraints (e.g., processing capacity, volume balance, feedstock purchases) and policy constraints (e.g., RFS, LCFS, AB32). The outputs of the LP include build/operate decisions, import/export decisions, domestic crude prices, and wholesale product prices. A mathematical description of the LP model is presented in Appendix B.

LP Post-Processing (lfreport.gms)

Lfreport.gms writes the file LFMM_TO_NEMS.gdx, which includes the following important information passed from the LFMM to other NEMS models and reports:

- Build/operate decisions for each liquid fuels production technology represented in the LFMM
- Domestic crude prices
- Wholesale product prices, based on shadow prices (duals) of selected LP constraints
- Retail product prices, based on wholesale prices and mark-ups for taxes and distribution costs
- Energy purchases and fuel use requirements
- Items useful for debugging

Appendix A. Data and Outputs

This appendix is divided in three parts: Section A.1 lists variables passed between the LFMM and the NEMS Integrating Module, Section A.2 lists data sources, and Section A.3 lists the data files used to create the LFMM's GDX data files that are loaded into the NEMS environment. The data files described in A.3 constitute the major portion of the LFMM data as they represent the liquid fuels process unit technologies and capacities, quality characteristics, and specifications.

A.1 Variables and definitions

NEMS variables are passed to the LFMM via file NEM_TO_LFMM1.gdx. LFMM results (including product prices) are passed to the NEMS Integrating module via variables included in the file LFMM_TO_NEMS.gdx. The NEMS text file varlistL.txt (version 1.47 for AEO2018) lists the NEMS variables and their associated include files that are passed between NEMS Fortran code and LFMM GAMS code. These variables are defined in another NEMS text file dict.txt (version 1.537 for AEO2018).

A.2 Data sources

Most of the data for the LFMM were developed by OnLocation, Inc./Energy Systems Consulting and their subcontractors. These data were based on (1) new analysis, and (2) existing analysis used in the LFMM's predecessor model, the Petroleum Market Module (PMM). For details on the new analysis, see the LFMM Component Design Report (http://www.eia.gov/forecasts/documentation/workshops/pdf/LFMM%20CDR.pdf).

Process technology and cost data

Refining process technology and cost data need periodic review and update. This is because environmental legislation, lighter product slates, and heavier crude slates have spurred new process technology developments affecting existing processes, new processes, and costs. Sources for new developments include research and other papers in industry journals, papers from industry conferences and surveys (such as AFPM), engineering and licensing contractor data, and published consultant studies.

Refinery capacity construction and utilization data

The base capacities for refinery process units are derived principally from EIA data (see section D.15) and annual surveys published in the *Oil & Gas Journal*. The approach used is to review all announced projects, but to only include as active those that have reached the engineering, construction, or start-up stage. (Unit capacity is measured in volume per calendar day.) Historical process unit utilization is derived from the EIA *Petroleum Supply Annual*.

Crude supply and product demand data

The crude oil supply data are provided by two of the NEMS models: OGSM, which incorporates a production function to estimate the domestic oil production, including Alaska; and the International Energy Module (IEM) which provides volumes and prices of international crude (in the form of supply curves by crude types) and non-US crude demands (by crude type). The IEM also provides volumes and prices of international petroleum product supply and demand curves that are used by the LFMM to determine product imports and exports to and from the United States. Individual crude oil streams for both domestic and imported crude oils are grouped into eleven crude categories, differentiated by API

gravity, sulfur content, and yield characteristics. These categories are detailed in *Assumptions to the Annual Energy Outlook 2018*.

Non-petroleum feedstocks

Data related to the following non-petroleum feedstocks are discussed in Appendix F:

- natural gas plant liquids supply (Oil and Gas Supply Module)
- coal supply curves (Coal Market Module)
- natural gas prices (Natural Gas Market Module)
- cellulosic biomass supply curves (Renewable Fuels Module)
- corn, seed oils, and bio-greases (Renewable Fuels Module and LFMM processing)

Products

Product demands are available from the NEMS restart file (determined by NEMS demand models and the electricity model) for a given scenario by year. The product list for the liquid fuels market includes: motor gasoline, CARB motor gasoline, E85, diesel, CARB diesel, jet fuel, heating oil, distillate oil, residual oil, LPG, naphtha (petrochemical feedstock), petroleum coke, ethane, propane, iso- and n-butane, natural gasoline, propylene, and others (lubes, aviation gasoline, asphalt, benzene, toluene, xylene). Some coproducts are also represented.

Product specification/grade split data

For the United States, surveys by industry organizations such as AFPM, API, and NPC, together with Government sources such as Department of Defense, provide relatively frequent and detailed insights into actual U.S. product qualities and grade splits. These data are important for establishing case studies.

Transportation data

LFMM transportation rates (dollars per volume or mass transported) and capacity data for the United States are represented for transport of crude and product via pipeline, rail, truck, vessel, and barge. These data were originally developed from the Office of Strategic Petroleum Reserves (OSPR) North American Crude Oil Distribution (NACOD) Model (prepared by ICF in 1990-91, updated in 2003), and updated for environmental costs (to reflect the Oil Pollution Control Act of 1990). Over the years, crude and pipeline capacity and tariff data have been updated based on research through FERC filings, as well as online searches and news releases related to pipeline companies.

Product yield and quality blending data

In addition to the general sources already mentioned, a number of sources relating to specific properties are given below:

Cetane Number: API Refining Dept., Vol. 61, p.39 and appendix for the modified ASTM D976 80 Equation (George Unzelman).

Net Heat of Combustion: ASTM D3338 (API range 37.5-64.5) (relaxing ASTM D2382).

Wt. percent hydrogen: ASTM Method D3343 (replacing D1018)

Smoke point vs. hydrogen content: empirical correlation developed by EnSys Smoke point to Luminometer Number conversion, ASTM D1322.

Viscosity prediction: based on the work of PLI Associates (Dr. Paul S. Kydd) and from the Abbott, Kaufman and Domashe correlation of viscosities. (See PLI report "Fuel and Engine Effect Correlations, Task 1.1, Computerize Fuel Property Correlations and Validate"). Viscosity interpolation included and based on computerized formulae for ASTM charts.

Viscosity blending indices: computerization of Gary & Handwerk formulae, p.172 (left-hand side).

Static and Dynamic Surface Tensions: API Technical DataBook method.

Flash point Blending Index Numbers: Gary & Handwerk, p.173.

Pour Point blending Indices: Gary & Handwerk, p.175.

Reid vapor pressure (RVP) blending indices have been gathered from several public and in-house sources and have been verified against Gary & Handwerk, p.166.

Research Octane Number (RON) and Motor Octane Number (MON) blending deltas reflective of base gasoline sensitivity have been drawn from many sources and averaged.

Units of measurement

The general rule adopted for input data in the LFMM is that quantities of oil and refinery products are in thousands of barrels per calendar day, prices or costs are in 1987 dollars per barrel, and quantities of money are in thousands of 1987 dollars per calendar day.

Exceptions to the above rule are:

- The LP itself uses nominal-year dollars for each NEMS year/iteration.
- Gases lighter than propane are measured in thousands of barrels fuel oil equivalent (FOE) per day. These are based on the following conversion factors:

Table A-1. Btu/bbl for gases lighter than propane

Gas stream	Code	bblFOE/lb	cf/bblFOE
Hydrogen	H2,H2U	.009620	19,646
Hydrogen sulfide	H2S	.001040	10,145
Methane/natural gas	NGS,CC1	.003414	6,917
Gas stream	Code	bblFOE/lb	cf/bblFOE
Ethane	CC2	.003245	3,861
Process gas	PGS	.003245	3,861

- One barrel FOE (fuel oil equivalent) is 6.287 million Btu (MMBtu).

The assumed Btu content for other major refinery streams is shown below:

Table A-2. Btu/bbl for other streams

Stream	Code	MMBtu/bbl
Gasoline	(multiple)	5.057
Jet Fuel	JTA	5.67
Diesel (ULSD)	DSU	5.77
No. 2 Heating Oil	N2H	5.825
Residual Oil	N6I,N6B	6.287
LPG	LPG, CC3	3.532
Ethanol	ETH	3.558

- Yields of coke are measured in short tons per barrel and demands are in short tons per day. A factor of 5.0 crude oil equivalent (COE) barrels per short ton is used. Heat content is 6.024 MMBtu/bbl.
- Yields of sulfur are also measured in short tons per barrel and demands are in short tons per day. A factor of 3.18 barrels per short ton is used.
- Process unit capacities are generally measured in terms of feedstock volume. Exceptions are process units, principally those with gaseous feeds and liquid products, whose capacities are measured in terms of product volume.
- Process unit activity levels for H2P, H2R, and SUL represent the production of fuel oil equivalent barrels of hydrogen and short tons of sulfur per day.
- Quality and specification units are those specified in each ASTM test method or are dimensionless (as in the case of blending indices). Sulfur specs are defined in parts per million for both gasoline and diesel blend streams, but are converted to volume percent (using specific gravity) for use in the LP.
- Steam consumption is in pounds per barrel (lb/bbl). Thus an activity in Mbbl/cd consumes steam in thousands of pounds per day (M lb/day). Steam generation capacity is in millions of pounds per day (MM lb/day). The consumption of 0.00668 fuel oil equivalent barrels per day to raise 1 pound per hour of steam is equivalent to 1225 Btu per pound steam (assuming 70% energy conversion efficiency).
- Electricity consumption is in KWh/bbl. Generation is in MWh/cd (megawatt-hours/calendar day).

A.3 Data tables

LFMinset.gdx contains names and content of sets used by the LFMM but not by other NEMS modules. Table A-3 presents the GAMS files and corresponding set names that are generated for the LFMinset.gdx file. Some example sets include:

- Process, ProcessMode: set of all production processes and their operating modes
- Stream: set of all physical and non-physical streams
- RecipeProd: set of products produced according to a specific recipe
- SpecProd: set of products blended to meet various quality specifications rather than according to a recipe (diesel, jet, #2 heating oil, California BOB, conventional BOB, reformulated BOB, residual fuel oil)
- DistProp, GasProp, ResidProp: set of quality specifications that need to be met for selected distillates, motor gasolines, and residual fuel
- EndProduct, EndProductNGL: set of products which are demanded by the various NEMS demand modules. Approximately equal to the union of sets SpecProd and RecipeProd.
- CoProduct: set of coproducts manufactured incidentally to the production of end products.

Table A-3. GAMS files used to make LFMinset.GDX

GAMS File (.gms)	Set names
SetBldStep	BldStep
SetIntStream	Crude, CrudeAll, CoalStr, BioStr, FCOType, NGLInputStr, MethanolInputStr, Purchase_Streams, AltPurchase_Streams, OtherPurchase_Streams, RefInputStr, Fueluse_Streams, EthStreamsRFS, EthStreamNoRFS, EthStream, Utility, LightGases, LightGasesExNaphtha, NaphthaLightBiofuels, NaphthaLightNPF, NaphthaLightPet, NaphthaMedium, NaphthaHeavyBiofuels, NaphthaHeavyNPF, NaphthaHeavyPet, ReformateBiofuels, ReformateNPF, ReformatePet, Alkylate, GasolineCat, GasolinePoly, IsomerateBiofuels, IsomerateNPF, IsomeratePet, PetNaphtha, KeroseneBiofuels, KeroseneNPF, KerosenePet, LightCycleOil, DieselBiofuels, DieselNPF, DieselPet, DieselHeavy, GasOilLight, GasOil, GasOilHeavy, PetDistillate, ResidualOil, Raffinate, PetResid, Solids, NaphthaAndLighter, Int_Misc, IntStream_Other, IntStream
SetInvParam	InvParam
SetLCFS	LCFS_BioImport_PetStream, LCFS_BioImports, LCFS_BioMode, LCFS_BioProcess
SetLrn	LearningProcess, LrnParam, LrnSpeed, LrnPhase, MoreLrnParam
SetMarkup	MarkupFuel, MarkupSector
SetMisc	Period, PrcPeriod, BldPeriod, t, tIdx, CapExpYr, ReportYr, Step
SetNFBaseYr	NFBaseYr
SetProcess	PetroleumProcess, CornProcess, NonCornProcess, EthanolProcess, AltFuel_Process, NPFProcess
SetProcessMode	ProcessMode
SetProcessRisk	BldRiskClass, ProcessRisk

SetProduct	EndProductGas, EndProductDist, EndProductResid, EndProductMisc, EndProduct, CoProduct, EthCoproduct, CoProductSales, endProductNGL, RecipeProd, RecipeOut

Table A-3. GAMS files used to make LFMinset.GDX (cont.)

GAMS File (.gms)	Set names
SetProperty	Property
SetRcpMode	RcpMode
SetRefType	RefType
SetRegionality	Source, DomRefReg, NonDomRefReg, RefReg, ActiveDem, CenDiv, CoalDReg, CoalSReg, CoalDReg_2_Census, NGPL_2_RefRe, State
SetRFSCategory	RFSCategory
SetSector	DieselSector, LPGSector
SetSpecProd	DistSpecprod, GasSpecProd, ResidSpecProd, SpecProd
SetSpecProdProp	GasProp, DistProp, ResidProp
SetStream	StreamOVC, Stream, NoMat, NonCrudeUtil, RecipeInputs, RecipeEnd
SetTranMode	MrineMode, NonMarineMode, TranMode

LFMinput.gdx defines parameters used by the LFMM, and created from input data originally stored in a group of Microsoft Excel data files. These Excel files are comprised of multiple worksheets (Table A-4). The following are examples of a few parameters residing in the LFMinput.gdx file that originated in an Excel file.

- ProcessTable: input streams, output yields, and fuel/utility requirements for each LFMM Process and ProcessMode
- RecipeBlending: a variety of recipe definitions available to produce the products listed in RecipeProd
- StreamProp: stream properties (API, sulfur, etc.) used to meet quality specifications defined by DistProp, GasProp, and/or ResidProp for blending of SpecProd products

Table A-4. Excel files used to make LFMINPUT.GDX

Excel File (.xlsx)	Worksheets
lfblending	Properties, RCP, StreamSpecProd, DieselFrac
lfcapacity	ForImport, OGJ Data, Notes, AltFuels, Calibrate, Calibrate PSA-O&GJ
lfcontrol	CoalDReg-to-RefReg, Census-to-RefReg, StateMaps, mappings, Streams, Processes, StreamFactors
lfdistconstr	RefReg-to-RefReg Cap, RefReg-to-RefReg Cost, RefReg-to-Census Cap, RefReg-to-Census Cost, IntReg-to-RefReg Cap, IntReg-to-RefReg Cost, RefReg-to-IntReg Cap, RefReg-to-IntReg Cost, RefReg-to-RefReg Cap Import, RefReg-to-RefReg Cost Import, RefReg-to-Census Cap Import, RefReg-to-Census Cost Import, IntReg-to-RefReg Cap Import, IntReg-to-RefReg Cost Import, RefReg-to-IntReg Cap Import, RefReg-to-IntReg Cost Import, E15MaxPen
lfdistcosts	StateFuelTax, ProductMarkups, FedFuelTax, EnvMarkups

Table A-4. Excel files used to make LFMINPUT.GDX (cont.)

Excel File (.xlsx)	Worksheets
lffeedstock	SPR_Withdraw, Crude_Import_Cap, Crude_Import_Cost, Crude_Export_Cap, Crude_Export_Cost, Allowed_Crude_Use, Crude_Import_Region, Crude_Export_Region, CornPriceExp, CornTranCost, SeedOilQnty, GrainQnty
lfimportpurch	ForImport, BrzAdvEthProd, BrzEthDmd, NonUSEthDmd, FBDImpQuant, FBDImpCoef
lfnonpetroleum	data, ForImport, EDH, EDM, IBA, SEW, NCE, AET, CLE, BPU, BTL, CBL, CBLCCS, FBD, GDT, CTL, CTLCCS, GTL
lfpetcrackers	FCC, RGN, HCD
lfpetcrudeunits	ACU, LTE, VCU, CSU
lfpetenviro	SUL, ARP, DDA
lfpetother	LUB, SGP, UGP
lfpetseparation	LNS, FGS, DC5, DC4
lfpetupgraders	DDS, SDA, KRD, KRD_orig, ALK, BSA, RCR, RSR, NDS, C4I, CPL, FDS, GDS, PHI, TRI
lfpolicy	RFSMandates, RFSScores, RFSCategory, RFSWaiver, LCFS_AltVehicles, LCFS_Penalty_Cost, LCFS_Target, LCFS_BioStreams, LCFS_PetStreams, LCFS_BioImports, AB32_CapAdjFactor, AB32_AssistFactor, AB32_BenchFactor, AB32_Control, ULSD_N2H, State_Biodiesel, BiofuelSubsidy
lfproducts	LPGPricing, CoproductPricing, Gas_Spec_UB, Gas_Spec_LB, Dist_Spec_LB, Dist_Spec_UB, Resid_Spec_UB, Resid_Spec_LB
lfrefpurch	1_RefReg -- 9_RefReg
lftransfers	TRS, old
lfutilities	FUM, KWG, STG, CGN, H2R, H2P

A third file, LFinvest.gdx, contains investment information that was obtained from original data that reside in another set of worksheets within another Microsoft Excel file (lfinvestment.xlsx), listed in Table A-5. The following describe some of the data in the gdx file that originated in the Excel worksheets.

- CapExpSize, CapExpISBL, CapExpLabor: these represent the unit size, ISBL cost, and expected labor associated with building a specific process unit
- InvFactors, InvLoc: list of multipliers associated with added investment costs as a function of base capital cost
- FedTax, StateTax: tax rates used during investment calculations
- LearningData: data specifically used to adjust the calculated capital investment to represent cost improvement due to learning

Table A-5. Excel files used to make LFinvest.GDX

Excel File (.xlsx)	Worksheets
lfinvestment	CapCostImp, NFImport, StateTax, FedTax, RegionalData, InvestmentFactors, Capital Costs, N-F Indicies, Learning, Learning2, AFGrowthRates, AFBldSteps (and OptimismWorksheet)

Appendix B. Mathematical Description of Model

The LFMM models the transformation of feedstock into intermediate streams that are blended to create intermediate and finished products (Figure B-1). The LFMM models two types of blending: spec-blending (specification-blending) and recipe-blending for intermediate and finished products. In spec-blending, intermediate streams are blended such that the resulting spec-product stream (Table B-1) meets certain quality restrictions. For example, various petroleum streams are mixed in different proportions to make a gasoline blendstock that meets sulfur limits, RVP requirements, benzene restrictions, and other required specifications. In recipe-blending, intermediate streams (including spec-product streams) are blended in fixed proportions to make final products, such as E10 gasoline blended from 90% gasoline blendstock and 10% denatured ethanol.

Figure B-1. Flow chart of stream flows

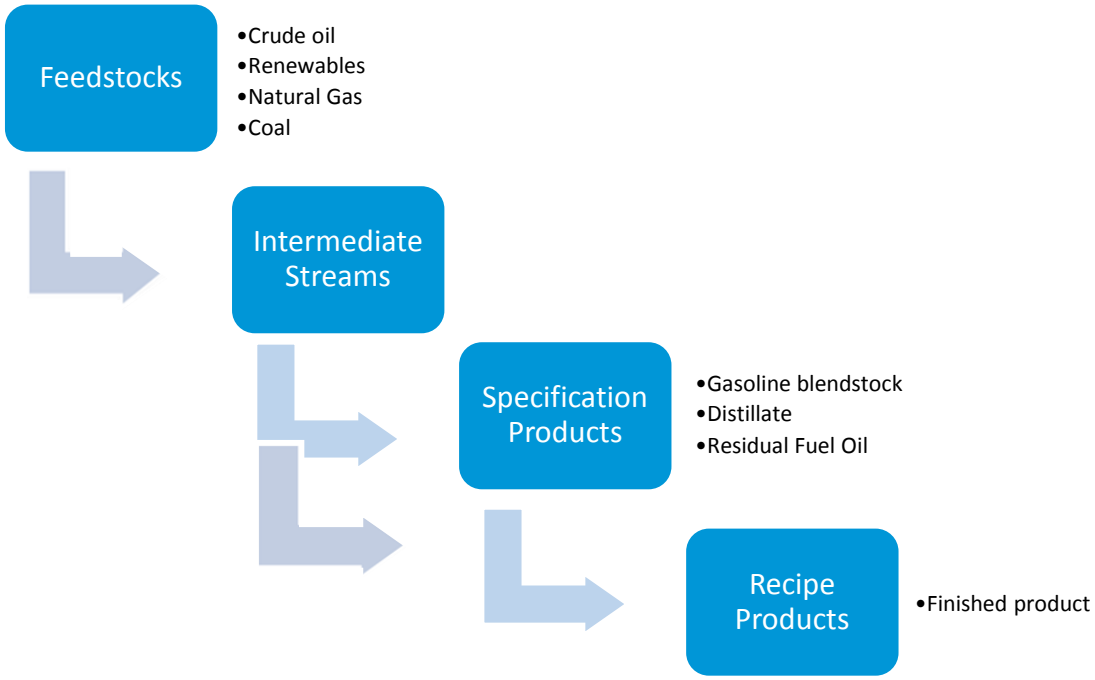


Table B-1. Specification-blended intermediate products

Spec-product	Description
Gasoline blendstock	
CaRBOB	California Reformulated Blendstock
CBOB	Conventional Blendstock
RBOB	Reformulated Blendstock
Distillate	
CarbDSU	California Ultra-Low Sulfur Diesel
DSL	Low Sulfur Diesel
DSU	Ultra-Low Sulfur Diesel
JTA	Jet Fuel
N2H	No. 2 Heating Oil
Residual Fuel Oil	
N6B	No. 6 Fuel Oil, High-Sulfur
N6I	No. 6 Fuel Oil, Intermediate-Sulfur

The LFMM models 91 recipes for blending recipe-products. Some recipes have single input streams, such as the recipes for the various Hydrocarbon Gas Liquids. Other recipes comprise multiple input streams, such as RCP_RFG10a which blends 90% RBOB gasoline blendstock and 10% denatured corn ethanol to make recipe-product RFGout. (Table B-2)

Table B-2. Recipe-blended (finished) products

Recipe-product	Description
Distillate	
CarbDSUout	diesel, ultra-low-sulfur, California
DSLout	diesel, low-sulfur
DSUout	diesel, ultra-low-sulfur
JTAout	jet fuel
N2Hout	No. 2 heating oil
Gasoline-like	
CaRBOBout	E10 from CaRBOB blendstock
CFG15out	E15 from CBOB blendstock
CFGb16out	Bu16 from CBOB blendstock
CFGout	E10 from CBOB blendstock
E85out	E85 from CBOB blendstock
RFG15out	E15 from RBOB blendstock
RFGb16out	Bu16 from RBOB blendstock

Table B-2. Recipe-blended (finished) products (cont.)

Recipe-product	Description
RFGout	E10 from RBOB blendstock
Residual Fuel Oil	
N6Bout	No. 6 fuel oil, high-sulfur
N6Iout	No. 6 fuel oil, low-sulfur
Hydrocarbon Gas Liquids	
CC2out	Ethane
LPGout	LPG (propane)
UC3out	Propylene
NC4out	normal butane
IC4out	iso butane
NATout	natural gasoline / pentanes+
Other	
ASPHout	asphalt / road oil
AVGout	aviation gasoline
BTXout	benzene-toluene-xylene
COKout	petroleum coke
LUBout	lubricants
PCFout	petrochemical feedstock

The LFMM is formulated as a linear program (LP) that is implemented in GAMS. The GAMS code has been structured based on functionality:

- lfshell.gms is the "main" GAMS program in LFMM that organizes the code structure, sets bounds in the LP, converts preprocessed data to the net present value (NPV) format required by the LP, and instructs the LP to solve;
- lf_nem.gms defines the data sets and parameters, and reads the relevant NEMS data provided by other NEMS modules;
- lfprep.gms also defines data sets and parameters, reads in LFMM-specific data, and prepares the data needed to set up the LP;
- lfmodel.gms defines the objective function, decision variables, and constraints in the LP;
- lfreport.gms extracts solution results and writes results to be sent to other NEMS modules.

The LFMM LP comprises three separate periods: Period 1 (current NEMS year), Period 2 (next NEMS year), Period 3 (next 19 NEMS years after Period 2). Period 1 represents operations based on existing capacity, without the option to build additional capacity. Period 2 and Period 3 represent operations based on existing capacity along with the capability to add new capacity. The Period 1 LP is executed

once per NEMS iteration (i.e., multiple times each NEMS year); the LP representing Period 2 and Period 3 is executed in the last iteration of each NEMS year. Period 2 capacity expansion decisions from the last iteration of a particular NEMS year are added to the Period 1 existing capacity for all iterations of the following NEMS years. Period 3 capacity expansion decisions are discarded; however, Period 3 representation helps to inform the capacity expansion decision made in Period 2 by representing the economic impact over the life of the new expansion.

The following information serves as a glossary of terms and abbreviations used in this section to define the LFMM LP model.

Notation

Sets

Biostr	= biomass types
Crude	= crude types (based on API gravity and sulfur content)
EthStream	= ethanol types (corn, sugar cane, cellulosic, etc.)
Em	= emission types (sulfur, mercury)
EndProductGas	= gasoline products, a subset of RecipeProd
IntStream	= streams that are purchased, including crude oil and biofuel feedstocks
IntStream_Other	= intermediate streams, neither inputs nor products
RecipeProd	= recipe-blended products
RFSCategory	= Renewable Fuel Standard categories: Total, Advanced, Biomass-based Diesel, Cellulosic
SpecProd	= spec-blended products

Indexes

b	= biomass type
c	= crude type
cp	= coproduct type
$\hat{e}$	= emission type (SO_2, Hg)
j	= general index for streams, which can take values for biodiesel *b*, crude *c*, ethanol *e*, product *p*, or stream type $\hat{s}$
m	= transportation mode
p	= product
$\hat{p}$	= process mode
r, r'	= region
$\hat{r}$	= recipe
s	= step on supply curve or demand curve
$\hat{s}$	= stream type, including *b*, *c*, *j*, *p*, *u*
u	= utility type

Parameters used in the objective function

(Unless otherwise indicated, objective function parameters are in dollars per barrel ($/bbl).)

Cbim_{rs}	= cost of FBD biodiesel imports into region *r* purchased on step *s* of the supply curve (FBDImpPrice)
Cbr_{s}	= cost of Brazilian sugarcane ethanol on supply step *s* (EthBrazilPrc)
Cbrex_{jr}	= transport cost per unit export of material in stream $j \in \mathrm{E}$ from region *r* to Brazil (TranCostToBrazil)
Cbrim_{jr}	= transport cost per unit import of material in stream $j \in \mathrm{E}$ to region *r* from Brazil (TranCostFromBrazil)
$\mathrm{Cbld}_{\hat{p}r}$	= net present value of capital costs and fixed operating cost of newly-added capacity of process mode $\hat{p}$ in region *r* (BuildCost)
$\mathrm{Ccr1}_{s}$	= base cost of crude at step *s* of the supply curve, $/bbl (CrudePriceTotal)
$\mathrm{Ccr2}_{cs}$	= incremental cost of crude type *c* at step *s* of the supply curve, $/ bbl (CrudePriceIncremental)
Ccrex_{crs}	= cost to export crude type *c* from region *r* at step *s,* $/bbl (CrudeExportCost)
Ccrim_{crs}	= cost to import crude type *c* from region *r* at step *s,* $/bbl (CrudeImportCost)
Ccrint_{cs}	= cost of non-U.S. demand for crude type *c* at step *s,* $/bbl (NonUSCrudeDemandPrice)
$\mathrm{Cfxoc}_{\hat{p}r}$	= fixed operating cost of existing capacity of process mode $\hat{p}$ in region *r* (FXOCCost)
$\mathrm{Cm}_{\hat{s}r's}$	= cost of stream $\hat{s}$ purchased in region r' at step *s* of the supply curve (BiomassPrc, CoalPrc)
Cpex_{pr}	= cost of exports of product *p* from region *r,* $/bbl (ImportPrice, NGLImportCost, GlobalImpPrice)
Cpim_{pr}	= cost of imports of product *p* to region *r,* $/bbl (ExportPrice, NGLExportCost)
$\mathrm{Cproc}_{\hat{p}r}$	= cost per unit of activity on process mode $\hat{p}$ in region *r*, typically in $/bbl of output (OpVarCost)
$\mathrm{Cpur}_{\hat{s}rs}$	= cost to purchase stream $\hat{s}$ in region *r* on step *s* of the supply curve (RefInpPrc)
$\mathrm{Crcp}_{\hat{r}}$	= cost per unit of activity on recipe $\hat{r}$ (RecipeOVC), typically in $/barrel of output.
$\mathrm{Ctran}_{jrr'}$	= cost to transport material in stream *j* from region *r* to region r' (REFtoREFTranCost, INTtoREFTranCost, REFtoINTTranCost, REFtoCDTranCost)
Cu_{ur}	= cost per unit of utility *u* used in region *r* (UtilityPrice). Units of measure vary.
$\mathrm{Rcp}_{\hat{p}r}$	= revenue per unit of coproduct *cp* in region *r*, typically in $/bbl (CoproductPrice)

Parameters used in constraints

(Unless otherwise indicated, constraint parameters are in thousands of barrels per day (mbbl/d). The corresponding GAMS parameter name is listed in parentheses following each parameter definition.)

$A_{\hat{p}j}$	= units of *j* produced or consumed per unit of activity of process mode $\hat{p}$ (ProcessTable)
$A_{\hat{p}u}$	= utility *u* used per unit of activity of process mode $\hat{p}$. Units of measure vary.
D_{pr}	= demand for product *p* in region *r*
$G_{\hat{s}r}$	= electricity market demand for stream $\hat{s}$ in region r. Units of measure = billion BTU per day
$H_{\hat{e}r\hat{s}}$	= emissions of stream type $\hat{e}$ per unit of coal stream $\hat{s}$ purchased in region *r*. Units of measure vary (eg, 1000 tons SO2 per MMBtu of coal; 0.001 tons mercury per MMBtu of coal).
$LCFSfactor_{p\hat{r}}$	= amount by which product *p* produced via recipe $\hat{r}$ exceeds the California Low Carbon Fuel Standard (LCFS) target carbon intensity
$MaxE15frac$	= maximum fraction of total motor gasoline demand that can be E15
N	= non-U.S. demand for ethanol
P_{cr}	= domestic production of crude type *c* in region *r*
$\hat{P}_{q\hat{s}}$	= level of property *q* in stream $\hat{s}$ (StreamProp)
$\hat{P}_{qp}^{max}$	= maximum level of property *q* in product *p*. Units of measure vary.
$\hat{P}_{qp}^{min}$	= minimum level of property *q* in product *p*. Units of measure vary.
Q	= maximum U.S. imports of Brazilian sugar cane ethanol
$R_{\hat{s}\hat{r}}$	= volume of stream $\hat{s}$ in recipe $\hat{r}$
$RFSScore_{k\hat{s}}$	= credits (ethanol-equivalent volume) of stream $\hat{s}$ toward Renewable Fuel Standard (RFS) category *k*
$RFSTarget_k$	= target volume for RFS category *k*, in ethanol-equivalent volume
$T_{rr'}$	= maximum volume of ethanol that can be transported from region *r* to region *r'*
$T_{mrr'}$	= maximum (non-ethanol) volume that can be transported via mode *m* from region *r* to region *r'*
UE_{rs}	= upper limit on total exports of crude from region *r*
UI_{rs}	= upper limit on total imports of crude into region *r*
$UE_{rr'}$	= upper limit on product shipments (exports) from region *r* to international region r'
$UI_{r'r}$	= upper limits on product shipments (imports) from international region $r'$to region *r*

Decision Variables

Notes

Unless otherwise indicated, decision variables are in thousands of barrels per day (mbbl/d).

Corresponding GAMS names are in parentheses after each variable description

Variables indexed by step *s* have upper bounds

a_{ur}	= amount of utility *u* used in region *r* (UTILPURCH)
$\hat{b}$	= non-U.S. (world) demand for sugar cane ethanol from Brazil (ETHNonUS)
$b_{\hat{s}r}$	= amount of stream $\hat{s}$ that is purchased and then used in region *r* (REFPURused)
cp_{pr}	= total coproduct *p* produced in region *r* (COPRODUCTS)
$d_{\hat{s}rs}$	= amount of stream $\hat{s}$ in region *r* that is purchased on step *s* of the supply curve (REFPURCH)
e_{jr}	= exports of material in stream *j* from region *r* (EXPORTS)
e_{crs}	= exports of crude type *c* from region *r* at step *s* (CRUDEEXPORT)
$e_{pr's}$	= total exports of product *p* to international region r' on step *s* of the demand curve (PRODEXP)
$E_{\hat{p}r}$	= usage of existing capacity of process mode $\hat{p}$ in region *r*. Upper-bounded by the existing capacity. (OPERATECAP)
$\hat{E}_{\hat{p}r}$	= newly-added capacity of process mode $\hat{p}$ in region *r*. Set to zero for Period 1. (BUILDS)
$f_{\hat{e}r}$	= emissions of type $\hat{e}$ in region *r*
g_r	= volume of sugarcane ethanol imported from Brazil into region *r* (ETHIMP)
$\hat{g}_r$	= volume of corn ethanol exported to Brazil from region *r* (ETHEXP)
h_{pr}	= recipe product *p* available in region *r* (TOTPROD)
i_{brs}	= imports of biodiesel into region *r* purchased on step *s* of the supply curve (BIODIMP)
i_{jr}	= total imports of material *j* into region *r* (IMPORTS, BIODIMPref)
i_{crs}	= imports of crude type *c* into region *r* at step *s* (CRUDETRANS)
$\hat{\imath}_{pr's}$	= total imports of product *p* from international region r'at step *s* (PRODIMP)
k_s	= total production of Brazilian sugar cane ethanol at step *s* (ETH_BRAZIL)
$\hat{m}_{\hat{s}r'r}$	= amount of stream type $\hat{s}$ purchased in region r' used for liquid fuels production in region *r* (BIOXFER, COALXFER)
$m_{\hat{s}r's}$	= amount of stream $\hat{s}$ purchased in region r' at step *s* of the supply curve (BIOPURCH, COALPURCH)
n_{cs}	= total non-U.S. demand for crude type *c* at step *s* (CRUDENONUS)
$t_{jrr'}$	= shipments of material in stream *j* from region *r* to region r' (RefRefTRAN, PRODImpTRAN, PRODExpTRAN)
w'_s	= total world consumption of all crude types at step *s* of the total supply curve (CRUDETOTAL)
w_{cs}	= total world purchases of crude type *c* at step *s* of the supply curve (CRUDEPURCH)
$x_{\hat{p}r}$	= activity on process mode $\hat{p}$ in region *r* (PROCMODE)
$\hat{x}_{r\hat{r}}$	= activity on recipe $\hat{r}$ in region *r* (RECIPEMODE)
$\check{x}_{rp}$	= volume of recipe-product *p* blended in region *r* (RECIPETOPROD)
$y_{jr\hat{r}}$	= volume of stream *j* recipe-blended into recipe-products in region *r* via recipe $\hat{r}$ (ToRECIPEBLEND)
$z_{\hat{s}pr}$	= volume of stream $\hat{s}$ spec-blended into spec-product *p* in region *r* (ToSPECBLEND)

Objective Function

The objective function represents net annual cost in thousands of nominal dollars per day. In the formulation below, multiple summation indexes are suppressed. In actuality, each term is summed over all the indexes of the summand. The LP has three periods over which costs are considered: Period 1 represents the current NEMS year (for operating decisions); Period 2 represents the next NEMS year (for capacity expansion decisions); and Period 3 represents the subsequent 19 years as a look-ahead period that enables capital expansion to meet upcoming demands while avoiding stranding capital assets. The objective function minimizes net annual costs, as defined below.

Minimize Total Cost =

Fixed operating cost of processing units

$$\sum \mathrm{Cfxoc}_{\hat{p}r} E_{\hat{p}r} +$$

Build cost of processing units

$$\sum \mathrm{Cbld}_{\hat{p}r} \hat{E}_{\hat{p}r} +$$

Variable operating cost of processing units

$$\sum \mathrm{Cproc}_{\hat{p}r} x_{\hat{p}r} +$$

Crude purchase cost

$$\sum \mathrm{Ccr1}_{s} w'_{s} + \sum \mathrm{Ccr2}_{cs} w_{cs} +$$

Cost to export crude and import crude

$$\sum \mathrm{Ccrex}_{crs} e_{crs} + \sum \mathrm{Ccrim}_{crs} i_{crs} +$$

Cost of crude to non-U.S. users

$$\sum \mathrm{Ccrint}_{cs} n_{cs} +$$

Cost to purchase sugar cane ethanol from Brazil

$$\sum \mathrm{Cbr}_s k_s +$$

Cost to transport sugar cane ethanol imported from Brazil

$$\sum \mathrm{Cbrim}_r g_r +$$

Cost to transport corn ethanol exported to Brazil

$$\sum \mathrm{Cbrex}_r \hat{g}_r +$$

Utility costs

$$\sum \mathrm{Cu}_{ur} a_{ur} +$$

Cost of non-crude refinery input streams and interregional crude and product transport

$$\sum \mathrm{Cpur}_{\hat{s}rs} d_{\hat{s}rs} +$$

$$\sum \mathrm{Cm}_{\hat{s}r's} m_{\hat{s}r's} + \sum \mathrm{Crcp}_{\hat{r}} \hat{x}_{r\hat{r}} + \sum \mathrm{Ctran}_{jrr'} t_{jrr'} + \sum \mathrm{Cfxoc}_{\hat{p}r} E_{\hat{p}r} +$$

Cost of U.S. product imports and exports

$$\sum \mathrm{Cpim}_{pr} i_{pr} + \sum \mathrm{Cpex}_{pr} e_{pr} +$$

Cost of FBD biodiesel imports

$$\sum \mathrm{Cbim}_{rs} i_{rs}$$

Revenue from coproduct sales

$$-\sum \mathrm{Rcp}_{pr} cp_{pr}$$

Crude-related constraints

Table B-3. Crude-related constraints

Constraint Name	GAMS Cross Reference
Crude Balance	CrudeBalance
Crude Import Limit	CrudeImportLimit
Crude Export Limit	CrudeExportLimit
Crude Export Limit to Sarnia, 393 mbbl/d	CrudeExportLimit3CAN
World Crude Supply	WorldCrudeSup
Foreign Crude Supply Curve	CrudeSupCurveForeign
Limit Re-exports of Crude	ExportDomCrudeOnly

Crude Balance

The volume of each crude type processed in a region is equal to domestic production plus net imports plus net shipments from other regions.

$$\sum_{\hat{p}} A_{\hat{p}c} x_{\hat{p}r} = P_{cr} + \sum_{s} i_{crs} - \sum_{s} e_{crs} + \sum_{r'} (t_{cr'r} - t_{crr'}) \qquad \text{for all } c, r$$

World Crude Supply

Total world supply of all crudes equals non-U.S. supply plus U.S. production.

$$\sum_{s} w'_{s} = \sum_{c} \sum_{s} n_{cs} + \sum_{c} \sum_{r} P_{cr}$$

Foreign Crude Supply

Total world consumption of each crude type equals non-U.S. consumption plus net imports to the U.S.

$$\sum_{s} w_{cs} = \sum_{s} n_{cs} + \sum_{r} \sum_{s} i_{crs} - \sum_{r} \sum_{s} e_{crs} \qquad \text{for all } c$$

Crude Import Limit

Total crude imports are limited on each step of the international crude supply curve.

$$\sum_{c} i_{crs} \leq UI_{rs} \qquad \text{for all } r, s$$

Crude Export Limit

Total crude exports are limited on each step of the international crude demand curve.

$$\sum_{c} e_{crs} \leq UE_{rs} \qquad \text{for all } r, s$$

Crude Export Limit to Sarnia

API>40 crude exports to Sarnia, Canada from LFMM region 3 are limited to 393 mbbl/d.

$$\sum_{c} e_{crs} \leq 393 \qquad \text{for all } r, s$$

Limit Re-exports of Crude

Any U.S. crude exports from a particular region must be from domestic production in that region or shipments from a different U.S. region, rather than immediate re-exports of imported crude.

$$P_{cr} + \sum_{r'} t_{cr'r} \leq \sum_{s} e_{crs} \qquad \text{for all } c, r$$

Product imports and exports

Table B-4. Product import/export constraints

Constraint Name	GAMS Cross Reference
Product Import Balance	ProdImpBalance
Product Import Supply Curve	ProdImpSupCurve
Product Import Transportation Limit	ImpTranLimit
Product Export Balance	ProdExpBalance
Product Export Demand Curve	ProdExpSupCurve
Product Export Transportation Limit	ExpTranLimit

Product Export Balance

The total exports of a product to an international region equals the sum of exports from all domestic regions.

$$e_{pr} = \sum_{r'} t_{prr'} \qquad \text{for all } p, r$$

Product Export Demand Curve

The total exports of a product to an international region equals the sum of exports over all steps of the demand curve.

$$\sum_{r} t_{prr'} = \sum_{s} \hat{e}_{pr's} \qquad \text{for all } p, r'$$

Product Export Transportation Limit

$$\sum_{p} t_{prr'} \leq UE_{rr'} \qquad \text{for all } r, r'$$

Product Import Balance

The total imports of a product to a domestic region equals the sum of imports to the region from all international regions.

$$i_{pr} = \sum_{r'} t_{pr'r} \qquad \text{for all } p, r$$

Product Import Supply Curve

The total imports of a product from an international region equals the sum of imports from the region over all steps of the supply curve.

$$\sum_{r} t_{pr'r} = \sum_{s} \hat{\imath}_{pr's} \qquad \text{for all } p, r'$$

Import Transportation Limit

$$\sum_{p} t_{pr'r} \leq UI_{r'r} \qquad \text{for all } r, r'$$

Brazil ethanol trade flow

Table B-5. Brazil ethanol constraints

Constraint Name	GAMS Cross Reference
Limit Ethanol Imports from Brazil	BrzMaxExportsToUS
World Balance for Brazilian Ethanol	EthWorldBal
Brazilian Ethanol Production Balance	BrzEthProdBal

Limit Ethanol Imports to U.S. From Brazil

U.S. demand for sugar cane ethanol must be no more than 50% of total consumption of sugar cane ethanol exported from Brazil.

$$\sum_{r} i_{jr} \leq Q \qquad \text{where } j = \text{sugar cane ethanol}$$

World Balance For Brazilian Ethanol

Total consumption of sugar cane ethanol exported from Brazil on all steps of the supply curve is no less than non-U.S. demand plus U.S. demand.

$$\sum_{s} k_s \geq \hat{b} + \sum_{r} i_{jr} \qquad \text{where } j = \text{sugar cane ethanol}$$

Brazilian Ethanol Production Balance

Total non-U.S. demand for sugar cane ethanol from Brazil plus total exports of corn ethanol from the U.S. is no less than the total non-U.S. demand for all ethanol.

$$\hat{b} + \sum_{r} \hat{g}_r \geq N$$

Ethanol Flows

Table B-6. Ethanol flow constraints

Constraint Name	GAMS Cross Reference
Ethanol Balance	EthBalance

Ethanol Balance

The total volume of ethanol produced in a region plus net imports plus net shipments from other domestic regions is equal to the total amount blended into finished products (gasoline and E85).

$$\sum_{\hat{p}} A_{\hat{p}j} x_{\hat{p}r} + \left(i_{jr} - e_{jr}\right) + \sum_{r'} \left(t_{jr'r} - t_{jrr'}\right) = \sum_{\hat{r}} y_{jr\hat{r}} \qquad \text{for all } r, j \in E$$

Refinery Input Streams (non-crude)

Table B-7. Refinery input stream constraints

Constraint Name	GAMS Cross Reference
Refinery Input Balance	RefInpBalance
Refinery Purchase Balance	RefPurchBal
Refinery Balance of Coal and Bio Streams	BioRefRegBal, CoalRefRegBal
Supply Balance of Coal and Bio Streams	BioBalance, CoalDemBalance, CoalSupBalance
Coal Emissions	SO2EmisBal, HGEmisBal

Refinery Input Balance

Refinery input streams that are purchased in a region must be consumed by a refinery process or used in recipe-blending or spec-blending in that region.

$$b_{\hat{s}r} = \sum_{\hat{p}} A_{\hat{p}\hat{s}} x_{\hat{p}r} + \sum_{\hat{r}} y_{\hat{s}r\hat{r}} + \sum_{p} z_{\hat{s}pr} \qquad \text{for all } r, \hat{s} \in \text{InputStream}$$

Refinery Purchase Balance

The total amount of a purchased refinery input includes amount purchased on all steps of a domestic supply curve plus net imports.

$$b_{\hat{s}r} = \sum_{s} d_{\hat{s}rs} + i_{\hat{s}r} - e_{\hat{s}r} \qquad \text{for all } r, \hat{s}$$

Refinery Balance of Coal and Bio Streams

$$\sum_{r'} \hat{m}_{\hat{s}r'r} \geq \sum_{\hat{p}} A_{\hat{p}\hat{s}} x_{\hat{p}r} \qquad \text{for all } \hat{s}, r$$

Supply Balance of Coal and Bio Streams

$$\sum_{s} m_{\hat{s}r's} = G_{\hat{s}r'} + \sum_{r} \hat{m}_{\hat{s}r'r} \qquad \text{for all } r', \hat{s}$$

Coal Emissions

$$f_{\hat{e}r} \geq \sum_{\hat{s}} \sum_{r'} H_{\hat{e}r\hat{s}} \hat{m}_{\hat{s}rr'} \qquad \text{for all } \hat{e}, r$$

Miscellaneous Constraints

Table B-8. Miscellaneous constraints

Constraint Name	GAMS Cross Reference
Utility Balance	UtilBalance
FBD Biodiesel Balance	BiodieselBalance
Stream Balance	StreamBalance
Capacity Balance	CapacityBalance
Limit regional growth in ADU condensers (LTE)	MaxLTE
Limit national growth in new technologies	RestrictGrowth
Limit national growth in CTL, CBL (carbon capture)	RestrictGrowthCTL, RestrictGrowthCBL
Limit national growth in CTL and GTL, combined	RestrictGrowthCTLGTL
Spec-blend Property – Maximum	GasSpecQualMax, DistSpecQualMax, ResidSpecQualMax
Spec-blend Property – Minimum	GasSpecQualMin, DistSpecQualMin, ResideSpecQualMin
Spec-blend Balance	GasSpecBalance, DistSpecBalance, ResidSpecBalance
Recipe Balance	RecipeBalance
Recipe Transfer	RecipeTransfer, RecipeBPTransfer
Inter-regional Transport	REFtoREFTran
Combine Recipe-product Supply	CombineSupply
Demand Satisfaction	RecipeDemands,RecipeEndBal, NGLDmd, NGLEndBal, TotProdTran,REFtoCDTran,REFtoCDCap, REFtoREFCapMB
Maximum E15	E15Max
OGSM CO2 demand balance	OGSM_CO2_Demand
LFMM CO2 CCS balance	CO2CCSBalance

Utility Balance

$$a_{ur} = \sum_{\hat{p}} A_{\hat{p}u} x_{\hat{p}r} \qquad \text{for all } r, u$$

FBD Biodiesel Balance

$$i_r = \sum_{s} i_{rs} \qquad \text{for all } r$$

Stream Balance

Intermediate streams that are produced in a region plus net imports, which are not otherwise consumed in a refinery process, must be used in recipe-blending or spec-blending in that region.

$$\sum_{\hat{p}} A_{\hat{p}\hat{s}} x_{\hat{p}r} + i_{\hat{s}r} - e_{\hat{s}r} = \sum_{\hat{r}} y_{\hat{s}r\hat{r}} + \sum_{p} z_{\hat{s}pr} \qquad \text{for all r}, \hat{s} \in \text{IntStream}$$

Capacity Balance

Period 1

$$x_{\hat{p}r} \leq E_{\hat{p}r} \qquad \text{for all } \hat{p}, r$$

Periods 2 and 3

$$x_{\hat{p}r} \leq E_{\hat{p}r} + \hat{E}_{\hat{p}r} \qquad \text{for all } \hat{p}, r$$

Limit regional growth in ADU condensers (LTE), Periods2 and 3 only

For ADU condensers, regional expansion is limited to regional-specific maxBld_r every model year.

$$\hat{E}_{\hat{p}r} \quad \leq maxBld_r \qquad \text{for all r}, \hat{p} = LTE$$

Limit national growth in new technologies, Periods2 and 3 only

For each new technology, total U.S. expansion is limited to maxBld every model year.

$$\sum_{r} \hat{E}_{\hat{p}r} \quad \leq maxBld \qquad \text{for all } \hat{p} = new\ tech$$

Limit national growth in CTL, CBL (carbon capture), Periods2 and 3 only

For CTL and CBTL separately, total U.S. expansion is limited to maxBld every model year.

$$\sum_{r} \hat{E}_{\hat{p}r} \quad \leq maxBld \qquad \text{for all } \hat{p} = CTL, CTLCCS, CBL, CBLCCS$$

Limit national growth in CTL, GTL, Periods2 and 3 only

For CTL and GTL combined, total U.S. expansion is limited to maxBld every model year.

$$\sum_{r} \hat{E}_{\hat{p}r} \quad \leq maxBld \qquad \text{for all } \hat{p} = CTL, CTLCCS, GTL$$

Spec-blend Property – Maximum

For every spec-product property subject to a maximum level, the volume-weighted property of all streams spec-blended into that spec-product may not exceed the maximum level.

$$\sum_{\hat{s}} \hat{P}_{q\hat{s}} z_{\hat{s}pr} \leq \sum_{\hat{s}} \hat{P}_{qp}^{max} z_{\hat{s}pr} \qquad \text{for all } q, r, \qquad p \in \text{SpecProd}$$

Spec-blend Property – Minimum

For every spec-product property subject to a minimum level, the volume-weighted property of all streams spec-blended into that spec-product may not be less than the minimum level.

$$\sum_{\hat{s}} \hat{P}_{q\hat{s}} z_{\hat{s}pr} \geq \sum_{\hat{s}} \hat{P}_{qp}^{min} z_{\hat{s}pr} \qquad \text{for all } q, r, \qquad p \in \text{SpecProd}$$

Spec-blend Balance

All spec-blended products must eventually be used in recipe-blending.

$$\sum_{\hat{s}} z_{\hat{s}pr} = \sum_{\hat{r}} y_{pr\hat{r}} \qquad \text{for all } r, p \in \text{SpecProd}$$

Recipe Balance

$$y_{\hat{s}r\hat{r}} = R_{\hat{s}\hat{r}} \hat{x}_{r\hat{r}} \qquad \text{for all } \hat{s}, r, \hat{r}$$

Recipe Transfer

$$\check{x}_{rp} = \sum_{\hat{r}} R_{\hat{s}\hat{r}} \hat{x}_{r\hat{r}} \qquad \text{for all } \; r, \hat{s} = p \in \text{RecipeProd}$$

Inter-regional Transport

$$\sum_{\hat{s}} t_{\hat{s}rr'} \leq T_{mrr'} \qquad \text{for all } \; r, r'$$

Combine Recipe-product Supply

$$h_{pr} = \check{x}_{rp} + i_{pr} - e_{pr} + \sum_{r'} \left(t_{pr'r} - t_{prr'} \right) \qquad \text{for all } r, p \in \text{RecipeProd}$$

Demand Satisfaction

$$h_{pr} = D_{pr} \qquad \text{for all } r, \qquad p \in \text{RecipeProd}$$

Maximum E15

The fraction of the total motor gasoline market that can be E15 is subject to an exogenous maximum value. This value changes over time, but the year subscript is suppressed in the equation.

$$\sum_{r} h_{E15,r} \leq MaxE15frac * \sum_{p \in \text{Gasoline}} \sum_{r} h_{pr}$$

LFMM CO2 CCS Balance

Carbon dioxide produced at CTL and CBTL facilities, captured, and compressed for sequestration in an LFMM region (r') must be sent either to saline aquifers for storage or transferred to OGSM regions (r̂) to meet CO2 demand for EOR.

$$\sum_{r' \hat{p}} A_{\hat{p}\hat{s}} x_{\hat{p}r'r} = \sum_{\hat{r}} xTLeor_{\hat{s}r\hat{r}} + CO2saline_r \quad \text{for all r}, \hat{s} = CO2, \hat{p} = CTLCCS, CBLCCS$$

OGSM CO2 Demand Balance

EOR demand for CO2 in an OGSM region is satisfied from multiple sources: CO2 produced at CTL and CBTL facilities (r), and transferred to OGSM regions (r̂); CO2 produced from a list of other sources (including ammonia plants, cement plants, power plants, etc.) in this (r̂) and other OGSM regions (r'). The LFMM LP includes a safety valve, not shown here, which allows purchase of CO2 to ensure that the LP is feasible.

$$\sum_{r'} OTHeor_{\hat{s}r'\hat{r}} + \sum_{r} xTLeor_{\hat{s}r\hat{r}} = CO2eorDmd_{\hat{r}} \quad \text{for all r̂}, \hat{s} = CO2$$

Policy Constraints

Table B-9. Policy constraints

Constraint Name	GAMS Cross Reference
RFS Requirements	RFSConstraintsPRD, RFSConstraintsRQM
LCFS Requirements	LCFS_Biofuel, LCFS_Petroleum
AB32 Requirements	AB32_Constraint

RFS Requirements

The total amount of credits earned from production of RFS-compliant biofuels must be at least as great as the adjusted RFS target.

$$\sum_{r} \sum_{\hat{p}} \sum_{\hat{s}} RFSScore_{k\hat{s}} A_{\hat{p}\hat{s}} x_{\hat{p}r} \geq RFSTarget_k \quad \text{for all } k \in \text{RFSCategory}, A < 0$$

LCFS Requirements

The total carbon intensity of motor fuels (gasoline and diesel) sold in California must be lower than the (adjusted) target carbon intensity. The LFMM LP includes a safety valve, not shown here, which allows purchase of carbon credits to ensure that the LP is feasible.

$\sum_p \sum_{\hat{r}} LCFSfactor_{p\hat{r}} h_{pr} \leq 0 \quad$ for $r =$ California, $p \in$ RecipeProd (gasoline and diesel)

Appendix C. Bibliography

The LFMM mid-term model development web page includes a section on the LFMM: http://www.eia.gov/outlooks/documentation/workshops/

- Overview and Summary of Stakeholder Inputs (4/3/09)
- Needs Assessment and Model Development Process (5/10/09, 11/24/09)
- Technical Workshop (9/30/09)
- Component Design Report (10/16/10)

Abt Associates Inc. 1991. A Methodology for Evaluating the Costs and Global Warming Implications of Ethanol. Report prepared for Office of Policy Analysis, U.S. Environmental Protection Agency, April 2, 1991.

F. Gerard Adams and James M. Griffin, "An Economic-Linear Programming Model of the U.S. Petroleum Refining Industry," Journal of the American Statistical Association (September 1972), 67:339, pp. 542-551.

ASM Consulting Services, Petroleum Market Module Review, prepared for the Office of Statistical Standards, EIA/DOE (July 1992).

American Petroleum Institute, How Much We Pay For Gasoline: 1996 Annual Review (Washington, DC, May 1997).

ASM Consulting Services, Petroleum Market Module Review, prepared for the Office of Statistical Standards, EIA/DOE (September 1992).

C.E. Bodington, "A History of Mathematical Programming in the Petroleum Industry," Interfaces (July-August 1990), 20:4, pp. 117-127.

Bureau of the Census, 1989 Annual Survey of Manufacturers, Statistics for Industry Groups and Industries (M89AS1).

Chemical Market Reporter, Methanol Capacity Data By Company, December 16, 2002.

Chowdhury, A., E.O. Heady, and S. Bhide. 1981. Optimum Crop Production and Resource Use Under Alternative Energy Prices and Agricultural Exports: A Separable and Change-Constrained Programming Analysis. Report 103. The Center for Agricultural and Rural Development, Ames, IA.

Christensen, D.A., R.J. Schatzer, E.O. Heady, and B.C. English. 1981. The Effects of Increased Energy Prices on U.S. Agriculture: An Econometric Approach. Report 104. The Center for Agricultural and Rural Development, Ames, IA.

CMAI, Houston, TX, United States Methanol Chemicals Demand Forecast, January 2004 and updated July 2005.

ConocoPhillips, S Zorb Process Overview, http://www/fuelstechnology.com/szorb_processover.htm.

Decision Analysis Corporation of Virginia, The Oil Trade Model (OTM) Draft Documentation, User's Manual [and] Data Base (Vienna, VA, October 31, 1989).

Decision Analysis Corporation of Virginia, Transportation and Refining of International Petroleum (TRIP) Model Documentation, Volume I (Vienna, VA, December 1988).

Decision Analysis Corporation of Virginia, Transportation and Refining of International Petroleum (TRIP) Model Documentation, Volume II (Vienna, VA, December 1988).

Defense Energy Support Center, Compilation of United States Fuel Taxes, Inspection Fees and Environmental Taxes and Fees, Edition: 2005-14, July 14, 2005.

DiPardo, Joseph. April 2000. Outlook for Biomass Ethanol Production and Demand. U.S. Energy Information Administration, U.S. Department of Energy.

Dvoskin, D., E.O. Heady, and B.C. English. 1978. Energy Use in U.S. Agriculture: An Evaluation of National and Regional Impacts from Alternative Energy Policies. The Center for Agricultural and Rural Development. Report 78. Ames, IA.

E85 Blending, Tax Incentives, and Pump Pricing, National Ethanol Vehicles Coalition. (A copy of the report may be obtained by calling (877) 485-8595.)

U.S. Energy Information Administration, Monthly Energy Review, DOE/EIA-0384, Washington, DC, September 2016.

U.S. Energy Information Administration, Assumptions to the Annual Energy Outlook 2013 (Washington, DC, May 2013).

U.S. Energy Information Administration, Component Design Report: The Integrating Module (Washington, DC, May 1992).

U.S. Energy Information Administration, Component Design Report: The Macroeconomic Activity Module of the National Energy Modeling System (Washington, DC, March 1992).

U.S. Energy Information Administration, Fuel Oil and Kerosene Sales 2014, DOE/EIA-0535(2014) (Washington, DC, December 2016).

U.S. Energy Information Administration, International Energy Annual 2000, DOE/EIA-0219(2000) (Washington, DC, May 2002).

U.S. Energy Information Administration, Modeling Environmental Costs, memorandum prepared by S.R. MacIntyre (Washington, DC, February 1993).

U.S. Energy Information Administration, Historical Natural Gas Annual 1930 Through 2000, DOE/EIA-0110(00), (Washington, DC, December 2001).

U.S. Energy Information Administration, NEMS Crude Oil Categories, memorandum prepared by Xavier Szebrat (Washington, DC, July 1992).

U.S. Energy Information Administration, The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply, SR/OIAF/2001-01 (Washington DC, May 2001).

U.S. Energy Information Administration, Impact of Renewable Fuels Standard/MTBE Provisions of S. 1766 Requested by the Senate Energy Committee (Washington DC, March 2002).

U.S. Energy Information Administration, Impact of Renewable Fuels Standard/MTBE Provisions of S. 517 Requested by Senators Daschle and Murkowski (Washington DC, April 2002).

U.S. Energy Information Administration, Summary – Analysis of Selected Transportation Fuel Issues Associated with Proposed Energy Legislation, by Joanne Shore (Washington DC, September 2002).

U.S. Energy Information Administration, Outstanding Issues of Refinery Plant Expansion, memorandum prepared by G.R. Harp (Washington, DC, May 1993).

U.S. Energy Information Administration, Petroleum Marketing Monthly, DOE/EIA Washington, DC, October 2016.

U.S. Energy Information Administration, Petroleum Supply Annual 2015, Volume 1, DOE/EIA-0340(2015/1)(Washington, DC, September 2016).

U.S. Energy Information Administration, Petroleum Supply Monthly, DOE/EIA Washington, DC, September 2016.

U.S. Energy Information Administration, PMM Procedure to Calculate Investment Recovery and Fixed Cost Charges on Existing U.S. Refinery Plant, memorandum prepared by G.R. Harp (Washington, DC, August 1993).

U.S. Energy Information Administration, Preliminary Design for the PMM and Detailed Refinery Model, memorandum prepared by S.R. MacIntyre (Washington, DC, February 1992).

U.S. Energy Information Administration, Proceedings of the National Energy Modeling System Conference, (Washington, DC, May 1993).

U.S. Energy Information Administration, NEMS Component Design Report for Biofuels (Ethanol) Supply Submodule - Renewable Fuels Model - National Energy Modeling System. Draft 3/12/93.

U.S. Energy Information Administration, Requirements Analysis for a National Energy Modeling System (Washington, DC, 18 May 1992).

U.S. Energy Information Administration, Test Plan for the Petroleum Market Module (PMM), memorandum prepared by G.R. Harp (Washington, DC, May 1993).

U.S. Energy Information Administration, The Treatment of Foresight and Expectation, Decision Memorandum, Mary J. Hutzler and Mark E. Rodekohr, (Washington, DC, March 12, 1992).

English, Smith, Atwood, Johnson, and Oamek. 1989. Resource Conservation Act Analysis; An Overview of the CARD Agricultural Resource Interregional Modeling System. The Center for Agricultural and Rural Development, Iowa State University, Ames, IA, Technical Report 89-TR11.

Ensys Energy & Systems, Inc., WORLD Reference Manual, prepared for the Department of Energy, Contract No. DE-AC01-87FE-61299, September 1992.

Farmer, Richard D., "Problems and Lessons in Estimating Supply Curves for Refined Petroleum Products," The Journal of Energy and Development, Autumn, 1986, Vol. XII, No. 1, pp. 27-42.

J.H. Gary and G.E. Handwerk, Petroleum Refining: Technology and Economics (New York: Marcel Dekker, 1975), Chapters 13 and 14 (Unless otherwise specified 3rd edition).

GAMS Development Corporation, www.gams.com .

GAMS Development Corporation, GDX Viewer, http://www.gams.com/dd/docs/tools/gdxviewer.pdf .

Giovando, CarolAnn June 1998. “1998 Powerplant Awards Sweeny Cogeneration Facility,” Power.

Haverly Systems, Inc., OMNI Linear Programming System, User Reference Manual, (Denville, NJ, January 1987).

ICF Resources, North American Crude Oil Demand Model, July 1992.

Independent Reviews of U.S. Energy Information Administration’s The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply, by Ray Ory and Kevin Waguespack, April 2001.

Kane, S.M., and J.M. Reilly. 1989. Economics of Ethanol Production in the United States. Agricultural Economic Report 607. USDA/ERS, Washington, DC.

LeBlanc, M. and J. Reilly. 1988. Ethanol: Economic and Policy Tradeoffs. Agricultural Economic Report No. 585. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Lee, Hyunok. June 1993. "Ethanol's Evolving Role in the U.S. Automobile Fuel Market." Industrial Uses of Agricultural Materials, Situation and Outlook Report. United States Department of Agriculture, Washington, DC.

Lee, R., S.M. Cohn, and R.D. Perlack. 1991. Prototype of an Integrated Model for Projecting Biofuels Consumption. Draft report prepared for U.S. Energy Information Administration, U.S. Department of Energy. Oak Ridge National Laboratory, Oak Ridge, TN.

Linear Programming, Inc., PAL/REMS Integration Methodology Study, final report prepared for the Office of Statistical Standards, EIA/DOE, Contract No. DE-AC01-84EI-19633 (April 1987).

MacIntyre, Stacy, “Motor Fuels Tax Trends and Assumptions,” Issues in Midterm Forecasting 1998, DOE/EIA-0607(98), (Washington DC, July 1998).

Macro International, Inc., EIA-888 and EIA-878 Data Comparisons and Performance Measures, Third Quarter 1997 (Washington, DC, December 15, 1997).

Marano, John J., Ph.D., Refinery Technology Profiles: IsoOctane/IsoOctene and Related Technologies, prepared for the National Energy Technology Laboratory, U.S. Energy Information Administration, DOE, January 2003.

Marano, John J., Ph.D., Refinery Technology Profiles: Gasification and Supporting Technologies, prepared for the National Energy Technology Laboratory, U.S. Energy Information Administration, June 2003.

Marland, G. and A.F. Turhollow. 1991. "CO2 Emissions From the Production and Combustion of Fuel Ethanol from Corn." Energy, 16(11/12):1307-1316.

Mitretech Technical Report, Coproduction: A Green Coal Technology, by David Gray and Glen Tomlingson, March 2001.

National Petroleum Council, Petroleum Storage and Transportation (Washington, DC, April 1989).

National Petroleum Council, U.S. Petroleum Refining (Washington, DC, June 2000).

National Renewable Energy Laboratory 1999. Bioethanol Multi-Year Technical Plan.

National Research Council, The National Energy Modeling System (Washington, DC, January 1992).

Oak Ridge National Laboratory, Review of the Component Design Report for the Petroleum Market Module, letter prepared by Jerry Hadder (Oak Ridge, TN, July 1992).

OnLocation, Inc. / Energy Systems Consulting, Liquid Fuels Market Model Component Design Report (October 26, 2010).

OnLocation, Inc. / Energy Systems Consulting, Liquid Fuels Market Model (LFMM) Documentation: Selective descriptions of key elements of the LFMM, Draft (April 25, 2012).

The Pace Consultants, Inc., Pace Petrochemical Service: Annual Issue, (Houston, TX, October 1990).

Solar Energy Research Institute. March 1990. The Potential of Renewable Energy: An Interlaboratory White Paper, SERI/TP-260-3674, Golden, CO, prepared for the Office of Policy, Planning, and Analysis, U.S. Department of Energy, in support of the National Energy Strategy.

Trumble, David A. 1994. Estimation of Supply Curve for Ethanol with Corn as the Feedstock. Draft report prepared for U.S. Energy Information Administration, U.S. Department of Energy. Oak Ridge National Laboratory, Oak Ridge, TN.

Turhollow, A.F. 1991. Economic Consideration for the Production of Wood for Energy. Presentation at Trees for Energy, First National Fuelwood Conference, November 11-13, 1991, Lincoln, NE.

Turhollow, A.F., D.A. Christensen, and E.O. Heady. 1984. The Potential Impacts of Large-Scale Fuel Alcohol Production from Corn, Grain Sorghum, and Crop Residues Under Varying Technologies and Crop Expert Levels. Report 126. The Center for Agricultural and Rural Development, Ames, IA.

Turhollow, A.F., C. Short, and E.O. Heady. 1983. Potential Impacts of Future Energy Price Increases on U.S. Agricultural Production. Report 116. The Center for Agricultural and Rural Development, Ames, IA.

Tyson, K.S. 1990. Biomass Resource Potential of the United States. Report prepared for Office of Transportation Technologies, U.S. Department of Energy, October 1990. Solar Energy Research Institute, Golden, CO.

The University of Oklahoma, Review of the Component Design Report for the Petroleum Market Module, letter prepared by D.J. O'Neil (Norman, OK, July 1992).

U.S. Department of Agriculture, USDA Agricultural Baseline Projections to 2009, Staff Report WAOB-00-1 (Washington, DC, September 2000).

U.S. Department of Energy, Integrated Analysis Supporting the National Energy Strategy: Methodology, Assumptions, and Results, Technical Annex 2, First Addition, 1991/1992, DOE/S-0086P, p.148.

U.S. Department of Energy, National Energy Strategy (Washington, DC, February 1991).

U.S. Department of Energy, Review of the Component Design Report for the Petroleum Market Module, memorandum prepared by A.E. Haspel (Washington, DC, June 1992).

U.S. Department of Energy, Review of the Component Design Report for the Petroleum Market Module, memorandum prepared by J.D. Pearson (Washington, DC, June 1992).

U.S. Environmental Protection Agency, Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule, 40 CFR, Parts 9, 69, et al.

U.S. Environmental Protection Agency, Heavy-Duty Engines and Vehicle Standards and Highway Diesel Sulfur Control Requirements, January 18, 2001.

U.S. Department of Energy, Review of the Component Design Report for the Petroleum Market Module, memorandum prepared by J.L. Petersen (Washington, DC, June 1992).

U.S. Department of Energy, Review of the Component Design Report for the Petroleum Market Module, memorandum prepared by C.P. Shirkey (Washington, DC, June 1992).

Urbanchuk, J.M. 1998. Review of Alternative Ethanol Supply Curves Used in the U.S. Energy Information Administration’s National Energy Modeling System.

Walsh, M. et al June 1997. Evolution of the Fuel Ethanol Industry: Feedstock Availability and Price. Oak Ridge National Laboratory.

Wang, M. et al 1997. Fuel-Cycle Fossil Energy Use and Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn.

Also see citations in Appendix A, the AEO2018 Assumptions Document, and the LFMM Component Design Report.

Appendix D. Model Abstract

Model name

Liquid Fuels Market Module

Model acronym

LFMM

Description

The Liquid Fuels Market Module is a simulation of the U.S. liquid fuels industry. The heart of the model is a linear programming optimization that ensures a rational economic simulation of decisions of feedstock sourcing, resource allocation, and the calculation of a marginal price basis for the products. The model accounts for over twenty refined products that are manufactured, imported, and marketed. These include specification-blended and recipe-blended products, as well as coproducts, unfinished products, and by-products. The LFMM models domestic liquid fuels production activities, and the marketing of petroleum products to consumption regions.

Capacity-limited transportation systems are included to represent existing intra-U.S. crude oil and product shipments (LPG, clean, dirty) via pipeline, marine tanker, barge, and truck/rail tankers. The export and import of crude oil and refined products is also simulated. All crude and product imports are purchased in accordance with import supply curves. Crude exports are allowed and connected to the world crude supply curves. Product exports are valued by individual export demand curves.

The majority of the LFMM is written in GAMS, but some parts are in Fortran.

Purpose of the model

The purpose of the LFMM is to project petroleum product prices, refining activities, and movements of petroleum across United States' borders and among domestic regions. In addition, the model contains adequate structure and is sufficiently flexible to examine the impact of a wide variety of petroleum-related issues and policy options. These capabilities allow for understanding of the petroleum refining and marketing industry as well as determining the effects of certain policies and regulations.

The LFMM projects sources of supply for meeting petroleum product demand. The sources of supply include crude oil, both domestic and imported; other inputs including alcohols and ethers and renewable feedstocks; hydrocarbon gas liquids (HGL) imports and exports; petroleum product imports; and refinery processing gain. In addition, the LFMM estimates domestic refinery capacity expansion and fuel consumption. Product prices are estimated at the Census Division (CD) level and much of the refining activity information is at the PADD (Petroleum Administration for Defense District) and sub-PADD level.

Most recent model update

This documentation describes the December 2017 version used to develop projections for AEO2018.

Part of another model?

The LFMM is a component of the National Energy Modeling System (NEMS).

Model interfaces

The LFMM receives information from the International Energy, Natural Gas Market, Oil and Gas Supply, Renewable Fuels, Electricity Market, and Residential, Commercial, Industrial, and Transportation Demand Modules and delivers information to each of the modules listed above plus the Macroeconomic Module within NEMS.

Official model representative

James Preciado
Office of Energy Analysis
Petroleum, Natural Gas, and Biofuels Analysis
(202) 586-8769

Documentation

EIA Model Documentation: Liquid Fuels Market Module of the National Energy Modeling System (NEMS), December 2016. (DOE/EIA-M059 (2016)).

Archive media and installation manual

Archived as part of the NEMS AEO2018 production runs.

Energy system described

Petroleum refining industry, non-petroleum liquid fuels industry, and refined products market.

Coverage

Geographic: Twelve domestic crude oil production regions (East Coast, Gulf Coast, Mid-Continent, Permian Basin, Rocky Mountain, West Coast, Atlantic Offshore, Gulf Offshore, Pacific Offshore, Alaska South, Alaska North, Alaska Offshore); eight domestic refining regions; nine market regions, the Census Divisions (New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific), one international refining region comprising eastern Canada and the Caribbean, and one Rest of World crude and product supply region.

Time unit/frequency: annual, 2017 through 2050.

Products: LPG, conventional motor gasoline, conventional high oxygen motor gasoline, reformulated motor gasoline, reformulated high oxygen motor gasoline, E85, jet fuel, distillate fuel oil, low-sulfur diesel, ultra-low-sulfur diesel, low-sulfur residual fuel oil, high-sulfur residual fuel oil, petrochemical feedstocks, asphalt/road oil, marketable coke, still gas, “other” petroleum products, ethanol, and biomass-based diesel.

Production Processes:

ACU	"Atmospheric Distillation Unit"
AET	"Advanced Ethanol (non-cellulosic)"
ALK	"Alkylation"
ARP	"Aromatics Plant"
BPU	"Pyrolysis"
BSA	"Benzene Saturation"
BTL	"Biomass-to-Liquids"
C4I	"Butane Isomerization"
CBL	"Coal-and-Biomass-to-Liquids"
CBLCCS	"Coal-and-Biomass-to-Liquids with CCS"
CGN	"Power Generation & Co-Generation"
CLE	"Cellulosic Ethanol"
CPL	"Catalytic Polymerization"
CSU	"Condensate splitter"
CTL	"Coal-to-Liquids"
CTLCCS	"Coal-to-Liquids with CCS"
DC4	"Debutanization"
DC5	"FCC Naphtha Depentanizer"
DDA	"Distillate Dearomatizer"
DDS	"ULSD Hydrotreater"
EDH	"Corn Ethanol - Dry Mill, High Efficiency"
EDM	"Corn Ethanol - Dry Mill"
FBD	"FAME Biodiesel"
FCC	"Fluid Catalytic Cracker"
FDS	"FCC Feed Hydrotreater"
FGS	"FCC Naphtha Fractionator"
FUM	"Fuel Psuedo-Unit"
GDS	"FCC Naphtha Hydrotreater"
GDT	"Green Diesel"
GTL	"Gas-to-Liquids"
H2P	"Hydrogen Production"
H2R	"Hydrogen Recovery"
HCD	"Hydrocracker"
KRD	"Delayed Coker"
KWG	"Electricity Generation"
LNS	"Light Naphtha Splitter"
LTE	"Light ends condenser on ADU"
LUB	"Lubricant Production"
NCE	"Non-corn Starch Ethanol"
NDS	"Naphtha Hydrotreater"

PHI	"Once-Thru Isomerization"
RCR	"Continuous Cyclic Reformer"
RGN	"FCC Catalyst Regenerator"
RSR	"Semi-Regenerative Reformer"
SDA	"Solvent Deasphalter"
SEW	"Corn Ethanol - Wet Mill"
SGP	"Saturated Gas Plant"
STG	"Steam Production"
SUL	"Sulfur Plant"
TRI	"Total Recycle Isomerization"
TRS	"Stream Transfer Pseudo-Unit"
UGP	"Unsaturated Gas Plant"
VCU	"Vacuum Distillation Unit"

Crude Oil: eleven crude oils that vary by API gravity and sulfur content.

Transportation Modes: Jones Act dirty marine tanker, Jones Act clean marine tanker, LPG marine tanker, import tankers, clean barge, dirty barge, LPG pipeline, clean pipeline, dirty pipeline, rail/truck tankers. These cover all significant U.S. links.

Modeling features

Model Structure: GAMS and Fortran

Model Technique: Optimization of linear programming representation of refinery processing and non-petroleum liquid fuels production and transportation that relates the various economic parameters and structural capabilities with resource constraints to produce the required product at minimum cost, thereby producing the marginal product prices in a manner that accounts for the major factors applicable in a market economy.

Special Features: Choice of imports or domestic production of products is modeled; capacity expansion of conversion units is determined endogenously; product prices include fixed, environmental, and policy-related costs.

Non-DOE input sources

Information Resources Inc. (IRI), National Petroleum Council, ICF Resources, Oil and Gas Journal, U.S. EPA gasoline properties survey, Jacobs Consulting Refinery Technology database, OnLocation, Inc. and its subcontractors.

DOE input sources

Forms:

EIA-14	Refiners' Monthly Cost Report
EIA-182	Domestic Crude Oil First Purchase Report
EIA-782A	Refiners'/Gas Plant Operators' Monthly Petroleum Product Sales Report
EIA-782B	Resellers'/Retailers' Monthly Petroleum Product Sales Report

EIA-782C Monthly Report of Prime Supplier Sales of Petroleum Products Sold for Local Consumption
EIA-759 Monthly Power Plant Report
EIA-810 Monthly Refinery Report
EIA-811 Monthly Bulk Terminal Report (information obtained from EIA-815 after 2009)
EIA-812 Monthly Product Pipeline Report
EIA-813 Monthly Crude Oil Report
EIA-814 Monthly Imports Report
EIA-815 Monthly Bulk Terminal and Blender Report
EIA-817 Monthly Tanker and Barge Movements Report
EIA-820 Annual Refinery Report
EIA-826 Monthly Electric Sales and Revenue with State Distributions Report
EIA-856 Monthly Foreign Crude Oil Acquisition Report
EIA-920 Combined Heat and Power Plant Report (and predecessor forms)
EIA-923 Power Plant Operations Report
FERC-423 Monthly Report of Cost and Quality of Fuels for Electric Plants (information obtained from EIA-923 after 2009)

In addition to the above, information is obtained from several U.S. Energy Information Administration publications: Petroleum Supply Annual, Petroleum Supply Monthly, Petroleum Marketing Annual, Petroleum Marketing Monthly, Fuel Oil and Kerosene Sales, Natural Gas Annual, Natural Gas Monthly, Annual Energy Review, Monthly Energy Review, State Energy Data Report, and State Energy Price and Expenditure Report.

Independent expert reviews conducted

None.

Independent reviews of the predecessor to the LFMM, the Petroleum Market Module (PMM), were conducted by:

A.S. Manne, ASM Consulting Services, July 1992
A.S. Manne, ASM Consulting Services, September 1992
N. Yamaguchi, Trans-Energy Research Associates, Inc., November 1997.
J. Urbanchuk, AUS Consultants, May 1998.
Ray Ory, independent consultant, June 2003
Terry Higgins, International Fuel Quality Center, June 2003
Fred Joutz and Inderjit Kundra, George Washington University and Statistics and Methods Group of EIA, December 2003
Julian Silk, Robert P. Trost, Michael Ye, and Inderjit Kundra, Statistics and Methods Group of EIA, November 2005
Michael Ye, Robert P. Trost, Michael Ye, Ramesh Dandekar, and Inderjit Kundra, Statistics and Methods Group of EIA, April 2009

Status of evaluation efforts by sponsor

None.

Appendix E. Data Quality

EIA Survey Forms

Form EIA-14, Refiners' Monthly Cost Report

The U.S. Energy Information Administration (EIA) Form EIA-14, "Refiners' Monthly Cost Report," is used to collect summary data that permit EIA to provide the government and the public certain cost and price statistics on the United States petroleum industry. The data appear on EIA's website at www.eia.gov and in the EIA publications, Petroleum Marketing Monthly, Monthly Energy Review, and Annual Energy Review.

Form EIA-182, Domestic Crude Oil First Purchase Report

The U.S. Energy Information Administration (EIA) Form EIA-182, "Domestic Crude Oil First Purchase Report," is designed to collect data on both the average cost and volume associated with the physical and financial transfer of domestic crude oil off the property on which it was produced. The monthly reported data represent the initial market value and volume of domestic crude oil production. The primary statistic is the weighted average wellhead price for selected domestic crude oil streams aggregated by state. First purchase volumes are also used in generating estimates of domestic crude oil production. Since the purpose of this report is statistical, definitions vary unavoidably from those of some state agencies whose purpose is strictly fiscal or regulatory (see Definitions). Data are used by the U.S. Department of Energy (DOE) in reviewing the supply, demand, quality, and price changes of crude oil. The average wellhead price(s) are published in the Petroleum Marketing Monthly, the Monthly Energy Review, the Annual Energy Review, and the Oil and Gas Lease Equipment and Operating Costs 1994-2009.

Form EIA-782A, Refiners'/Gas Plant Operators' Monthly Petroleum Product Sales Report

The U.S. Energy Information Administration (EIA) Form EIA-782A, "Refiners'/Gas Plant Operators' Monthly Petroleum Product Sales Report," is used to collect data on the sales of selected petroleum products (volumes and prices) to various categories of end-users and resellers at the state level. The data are used by the Department of Energy to analyze and report on petroleum product supply, demand, and price changes. In addition, the data are used by state and federal agencies (such as the Bureau of Economic Analysis and the Defense Logistics Agency (DLA) Energy), Congress, industry analysts, trade publications, academia, and the public to analyze, model and forecast petroleum product prices and sales by state and end-use category.

Form EIA-782B, Resellers'/Retailers' Monthly Petroleum Product Sales Report

The U.S. Energy Information Administration (EIA) Form EIA-782B, "Resellers'/Retailers' Monthly Petroleum Product Sales Report," is used to collect data on the sales of selected petroleum products (volumes and prices) to various categories of end-users and resellers at the state level. The data are used by the Department of Energy to analyze and report on petroleum product supply, demand, and price changes. In addition, the data are used by state and federal agencies (such as the Bureau of Economic Analysis and the DLA Energy), Congress, industry analysts, trade publications, academia, and the public to analyze, model and forecast petroleum product prices and sales by state and end-use category. This report was suspended in 2011.

Form EIA-782C, Monthly Report of Prime Supplier Sales of Petroleum Products Sold for Local Consumption

The U.S. Energy Information Administration (EIA) Form EIA-782C, "Monthly Report of Prime Supplier Sales of Petroleum Products Sold for Local Consumption," is used to collect data on the sales of selected petroleum products by prime suppliers delivered into states for local consumption. The data are used by the Department of Energy to analyze and report on petroleum product demand. In addition, the data are used by state and federal agencies (such as the Bureau of Economic Analysis), Congress, industry analysts, trade publications, academia, and the public to analyze, model and forecast petroleum product consumption by state.

Form EIA-810, Monthly Refinery Report

The Energy Information Administration (EIA) Form EIA-810, "Monthly Refinery Report," is used to collect data on the operations of all petroleum refineries located in the 50 states, District of Columbia, Puerto Rico, the Virgin Islands, Guam, and other U.S. possessions. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-811, Monthly Bulk Terminal Report (terminated after 2009; now using EIA-815)

The Energy Information Administration (EIA) Form EIA-811, "Monthly Bulk Terminal Report," is used to collect data on end-of-month stocks of petroleum products. The data appear on EIA's website at www.eia.doe.gov and in numerous government publications.

Form EIA-812, Monthly Product Pipeline Report

The Energy Information Administration (EIA) Form EIA-812, "Monthly Product Pipeline Report," is used to collect data on end-of-month stocks and movements of petroleum products transported by pipeline. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-813, Monthly Crude Oil Report

The Energy Information Administration (EIA) Form EIA-813, "Monthly Crude Oil Report," is used to collect data on end-of-month stocks of crude oil, and movements of crude oil by pipeline. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-814, Monthly Imports Report

The Energy Information Administration (EIA) Form EIA-814, "Monthly Imports Report," is used to collect data on imports of crude oil and petroleum products. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-815, Monthly Bulk Terminal and Blender Report

The Energy Information Administration (EIA) Form EIA-815, "Monthly Bulk Terminal and Blender Report," is used to collect data on end-of-month stocks of petroleum products. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-817, Monthly Tanker and Barge Movements Report

The Energy Information Administration (EIA) Form EIA-817, "Monthly Tanker and Barge Movements Report," is used to collect data on the movement of crude oil and petroleum products. A summary of the data appears on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-820, Annual Refinery Report

The Energy Information Administration (EIA) Form EIA-820, "Annual Refinery Report," is used to collect data on current and projected capacities of all operable petroleum refineries. The data appear on EIA's website at www.eia.gov and in numerous government publications.

Form EIA-826, Monthly Electric Utility Sales and Revenue Report with State Distributions

Form EIA-826 collects information from electric utilities, energy service providers, and distribution companies that sell or deliver electric power to end users. Data collected on this form include sales and revenue for all end-use sectors (residential, commercial, industrial, and transportation). The data from this form appear in the following EIA publications: Electric Power Monthly, Monthly Energy Review, and Annual Energy Review. The data collected on this form are used to monitor the current status and trends of the electric power industry and to evaluate the future of the industry.

Form EIA-856, Monthly Foreign Crude Oil Acquisition Report

The U.S. Energy Information Administration (EIA) Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report," is used to collect data on the cost and quantities of foreign crude oil (by country of origin) acquired for importation into the United States, including U.S. territories and possessions. The data are used by the Department of Energy, the International Energy Agency (IEA), other federal agencies, and industry analysts for forecasting and analytical purposes.

Form EIA-923, Power Plant Operations Report

Form EIA-923 collects information from electric power plants and combined heat and power (CHP) plants in the United States. Data collected on this form include electric power generation, fuel consumption, fossil fuel stocks, delivered fossil fuel cost, combustion by-products, operational cooling water data, and operational data for NO_x, SO_2, and particulate matter control equipment. These data are used to monitor the status and trends of the electric power industry and appear in many U.S. Energy Information Administration (EIA) publications including: Electric Power Monthly, Electric Power Annual, Monthly Energy Review, Annual Energy Review, Natural Gas Monthly, Natural Gas Annual, Cost and Quality of Fuels, Quarterly Coal Report, and Renewable Energy Annual.

In addition to the above, information is obtained from several EIA publications: Petroleum Supply Annual, Petroleum Supply Monthly, Petroleum Marketing Annual, Petroleum Marketing Monthly, Fuel Oil and Kerosene Sales, Natural Gas Annual, Natural Gas Monthly, Annual Energy Review, Monthly Energy Review, State Energy Data Report, and State Energy Price and Expenditure Report.

Quality of distribution cost data

Costs relating to distributing petroleum products to end-users are incorporated by adding fixed transportation markups to the wholesale prices which include the variable and fixed refinery costs. Transportation markups for petroleum products are estimated as the average annual difference between retail and wholesale prices over the years 1990 through 2013.[2] The differences are based on wholesale prices in the producing Census Division and end-use prices (which do not include taxes) in the consuming Census Division. See Appendix F for a discussion of programs and input files used in estimating these markups.

[2] Transportation markups for kerosene are based on the difference between end-user kerosene prices and wholesale distillate prices.

Annual wholesale prices for all petroleum products are aggregated from state-level prices from the EIA-782A. The estimation and reliability of the EIA-782A data are discussed in the Petroleum Marketing Annual. See Explanatory Notes for inputs and sources. http://www.eia.gov/oil_gas/petroleum/data_publications/petroleum_marketing_annual/pma.html

With the exception of gasoline, non-utility distillate fuel, and jet fuel, sectoral end-user prices through 2015 are aggregated from prices from State Energy Data System 2015: select State, then Prices (SEDS) (http://www.eia.gov/state/seds/). The methodology behind these state-level sectoral prices is discussed in the Technical Notes and Documentation section near the bottom of the web page (http://www.eia.gov/state/seds/seds-technical-notes-complete.cfm?sid=US).

Gasoline, jet fuel, and non-utility distillate prices are estimated as weighted averages using end-user prices from EIA-782A and sectoral consumption from the State Energy Data System 2015: select State, then Consumption & Expenditures (SEDS) (http://www.eia.gov/state/seds/).

Due to a lag in the publication of the SEDS data, end-use price estimates for 2016 are calculated using the same data series and methodology described in SEDS. The SEDS methodology uses prices from EIA-782A, EIA-923, EIA-906 (Table E-1), and weights them with most recent consumption volumes from SEDS. Refer to SEDS for a discussion of the reliability of consumption data (http://www.eia.gov/state/seds/seds-technical-notes-complete.cfm?sid=US). Year 2017 and 2018 are estimated by applying the percentage change of national product prices as reported in the September October 2017 Short-Term Energy Outlook (STEO) to the sectoral volume weighted average price estimates in 2016.

Table E-1. Sources of markup inputs

Products	Sectors	Data Series Inputs
Distillate	CM, IN, RS	EIA-782A, SEDC
Jet Fuel	TR	EIA-782A, SEDC
Low-Sulfur Diesel Fuel	TR	EIA-782A, SEDC
Motor Gasoline	CM, IN, TR	EIA-782A, SEDC
Asphalt and Road Oil	IN	SEDP, EIA-782A, SEDC
Kerosene	CM, IN, RS	SEDP, EIA-782A, SEDC
Liquefied Petroleum Gases	CM, IN, RS, TR	SEDP, EIA-782A, SEDC
Low-Sulfur Residual Fuel	CM, IN	SEDP, EIA-782A, SEDC
High-Sulfur Residual Fuel	TR	SEDP, EIA-782A, SEDC
Distillate	EU	SEDP, EIA-906, EIA-923
Low-Sulfur Residual Fuel	EU	SEDP, EIA-906, EIA-923
High-Sulfur Residual Fuel	EU	SEDP, EIA-906, EIA-923

Quality of tax data

In the LFMM, state and federal taxes are added to the prices of gasoline, distillate fuel, liquefied petroleum gas (LPG), jet fuel, ethanol, and methanol in the transportation sector. State taxes are assumed to keep pace with inflation (held constant in real terms) while federal taxes are held at current

nominal levels (deflated in each forecast year).[3] The federal tax assumption reflects the overall forecast assumption of current laws and legislation. The assumption that state taxes will increase at the rate of inflation reflects an implied need for additional highway revenues as driving increases. An additional 1% per gallon of gasoline price is added to the state gasoline taxes to approximate local taxes.

State taxes are added as Census Division weighted averages which are based on tax data available as of 2014. State taxes for jet fuel are derived from unpublished data collected by EIA. State and federal taxes for gasoline, transportation distillate, and LPG are based on data from the Federal Highway Administration, but are modified to include other known changes to state taxes. The quality of the state-level tax data is unknown but deemed reliable. The local tax estimate of 1% per gallon of gasoline price is reasonable given that a comparison of two EIA data series, one including local taxes and one not, revealed a gasoline price difference of 1.6 cents per gallon. Federal taxes, which were adjusted in January of 2001, are widely published and deemed highly reliable.

See Appendix G for a description of programs and input files used in the calculation of historical taxes and the estimation of taxes used in the price projections.

Critical variables

The LFMM contains numerous variables and parameters. Some variables have greater impact on model results than others. The following is a list of variables that we believe have a high degree of influence on LFMM results. It is provided to help users understand the critical factors affecting the LFMM.

World oil price
Product demands
Imported crude supply curves
Imported product supply curves
Domestic crude production
Prices and available supplies of renewable liquid fuels and their feedstocks
Investment cost for capacity expansion
Market shares for gasoline and distillate types
NGPL supply volumes

Most of these variables are provided by other models in the NEMS system. The investment cost and market share data are developed offline and read in to the LFMM.

[3] Refer to Stacy MacIntyre, Motor Fuels Tax Trends and Assumptions, Issues in Midterm Analysis and Forecasting 1998, DOE/EIA-0607(98), (Washington, D.C., July 1998).

Appendix F. Estimation Methodologies

Refinery investment recovery thresholds

The threshold for expansion investment decisions is represented by the process plant cost function (PCF). The PCF considers actual cash flows associated with the operation of the individual process plants within the refinery, as well as cash flows associated with capital for the construction of new plants. It includes terms for capital-related financial charges (CFC), fixed operating costs (FOC), and other variable operating costs (OVC):

$$PCF = \sum_i (CFC_i + FOC_i + OVC_i), \quad (1)$$

where i indexes the individual process units that make up the petroleum refinery, such as the atmospheric crude distillation unit, fluid catalytic cracking unit, etc.

In the LFMM, the variable operating costs (OVC) are defined directly from input data (so will not be addressed in this section), while the capital-related financial charges (CFC) and the fixed operating costs (FOC) are derived using a series of process investment cost equations. The methodologies used to calculate these cost components are presented below.

Capital-Related Financial Charges (CFC)

The CFC equation includes an annual capital recovery charge (ACR) minus a depreciation tax credit (DTC):

$$CFC_i = ACR_i - DTC_i. \quad (2)$$

A discounted cash flow calculation is generally used to determine the annual capital charge for any given plant investment. The annual capital recovery charge assumes a discount rate equal to the cost of capital (COC), which includes equity (cost of equity, COE) and interest payments on any loans or other debt instruments used as part of capital project financing (cost of debt, COD). The depreciation of capital equipment is used for the purpose of determining the depreciation tax credit (DTC). Both the ACR and DTC are estimated on an after-tax basis.

Since the LFMM and other energy forecasting models employ "notional" representations of U.S. petroleum refineries involving aggregation of data for many individual refineries, the cost estimating algorithm has been simplified while still capturing all the factors and costs refiners must consider when adding a new processing unit. The methodology draws upon the National Petroleum Council (NPC) study[4] and other sources.[5] Some of the steps for the cost estimate are conducted exogenous to

[4] National Petroleum Council, U.S. Petroleum refining – Meeting Requirements for Cleaner Fuels and Refineries, Washington, D.C., August 1993.

[5] J.H. Gary and G.E. Handwerk, Petroleum Refining: Technology and Economics, 4th edition (New York: Marcel Dekker, 2001), Chapters 17 and 18.

NEMS (Step 1 below), either by the analyst in preparing the input data or during input data preprocessing. The individual steps in the plant capital cost estimation algorithm are:

1. Estimation of the inside battery limits (ISBL) field cost (done exogenous to NEMS)
2. Estimation of the ISBL field cost for different refinery locations (location factor)
3. Estimation of the outside battery limits (OSBL) field cost (added to ISBL to define total field cost)
4. Estimation of total project cost
5. Estimation of capital-related financial charges
6. Conversion of capital-related charges to a "per-day," "per-capacity" basis

Step 1 may involve several adjustments which must be made prior to input into the LFMM. The remaining steps are performed within the LFMM.

Step 1 - Estimation of ISBL field cost

The inside battery limits (ISBL) field costs include the direct cost such as major equipment, bulk materials, direct labor costs for installation, construction subcontracts, and indirect costs. The ISBL investment cost and labor costs for most of the refinery processing unit types modeled were initially obtained from a study by Bonner and Moore Associates (BMA),[6] and updated annually with revised estimates from EnSys Energy and Systems, Inc. (EnSys). The data for typical unit sizes and stream factors, as well as supplementary investment and labor, were obtained from the World Oil Refining, Logistics, and Distribution (WORLD) model.[7] The data used by the LFMM currently represent process plants sited at a generic U.S. Gulf Coast (PADD III) location, and are in year 1993 dollars.

Step 2 - Year-dollar and location adjustment to ISBL field costs

The ISBL investment cost data must be adjusted to include location factors and correct year-dollars.:

a. Adjust the ISBL field costs and labor costs for each processing unit (*j*) from 1993 dollars, first to the year-dollar (rptyr) reported by NEMS (e.g., 2012 dollars for AEO2014), using the Nelson-Farrar refining-industry cost-inflation indices. Then the GDP chain-type price indices provided by the NEMS Macroeconomic Activity Model are used to convert from report-year dollars to 1987 year dollars used internally by NEMS.
b. Convert the ISBL field costs in 1987 dollars for each processing unit from a PADD III (Gulf Coast) basis (*BM_ISBL*) to costs of the same processing unit for other regions (*ISBL*) via location multipliers (*INVLOC).* The location multipliers represent differences in material costs between the various PADD regions.

$$ISBL_j = \frac{BM_ISBL_i * INVLOC_j}{1000} \quad (3)$$

where

[6] Bonner & Moore Associates, Inc., *A Capital Expansion Methodology Review of the Department of Energy's Petroleum Market Model*, prepared for the United States Department of Energy, Contract No. EI-94-25066 (Houston, TX, July 1994).
[7] EnSys Energy & Systems, Inc., *WORLD Reference Manual*, a reference for use by the analyst and management prepared for the United States Department of Energy, Contract No. DE-AC-01-87FE-61299 (Washington, D.C., September 1992).

i = process unit in PADD III

l = refining region

j = process unit i in refining region l

$ISBL_j$ = ISBL costs for processing unit i in refining region (PADD) l (j), in million 1987 dollars

BM_ISBL_i = ISBL costs for processing unit$i$ in PADD III, in thousand 1987 dollars

$INVLOC_l$ = Location multiplier for refining region l

Location multipliers for refinery construction were developed on a PADD basis using the most recent data available from the U.S. Bureau of Labor Statistics (BLS)[8] and EIA.[9] The development of these multipliers and assumed values for other factors is described elsewhere.[10] The recommended location multipliers for refinery construction are given below:

Table F-1. Location multipliers for refinery construction

Location	Location Construction Multiplier
PADD I – U.S. East Coast	1.16
PADD II – U.S. Midwest- inland	1.00
PADD II – U.S. Midwest- lakes	1.00
PADD III – U.S. Gulf Coast- gulf	1.00
PADD III – U.S. Gulf Coast- inland	1.00
PADD IV – U.S. Rocky Mountain	1.08
PADD V – U.S. West Coast- California	1.15
PADD V – U.S. West Coast- Other	1.15

Step 3 - Estimation of OSBL cost and total field cost

The outside battery limit (OSBL) costs include the cost of cooling water, steam and electric power generation and distribution, fuel oil and fuel gas facilities, water supply, etc. The total field cost (FDC) is

[8] Wages Data, U.S. Department of Labor, Bureau of Labor Statistics, available on the web at www.bls.gov/bls/blswage.htm.
[9] Refinery Capacity Data, U.S. Department of Energy, U.S. Energy Information Administration, available on the web at www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcapacity.html.
[10] *A General Cost Estimating Methodology for New Petroleum Refinery Process Capacity,* Appendix D, prepared for the U.S. Department of Energy, National Energy Technology Laboratory, and U.S. Energy Information Administration by John Marano, Ph.D., September 2004.

the sum of the ISBL and OSBL field costs. The OSBL field cost is estimated as a fraction (OSBLFAC) of the ISBL costs. Thus, the resulting FDC equation is:

$$FDC_j = (1 + OSBLFAC) * ISBL_j \quad (4)$$

j = process unit *i* in refining region *l*

FDC_j = Total field costs for processing unit in refining region *(j)*, in million 1987 dollars

$ISBL_j$ = ISBL costs for processing unit in refining region *(j)*, in million 1987 dollars

OSBLFAC = OSBL fraction of ISBL costs (assumed to be 0.45 in the LFMM)

Step 4 – Estimation of total project investment

The total project investment (TPI) is the sum of the total field cost (Eq. 4) and other one-time costs (OTC):

$$TPI_j = FDC_j - OTC_j \quad (5)$$

j = process unit *i* in refining region *l*

TPI_j = Total project investment for processing unit in refining region *(j)*, in million 1987 dollars

FDC_j = Total field costs for processing unit in refining region *(j)*, in million 1987 dollars

OTC_j = Other one-time costs for processing unit in refining region *(j)*, in million 1987 dollars

Other one-time costs (OTC) include the contractor's cost (such as home office costs), the contractor's fee and a contractor's contingency, the owner's cost (such as pre-startup and startup costs), and the owner's contingency and working capital (WC). The OTCs are estimated as a function of total field costs (FDC), using cost factors (OTCFAC). The corresponding equations are presented below.

$$OTCFAC = PCTENV + PCTCNTG + PCTLND + PCTSPECL + PCTWC \quad (6)$$

where

PCTENV = *0.10* Home, office, contractor fee

PCTCNTG = *0.05* Contractor & owner contingency

PCTLND = *0.00* Land (assuming expansion only at existing refinery)

PCTSPECL = *0.05* Prepaid royalties, license, start-up costs

PCTWC *= 0.10* Working capital

thus,

OTCFAC *= 0.30*

and

$$OTC_j = OTCFAC * FDC_j \quad (7)$$

The TPI given above represents the total project investment (cost) for "overnight construction." The TPI at project completion and startup will be discussed in Step 5 below.

Closely related to the total project investment are the fixed capital investment (FCI) and total depreciable investment (TDI). The fixed capital investment is equal to the total project investment less working capital. It is used to estimate capital-related fixed operating costs (discussed later). A default value of 0.10 is assumed for the WC factor (PCTWC):

$$WRKCAP_j = PCTWC * FDC_j \quad (8)$$

and,

$$FCI_j = TPI_j - WC_j \quad (9)$$

where,

j = process unit *i* in refining region *l*

WC_j = Total working capital for processing unit in refining region *(j),* in million 1987 dollars

FDC_j = Total field costs for processing unit in refining region *(j)*, in million 1987 dollars

PCTWC = Working capital as percent of FDC_j

FCI_j = Fixed capital investment for processing unit in refining region *(j)*, in million 1987 dollars

TPI_j = Total project investment for processing unit in refining region *(j)*, in million 1987 dollars

The total depreciable investment is equal to the total project investment less the cost of land, interest during construction and working capital (as discussed in Step 4 below). For construction at an existing refinery site through expansion, as would most likely be the case in the United States, the cost of land can be assumed to be zero, and interests during construction are considered implicitly in the calculation

of the capital charge factor (Step 5); thus, total depreciable investment is assumed to be approximately equal to fixed capital investment:

$$TDI_j = FCI_j \quad (10)$$

where,

j = process unit i in refining region l

TDI_j = Total depreciable investment for processing unit in refining region (j), in million 1987 dollars

FCI_j = Fixed capital investment for processing unit in refining region (j), in million 1987 dollars

Step 5 - Estimation of capital-related financial charges

For the purpose of determining the economic viability of expanding refinery processing capacity, capital-related financial charges (CFC), which consist of an annual capital recovery charge (ACR) and a depreciation tax credit (DTC), must be estimated from the total project investment (TPI). The ACR is based on the cost of capital (COC) for the corporation that owns the refinery where the project is located.

It is assumed that projects will be financed by both debt and equity and will return the expected interest payments to creditors and the expected dividends to shareholders. Therefore, the after-tax weighted average cost of capital is an appropriate discount rate for evaluating investment opportunities.

Cost of capital

The cost of capital (COC) is the weighted average of the cost of equity (COE) and cost of debt (COD). The COE represents an implied opportunity of financial return to the corporation's stockholders in the form of dividend payments and stock price appreciation. The COD is the after-tax interest rate, which a company would pay for new, long-term borrowing. In general, the required rate of return for equity investors is much higher than the required rate of return for debt investors (creditors) since the holders of common stock (equity investors) accept all the risks involved in business ownership. The COC is related to COE and COD as follows:

$$COC = X_{eq} \times COE + X_{debt} \times COD(at) \quad (11)$$

and

$$COD(at) = (1 - T_{eff,l}) \times COD(bt) \quad (12)$$

Where:

X_{eq}, X_{debt} = Fractions of equity and debt financing, respectively (X_{debt} = 1 - X_{eq})

$T_{eff,l}$ = Effective corporate income tax rate; "l" is for refining region index where all state taxes in that region are averaged to represent a single value

at, bt = Indices for after-taxes and before-taxes, respectively

Based on a review of annual financial reports of refining companies or their parent companies, the relative fraction of equity and debt used in the model is set to the capacity-weighted average determined for 2002 (x_{eq} = 0.60 and x_{debt} = 0.40).

Also, the effective tax rate (T_{eff}) is related to the federal tax rate T_{fed} and state tax rate $T_{state,l}$ as follows:

$$Teff,l = Tstate,l + Tfed \times (1 - Tstate,l) \quad (13)$$

Average state and federal income tax rates were developed on a PADD basis using the most recent tax information available as of January 1, 2004.[11] PADD averages were weighted based on the crude oil processing capacity within the states making up each PADD. The resulting state and federal tax rates used in the model are:

Table F-2. State and federal corporate income tax rates

Location	State	Federal
PADD I – U.S. East Coast	9.32%	35%
PADD II – U.S. Midwest	7.38%	35%
PADD III – U.S. Gulf Coast	3.32%	35%
PADD IV – U.S. Rocky Mountain	4.21%	35%
PADD V – U.S. West Coast	6.76%	35%

The pre-tax cost of debt (COD(bt)) will vary based on the proportions of short-term loans and bonds. A Baa average corporate bond rate (MC_RMCORPBAA from the NEMS Macroeconomic Activity Model) is used for COD(bt).

The expected opportunity cost, or cost of equity (COE), for stockholders should be comparable to what could be realized from alternative investments of similar risk. The Capital Asset Pricing Model (CAPM) is used to compute a cost of equity,[12] which is an implied investor's opportunity cost or the required rate of return of any risky investment. The model is:

$$COE = RFR + \beta \times EMRP \quad (14)$$

The COE is computed as a function of three variables: *RFR*, a "risk-free" rate; EMRP, an expected market risk premium; and β, a systematic risk coefficient relative to the stock market (referred to as the "equity beta"). In the model, the risk-free rate is based on 10-year Treasury note rates (MC_RMTCM10Y, provided by the NEMS Macroeconomic Activity Model). The EMRP and β are assumed to be constant. Thus, the EMRP is assumed at 6.75 percent (7.5% for high risk and non-petroleum based technologies) based on the expected return on market over the rate of a 10-year Treasury note (risk-free rate); and,

[11] State Corporate Income Tax Rates, available on the web at: www.taxfoundation.org/corporateincometaxrates.html, and at www.taxadmin.org/fta/rate/corp_inc.html.

[12] The capital asset pricing model (CAPM) was introduced by Treynor (1961), Sharpe (1964) and Lintner (1965). It extended portfolio theory to introduce the notions of systematic and specific risk. More description of the model can be found at: http://www.riskglossary.com/articles/capital_asset_pricing_model.htm .

the β is set based on the risk level of the processing unit investment (for average risk, β = 0.8; for high risk and non-petroleum based technologies, β = 1.8).

Annual Capital Recovery

The annual capital recovery (ACR) is the difference between the total project investment (TPI) and the recoverable investment (RCI), all in terms of present value (e.g., at startup). The TPI estimated in Step 4 is for overnight construction (ONC). In reality, the TPI is spread out through the construction period. Land costs (LC) will occur as a lump-sum payment at the beginning of the project, construction expenses (TPI – WC – LC) will be distributed during construction, and working capital (WC) expenses will occur as a lump-sum payment at startup. Thus, the TPI at startup (present value) is determined by discounting the construction expenses (assumed as discrete annual disbursements), adding land costs (as lump payment at beginning of project), and adding working capital (WC):

$$TPI(startup) = F_v(COC,N_{con}) \times LC + F_{v,n}(COC,N_{con}) \times (TPI(ONC) - LC - WC) + WC \quad (15)$$

where

TPI(startup) = Total project investment at *startup*, in million 1987 dollars

TPI(ONC) = Total project investment (overnight construction), in million 1987 dollars

WC = Total working capital, in million 1987 dollars

LC = Total land costs, in million 1987 dollars

F_v = Future-value compounding factor for an instantaneous payment made *n* years before the *startup* year

$F_{v,n}$ = Future-value compounding factor for discrete uniform payments made at the beginning of each year starting *n* years before the *startup* year

N_{con} = Construction time in years before *startup* year

COC = Cost of capital

The future-value factors are a function of the number of compounding periods (n) and the interest rate assumed for compounding. In this case, n equals the construction time in years before startup (N_{con} years), the compounding rate used is the cost of capital (*COC*), and the future value refers to the startup year. The formulae for computing each of the discrete compounding factors are:

$$F_v(COC,N_{con}) = (1 + COC)^{Ncon} \quad (16)$$

$$F_{v,n}(COC,N_{con}) = \left(\sum_{k=1, N_{con}} ((1+ COC)^k) \right) / N_{con} \quad (17)$$

The recoverable investment (RCI) includes the value of the land and the working capital (assumed not to depreciate over the life of the project), as well as the salvage value (*SV*) of the used equipment:

$$RCI = LC + WC + SV \quad (MM87\$) \tag{18}$$

The present value of *RCI* is subtracted from the TPI at startup to determine the present value (startup year) of the project investment (*PVI*):

$$PVI(startup) = TPI(startup) - P_v(COC,N_{asset}) * RCI \quad (MM87\$\} \tag{19}$$

where

$PVI(startup)$ = Present value of project investment at *startup*, in million 1987 dollars

RCI = Recoverable investment, in million 1987 dollars

$TPI(startup)$ = Total project investment at *startup*, in million 1987 dollars

P_v = Present-value discounting factor for an instantaneous payment made n years (project life) in the future

N_{asset} = Asset's economic life in years after *startup* year

COC = Cost of capital

The present-value factor is a function of the number of discounting periods (*n*) and the interest rate used for discounting. In this case, *n* equals the asset's economic life in years N_{asset}, and the discounting rate is the cost of capital *COC*:

$$P_v(COC,N_{asset}) = 1. / ((1.+COC)^{Nasset}) \quad (MM87\$) \tag{20}$$

If the cost of land is assumed to be zero, and the salvage value is equal to dismantling costs, then the *PVI(startup)* can be reduced to:

$$PVI(startup) = F_{v,n}(COC,N_{con}) \times FCI + (1 - P_v(COC,N_{asset}) \times WC) \tag{21}$$

Thus, the annual capital recovery (*ACR*) is given by:

$$ACR(at) = Av\ (COC,Nasset) * PVI(startup) \quad (MM87\$/yr) \tag{22}$$

where

$ACR(at)$ = Annual capital recovery, where (*at*) signifies that this is on an after-tax basis

$PVI(startup)$ = Present value of project investment at *startup*, in million 1987 dollars

A_v = Uniform-value leveling factor for a periodic payment (annuity) made at the end of each year for (*n*) years in the future

N_{asset} = Asset's economic life in years after *startup* year

COC = Cost of capital

The uniform-value factor is a function of the number of periods (*n*) and the interest rate used for discounting, where *n* equals the asset's economic life in years N_{asset}, and the discounting rate is the cost of capital *COC*, as defined by:

$$A_v\,(COC,N_{asset}) = (COC*((1.+COC)^{Nasset})) \;/\; (((1.+COC)^{Nasset}) - 1.) \quad (23)$$

A construction period of 2 years and asset life of 20 years are assumed for construction of a new process unit within an existing refinery.

Depreciation tax credit & capital-related financial charges

The depreciation tax credit (DTC) is based on the depreciation schedule for the investment and the total depreciable investment (TDI) (defined in step 4 above). The simplest method (DPM) used for depreciation calculations (and used in the LFMM) is the straight-line method, where the total depreciable investment is depreciated by a uniform annual amount over the tax life of the investment. The following generic equations represent the present value of the TDI (PVDDPM) and the levelized value of the annual depreciation charge (DTC(at)), on an after-tax basis.

$$PVD_{DPM}(startup) = P_{v,DPM}(COC,N_{tax}) * TDI \quad (MM87\$) \quad (24)$$

$$DTC(at) = A_v\,(COC,N_{asset}) * T_{eff} * PVD_{DPM}(startup) \quad (MM87\$/yr) \quad (25)$$

where

$PVD_{DPM}(startup)$ = Present value of total depreciable investment, at startup, where *DPM*=straight line depreciation method, in million 1987 dollars

DTC(at) = Annualized depreciation tax credit, where *at*=after tax basis, in million 1987 dollars

TDI = Total depreciable investment, in million 1987 dollars

T_{eff} = Effective combined income tax rate

$P_{v,DPM}$ = Present-value discounting factor for depreciation, which is a function of the number of discounting periods (tax life), and the cost of capital

A_v = Uniform-value leveling factor for a periodic payment (annuity) made at the end of each year for *n* years in the future and an interest rate *r*, where *n* is the asset life and *r* is the cost of capital (*COC*)

at = Signifies the depreciation tax credit on an after-tax basis

N_{asset} = Asset's economic life, in years after *startup* year

N_{tax} = Tax life, in years after *startup* year

COC = Cost of capital

N_{asset} = Asset's economic life, in years after *startup* year

N_{tax} = Tax life, in years after *startup* year

COC = Cost of capital

If the tax life N_{tax} is assumed to be equal to the asset life N_{asset}, then the leveled depreciation tax credit (DTC) can be represented as follows:

$$DTC(at) = T_{eff} \times TDI / N_{asset} \quad (MM87\$/yr, DPM = SRL, Ntax = Nasset) \qquad (26)$$

Finally, the capital-related financial charges (CFC) are set equal to the annual capital recovery (ACR) less the DTC, after taxes (at) and before taxes (bt):

$$CFC(at) = ACR(at) - DTC(at) \quad (MM87\$/yr) \qquad (27)$$

and,

$$CFC(bt) = CFC(at) / (1 - T_{eff}) \quad (MM87\$/yr) \qquad (28)$$

Step 6 - Convert fixed operating costs to a "per-day," "per-capacity" basis

The annualized capital-related financial charge is converted to a daily charge, and then converted to a "per-capacity" basis by dividing the result by the operating capacity of the unit being evaluated. The result is a fixed operation cost on a per-barrel basis. It is the after-tax CFC that is included in the process plant cost function (PCF) presented in equation (1) above.

Refinery unit fixed operating costs

Fixed operating costs (FOC), a component of total product cost, are costs incurred at the plant that do not vary with plant throughput, and any other costs that cannot be controlled at the plant level. These include such items as wages, salaries and benefits; the cost of maintenance, supplies and repairs; laboratory charges; insurance, property taxes and rent; and other refinery overhead. These components can be factored from either the operating labor requirement or the capital cost. The accuracy of this type of estimate should be within ±50%.

Like capital cost estimations, operating cost estimations, involve a number of distinct steps. Some of the steps associated with the FOC estimate are conducted exogenous to NEMS (Step 1 below), either by the analyst in preparing the input data or during input data preprocessing. The individual steps in the plant fixed operating cost estimation algorithm are:

1. Estimation of the annual cost of direct operating labor
2. Year-dollar and location adjustment for operating labor costs (OLC)
3. Estimation of total labor-related operating costs (LRC)

4. Estimation of capital-related operating costs (CRC)
5. Conversion of fixed operating costs to a "per-barrel" basis

Step 1 involves several adjustments which must be made prior to input into the LFMM; steps 2-5 are performed within the LFMM.

Step 1 – Estimation of direct labor costs

Direct labor costs are inputs to the LFMM and are reported based on a given processing unit size. The operating labor cost data for most of the processing unit types modeled in the LMM were initially obtained from a study by Bonner and Moore Associates (BMA), and updated annually with revised estimates from EnSys. The actual data were obtained from the World Oil Refining, Logistics, and Distribution (WORLD) model.[13] The data used by the LFMM currently represent processing plants sited at a generic U.S. Gulf Coast (PADD III) location, and are in 1993 dollars.

Step 2 – Year-dollar and location adjustment for operating labor costs

Operating labor cost (OLC) data must be adjusted for location and correct year-dollars:

a. The labor costs for each processing unit (i) are adjusted from 1993 dollars, first to the year-dollar (rptyr) reported by NEMS for AEO2014, which is in 2012 dollars, using the Nelson-Farrar refining-industry cost-inflation indices. Then the GDP chain-type price indices provided by the NEMS Macroeconomic Activity Model are used to convert from report-year dollars to 1987 dollars used internally by NEMS. This defines the interim operating labor cost (BM_LABOR).
b. The 1987 operating labor costs for each processing unit (i) are converted from a PADD III (Gulf Coast) basis into regional (other U.S. PADDs) costs using regional (l) location factors. The location multiplier (LABORLOC) represents differences between labor costs in the various locations and includes adjustments for construction labor productivity.

$$OLC_j = BM_LABOR_i * LABORLOC_l \quad (29)$$

where

i = process unit in PADD III

l = refining region

j = process unit *i* in refining region *l*

cd = calendar day

OLC_j = Operating labor costs for processing unit *i* in refining region (PADD) *l (j)*, in 1987 dollars/cd

BM_LABOR_i = Operating labor costs for processing unit *i* in PADD III, in 1987 dollars/cd

$LABORLOC_l$ = Location multiplier for refining region *l*

[13] EnSys Energy & Systems, Inc., *WORLD Reference Manual*, a reference for use by the analyst and management prepared for the U.S. Department of Energy, Contract No. DE-AC-01-87FE-61299 (Washington, D.C., September 1992).

Location multipliers for process unit operating labor were developed on a PADD basis using data available from the U.S. Bureau of Labor Statistics (BLS)[14] and EIA.[15] The recommended location multipliers for process unit construction are given below:

Table F-3. Location multipliers for refinery operating labor

Location	Operating Labor Multiplier
PADD I – U.S. East coast	1.11
PADD II – U.S. Midwest- inland	0.98
PADD II – U.S. Midwest- lakes	0.98
PADD III – U.S. Gulf Coast- gulf	1.00
PADD III – U.S. Gulf Coast- inland	1.00
PADD IV – U.S. Rocky Mountain	1.07
PADD V – U.S. West Coast- California	1.06
PADD V – U.S. West Coast- Other	1.06

Step 3 - Estimation of labor-related fixed operating costs

Fixed operating costs related to the cost of labor for a processing unit include the salaries and wages of supervisory and other staffing, charges for laboratory services, and payroll benefits and other plant overhead. These labor-related fixed operating costs (LRC) consist of:

$$LRC = OLC + FXOC_STAFF + FXOC_OH \quad (30)$$

where

LRC = labor-related fixed operating cost, in 1987$/cd

OLC = direct operating labor costs, in 1987$/cd

FXOC_STAFF = supervisory/staff fixed operating costs, in 1987$/cd

FXOC_OH = benefits/overhead fixed operating costs, in 1987$/cd

These component FXOC cost terms can be defined as a function of the direct operating labor costs (OLC), with the following relationships: FXOC_STAFF = 0.55*OLC, and FXOC_OH = 0.39*(OLC+FXOC_STAFF). The LRC equation is simplified to the following relationship.

$$LRC = 2.15 * OLC \quad (1987\$/cd) \quad (31)$$

[14] Wages Data, U.S. Department of Labor, Bureau of Labor Statistics, available on the web at www.bls.gov/bls/blswage.htm .
[15] Refinery Capacity Data, U.S. Department of Energy, U.S. Energy Information Administration, available on the web at www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcapacity.html.

Step 4 - Estimation of capital-related fixed operating costs

Capital-related fixed operating costs (CRC) include insurance, local taxes, maintenance, supplies, non-labor-related plant overhead, and environmental operating costs. These costs can be defined as a function of the fixed capital investment (FCI) (defined in equation 9 above). This relationship is expressed by:

$$CRC = M_{CRC} * FCI \quad (87\$/cd) \quad (32)$$

where

M_{CRC} = Sum of CRC cost multipliers (defined in Table F-4)

Table F-4. Capital-related fixed operating cost multipliers

Yearly Insurance	0.005
Local Tax Rate	0.01
Yearly Maintenance	0.03
Yearly Supplies; Overhead, Etc.	0.005

Step 5 - Convert fixed operating costs to a "per-capacity" basis

On a "per-capacity" basis, the total fixed operating costs (FOC) is the sum of the capital-related operating costs (CRC) and the labor-related operating costs (LRC), divided by the operating capacity of the unit being evaluated.

Natural gas plant liquids

Beginning with AEO2016, the natural gas plant liquids supply to the LFMM is provided by the Oil and Gas Supply Module through the NEMS common variables OGNGPLET, OGNGPLPR, OGNGPLIS, OGNGPLBU, OGNGPLPP, representing ethane, propane, isobutene, n-butane, and pentanes plus, respectively. All variables are dimensioned by OGSM production districts and model year. See the OGSM documentation for more details.

Estimation of distribution costs

Costs related to distributing petroleum products to end-users are incorporated by adding fixed transportation markups to the wholesale prices (model results) that include the variable and fixed refinery costs. Transportation markups for petroleum products except gasoline are estimated as the average annual difference between retail and wholesale prices. These markups are held constant throughout the projection period.

Historically, these values were obtained by transforming a variety of files from different data sources into files that could be read and manipulated by mainframe SAS. EIA is transitioning away from mainframe data storage to storing and manipulating data within Oracle and MS SQL Server repositories via the Refinery Markups Database (RMD). When direct database links are available, the RMD uses connections to these servers to automatically retrieve data that are necessary to compute sector markups and generate input flat files. When direct database links are not available (as is the case with

state price and consumption data), import routines have been coded so that data for a specifically designed input format can be efficiently shared in NEMS.

Sector-level prices provided by EIA's State Energy Data System (SEDS) typically lag behind current average prices to all sectors by more than two years. The RMD uses various calculations from available Oil and Gas Information Resource System (OGIRS) data to compute suitable proxies for sector-level prices during this time. These include algorithms filling in missing data by way of OGIRS state-level and sectoral price data when available, calculated volume-weighted regional averages, or in some cases (when data are missing completely) price data that are estimated offline and entered manually. Computer programs and data files used to estimate transportation markups are discussed below.

Data-Reading Programs

Database: RefineryMarkups.mdb

Input Files:

1. pr_pet_all_price.csv: This is imported from a file generated by the Combined State Energy Data System (CSEDS). It contains retail prices in comma-delimited format.
2. use_pet_all_btu.csv: This is imported from a file generated by CSEDS, at the direction of Survey Development and Statistical Integration (SDSI) staff. It contains petroleum volumes in comma-delimited format.
3. taxfile.csv: This file is manually developed. It contains petroleum tax information, listed by state, in comma-delimited format. It includes dollar amounts and percentages, where applicable.
4. OGIRS_data: This includes the wholesale price data that are imported from the Oil and Gas Information Resource System (OGIRS); data are imported via a direct read-only connection to OGIRS.

From the Data Import dialog box, one may select the desired file to import from a drop-down list. Each file to be imported must be copied to the same directory in which the RefineryMarkup.MDB file resides. Select the desired option and click the Import Data button. Data import is then performed and the various forms and tables within the MSAccess database are automatically updated and populated.

Updating to the current year

The last year of markups database output that is generated is based on the HeatContent_Year table when the data is imported and created. Also, for missing values to be populated, the "IRAC" Table (IRAC stands for Imported Refiner Acquisition Cost) needs to have the most current IRAC value, which are used to calculate some missing prices.

The "qRetailPrice_KSRAFN_2002" query is updated to include the year of the most recent SEDS retail prices (increasing the year by 1 from the last AEO cycle). This allows the IRAC proxy variable calculations to only calculate for those years after which we already have retail prices for these fuels. This same year should be applied and updated in the "qRetailPriceList_CDBasedPrice_KSARFN" query for the IRAC calculation (the > [year] criteria) to only occur after the last CSEDS year.

Also, the Federal Tax Table (CSeds_Fedtax) is manually updated to include tax rates for the most recent year of markup calculations.

The three SEDS *.csv input files include the following data series from 1960 to the most recent SEDS year:

Table F-5. Data series from federal tax table (CSeds_Fedtax)

ARICB	ARICD	ARICV	AVACB	AVACD
AVACV	DFACB	DFACD	DFACV	DFCCB
DFCCD	DFCCV	DFEUB	DFEUD	DFEUV
DFICD	DFICV	DFISB	DFRCB	DFRCD
DFRCV	FNICB	FNICD	FNICV	FOICB
FOICD	FOICV	FSICB	FSICD	FSICV
JFACB	JFACD	JFACV	JFEUB	JFEUD
JFEUV	KSCCB	KSCCD	KSCCD	KSICB
KSICD	KSICV	KSRCB	KSRCD	KSRCV
LGACB	LGACD	LGACV	LGCCB	LGCCD
LGCCV	LGICD	LGICV	LGISB	LGRCB
LGRCD	LGRCV	LUACB	LUACD	LUACV
LUICB	LUICD	LUICV	MGACB	MGACD
MGACV	MGCCB	MGCCD	MGCCV	MGICB
MGICD	MGICV	MSICB	MSICD	MSICV
PCEUB	PCEUD	PCEUV	PCICD	PCICV
PCISB	RFACB	RFACD	RFACV	RFCCB
RFCCD	RFCCV	RFEUB	RFEUD	RFEUV
RFICD	RFICV	RFISB	SNICB	SNICD
SNICV	WXICB	WXICD	WXICV	

The five-letter codes above correspond to the following information.

Table F-6. Data identification codes

Data Identification Codes

Characters	Identity
1 and 2	Represent an Energy Source (Fuel)
3 and 4	Represent an Energy Consumption End-Use Sector (Sector)
5	Represent a Type of Data (Type)

Energy Source (Characters 1 and 2)

Code	Name
AR	Asphalt and road oil
AV	Aviation gasoline
DF	Distillate fuel
FN	Petrochemical feedstocks - naphtha less than 401 degrees F
FO	Petrochemical feedstocks - other oils equal to or greater than 401 degrees F
JF	Jet fuel
KS	Kerosene
LG	Liquefied petroleum gases
LU	Lubricants
MG	Motor gasoline
MS	Miscellaneous petroleum products
PC	Petroleum coke
RF	Residual fuel
WX	Waxes

Energy End-Use Sectors (Characters 3 and 4)

Code	Name
AC	Transportation sector estimates
CC	Commercial sector estimates
EI	Electric power sector estimates
EU	Electric utility sector estimates
IC	Industrial sector estimates
RC	Residential sector estimates
TC	Total energy sector estimates

Type of Data (Character 5)

Code	Name
B	Consumption in billion Btu.
D	Current price in dollars per million Btu.
P	Consumption in various physical units.
V	Expenditures in millions of current dollars.

Other tables that might require updating include Btu to Barrels (conversion factors) and GDP87 (Macroeconomic inflators).

The Refinery Markups Database (RMD) contains state and sector-level retail prices that are used to estimate sector-level retail prices by Census Division.

Markup estimating program

The Refinery Markups Database (RMD) is built into a single Microsoft Access database (.MDB) file, called RefineryMarkups.mdb and is used in estimating the differences between wholesale and retail product prices. It includes 1 Form, 2 Macros, 53 Tables, 2 Reports, and over 100 Queries. In order to be able to import data from the Oil and Gas Information Resource System (OGIRS), the user must have "read data" permission, provided by Office of Energy Statistics, Survey Support and Application Management (SSAM), on the OGIRS database.

System Flow

The RMD database inputs include CSEDS data (pr_pet_all_price.csv, use_pet_all_btu.csv, and taxfile.csv) and OGIRS data. Outputs include retail prices, wholesale prices, and markups by Census Division and sector.

NOTE: Users of the RMD are granted read-only access to OGIRS, for importing purposes only. Therefore, the RMD can never be used to make any changes within OGIRS, e.g., alter any Sourcekeys. More detailed instructions can be found through the Refinery Markups Documentation provided by Abacus Technology Corporation.

Estimation of taxes

In the LFMM, taxes are added to the prices of gasoline, transportation distillate fuel (diesel), transportation liquefied petroleum gases (LPG), and jet fuel. Taxes are also estimated for E85 (transportation ethanol). Weighted averages of the most recent available state and federal taxes are developed for each Census Division (CD) using periodic state survey data collected by the Defense Logistics Agency (DLA) Energy (formally known as the Defense Energy Support Center (DESC)).[16] The DLA Energy data are then aggregated to the CD level in an analyst's spreadsheet using state annual product volumes obtained from the Petroleum Marketing Annual to calculate a volume-weighted CD average.

The state taxes are fixed in real terms; the real value of federal taxes declines at the rate of inflation (i.e., federal taxes are fixed in nominal terms). An additional 1% of the retail product CD value is added to the gasoline and diesel taxes to approximate local taxes. Historical tax values are also calculated for gasoline, transportation distillate, jet fuel and LPG, which are then added to historical end-use prices excluding taxes in order to develop a series with taxes included.

The federal taxes are updated each projection year by deflating the current value by the rate of inflation for that projection year.

[16] American Petroleum Institute, "State Motor Fuel Taxes," January, 2017.

Gasoline specifications

The LFMM models the production and distribution of three different types of gasoline: conventional, reformulated, and CARB (California) gasoline. The following specifications are included in the LFMM to differentiate between conventional and reformulated gasoline blends, according to EPA and California regulations: octane (CON), oxygen content, Reid vapor pressure (RVP), benzene content (BNZ), aromatic content (ARO), sulfur content (Sulfur), olefin content (OLE), and the percent evaporated at 200 and 300 degrees Fahrenheit (E200 and E300). In accordance with the EPA Tier-3 regulatory announcement, refiners are required to reduce their average sulfur spec to a maximum of 10ppm beginning in 2017. NOTE: Beginning in model year 2017, the LFMM reduces this to 5ppm at the refinery gate to allow for potential contamination during transport. Also, due to a trend in higher octane gasoline, the average "CON" increases linearly from 84.9 (86.3) in 2017 to 87 (88.3) by 2050 for conventional and reformulated (CARB) gasoline.

Table F-7. Gasoline specification

	ARO (max)	BNZ (max)	OLE (max)	RVP (max)	Sulfur (max)	CON (min)	E200 (min)	E300 (min)
Conventional	24.23	0.62	10.80	10.11	22.48[1]	84.9	45.9	81.7
Reformulated	21.00	0.62	10.36	8.80	23.88[1]	84.9	54.0	81.7
California Reformulated	23.12	0.58	6.29	7.70	10.00[1]	86.3	42.9	86.3

[1]Maximum sulfur spec is reduced to 10ppm beginning in 2017 to meet EPA final ruling.

"EPA Sets Tier 3 Motor Vehicle Emission and Fuel Standards," https://www.epa.gov/fuels-registration-reporting-and-compliance-help/epa-webinar-slides-tier-3-gasoline-sulfur. To account for potential contamination during transport, sulfur spec is set to 5pmm at the refinery gate in the LFMM beginning 2017.

Estimation of gasoline market shares

Within the LFMM, total gasoline demand is disaggregated into demand for conventional, reformulated and CARB gasolines by applying assumptions about the annual market shares for each type. Annual assumptions for each region account for the seasonal and city-by-city nature of the regulations. The market shares are assumed to remain constant over the projection period.

Diesel specifications

The LFMM models three types of distillate fuel oil: heating oil (N2H), low-sulfur diesel (DSL), and ultra-low-sulfur diesel (DSU). The two types of diesel fuel differ in their specifications for sulfur, cetane index, aromatics content, and API gravity. DSL reflects a higher sulfur allowance, while DSU reflects the tighter "ultra-low-sulfur diesel" (ULSD) requirement which followed a scheduled phase-in between 2006 and 2014. Currently, all diesel demand in the U.S. is classified as DSU in the LFMM projection years, with some small amounts of DSL produced for export.

Table F-8. EPA diesel fuel sulfur Limits

Refiner Class	6/1/2006	6/1/2007	6/1/2010	6/1/2012	6/1/2014 +
HIGHWAY DIESEL					
NON-"SMALL" REFINERIES		>80% 15 ppm		15 ppm	
"Small" refineries (<155,000 bbl/day; <1,500 employees)		-		15 ppm	
NONROAD AND LOCOMOTIVE/MARINE (NRLM) DIESEL					
Non-"small" refineries nonroad (NR) diesel	-	500 ppm		15 ppm	
Non-"small" refineries locomotive/marine (LM) diesel	-	500 ppm		15 ppm	
"Small" refineries (< 155,000 bbl/day; < 1,500 employees)	-	-[a]		500 ppm	15 ppm[b]

[a]Northeast/Mid-Atlantic requires 500 ppm for all NRLM diesel starting mid-2007.

[b]LM diesel downgrade to 500 ppm is allowed indefinitely. 15 ppm sulfur is required at refinery gate only.

According to the "ultra-low-sulfur diesel" (ULSD) regulation finalized in December 2000, ULSD is highway diesel that contains no more than 15 ppm sulfur at the pump, is limited to a minimum cetane index of 40, and has an aromatics content of 35% by volume. ULSD in California is assumed to meet California Air Resources Board (CARB) standards that limit maximum sulfur content to 15 ppm (modeled as 10 ppm at the refinery gate to account for potential contamination during transport), minimum cetane index of 53, and maximum aromatics to 10% by volume.[17]

During mid-2004, the U. S. Environmental Protection Agency (EPA) finalized its nonroad diesel rules which effectively parallel the highway standards but lag by several years in implementation. The specifications and timing of each quality type by refiner class are summarized in Table F-9.

Estimation of diesel market shares

The 2000 ULSD federal regulations and the 2004 nonroad diesel rules were fully implemented after 2014, resulting in three distillate fuels in the marketplace: (a) 15 ppm highway, (b) Nonroad Locomotive & Marine (NRLM) diesel; (c) high-sulfur heating oil. The LFMM reflects this rule and at the same time has been calibrated regarding market shares of highway and NRLM diesels, as well as other distillate (including heating oil but excluding jet fuel and kerosene).

[17] http://www.arb.ca.gov/enf/fuels/dieselspecs.pdf .

Historically, volumes of highway-grade diesel supplied have nearly matched total volumes of transportation distillate sold, although some highway-grade diesel has gone to non-transportation uses such as agriculture and construction. An analysis was performed to aggregate diesel fuel by sector and by quality to reflect individual uses for the LFMM. Year 2007 historical percentages were computed from sector level data available from the EIA report "Fuel Oil and Kerosene Sales, 2007."[18] Table F-9 provides an overview of how the categories were grouped.

Table F-9. Screenshot of spreadsheet for estimation of diesel market shares

Distillate Consumption

Fuel Oil & Kerosene Sales Total Distillate Consumption by Sector (Thousands of gallons per year; adjusted sales)													
NEMS (SEDS) Sectors	FO & Kero Sectors					In MMBCD							
						1998	1999	2000	2001	2002	2007		
U.S. Total						3.461	3.572	3.732	3.847	3.776	4.197		
Residential						0.367	0.381	0.399	0.409	0.384	0.328		
Commercial						0.199	0.196	0.217	0.229	0.199	0.180		
Industrial						0.147	0.142	0.138	0.152	0.145	0.167		
	Oil Company					0.037	0.038	0.044	0.054	0.054	0.057		
	Farm					0.198	0.189	0.204	0.224	0.206	0.229		
	0.35	road				0.069	0.066	0.071	0.078	0.072	0.080	<- "Road" diesel	
	0.65	off-hwy				0.129	0.123	0.132	0.146	0.134	0.149	<- "Off-highway" diesel	
	Off-Highway Diesel					0.142	0.140	0.150	0.164	0.144	0.174		
	Total Industrial					0.524	0.508	0.535	0.594	0.549	0.627		
Transportation													
	On-Highway Diesel					1.967	2.091	2.161	2.167	2.238	2.596		
	Railroad					0.185	0.182	0.197	0.193	0.200	0.257		
	Vessel Bunkering					0.139	0.135	0.133	0.137	0.134	0.141		
	Military					0.018	0.019	0.015	0.023	0.021	0.024		
	Total Transportation					2.308	2.427	2.507	2.519	2.593	3.018		
Electric Power						0.063	0.060	0.074	0.095	0.052	0.043		
Diesel used for highway diesel engines & Military						1.985	2.110	2.176	2.189	2.259	2.621	<- tracked separately fr	
Rail (locomotive) & Vessel (marine)						0.323	0.317	0.331	0.330	0.334	0.397	<- tracked separately fr	
	(2007 data)	60%	(1998-2002,2007 avg)	63%	off-highway	0.335	0.320	0.340	0.378	0.348	0.374	<- Nonroad Farm + Off	
Industrial		27%		23%	highway	0.106	0.108	0.124	0.134	0.123	0.168	<- Industrial Low-Sulfur	
		14%		14%	heating oil	0.083	0.080	0.073	0.082	0.078	0.085	<- Industrial: No.1dist +	
Residential & Electric HO						0.430	0.441	0.474	0.504	0.435	0.371	<- Residential and Elec	
	(2007 data)	38%	(1998-2002,2007 avg)	33%	highway	0.063	0.060	0.069	0.079	0.066	0.068	<- Commerical Low-Sul	
Commercial		11%		14%	off-highway	0.032	0.031	0.031	0.032	0.031	0.019	<- Commerical High-Su	
		52%		52%	heating oil	0.104	0.104	0.120	0.118	0.102	0.093	<- Commercial: No.2FC	
Highway (Road) Diesel						2.155	2.278	2.369	2.402	2.448	2.856		
Non-Road (Off-Highway) Diesel						0.366	0.351	0.371	0.409	0.379	0.393		
Heating Oil (HO)						0.617	0.626	0.667	0.705	0.615	0.550		
Locomotive/Marine (LM)						0.323	0.317	0.331	0.330	0.334	0.397		

Data Sources:
Fuel Oil and Kerosene Sales with Data for 2007, http://www.eia.gov/petroleum/fueloilkerosene/archive/2007/pdf/foksall.pdf .

The ULSD regulation includes a phase-in period under the "80/20" rule that requires the production of 80% ULSD and 20% 500 ppm highway diesel between June 2006 and June 2010, and a 100% requirement for ULSD thereafter. The phase-in path for ULSD is available in the input file lfblending.xlsx (and listed in Table F-10 below).

[18] Department of Energy/ Energy Information Administration, "Fuel Oil and Kerosene Sales, 2007," December, 2008, DOE/EIA-0535(07).

Table F-10. Distillate consumption distribution

		2006	2007	2008	2009	2010	2011	2012	2013
DSU	HWY	0.443	0.76	0.76	0.76	0.9	1	1	1
DSL	HWY	0.557	0.24	0.24	0.24	0.1	0	0	0
N2H	HWY	0	0	0	0	0	0	0	0
DSU	ONR	0	0	0	0	0.443	1	1	1
DSL	ONR	0	0.443	1	1	0.557	0	0	0
N2H	ONR	1	0.557	0	0	0	0	0	0
DSU	OLM	0	0	0	0	0	0	0.443	1
DSL	OLM	0	0.443	1	1	1	1	0.557	0
N2H	OLM	1	0.557	0	0	0	0	0	0

HWY = on-highway, ONR = off-highway (non-road), OLM = off-highway, locomotive, marine
DSU = ultra-low sulfur diesel, DSL = low sulfur diesel, N2H = heating oil

Heating oil is not subject to ULSD rules; however, a number of states in the northeast and mid-Atlantic have passed mandates requiring ultra-low sulfur heating oil by a certain date. These are listed in Table F-11 below.

Table F-11. States and start years for ultra-low sulfur heating oil

State	Census Division	Start Year
Connecticut	CD 1	2018
Maine	CD 1	2018
Massachusetts	CD 1	2018
New Hampshire	CD 1	2018
Rhode Island	CD 1	2018
Vermont	CD 1	2018
New Jersey	CD 2	2016
New York	CD 2	2012
Delaware	CD 5	2016
DC	CD 5	2018

Source: "SULFUR & BIOHEAT REQUIREMENTS FOR No. 2 HEATING OIL IN THE NORTHEAST & MID-ATLANTIC STATES", Chart 1. Summary, updated 6-29-2017, http://oilandenergyonline.com/wp-content/uploads/2017/07/NEMARegion_HOspecs_2017.pdf

Estimation of regional conversion coefficients

Differing regional definitions necessitate the conversions of certain variables from one regional structure to another. Regional conversions are not extensive in the LFMM, but are needed for some refinery input prices, refinery fuel consumption, and cogeneration information. The factors are used to convert prices,

consumption, or cogeneration from the regional level used by the LFMM to Census Divisions. These factors are generated based on state level ADU capacity, each mapped and aggregated into LFMM regions, and then mapped into Census Divisions, as a percent of capacity in each LFMM region.

Product pipeline capacities and tariffs

Products in the LFMM are produced domestically, imported, and/or exported based on domestic demand levels and relative market economics. Within the LFMM, products are transported between refining (LFMM) regions mainly via pipeline, but with the option to move via more expensive modes (such as rail, truck, tanker, or barge), usually if pipeline flows exceed available capacity.

Originally, the pipeline distribution network in the LFMM was based on the distribution network used by its predecessor model PMM (last used for AEO2012). This was later updated for AEO2014 based on a proposal from OnLocation Inc, with corresponding capacity and tariff data generated by EIA from online news releases, pipeline company sites, and detailed research of FERC filings. Only a few minor updates were made for AEO2018, with a major effort to be completed for AEO2019. Current data used for AEO2018 are listed in Tables F-12. Note that these data represent an aggregate of multiple product pipelines connecting the regions.

Table F-11. LFMM product pipeline capacity and tariff data represented in AEO2018

RefReg code	Source Region	RefReg code	Destination Region	Capacity (1000 bbl/d)	Tariff range (2017$/bbl)
1	PADD I	3	PADD II, lakes	240	1.50 – 2.50
2	PADD II, inland	3	PADD II, lakes	2492	2.00 – 3.30
4	PADD III, gulf	5	PADD III, inland	4434	1.10 – 1.90
5	PADD III, inland	1	PADD I	3000	1.10 – 1.80
5	PADD III, inland	2	PADD II, inland	2450	2.30 – 3.80
5	PADD III, inland	6	PADD IV	84.7	1.60 – 2.70
6	PADD IV	2	PADD II, inland	40	1.30 – 2.20
6	PADD IV	8	PADD V, other	66	0.60 – 1.00
7	PADD V, California	8	PADD V, other	128	1.00 – 1.65

Cogeneration methodology

Electricity consumption in the refinery is a function of the throughput of each unit. Sources of electricity consist of refinery power generation, utility purchases, and refinery cogeneration. Power generators and cogenerators are modeled in the LFMM as separate units which are allowed to compete along with purchased electricity.

Refinery cogeneration

The refinery cogeneration unit in the LFMM was modeled using historical data as a guideline. Cogeneration activity for each refinery was aggregated to the LFMM regional level. Cogeneration capacity was estimated from the 2016 version of EIA-920 Combined Heat and Power Plant Report. Cogeneration operating costs were derived from the 1980 Office of Technology Assessment (OTA) report "Industrial Cogeneration." Cogeneration capacity (including planned capacity) for each LFMM region was also derived from the EIA-920. The LP limits utilization to 90% of capacity. No unplanned builds for refinery cogeneration are allowed.

The LFMM has the capability of modeling cogeneration of electricity and steam at the petroleum refinery by burning still gas and natural gas. In general, refinery cogeneration units tend to be small, designed to supply the refinery's steam and electricity needs, with a small amount of leftover capacity sold to the grid. However, if it is profitable to sell cogeneration electricity, the LP constraints will reflect the assumption that all of it is sold. Likewise if it is not profitable, the model will reflect the assumption that none of it is sold.

Non-petroleum feedstock supplies

Coal

The LFMM models a Coal-To-Liquids (CTL) production process. The coal feedstock is represented as a coal supply curve in each coal supply region, by coal type, provided by the Coal Market Module (CMM) of NEMS.

Natural gas

The LFMM models a Gas-To-Liquids (GTL) production process. The natural gas feedstock prices are provided by the Natural Gas Market Module (NGMM) of NEMS.

Cellulosic biomass

The LFMM models cellulosic ethanol and Biomass-To-Liquids (BTL – Fischer-Tropsch, BTL – Pyrolsis) production processes. The feedstock consists of three cellulosic biomass supply curves (agricultural residue, forest residue, urban wood waste) which are generated from data provided by the Renewable Fuels Module (RFM) of NEMS.

Corn

The LFMM also models ethanol production from corn. Price/quantity (P/Q) corn-to-ethanol data from the RFM (NEMS) is used to develop the corn feedstock supply curve for the Midwestern region (LFMM regions 2 and 3) in the LFMM. The initial P/Q pair are used to represent step 5 on the 27-step supply curve, with the remaining steps defined as a function of the initial P/Q pair. Thus, the first 5 steps represent the starting production level projected by RFM, and the remaining steps represent the

additional supply available (not to exceed a maximum of 19 and 15 million bushels/day for LFMM regions 2 and 3, respectively) if the LFMM determines it economic to demand more. Corn supply available in all other LFMM regions are small (between 1 and 3 percent of total supply in regions 2/3), and therefore are represented as constant supply.

For LFMM regions 2 and 3, the corn price for each step on the supply curve is defined as a function of the initial P/Q pair (Po and Qo), the supply on each step, and an exponential factor (1.2). A small cost to transport from the production point to the ethanol plant (tranCost) is also added – estimated as a function of diesel cost.

$$P_s/P_o = (Q_s/Q_o)^{1.2}$$

$$P_s = P_o * (Q_s/Q_o)^{1.2} + tranCost$$

Where

P_s = Price of corn on step s, 2008 $/bushel

Q_s = Quantity of corn supplied on step s, 1000 bushels/day

Po, Qo = initial price and quantity of corn supplied provided by RFM,

2008 $/bushel, 1000 bushels/day

tranCost = Charge added to the farm price of corn to represent the cost of delivering corn to ethanol plants (1987 dollars per bushel corn); defined as a function of diesel price (P_{diesel}, 87$/gal), all converted to 2008 dollars

$$= b' + m' * P_{diesel}$$

Where,

m' = 0.2664 gal diesel to transfer 1 bushel corn

b' = -0.3242 error adjustment (87$/bushel corn)

The cost of corn to ethanol plants in other LFMM regions is simply defined as a transport cost differential between the other regions and LFMM region 3, as defined below.

RefReg	CornTranCost (87$/bushel)
1_REFREG	0.415
4_REFREG	0.47
5_REFREG	0.505
6_REFREG	0.61
7_REFREG	0.71
8_REFREG	0.71

Seed oils, fats, and greases

The production of biodiesel and renewable diesel from virgin vegetable oil, yellow grease, white grease, and imported palm oil are represented in the LFMM. Virgin oil supplies to biodiesel producers consist of regional quantities of soybean, cottonseed, canola, and sunflower oils. Yellow grease consists primarily of used cooking oil from restaurants. As such, its availability is nationwide and is assumed to grow at the same rate that population grows. White grease consists of fats from rendering. Total fat production is assumed to be 5.51 gallons per person per year, of which 1.84 gallons per person per year is available for biodiesel production. Yellow grease production is assumed to be 11.3% of total available for biodiesel, and white grease is assumed to be about 75%. Biodiesel production capacity by feedstock is allocated among Census Divisions according to the National Biodiesel Board's map of existing and potential producers and according to potential feedstock supplies.[19]

The approach to defining biodiesel feedstock supply data representing virgin oil supply (soybean and seed oils) in the LFMM has been updated for AEO2018. The soy oil production and cost data from Polysys (in the RFM) are used as a proxy to build the biodiesel virgin oil (FCO) feedstock curve. The production data are reallocated from coal demand regions into LFMM regions, and estimated for each step on the FCO supply curve as a function of the initial quantity. As with the corn supply curves, the price for each step on the FCO supply curve is defined as a function of the initial P/Q pair (Po and Qo), the supply defined for each step, and an exponential factor (1.2). A small cost to transport from the production point to the biodiesel plant is also added – estimated as a function of diesel cost.

E85 Infrastructure representation

The large renewable fuel volumes mandated by EISA2007 effectively anticipate increased E85 use in vehicles. By existing rules and regulations, ethanol can only enter the transportation fuel supply as E10, E15, or E85. Once the E10 market is projected to be saturated, any ethanol used to meet the mandate would have to come into the market as E15 or E85. The E85 market requires the building of additional station infrastructure.

E85 infrastructure costs for modifying the retailer equipment to dispense E85 fuel were estimated and amortized over the lifetime of the equipment. Demand for E85 is represented by a logit function describing the interaction between E85 availability (i.e., percentage of retail stations that provide E85 within a given region), the price differential between motor gasoline and E85, and the share of flex-fuel vehicle demand that is E85 rather than E10/E15.

Renewable Fuels Standard (EISA 2007) Representation

The LFMM includes provisions outlined in Section 202 of the Energy Independence and Security Act of 2007 (EISA2007) concerning the Renewable Fuels Standard (RFS), which require increases in the total U.S. consumption of renewable fuels. The total renewable fuels requirement is expanded over the requirement specified in the Energy Policy Act of 2005 to include four categories of renewable fuels: Total, Advanced Biofuels, Cellulosic Biofuels, and Biomass-based Diesel (biodiesel and renewable diesel).

[19] http://www.biodiesel.org/production/plants .

Advanced biofuels are defined to be any renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions that are at least 50% less than baseline lifecycle greenhouse gas emissions (gasoline or diesel fuel, EISA07 Sec 201(1)(C)). Cellulosic biofuel is defined as a renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions that are at least 60% less than the baseline lifecycle greenhouse gas emissions. Biomass-based diesel is defined as a renewable fuel that is biodiesel as defined in Section 312(f) of the Energy Policy Act of 1992 (42 U.S.C. 13220(f)) and that has lifecycle greenhouse gas emissions that are at least 50% less than the baseline lifecycle greenhouse gas emissions. Cellulosic biofuels and biomass-derived diesel both count toward the advanced biofuels subtotal. The EPA is authorized to reduce mandate levels per specific authority in the statute. As implemented in the LFMM for AEO2018, the RFS target volumes are as follows:

Table F-12. EISA2007 RFS schedule

billion ethanol-equivalent gallons/year

Year	Renewable Fuels	Advanced Biofuels	Cellulosic Biofuels	Biomass-based Diesel
2006	4	0	0	0
2007	4.7	0	0	0
2008	9	0	0	0
2009	11.1	0.6	0	0.75
2010	12.95	0.95	0.1	0.975
2011	13.95	1.35	0.25	1.2
2012	15.2	2	0.5	1.5
2013	16.55	2.75	1	1.92
2014	18.15	3.75	1.75	1.92
2015	20.5	5.5	3	1.92
2016	22.25	7.25	4.25	1.92
2017	24	9	5.5	1.92
2018	26	11	7	1.92
2019	28	13	8.5	1.92
2020	30	15	10.5	1.92
2021	33	18	13.5	1.92
2022	36	21	16	1.92

Starting in calendar year 2005, EIA is required to project the use of all transportation fuel, biomass-based diesel, and cellulosic biofuel for the following calendar year no later than October 31 (Clean Air Act 42 U.S.C 7545(o)(3)(A)). The existing waiver authority is retained, but specific procedures are established for waivers of the cellulosic biofuels requirement and for the biomass-based diesel requirement. By November 30 of each calendar year, the EPA Administrator is required to adjust the cellulosic biofuels requirement for up to one year using EIA's projected quantity as a guideline if the projected available quantity is lower than the requirement. The legislation also directs the EPA Administrator to make credits for cellulosic biofuels available at a price equal to ($3.00 per gallon –

wholesale gasoline price) or $0.25 per gallon, whichever is greater. The number of cellulosic biofuels credits is limited "…to the minimum applicable volume (as reduced under this subparagraph) of cellulosic biofuel for that year." (EISA07 Section 202(e)(2)(D)(i))

The EPA Administrator also is required to reduce the applicable volumes in succeeding years after issuing wavers that pass a certain size threshold, stated as follows. If either 20% or more of any requirement is waived in two consecutive years, or if 50% or more of any requirement is waived in one year, then the applicable volume requirement must be modified in all years following the final year of the waiver. However, applicable volumes for years prior to 2016 may not be modified under this subparagraph (EISA07 Section 202(e)(3)(F)). The LFMM LP implicitly accounts for this EPA authority by including escape valve variables in the relevant LP constraints.

EISA2007 also allows the EPA Administrator to waive the biomass-based diesel requirement if a determination is made that the market circumstances will cause the price of biomass-based diesel to increase substantially. The waiver is limited to 15% of the annual requirement for a maximum of 60 days but can be renewed thereafter, every 60 days. No credits are required in the event of a waiver of the biomass-based diesel requirement. The Administrator may also reduce the applicable volume of renewable fuel and advanced biofuels requirements by the same or a lesser volume (EISA2007 Section 202(e)(3)(E)(ii)).

For AEO2018, the LFMM uses RFS targets exogenously set by EIA analysts. The exogenously revised targets were set such that they could actually be achieved over the projection period.

Table F-13. RFS schedule implemented in AEO2018

billion ethanol-equivalent gallons/year

Year	Renewable Fuels	Advanced Biofuels	Cellulosic Biofuels	Biomass-based Diesel
2006	4	0	0	0
2007	4.7	0	0	0
2008	9	0	0	0
2009	11.1	0.6	0	0.75
2010	12.95	0.95	0	0.975
2011	13.95	1.35	0	1.2
2012	15.03	2.00	0	1.5
2013	15.56	2.75	0.00081	1.92
2014	15.77	2.64	0.001	2.445
2015	16.45	2.77	0.011	2.595
2016	17.26	3.39	0.010	2.850
2017	16.63	3.06	0.014	2.70
2018	17.66	3.47	0.020	2.84
2019	17.81	3.70	0.026	3.06
2020	17.81	3.89	0.034	3.24
2021	17.74	3.90	0.044	3.24

2022	17.71	3.91	0.057	3.24

California Low Carbon Fuel Standard (LCFS) representation

The Low Carbon Fuel Standard (LCFS), which is administered by the California Air Resources Board (CARB)[20] , was signed into law on January 12, 2010. The regulated parties under this legislation are generally the fuel producers or importers who sell motor gasoline or diesel fuel in California. This legislation is designed to reduce the Carbon Intensity (CI) of motor gasoline and diesel fuels sold in California by 10% between 2012 and 2020 through the increased sale of alternative "low-carbon" fuels. Each alternative low carbon fuel has its own CI based on a life cycle analyses conducted under the guidance of CARB for a number of approved fuel pathways. The CIs are calculated on an energy equivalent basis and measured in grams of CO_2 equivalent emissions per megajoule (gCO_2e/MJ).

The AEO2018 Reference case uses the CARB mandated CIs and approved fuel pathways included in the LCFS.[21] To represent non-compliance, EIA computed a monetary penalty to encourage compliance within the Reference case based on relevant provisions in the California Health and Safety Code.[22]

The CIs are a measure of the complete well-to-wheels or lifecycle emissions of each fuel pathway and include indirect land use change (ILUC) penalties for applicable fuels. The ILUC penalty is a controversial additional CI value that attempts to account for potential land use changes due to increased biofuels production. The science behind the ILUC penalty is relatively new, so potential revisions and updates to these numbers are expected as the LCFS evolves. These fuel pathways include existing technologies such as Midwestern corn ethanol, imported sugarcane ethanol, and soy-based biodiesel, as well as a number of "next-generation" technologies like cellulosic ethanol and biomass-to-liquid diesel fuels. There are also provisions in the legislation that allow non-regulated parties such as electricity and hydrogen producers to contribute to the carbon reduction.

The following two tables show carbon intensity targets and factors used for AEO2018 (which have not changed significantly over the years).

[20] LCFS Final Regulation Order: http://www.arb.ca.gov/regact/2009/lcfs09/finalfro.pdf .
[21] LCFS Fuel Pathway Lookup Tables: http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf .
[22] California Health and Safety Code, Section 43025 through 43029.

Table F-14. California LCFS carbon intensity targets

	Carbon Intensity (g CO_2e/MJ)	
Year	**Diesel**	**Motor Gasoline**
2011	94.41	95.55
2012	94.18	95.31
2013	96.99	97.90
2014	96.50	97.41
2015	95.52	96.42
2016	94.54	95.43
2017	93.07	93.94
2018	91.60	92.46
2019	90.14	90.98
2020-2040	88.18	89.01

Table F-15. Sample carbon intensities

Fuel	Description & Notes	g CO_2e/MJ	Note
DSU	petroleum diesel (ULSD)	**94.71**	**(1)**
BTL_NOCCS	Liquids from Biomass with no Carbon Sequestration	**-3.00**	**(2)**
CTL_NOCCS	Liquids from Coal Low Efficiency with no Carbon Sequestration	**233.93**	**(3)**
CBTL_NOCCS	Liquids from 80-20 Coal/Biomass Mix with no Carbon Sequestration	**186.54**	**(4)**
FAME_SBO	biodiesel: soybean (Midwest soybean oil transesterification)	**83.25**	**(5)**
FAME_PLM	biodiesel: palm oil	**83.25**	**(6)**
FAME_YGR	biodiesel: waste yellow grease	**13.80**	**(7)**
FAME_WGR	biodiesel: white grease (calculated)	**39.85**	**(8)**
NERD_SBO	renewable diesel: Midwest soybean oil hydrogenation	**82.16**	**(9)**
NERD_PLM	renewable diesel: palm oil (calculated)	**82.16**	**(10)**
NERD_YGR	renewable diesel: yellow grease (calculated)	**13.62**	**(11)**
NERD_WGR	renewable diesel: tallow (white grease)	**39.33**	**(12)**
MG	CA E10 baseline gasoline	**95.86**	**(13)**
ETA	ethanol: Brazilian sugarcane	**58.40**	**(14)**
ETC	ethanol: cellulosic	**21.30**	**(15)**
ETH	ethanol: CA average corn (80% dry mill, 20% wet mill)	**81.66**	**(16)**
GN_SBO	green naphtha: same as NERD (calculated)	**82.16**	**(17)**
GN_PLM	green naphtha: same as NERD (calculated)	**82.16**	**(18)**
GN_YGR	green naphtha: same as NERD (calculated)	**13.62**	**(19)**
GN_WGR	green naphtha: same as NERD (calculated)	**39.33**	**(20)**
CNG	natural gas (non-renewable) (for CNG vehicles)	**67.70**	**(21)**
EV	electricity (average CA mix)	**41.37**	**(22)**
LPG	LPG from refinery	**78.00**	**(23)**
PYO	Product refined from pyrolysis oil	**31.00**	**(24)**

(1) Table 7 of http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf.

(2) Table 2-3 (GREET analysis) of "A Low Carbon Fuel Standard for California Part 1: Technical Analysis (Farrel and Sperling August 2007); see also page 4 Table 1-1 NETL's "Affordable, Low Carbon Diesel Fuel from Domestic Coal and Biomass" (January 14, 2009) which shows over 100% reduction in CO_2 for BTL.

(3) http://www.clf.org/our-work/clean-energy-climate-change/reducing-greenhouse-gas-emissions/regional-greenhouse-gas-initiative/ . Also see Table 1-1 on page 4 of NETL's "Affordable, Low Carbon Diesel Fuel from Domestic Coal and Biomass" (January 14, 2009).

(4) 20% BTL (2) and 80% CTL (3)

(5) Table 7 of http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf .

(6) Same as soy biodiesel since palm oil feedstock is lumped with other seed oil feedstock within the LFMM. Note that neither CARB nor the EPA considers palm-oil-based biodiesel to be a fuel worth considering in any significant supply. See EPA's discussion of palm oil biodiesel on pp. 60-63 in the "Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program" published May 2009.

(7) Average of yellow grease values from Table 7 of http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf .

(8) Calculated based on Renewable Diesel values in lieu of ARB value

(9) Table 7 of http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf .

(10) Assumed value of Midwest Soy Renewable Diesel value in lieu of ARB value.

(11) Calculated based on FAME Biodiesel values in lieu of ARB value

(12) Table 7 of http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf .

(13) http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carbob.pdf .

(14) Table 8 of http://www.arb.ca.gov/fuels/lcfs/100609lcfs_updated_es.pdf . Assumes latest CARB instinct to count all Brazilian ethanol as cofired with bagasse.

(15) Although according to the October 2009 CARB update on the LCFS program the cellulosic materials-to-ethanol conversion process is still a fuel pathway under development in terms of defining a CI (see Table 6 of http://www.arb.ca.gov/fuels/lcfs/100609lcfs_updated_es.pdf), an average of the two values from earlier analyses published by CARB on ethanol from farmed trees (http://www.arb.ca.gov/fuels/lcfs/022709lcfs_trees.pdf) and ethanol from forest waste (http://www.arb.ca.gov/fuels/lcfs/022709lcfs_forestw.pdf) provide the CI shown here.

(16) Table C of http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cornetoh.pdf with assumed reduced ILUC penalty.

(17) Assumed same values as same feedstock Renewable Diesel pathways.

(18) Assumed same values as same feedstock Renewable Diesel pathways.

(19) Assumed same values as same feedstock Renewable Diesel pathways.

(20) Assumed same values as same feedstock Renewable Diesel pathways.

(21) Table 6 of http://www.arb.ca.gov/regact/2009/lcfs09/lcfsfsor.pdf .

(22) Takes into account EER for better electric car use of energy over conventional vehicle. Table ES-8 of "Proposed Regulation to Implement the Low Carbon Fuel Standard vol. 1" from CARB (Table ES-8 of http://www.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol1.pdf).

(23) Table 2-3 (GREET analysis) of "A Low Carbon Fuel Standard for California Part 1: Technical Analysis (Farrel and Sperling August 2007).

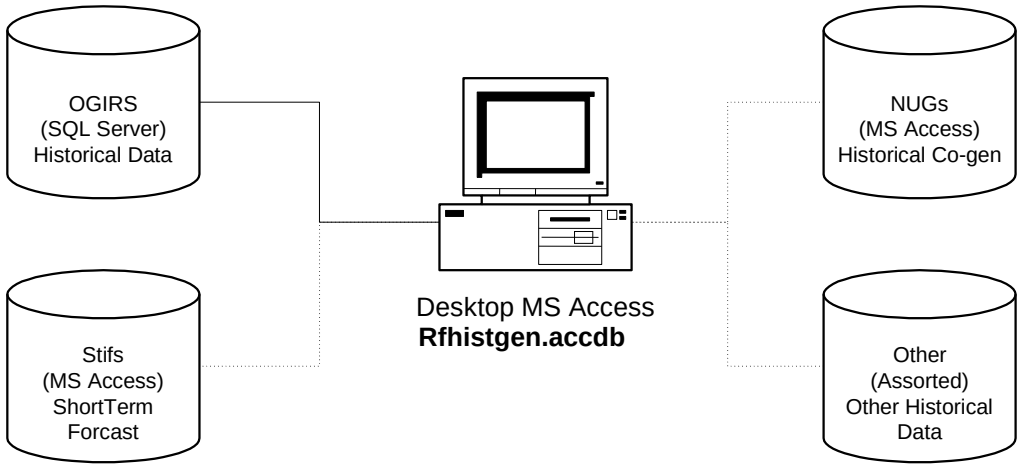
(24) memo from Steve Umnasch 4/29/10.

Appendix G. Historical Data Processing

Processing data for LFMM history file

The LFMM uses historical data from a variety of sources. The Microsoft Access database "rfhistgen.accdb" collects and aggregates this data to prepare the LFMM input file rfhist.txt. The three principal databases it collects from are the Oil and Gas Information Resource System (OGIRS) which contains most historical wholesale price and volume information, the Non-Utility Generators (NUGs) database which contains refinery co-generation information, and the Short-Term Integrated Forecasting System (STIFS) database which contains data from the end of the historical period to the first NEMS projection year. Additional individual data elements are added as tables to the rhistgen.accdb database, as described below.

Figure G-1. Database linkages for historical data processing



Accessing data

The file "rfhistgen.accdb" currently resides in the set of defaults within the NEMS revision control system. The following explains how to connect to the component databases that are used in processing the historical input file.

- OGIRS: The OGIRS database is called via a short Visual Basic Application (VBA) script called "modOgirsFunction." This script searches the table "tblParkList" for the OGIRS keys and frequency of the data required to form a request to the main OGIRS server. Executing this function creates the local table "dbo_Ogidata" (Ogidata) with all data for the requested keys and frequency. For example, to pull annual data for kerosene-based jet fuel production for all the U.S. PAD Districts, enter the OGIRS Sourcekeys for the data series in the Sourcekey column and an "A" (for annual) in the "FrqncName" column as shown in the accompanying table. While it is unnecessary to complete the "SERIES" field, having a local reference to the Sourcekey definition is advisable.

Table G-1. Park list sample

SOURCEKEY	SERIES	FrqncName
MKJRPP12	PADD I Jet Fuel Kero Refinery Production (Mbbl/d)	A
MKJRPP22	PADD II Jet Fuel Kero Refinery Production (Mbbl/d)	A
MKJRPP32	PADD III Jet Fuel Kero Refinery Production (Mbbl/d)	A
MKJRPP42	PADD IV Jet Fuel Kero Refinery Production (Mbbl/d)	A
MKJRPP52	PADD V Jet Fuel Kero Refinery Production (Mbbl/d)	A
MKJRPUS2	U.S. Jet Fuel Kero Refinery Production (Mbbl/d)	A

Most of data used by the LFMM are pulled from OGIRS as annual numbers. The only time monthly data are used is for the computation of Refinery Operable Capacity or for year-to-date current year data for refinery input/output variables that aren't provided by the Short-Term Energy Outlook (STEO). For Refinery Operable Capacity, the January data values are the previous year's capacity.

The OGIRS database is mostly complete; however, there are a few missing fields in the database. To prevent errors from occurring when the queries are executed, the short list of missing values can be appended to Ogidata by running the query "Add Missing Keys to data." This query pulls known missing data from the table "Missing Keys." For instance the last version of OGIRS is missing some of the elements of refinery production: nfrpp1-p5 (naphtha feedstocks), otrpp1-p5 (other oils for feedstock), msrpp1-us (miscellaneous products for non-fuel use), and pfrp-us (total petrochemical feedstocks). An even rarer occurrence is when data are incorrect in OGIRS. Should this be discovered, the correct values can be placed in the table "Data Errors" which will update Ogidata when the query "Update data" is executed. All new missing or incorrect data should be reported to the OGIRS database administrator (currently Jaime Chan, 202-586-1515). Assuming correct entries in the tables "Missing Keys" and "Data Errors," the entire download process can be accomplished automatically by running the "Update From OGIRS and add missing Keys" Macro.

STIFS: The Current Month's STIFS database is created using a series of Excel spreadsheets. The original data set is located on the EIA LAN at: \\fs-f1\L6489\PRJ\EVIEWS\MonthYYYY\a15bbb.xls, with MonthYYYY representing the Month and year of the corresponding STEO release. Assistance in obtaining access to this file can be arranged with Tancred Lidderdale (202-586-7321). This file is then saved in the same directory as the Table_PA_creator.xls (saved on the EIA LAN at M:/ogs/amz) file, and after opening both spreadsheets, automatically organizes the data into the proper format for input into the rfhistgen.accdb MSAccess database. After completing these steps, open "rfhistgen.accdb" and from the "Database Tools" ribbon select "Linked Table Manager." Check the tables "Dates," "Table_PA," "Table_PA1" and the box "Always prompt for new location." Click OK and Browse to the location of Table_PA_creator.xls. This enables the database to extract the latest STEO database.

COGEN DATA: Annual cogeneration data updates are distributed in a spreadsheet from the NEMS Industrial team (previously by Mark Schipper). The new annual data is filtered by Industry to show only "Oil Refining" and then the most recent year is pasted into the "Cogen Update" Access table. This table

is the source of a number of queries that re-organize the data for the rfhist.txt flat file, eventually creating the following updates tables in "rfhistgen.mdb."

- Cogen Gen Cap
- Cogen Gen Cap
- Cogen Gen Fuel Use
- Cogen Gen Grid
- Cogen Gen Own

Other Data: Additional sources are used for creation of the LFMM history data file.

- Fuel consumption data in Table 47 of the Petroleum Supply Annual must be manually updated to table "PSA Table 47."
- Global Database Variables: STEOYEAR, HISOYEAR, and STEOYEARS must be reset each year the History file generator is used. Running the Macro "STEO-HISTO" will prompt the user to enter the last Historical information year and the remaining keys will be updated automatically.
- Index for GDP Price deflators for the forecast period is stored in table "GDP87." These are generally updated each year by the Macro team and can be found in Table 101 of the Ftab report.
- Historical Petroleum Product Prices are from the State Energy Data 2010: Prices (SEDP) and stored in the "Product price data" Table. For AEO2014, aggregated Census District level data from the previous year was used through 2010. For years 2011 through 2013 these prices were scaled by the change in the equivalent national numbers reported in the September 2012 Short-Term Energy Outlook.

Data processing queries

After all the data from the different sources have been input (or linked) to the database, several queries are executed to manipulate the data into LFMM variables. The numbers correspond with the position of the variable being generated in the rfhist.txt file. This code should not need to be changed absent a change in the definition of LFMM variable it represents. Should this occur, the individual variable query can be examined and edited.

LFMM variables are linked to variables in input databases (primarily OGIRS and STIFS) by table "Map PMM to OGIRS." A complete list of mappings for both historical and STEO years is available in the following table. Multiple entries for an LFMM variable indicate that more than one OGIRS or STEO variable is needed to calculate the value for these variables. The multiple entries are summed to obtain the LFMM variable. For example the OGIRS keys for RFPRDOTH are the sum of the keys in that row (Aviation Fuel, Lubes, Naphtha, and Waxes). In the case where a (-) appears before a variable, the key is multiplied by -1 before summation.

LFMM Variable	Definition	OGIRS Keys	OGIRS Description	STEO Years
RFQEXCRD	CRUDE EXPORTS IN MBD	OGIRS- MCREXPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Exports (Mbbl/d)	Assume last historical year
RFQICRD	Crude oil imports in MMbbl/d	OGIRS- MCRIMPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Imports (Mbbl/d)	CONXPUS use last historical year % to parse to PADDs
RFPQNGL	NGL production in MMbbl/d	OGIRS- MNGFPx1 (Where x is PADD#)	PADD x Averages/Totals Natural Gas Liquids and LRGs Totals Field Production (Mbbl/d)	NLPRPUS use last historical year % to parse to PADDs
RFBDSTCAP	Base distillation capacity in Mbbl/cd	OGIRS- MOCLEPx1 (Where x is PADD#)	PADD x Averages/Totals Refinery Operable Capacity (Mbbl/d) - January Value	Not available use most recent historical year -proxy: CODIPUS
RFDSTUTL	Distillation utilization rate in Mbbl/d	OGIRS- MOPUEPx2 (Where x is PADD#)	PADD x Averages/Totals Other Petroleum Products % Utilization Ref	CODIPUS/Last historical year's Capacity
RFQEXPRDT	Product exports in MMbbl/d	OGIRS- MTPEXPx2 (Where x is PADD#)	PADD x Averages/Totals Total Crude Oil and Petroleum Products Exports (Mbbl/d)	Last year's exports of Petroleum Products
RFPQIPRDT	Product imports in MMbbl/d	OGIRS- MNGEXPx2 (Where x is PADD#)	PADD x Finished Petroleum Products Imports (Mbbl/d)	PANIPUS
		OGIRS- MTPIMPx2 (Where x is PADD#)	PADD x Averages/Totals Natural Gas Liquids and LRGs Totals Imports (Mbbl/d)	Last year's exports of Petroleum Products
CRDUNACC	Unaccounted crude	OGIRS - MCRAUPx2 (Where x is PADD #)	PADD x Averages/Totals Crude Oil Unaccounted for (Mbbl/d)	COUNPUS
CRDSTWDR	Crude stock withdrawals	OGIRS- MCRSCPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Stock Change (Mbbl/d)	COSQ_DRAW
				COSX_DRAW
RFQPRCG	Processing gain in MMbbl/d	OGIRS- MPGRPUS1/365	US Processing Gain Net Production (Mbbl)	PAGLPUS
BLDIMP	Blending component imports	OGIRS- MBCIMUS2	US Blending Components Gasoline Imports (Mbbl/d)	MBNIPUS
NGLRF(2)	NGL input to refinery and blenders	OGIRS- MNGRIUS2	U.S. Refinery and Blender Net Inputs of Natural Gas Liquids and Liquefied Refinery Gases (Mbbl)	

LFMM Variable	Definition	OGIRS Keys	OGIRS Description	STEO Years
BLDREFIN	Product blending component used at refinery	OGIRS - mbcro_nus_1		
NGLIMP		OGIRS - MNGIMUS2	NGL Imports	
NGLRF(1)	NGL input to refinery	OGIRS- M_EPL0_YIY_NUS_2	U.S. Natural Gas Liquids and LRGs Totals Input into Refineries (Mbbl/d)	LGRIPUS
		OGIRS - MNGEXUS2		PPRIPUS
NGLEXP	NGL Exports	STEO: MBRIPUS, OXRIPUS, UORIPUS	NGL Exports	
OTHOXYFP	Other oxygenates (Field production)	OGIRS - MOHIMUS2		
OTHOXYIMP	Imported oxygenates	OGIRS- MOYRIUS2		
RFHCXH2IN	Merchant Hydrogen	OGIRS - MOORIUS2		
RFOHOXYIN	Oxygenates Other Inputs into Refineries	OGIRS - moxro_nus_1		
OTHPRDSP	Other Liquids Product Supplied	OGIRS -molro_nus_1		
PRDSTKWDR	Product stocks withdrawals	OGIRS- MTTSCUS2	U.S. Total Crude Oil and Petroleum Products Stock Change (Mbbl/d)	Assume Zero
		OGIRS- MCRSCPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Stock Change (Mbbl/d)	
RFETHETB	Zeroes			
RFETHE85	Ethanol for E85 production		Oxy Fuel News Data	Oxy Fuel News Data
RFETHMGS	Ethanol for motor gasoline	OGIRS- OFETPUS2	U.S. Oxygenates Fuel Ethanol Production (Mbbl/d)	EOFPPUS
RFMTBI	Imported MTBE		U.S. Oxygenates MTBE Imports (Mbbl/d)	Assume Zero
RFETHIN	Total Ethanol into Refinery	OGIRS - mfero_nus_1		
RFPQUFC	Total imports of unfinished crude	OGIRS- MUOIMUS2	U.S. Unfinished Oils Imports (Mbbl/d)	UORIPUS

LFMM Variable	Definition	OGIRS Keys	OGIRS Description	STEO Years
RFSPRFR	SPR fill rate	OGIRS- -MCSSCUS1/365	U.S. Crude Oil Stock Change SPR (Mbbl)	CONQPUS
PALMG	U.S. Wholesale Motor Gasoline Price	OGIRS - A103700002		
PDS11	U.S. No. 2 Distillate Wholesale Price	OGIRS - A213700002		
PDSL11	U.S. Diesel Fuel Wholesale Price	OGIRS - D230700002		
BIODIMP	U.S. Biodiesel Imports	MER Table 10.4	Historic Biodiesel Impots in Static BIODIMP Table	BDNIPUS
BIODEXP	U.S. Biodiesel Exports	MER Table 10.4	Historic Biodiesel Exports in Static BIODEXP Table	BDNIPUS
TDIESEL	Transportation Diesel Product Supplied	OGIRS - md1up_xxx_2 & md0up_xxx_2	STEO Years are calculated as prior years TDIESEL % of total distillate	
AST	Asphalt Product Supplied (Mbbl/d)	OGIRS- MAPUPPx2 (Where x is PADD#)	PADD x Averages/Totals Asphalt Product Supplied (Mbbl/d)	ARTCPUS
COK	Petroleum Coke Product Supplied (Mbbl/d)	OGIRS- MCKUPPx2 (Where x is PADD#)	PADD x Averages/Totals Petroleum Coke Product Supplied (Mbbl/d)	PCTCPUS
JTA	Jet Fuel Kero Product Supplied (Mbbl/d)	OGIRS- MKJUPPx2 (Where x is PADD#)	PADD x Averages/Totals Jet Fuel Kero Product Supplied (Mbbl/d)	JFTCPUS
KER	Kerosene Product Supplied (Mbbl/d)	OGIRS- MKEUPPx2 (Where x is PADD#)	PADD x Averages/Totals Kerosene Product Supplied (Mbbl/d)	KSTCPUS
LPG	Product Supplied; LPG	OGIRS- MLPUPPx2 (Where x is PADD#)	PADD x Averages/Totals Liquefied Petroleum Gases Product Supplied (Mbbl/d)	LGTCPUS
N2H	Product Supplied; No. 2 distillate	OGIRS- MDIUPPx2 (Where x is PADD#)	PADD x Averages/Totals Total Distillate Product Supplied (Mbbl/d)	DFTCPUS
N6B	Product Supplied; high-sulfur residual oil	Computed- MRSUPHx2 (Where x is PADD#)	PADD x Averages/Totals Residual Fuel Oil Sulfur > 1.0 Product Supplied (Mbbl/d)	RFTCPUS * High%
N6I	Product Supplied; low-sulfur residual oil	Computed- MRSUPLx2 (Where x is PADD#)	PADD x Averages/Totals Residual Fuel Oil Sulfur < 1.0 Product Supplied (Mbbl/d)	RFTCPUS* Low%
OTH	Product Supplied; other petroleum	OGIRS- MGAUPPx2 (Where x is PADD#)	PADD x Averages/Totals Aviation Gasoline Product Supplied (Mbbl/d)	AVTCPUS
		OGIRS- MLUUPPx2 (Where x is PADD#)	PADD x Averages/Totals Lubes Product Supplied (Mbbl/d)	LUTCPUS
		OGIRS- MNSUPPx2 (Where x is PADD#)	PADD x Averages/Totals Naphtha Special Product Supplied (Mbbl/d)	SNTCPUS
		OGIRS- MWXUPPx2 (Where x is PADD#)	PADD x Averages/Totals Waxes Product Supplied (Mbbl/d)	WXTCPUS
PCF	Product Supplied; petrochemical feeds	OGIRS- MPFUPPx2 (Where x is PADD#)	PADD x Averages/Totals Petroleum Products Product Supplied (Mbbl/d)	FETCPUS
STG	Product Supplied; still gas	OGIRS- MSGUPPx2 (Where x is PADD#)	PADD x Averages/Totals Still Gas Product Supplied (Mbbl/d)	SGTCPUS
RFQPRDT	Total product supplied	OGIRS- MTTUPPx2 (Where x is PADD#)	PADD x Averages/Totals Total Crude Oil and Pet Products Supplied (Mbbl/d)	Sum STEO Product Quantities
		OGIRS- MCRUPPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Product Supplied (Mbbl/d)	

LFMM Variable	Definition	OGIRS Keys	OGIRS Description	STEO Years
TRG	Product Supplied; motor gasoline	OGIRS- MGFUPPx2 (Where x is PADD#)	PADD x Averages/Totals Finished Gasoline Product Supplied (Mbbl/d)	MGTCPUS
QELETH	Historical Electricity use at Ethanol plants -	Multiply EOFPPUS ethanol production by Tony Radich's formulas for energy consumption		
QCLETH	Historical Coal use at Ethanol plants			
PETHM	Historical Ethanol price			
ETHEXP	Historical Ethanol Exports	OGIRS - m_epooxe_eex_nus		
QCLRF	Refinery Fuel - Coal	Paste in from table 47 of PSA	Use In MMBtu	Assume last Historical Year ratio of fuel to production
QDSRF	Refinery Fuel - Distillate Fuel Oil	Paste in from table 47 of PSA	Use In MMBtu	Average refiner price of residual fuel oil
QELRF	Refinery Fuel - Purchased Elec.	Paste in from table 47 of PSA	Use In MMBtu	
QLGRF	Refinery Fuel - LPG	Paste in from table 47 of PSA	Use In MMBtu	
QNGRF	Refinery Fuel - Nat Gas	Paste in from table 47 of PSA	Use In MMBtu	
QOTRF	Refinery Fuel - Other	Paste in from table 47 of PSA	Use In MMBtu	
QPCRF	Refinery Fuel - Pet Coke	Paste in from table 47 of PSA	Use In MMBtu	
QRSRF	Refinery Fuel - Residual Fuel	Paste in from table 47 of PSA	Use In MMBtu	
QSGRF	Refinery Fuel - Still Gas	Paste in from table 47 of PSA	Use In MMBtu	
PASIN	Asphalt, Road Oil, Industrial	SEDS	Product prices in 1987$ per MMBtu	RFTCUUS
PDSCM	Distillate, Commercial		Product prices in 1987$ per MMBtu	DSTCUUS
PDSEL	Distillate, Electricity (+petroleum coke)		Product prices in 1987$ per MMBtu	PRODUCT PRICES IN 87$ PER MMBTU
PDSIN	Distillate, Industrial		Product prices in 1987$ per MMBtu	DSTCUUS
PDSRS	Distillate, Residential		Product prices in 1987$ per MMBtu	DSTCUUS
PDSTR	Distillate, Transportation		Product prices in 1987$ per MMBtu	DSTCUUS
PJFTR	Jet Fuel, Transportation		Product prices in 1987$ per MMBtu	JKTCUUS
PKSCM	Kerosene, Commercial		Product prices in 1987$ per MMBtu	JKTCUUS
PKSIN	Kerosene, Industrial		Product prices in 1987$ per MMBtu	JKTCUUS
PKSRS	Kerosene, Residential		Product prices in 1987$ per MMBtu	JKTCUUS
RFQEXCRD	Crude exports in Mbbl/d	OGIRS- MCREXPx2 (Where x is PADD#)	PADD x Averages/Totals Crude Oil Exports (Mbbl/d)	Assume last historical year
PLGCM	Liquid Petroleum Gases, Commercial		Product prices in 1987$ per MMBtu	PRTCUUS

LFMM Variable	Definition	OGIRS Keys	OGIRS Description	STEO Years
PLGIN	Liquid Petroleum Gases, Industrial		Product prices in 1987$ per MMBtu	PRTCUUS
PLGRS	Liquid Petroleum Gases, Residential		Product prices in 1987$ per MMBtu	PRTCUUS
PLGTR	Liquid Petroleum Gases, Transportation		Product prices in 1987$ per MMBtu	PRTCUUS
PMGCM	Motor Gasoline, Commercial		Product prices in 1987$ per MMBtu	MGEIRUS
PMGIN	Motor Gasoline, Industrial		Product prices in 1987$ per MMBtu	MGEIRUS
PMGTR	Motor Gasoline, Transportation		Product prices in 1987$ per MMBtu	MGEIRUS
PPFIN	Petrochemical Feedstocks, Industrial		Product prices in 1987$ per MMBtu	PRTCUUS
PRHEL	Residual Fuel, High-Sulfur, Electricity		Product prices in 1987$ per MMBtu	RFTCUUS
PRHTR	Residual Fuel, High-Sulfur, Transp.		Product prices in 1987$ per MMBtu	RFTCUUS
PRLCM	Residual Fuel, Low-Sulfur, Commercial		Product prices in 1987$ per MMBtu	RFTCUUS
PRLEL	Residual Fuel, Low-Sulfur, Electricity		Product prices in 1987$ per MMBtu	RFTCUUS
PRLIN	Residual Fuel, Low-Sulfur, Industrial		Product prices in 1987$ per MMBtu	RFTCUUS
PETTR	E85 Price	EERE: Alternative Fuel Report	Product prices in 1987$ per MMBtu	
OG GEN GRID90	Cogeneration in MBtu		Aggregates plant data to CD regions	Use Last Historical Year for STEO Years 1 & 2
PT GEN GRID90	Cogeneration in MMBtu			
NG GEN GRID90	Cogeneration in MMBtu			
OT GEN GRID90	Cogeneration in MMBtu			
OG GEN OWN 90	Cogeneration in MMBtu			
PT GEN OWN 90	Cogeneration in MMBtu			
NG GEN OWN 90	Cogeneration in MMBtu			
OT GEN OWN 90	Cogeneration in MMBtu			
OG CAP	Capacity MW			
PT CAP	Capacity MW			
NG CAP	Capacity MW			
OT CAP	Capacity MW			
OG FUL	Cogeneration Fuel consumption			
PT FUL	Cogeneration Fuel consumption			
NG FUL	Cogeneration Fuel consumption			
OT FUL	Cogeneration Fuel consumption			

EIA-923 Survey

Creating LFMM flat-file

To create the final rfhist.txt, file query results are first aggregated and organized into Access tables via a series of saved Access macros. These macros are titled "Update everything – Including STEO years-Final" and then "GAMS 5 Padd Table" and "GAMS US Table" and are run in that order to update the data. These macros will run and then generate the necessary Access tables used to create the final rfhist.txt file.

The next step is export the Access tables to spreadsheets where they will be converted to the final text file via a python script. They are exported to Excel spreadsheets via a series of saved External data exports within the rfhistgen.accdb Access database. These exported spreadsheets are then converted into the rfhist.txt input file with the necessary formatting specifications via a python script. The saved exports are located within the rfhistgen.accdb Access database under External Data > Saved Exports, where there are three saved exports for three different Access tables. These three exports save the Excel spreadsheets in the M:\ogs\sh7\python directory, and are converted into the necessary rfhist.txt file using the create_RFHIST.py script, which is run from within a Korn shell or a Cygwin window using python.

Processing other historical data

In addition to developing an input history file, the LFMM utilizes other historical data to develop some inputs and to support analysis of the model results. This section describes the updating of these data, which is usually done on an annual basis.

Petroleum product price data

Data on petroleum product prices are obtained from the EIA-782 surveys. The EIA-782A survey contains only refiner data, and the EIA-782B survey includes petroleum marketers. The EIA-782B survey was used only prior to 2011 (when the survey was suspended). Prices and volumes are produced monthly for the Petroleum Marketing Monthly and prior to 2010 were updated for annual publication in the Petroleum Marketing Annual. Post-2010 annual prices are calculated from monthly data published in the Petroleum Marketing Monthly. This information is also available as a series of OGIRS keys from which the state-level data (by product) can be retrieved. By matching equivalent product volume and price information for each state, a weighted average for each Census Division can be determined. Retail ethanol prices (E85) are collected from the Clean Cities Alternative Fuels Price Report published by the office of Energy Efficiency and Renewable Energy. This quarterly report is used to create an annual average by Census Division.

Historical prices and margins

Historical wholesale and end-use prices from the EIA-782 are aggregated and presented in tabular form by product type and Census Division. The end-use transportation prices include state and federal taxes, but for jet fuel and LPG the state taxes are not included prior to 1995.

Differentials with the world oil price (the refiner acquisition cost of imported oil from the EIA-14) are also calculated by product type and Census Division and presented in tabular form for analyzing similar margin calculations from the LFMM. The margins include the 1% local tax that is currently being added to gasoline price projections.