ENERGY 2020 Documentation

Volume 6

Supply Sector
Oil, Gas, Refining, and Biofuels

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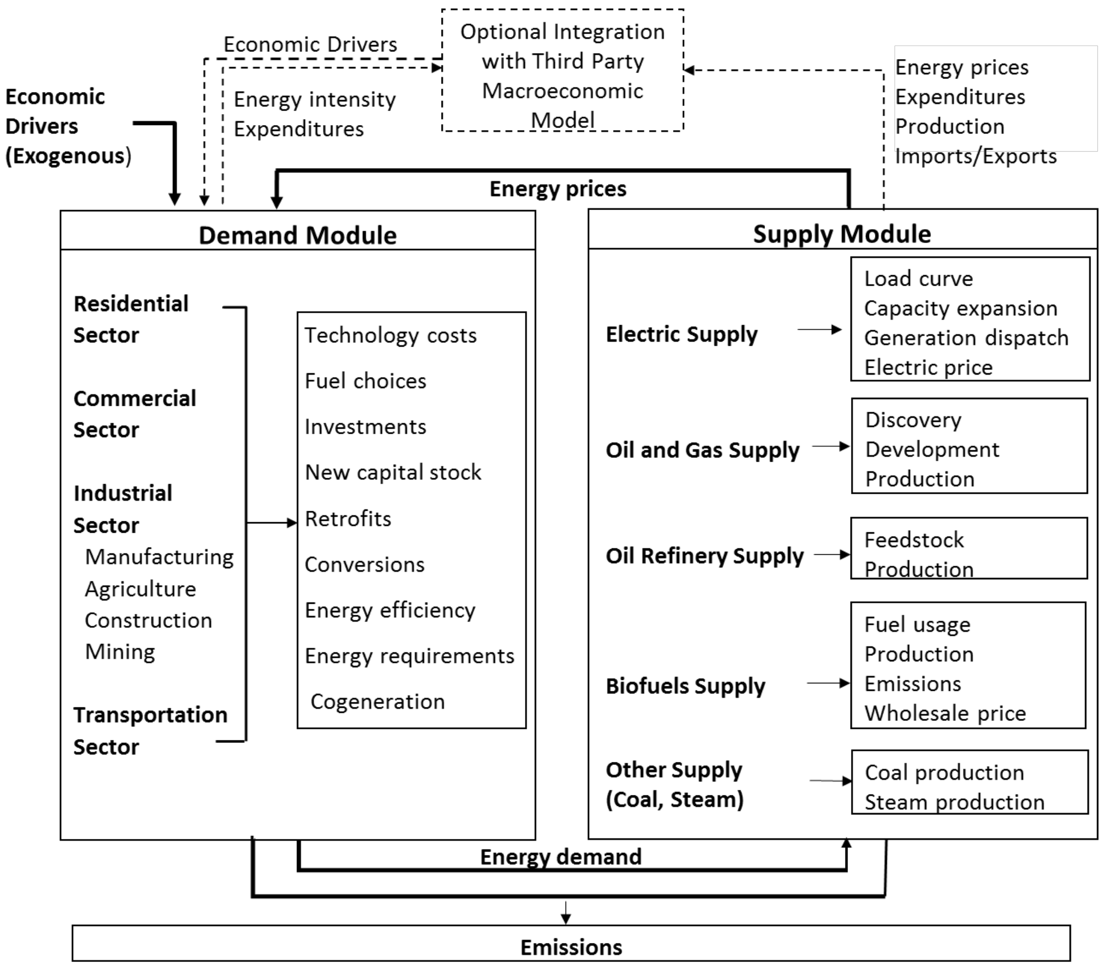
1. Introduction

ENERGY 2020 simulates the North American energy system providing long-range energy and emissions forecasts with the ability to analyze energy-related policies. The overall structure of ENERGY 2020 consists of both a demand and supply module with the ability to link to a third party macroeconomic model as is shown in Figure 1. The demand module simulates the energy demand from residential, commercial, industrial, and transportation energy demands, and the supply module simulates energy supply required by the demand sector. The energy supplies simulated include electricity, oil and gas, refined petroleum products from oil refineries, biofuels, and other supplies (coal and steam).

Figure 1. Structure of ENERGY 2020



This documentation specifically focuses on the non-electricity portions of the supply module consisting of: 1) oil and gas production, 2) oil refinery production, 3) biofuel production, and 4) other supply (coal and steam production). For information on the electric supply sector portion of the supply module, refer to Volume 5 (Supply Sector Electricity).

During 2017 the methodologies used to simulate oil, gas, refinery, and biofuel production have been undergoing significant enhancement. Prior to 2017, exogenous production forecasts were input for the oil, gas, refinery, and biofuel supply with price response mechanisms added to the oil and gas production forecast. The enhanced methodologies will allow for endogenous projections of any one or all of the supply sectors (based on switches set by the user). Natural gas pipelines have been added to the model, but are not active yet as they are in the testing phase.

The methodologies for each non-electric supply sector are broadly summarized in Table 1, including current methodologies (through June 2017) as well as the 2017 enhancements.

Table 1. Non-Electric Supply Sector Methodologies At-A-Glance

Supply Sector	Methodology Snapshot
Oil and gas production	**Current** The oil and gas production forecast is exogenous with direct price impacts, meaning it is calibrated to an exogenous forecast with an endogenous price response built in for policy analysis. **Revision in 2017** The discoveries, development, and production of oil and gas are projected for an aggregate set of oil and gas plays each using oil and gas prices and the characteristics of each play including capital, O&M, and fuel costs, taxes and royalties, and reserves.
Oil refinery production	**Current** Refined petroleum product production, imports, and exports are exogenously specified. **Revision in 2017** The oil refinery module uses a linear programming (LP) algorithm to simulate RPP oil refinery production that meets North American demand and minimizes costs subject to constraints of individual refinery capacities, yields (maximum and minimum RPP outputs per barrel of crude input), and transportation limits for pipelines, train, marine, and trucks.

Supply Sector	Methodology Snapshot
Biofuel production	**Current** Ethanol and biodiesel production are exogenously specified. **Revision in 2017** Biofuel production is determined from biofuel demands plus exports less imports where imports and exports are determined based on historical fractions. ENERGY 2020 uses consumer choice logic to determine the market share of the type of production process (feedstock and fuel) the biofuel producers will choose.
Coal production	Coal production is determined based on demand for coal plus exports minus imports. Demand for coal is input from the demand sector and the electric utility supply sector. For areas identified as able to increase production, coal exports from North America to the rest of the world are based on the local coal price relative to the export market coal price. Coal imports are used to balance demand, production, and exports for areas with limited production.
Steam generation	Most steam generation is simulated inside the sector which utilized the steam. The "steam generation sector" simulates the facilities which are operated to sell steam to other sectors. As such the steam generated is the steam which is purchased by other sectors. The steam generation sector simulates the fuel use and emissions required to generation the steam sold to other sectors.

This Volume 6 of ENERGY 2020 documentation provides methodology, key input and output variables, and a description of model code used to simulate oil and gas production, oil refining, biofuel production, and other supply (coal and steam). Due to the nature of the sectors being under development, this documentation is preliminary. The sections are organized as follows:

- Section 1. Introduction
- Section 2. Oil and Gas Production
- Section 3. Oil Refinery Production
- Section 4. Biofuel Production
- Section 5. Other Supply (Coal and Steam)

2. Oil and Gas Production

ENERGY 2020 projects oil and gas production either by 1) incorporating an exogenous forecast and adding a direct price response; or by 2) simulating oil and gas production endogenously through projections of discoveries, development, and production of a representative set of oil and gas plays across North America.

2.1. Relationship of Oil and Gas Supply Sector to ENERGY 2020 Demand Sector

The level of oil and gas production from oil and gas suppliers is independent of oil and gas demand calculated in ENERGY 2020's demand sector. It is assumed that the oil and gas sector will produce to their potential as long as it is economical to do so.

The oil and gas production and prices output from this supply sector are sent as input to the demand sector as drivers of energy demand. Oil and gas prices impact fuel demands across all demand sectors, and oil and gas production levels drive fuel demands of the oil and gas suppliers and distributors (pipelines). Either local or national-level production levels are chosen to drive each particular oil or gas industry. For example, the Oil Pipeline sector is driven by national oil production, meaning as production increases then total energy consumption needed for providing the oil pipeline service will increase. Table 2 identifies the drivers for each of the oil and gas suppliers or distributors for each of Canada, the U.S., and Mexico.

Table 2. Oil and Gas Production Used to Drive Energy Demands in Oil and Gas Industries

Sector	Canada	U.S.	Mexico
Commercial			
Oil Pipelines	National Oil Production	Gross Output	Industry Gross Output
Natural Gas Pipelines	Local Gas Production (BC,AB)	Gross Output	Industry Gross Output
Industrial			
Light Oil Mining	Local Oil Production	Local Oil Production	Local Oil Production
Heavy Oil Mining	Local Oil Production	N/A	N/A
Frontier Oil Mining	Local Oil Production	N/A	N/A
Primary Oil Sands	Local Oil Production	N/A	N/A
SAGD Oil Sands	Local Oil Production	N/A	N/A
CSS Oil Sands	Local Oil Production	N/A	N/A
Oil Sands Mining	Local Oil Production	N/A	N/A
Oil Sands Upgraders	Local Oil Production	N/A	N/A
Conventional Gas Production	Local NG Production	Local NG Production	Local NG Production
Sweet Gas Processing	Local NG Production	N/A	N/A
Unconventional Gas Production	Local NG Production	N/A	N/A
Sour Gas Processing	Local NG Production	N/A	N/A

2.2. Exogenous or Endogenous Forecast Options

Exogenous Forecast with Direct Price Impacts

If an exogenous production forecast is input to the model, ENERGY 2020 calibrates to the exogenous forecasts and incorporates direct price impacts. The model develops a baseline forecast that matches the exogenous forecast input given a certain level of exogenous price in the forecast years. Policy scenarios can then directly or indirectly alter price factors in the forecast, producing an endogenous response for oil and gas production compared to a baseline forecast.

Endogenous Forecast of Discoveries, Development, and Production

With the endogenous option, the oil and gas supply sector forecasts oil and gas discoveries, development, and production for a representative set of oil and gas plays within Canada, the United States, and Mexico. Each play reflects a group of production possibilities for a defined region. The sector is designed to be generic, with each oil and gas plays treated in a similar fashion, but also flexible to allow the simulation to incorporate any unique aspects of each play. The model structures used to simulate oil and gas production consist of individual oil and gas production plays (similar to electric generating units in the electric supply sector), oil and gas nodes, production processes, and oil and gas production fuel types.

The documentation of oil and gas production describes the structures, methodology, and model code associated with the endogenous simulation of discoveries, development, and production of oil and gas plays. Specific algorithms used to simulate the production can vary by oil and gas play, including the use exogenous values.

2.3. Oil and Gas Supply Structures

The current representation of oil and gas plays is at an aggregate, regional level and are defined in the model within a set *OGUnit*. Each oil gas unit has a set of characteristics assigned to it, such as its location, the primary type of production process used, the type of fuel used, which industry is represented (for example, light oil mining, conventional gas production, etc), and an initial project year. The model can be used to split up in-situ oil sands into primary, CCS and SAGD. Primary, CSS, and SAGD are all oil sands plays so the production of each type is available.

Play Characteristics	Variable	Sample Value
Unit Code	OGUnCode	AB_LightOil_0001
Area	OGArea	Alberta
Production Process	OGProcess	Light Oil Mining
Fuel Type	OGFuel	Light Oil
Economic Sector	OGECC	Light Oil Mining
Initial Year	OGInitYear	1990

Each play simulated is assigned an associated production process (Table 3) and fuel type (such as bitumen, heavy or light oil, synthetic crude oil, natural gas, shale gas, sweet gas, sour gas). Each oil and gas play produces a specific type of oil or gas.

Table 3. Oil and Production Processes of Current Oil and Gas Plays

Oil and Gas Production Processes		
Light Oil Mining	Oil Sands Mining	Conventional Gas production
Heavy Oil Mining	Shale Oil	Unconventional Gas production
Frontier Oil Mining	Primary Oil Sands	Shale Gas
SAGD Oil Sands	Oil Sands Upgraders	Tight Gas
CSS Oil Sands		Coalbed Methane

The types of fuels produced by the oil and gas plays are represented by a set in the model called *OGFuel*. These oil and fuels and their mapping to one of ENERGY 2020's standard oil and gas fuels as shown are shown in Table 4.

Table 4. Fuel Types Produced by Oil and Gas Plays

Fuels Types Produced (OGFuel Set)	Mapped to Standard Fuel Type (Fuel Set)
Light Oil Synthetic Crude Oil	Oil, Unspecified
Heavy Oil Bitumen	Heavy Fuel Oil
Sweet Gas Sour Gas	Natural Gas

Many of the current modeled plays are at an aggregate level designated by region and type of production process, such as British Columbia Light Oil Mining. However, several specific oil or gas plays that are of key interest are modeled explicitly, such as Hibernia in Newfoundland and Labrador or Sable Island in Nova Scotia. It is expected that this list of plays will be further modified and disaggregated based on interest and subject to availability of data. See *Other Supply (Coal and Steam)*

Coal Production

The coal supply sector is represented by the Coal Mining economic category. Coal production is determined based on demand for coal plus exports minus imports. Demand for coal is input from the demand sector and the electric utility supply sector. For areas identified as able to increase production, coal exports from North America to the rest of the world are based on the local coal price relative to the export market coal price. Coal prices are increased by emission taxes if present. Coal imports are used to balance demand, production, and exports for areas with limited production. Using a switch, any model area's coal production, exports, or imports can be specified exogenously.

Each region's coal production capacity is identified as unlimited, limited, or exogenous using a model switch. If the switch is set equal to exogenous, then production is the maximum of the exogenous production or the demand from the region. Areas with unlimited production have exogenous levels of imports.

Each province or territory's exports are treated uniquely based on the characteristics of their coal industry. Exports being determined based on the local coal price relative to the export price is an option available for areas where this is appropriate. The other areas tend to have a fixed level of exports, if any.

2.4. Steam Production

Most steam generation is simulated inside the sector which utilized the steam. The "steam generation sector" simulates the facilities which are operated to sell steam to other sectors. As such the steam generated is the steam which is purchased by other sectors. The steam generation sector simulates the fuel use and emissions required to generation the steam sold to other sectors.

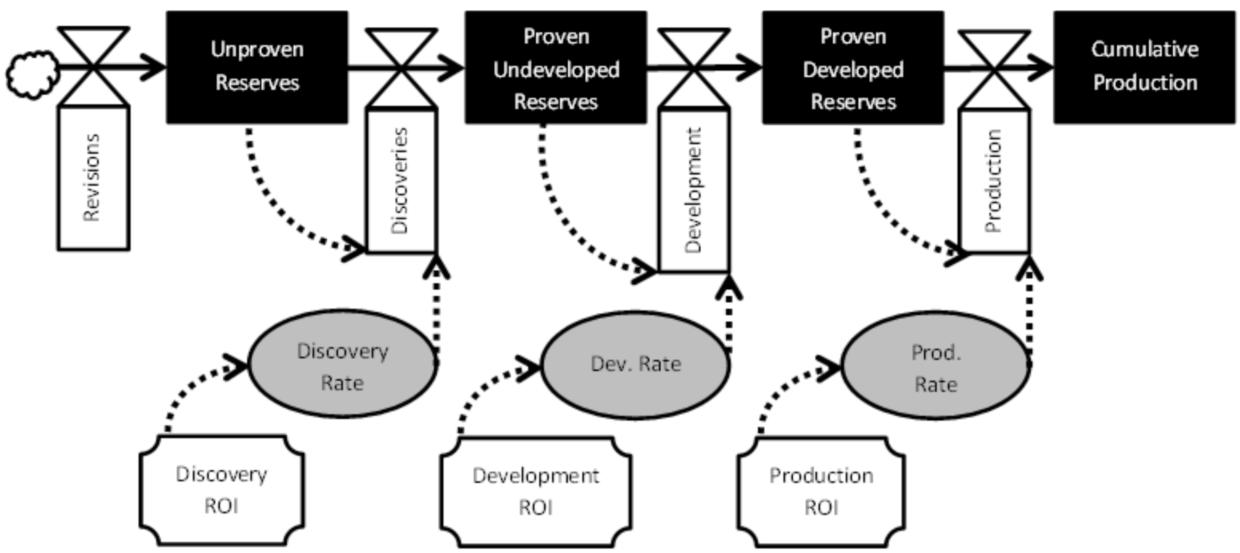
Appendix 1. Oil and Gas Plays Represented in ENERGY 2020 for a list of the specific oil and gas plays and their production processes represented at the time of this documentation.

2.5. Methodology

The long-term oil and gas production forecast is built on the discovery and development of oil and gas reserves and depends on many factors, including the total oil and gas available, oil and gas prices, oil and gas demands, discovery, development, and production costs, tax policies, and environmental constraints.

The generic structure of the relationships modeled in ENERGY 2020 that impact cumulative production is illustrated in Figure 2.

Figure 2. Oil and Gas Module Structure



Production levels for each oil and gas play are initiated with a starting level of reserves. At that point, production levels are increased by the expected levels of unproven reserves as well as reserves that have been proven to exist (proven reserves). The proven reserves are further delineated by those that have been developed and those that are not yet developed. The levels of unproven reserves, proven undeveloped reserves, and proven developed reserves are affected by revisions to the estimates of unproven reserves, the discoveries made, and development that occurs. Assumptions about the rates of revisions to estimates of unproven reserves, rates of discoveries, rates of developments, and rates of production are combined to calculate the expected cumulative production. Those rates are driven by the return on investment of discoveries, developments, and production.

Oil and Gas Definitions

The definitions of the terms used in the structure of the oil and gas model are listed below.

- *Total Available* – total amount of oil and gas available and is the sum of cumulative production, proven developed reserves, proven undeveloped reserves, and unproven reserves.
- *Unproven Reserves (RsUnprov)* – amount of oil and gas which is statistically expected to exist in a play given the geology and other factors.
- *Proven Undeveloped Reserves (RsUndev)* – amount of oil and gas which has been discovered, but has not been developed to be able to produce oil and gas.
- *Proven Developed Reserves (RsDev)* – reserves which have been developed and are currently able to produce oil and gas.
- *Cumulative production (PdCum)* – the cumulative amount of oil and gas production which has been produced through all time
- *Discoveries (Dis)* – move reserves from the Unproven Reserves into the Proven Undeveloped Reserves.
- *Development (Dev)* – moves reserves from the Proven Undeveloped Reserves into the Proven Developed Reserves.
- *Production (Pd)* – production of oil and gas which removes reserves from the Proven Developed Reserves and increases the Cumulative production.

Oil and Gas Production Algorithms

The oil and gas production algorithms within ENERGY 2020 consist of the set of equations used to calculate rates and levels of discoveries, development, and production. These algorithms are designed to facilitate the generation of a long-term forecast and for policy and sensitivity analysis. The module was designed to be flexible so changes to the basic algorithm are easily incorporated into the model. The different algorithms can be mixed or matched to best simulate each individual play.

Options for Discovery, Development, and production Algorithms

Table 5 lists the potential options for variants of the oil and gas production algorithms. These options allow for a unique method to be chosen for each play if desired.

Table 5. Oil and Gas Production Algorithms

Algorithm Options	Description of Method
Direct Input	Direct set the value based on specific research or forecast.
Direct Input with Price Impacts	Start with a forecast from another source as a baseline then adjust the forecast as the economics change.
Historical Rates	Forecast the rates based on historical and expected rates.
Industry Return on Investment (ROI)	Forecast the rates based on the marginal return on investment relative to an industry standard.
Extension of Direct Input	Extend a forecast from another source using the implied decision criteria of the other source.
Other Methods	An alternative method of calculating discoveries, development, or production may be used that is very specific to an individual oil or gas play.

Direct Input
The simplest method sets the value based on specific research or forecast. This method may initially be used for the small plays, the existing, well established plays, plays where we have expert opinion which we do not want the model to change, or when building scenarios where we want to use a forecast from another source.

Direct Input with Price Impacts
This method will allow us to use a baseline forecast developed offline, but to have the model adjust the forecast as prices and other factors change. The baseline forecast will be adjusted up or down as the ROI moves up or down due to changes in oil or gas prices or any of the costs or investments required to produce oil or gas. These costs would include, but not be limited to, capital costs, O&M costs, fuel costs, emission costs, royalty payments, or income tax rates.

Historical Rates
With this method, we examine the historical rates and determine a method to forecast these rates into the future. For example, the production rate is the fraction of the proven developed reserves which are produced each year (similar to a reserve to production ratio). By examining the historical rates the analyst can set a method for forecasting the future rate. The method

may be as simple as holding the value constant, incorporating a growth rate on the historical rate, or using the average historical rate. Or the method may be more complicated with a relationship to another variable, such as product prices. The historical rates method can also incorporate the impact of changes to the ROI, if needed.

Industry Return on Investment (ROI)

Production, development, and discovery rates will increase or decrease as the expected ROI increases or decreases above an industry standard ROI. This method is driven by the cost of producing oil and gas as compared to the price of oil and gas and relies on having accurate financial information regarding each play.

Extension of Direct Input

This method extends the forecast developed offline further into the future using the implied decision criteria of the offline forecast. The model computes the ROI during the offline forecast period, then uses the ROI of the last year of the offline forecast period as the required ROI for the extended forecast period. This required ROI is combined with the economic past the end of the forecast period projects the level of production, development, and discoveries.

Other Methods

The oil and gas production sector has a standard structure for each play while also containing flexibility to adjust the calculations to meet the needs of simulating each play. The standard structure facilitates policy analysis, scenario construction, report writing, and model understanding by enabling the user of the model to work with the same basic structure for each oil and gas play. The same policy or output variable is used for the emission costs or the product price or the levelized cost of production across plays. This structure also supports consistency between policies and incentives for each play.

The flexibility to build and combine different production algorithms enables us to provide the level of detail and complexity to each play all within the same basic structure. Small and established plays can be treated simply while large and uncertain plays can be given more detail and comprehensive treatment.

Oil and Gas Financial and Cost Algorithms

ENERGY 2020 uses financial and cost data in three ways:

1) Forecast oil and gas production, development and discovery rates;
2) Report the financial impacts; and
3) Send financial impacts to the macroeconomic model.

When using the financial data in forecasting oil and gas production, development, and discovery rates, the marginal values of the financial variables are the most significant to the model. This is needed to compute the cost of the next new discovery, development, or unit of production. When reporting the financial variables or sending the value to the macroeconomic model, the total revenues and expenses, not just the marginal, are important. Two sets of financial calculations are made within the model in order to obtain both the marginal values and the totals required to meet the above three purposes.

Return on Investment Algorithms

Each oil and gas unit is determined to have a set of financial characteristics which are used in the calculation of a return on investment. The equations used within ENERGY 2020 to calculate return on investment (ROI) for production, development, and discoveries are listed below.

Production Return on Investment =
(Revenues - Operating Expenses - Depreciation from Sustaining Investments - Royalty Payments) / (1-Income Tax Rate) / Sustaining Capital Costs

Development Return on Investment =
(Revenues - Operating Expenses – (Depreciation from Sustaining and Development Investments) - Royalty Payments) / (1-Income Tax Rate) / (Sustaining and Development Capital Costs)

Discovery Return on Investment =
(Revenues - Operating Expenses – (Depreciation from Sustaining, Development, and Discovery Investments) - Royalty Payments) / (1-Income Tax Rate) / (Sustaining, Development, and Discovery Capital Costs)

The definitions of the financial and cost variables are as defined below.

- *Product Price (OGFP)* – price for selling oil and natural gas produced at a facility
- *By-Product Revenues (ByRev)* – revenues from selling by-products from the production of oil and natural gas
- *Revenues (OGRev)* - the sum of the Product Price and the By-Product Revenues
- *Discovery Capital Costs (DisCap)* – all the costs of adding proved undeveloped reserves of oil and natural gas via exploration activities and the purchase of properties that might contain reserves. These are considered capital costs since all costs (even labor costs) are expected to be capitalized for each project. The cost of a lease to drill and develop oil and natural gas would be included in the Discovery Capital Costs.

- *Development Capital Costs (DevCap)* - all the costs of adding proved developed reserves of oil and natural gas via development activities. These are considered capital costs since all costs (even labor costs) are expected to be capitalized for each project.
- *Sustaining Capital Costs (SusCap)* – on-going investments required to continue production of oil and natural gas. These differ from fixed O&M since these are capitalized while fixed O&M would be expensed.
- *Abandonment Capital Costs (OGAbCosts)* – costs associated with abandoning a well or production facility and typically include the plugging of wells; removal of well equipment, production tanks and associated installations; and surface remediation.
- *Variable O&M Expenses (OGOMCosts)* – expenses which vary by quantity of oil and natural gas produced excluding energy use, diluent, and emission expenses.
- *Fixed O&M Expenses (OGFCosts)* – expenses required to maintain a facility for producing oil and natural gas which do not vary with the quantity of oil and natural gas produced.
- *Fuel Expenses (OGFCosts)* – costs of fuel and electricity used to produce oil and natural gas. These expenses will be computed in the energy demand sector of the model and transferred over to the oil and natural gas supply sector. Electricity costs will include the cost of self-generated electricity and electricity purchased from the grid.
- *Diluent Expenses (DilCosts)* – cost of obtaining diluent required for transporting the bitumen.
- *Emission Expenses (OGPolCosts)* – expenses related to meeting emission limits or purchasing emission allowances. These are expected to be computed in the energy demand sector of the model and transferred to the oil and natural gas supply sector.
- *Operating Expenses (OpExp)* – sum of Variable O&M Expenses, Fixed O&M Expenses, Fuel Expenses, Diluent Expenses, and Emission Expenses.
- *Royalty Payments (RyLev)* – payments for the right to extract oil and natural gas from a property
- *Income Taxes (DisITax, DevITax, PdITax)* – taxes paid based on the income of entity. In Canada there are provincial and national income taxes. Calculated separately for revenues from discovery, development and production
- *Depreciation from Discovery Investments (DisDep)* – the capitalized investment from discoveries is depreciated each year to generate the depreciation expenses.
- *Depreciation from Development Investments (DevDep)* – the capitalized investment from development is depreciated each year to generate the depreciation expenses.
- *Depreciation from Sustaining Investments (SusDep)* – the capitalized investment needed to sustain production is depreciated each year to generate the depreciation expenses.

Depletion and Learning Curves

Two mechanisms, depletion and learning curve, have an impact on oil and gas production costs and rates and are a function of the production at each oil and gas play. The depletion mechanism increases costs and reduces production as the oil and gas reserves are depleted. The learning curve mechanism reduces costs and increases production as the industry learns ways to operate more efficiently and thus reducing costs. The learning curve is more important in relatively new technologies, like SAGD oil sands production. The depletion mechanism will increase costs as oil and gas is produced from the highest quality sites leaving the more marginal areas for new development. The depletion and learning curve mechanisms are specified for discoveries, development, and production.

2.6. Oil and Gas Production Model Code

Table 6 identifies the names of the files that contain source code and input data of the oil and gas supply sector. Source code for the oil and gas production module is located in the Engine subfolder of model directory. The endogenous oil and gas production code (SPOGProd.src) requires setting the appropriate model run parameter switch to be executed. Code to calculate the aggregate oil and gas production and price forecasts from either the endogenous code or from an exogenous forecast are located in separate files.

The endogenous production sector is dependent on input data that is read into the model via text files in the 2020Model model subfolder. These files read in default oil and gas production parameters, plays, and sets switches to determine which algorithms are used in the module. Currently, data from these files is read in for each model run but the endogenous code is disabled via the model switch.

Table 6. Oil and Gas Sector Model Files and Input Data Files

File Description	File Name
Source Code	
Endogenous oil and gas production code	SPOGProd.src
Exogenous/accumulated gas production	SPGas.src
Exogenous/accumulated oil production	SPOil.src
Input Data/Model Switches	
Price parameters for discovery ROI calculations	SpOGFPMaxMinAdd.txt
Parameters for oil and gas plays	SpOGUnitData.txt
Discovery and production parameters and model switches	SpOGData.txt
Oil and gas production and reserve data	SpOGResData.txt
Oil and gas financial data	SpOGFinData.txt
Gas transportation parameters	SpGTrData.txt

Switches used for Calculations of Discoveries, Development, and Production

A set of switches are used to indicate which methods to use in the calculations of discoveries, development, and production. This section describes the equations associated with each model switch.

Exploration (Discoveries): Discoveries from Undiscovered Reserves are calculated with the method determined by the switch, DisSw.

DisSw=1: Discovery Rate (DisRate) is an input (XDisRate). Discoveries (Dis) are the product of Rate (DisRate) and Undiscovered Reserves (RsUnprov).

DisRate=XDisRate
*Dis=RsUnprov*DisRate*

DisSw=2: Discovery Rate (DisRate) is adjusted by a discovery rate multiplier (DisRateM) defined as the Discovery ROI (DisROI) relative to the Reference Case (DisROIRef) with an assumed level of impact of ROI on Discoveries (Discovery Variance Factor, DisVF). The multiplier is constrained by a minimum (DisMinM) and maximum (DisMaxM). Discoveries (Dis) are the product of the Rate (DisRate) and Undiscovered Reserves (RsUnprov).

*DisRateM=2.0/(1+(DisROI/DisROIRef)**DisVF)*
*DisRate=XDisRate*DisRateM*
*Dis=RsUnprov*DisRate*

DisSw=3: Discovery Rate (DisRate) is adjusted by a multiplier (DisRateM) defined as the Discovery ROI (DisROI) relative to the Normal ROI (OGROIN) given an assumed level of impact of ROI on Discoveries (Discovery Variance Factor, DisVF). The multiplier is constrained by a minimum (DisMinM) and maximum (DisMaxM). Discoveries (Dis) are the product of the Rate (DisRate) and Undiscovered Reserves (RsUnprov).

*DisRateM=2.0/(1+(DisROI/OGROIN)**DisVF, constrained by DisMaxM and DisMinM*
*DisRate=XDisRate*DisRateM*
*Dis=RsUnprov*DisRate*

DisSw=4: Discovery Rate (DisRate) is the Discovery Rate in the last year of the exogenous forecast (DisRateLastExo) adjusted by a multiplier (DisRateM) defined as the ROI of Discovery (DisROI) relative to the ROI in the last year of the exogenous forecast (DisROILastExo) given an assumed level of impact of ROI on Discoveries (Discovery Variance Factor, DisVF) and constrained by a minimum and maximum multiplier

(DisMinM, DisMaxM). Discoveries (Dis) are the product of the Rate (DisRate) and Undiscovered Reserves (RsUnprov).

*DisRateM=2.0/(1+(DisROI/DisROILastExo)**DisVF, constrained by DisMaxM and DisMinM*
*DisRate=DisRateLastExo*DisRateM*
*Dis=RsUnprov*DisRate*

DisSw=0: Discoveries (Dis) are an input (XDis). Discovery Rate (DisRate) is equal to Discoveries (Dis) divided by Undiscovered Reserves (RsUnprov).

Dis=XDis
DisRate=Dis/RsUnprov

Development: Development from Undeveloped Reserves are calculated with a method determined by the switch, DevSw.

DevSw=1: Development Rate (DevRate) is an Input (XDevRate). Development (Dev) is the product of Rate (DevRate) and Undeveloped Reserves (RsUndev).

DevRate=XDevRate
*Dev=RsUndev*DevRate*

DevSw=2: Development Rate (DevRate) is adjusted by a multiplier (DevRateM) defined as the Development ROI (DevROI) relative to the Reference Case (DevROIRef) given an assumed level of ROI impact (Development Variance Factor, DevVF) and constrained within and minimum and maximum (DevMinM, DevMaxM). Development (Dev) is the product of Rate (DevRate) and Undeveloped Reserves (RsUnprov).

*DevRateM=2.0/(1+(DevROI/DevROIRef)**DevVF, constrained by DevMaxM and DevMinM*
*DevRate=XDevRate*DevRateM*
*Dev=RsUndev*DevRate*

DevSw=3: Development Rate (DevRate) is adjusted by a multiplier (DevRateM) defined as the Development ROI (DevROI) relative to the Normal ROI (OGROIN) given an assumed level of impact of ROI on Development (Development Variance Factor, DevVF). The multiplier is constrained by a minimum (DevMinM) and maximum (DevMaxM). Developments (Dev) are the product of the Rate (DevRate) and Undeveloped Reserves (RsUndev).

*DevRateM=2.0/(1+(DevROI/OGROIN)**DevVF, constrained by DevMaxM and DevMinM*
*DevRate=XDevRate*DevRateM*
*Dev=RsUndev*DevRate*

DevSw=4: Development Rate (DevRate) is the Development Rate in the last year of the exogenous forecast (DevRateLastExo) adjusted by a multiplier (DevRateM) defined as the ROI of Development (DevROI) relative to the ROI in the last year of the exogenous forecast (DevROILastExo) given an assumed level of impact of ROI on Development (Development Variance Factor, DevVF) and constrained by a minimum and maximum multiplier (DevMinM, DevMaxM). Development (Dev) is the product of the Rate (DevRate) and Undeveloped Reserves (RsUndev).

*DevRateM=2.0/(1+(DevROI/DevROILastExo)**DevVF, constrained by DevMaxM and DevMinM*
*DevRate=DevRateLastExo*DevRateM*
*Dev=RsUndev*DevRate*

DevSw=9: Developments (Dev) are equal to Discoveries (Dis). Development Rate (DevRate) is Developments (Dev) divided by Undeveloped Reserves (RsUndev).

Dev=Dis
DevRate=Dev/RsUndev

DevSw=0: Developments (Dev) are an input (XDev). Development Rate (DevRate) is equal to Development (Dev) divided by Undeveloped Reserves (RsUndev).

Dev=XDev
DevRate=Dev/RsUndev

Production: Production from Developed Reserves are calculated with the method determined by the switch, PdSw.

PdSw=1: Production Rate (PdRate) is an Input (XPdRate). Production (Pd) is the product of Rate (PdRate) and Developed Reserves (RsDev), constrained by a maximum production level (PdMax).

PdRate=XPdRate
*Pd=RsDev*PdRate, constrained by PdMax*

PdSw=2: Production Rate (PdRate) is calculated as an exogenous production rate (XPdRate) adjusted by a multiplier (PdRateM) defined as the Production ROI (PdROI) relative to the Reference Case (PdROIRef) given an assumed level of ROI impact (Production Variance Factor, PdVF) and constrained within and minimum and maximum (PdMinM, PdMaxM).. Production (Pd) is the product of Rate (PdRate) and Developed Reserves (RsDev), constrained by a maximum production level (PdMax).

*PdRateM=2.0/(1+(PdROI/PdROIRef)**PdVF, constrained by PdMaxM and PdMinM*
*PdRate=XPdRate*PdRateM*
*Pd=RsDev*PdRate, constrained by PdMax*

PdSw=3: Production Rate (PdRate) is adjusted by a multiplier (PdRateM) defined by the Production ROI (PdROI) relative to the Normal ROI (OGROIN) given an assumed level of impact of ROI on Production (Production Variance Factor, PdVF). The multiplier is constrained by a minimum and maximum (PdMinM, PdMaxM). Production (Pd) is the product of Rate (PdRate) and Developed Reserves (RsDev), constrained by a maximum production level (PdMax).

*PdRateM=2.0/(1+(PdROI/OGROIN)**PdVF, constrained by PdMaxM and PdMinM*
*PdRate=XPdRate*PdRateM*
*Pd=RsDev*PdRate, constrained by PdMax*

PdSw=4: Production Rate (PdRate) is the Production Rate in the last year of the exogenous forecast (PdRateLastExo) adjusted by a multiplier (DevRateM) defined as the ROI of Production (PdROI) relative to the Normal ROI (OGROIN) given an assumed level of impact of ROI on Production (Production Variance Factor, PdVF) and constrained by a minimum and maximum multiplier (PdMinM, PdMaxM). Production (Pd) is the product of the Rate (PdRate) and Developed Reserves (RsDev), constrained by a maximum production level (PdMax).

*PdRateM=2.0/(1+(PdROI/OGROIN)**PdVF, constrained by PdMaxM and PdMinM*
*PdRate=PdRateLastExo*PdRateM*
*Pd=RsDev*PdRate, constrained by PdMax*

PdSw=0: Production (Pd) is an Input (XPd). Production Rate (PdRate) is the Production (Pd) divided by the Developed Reserves (RsDev).

Pd=XPd
PdRate=Pd/RsDev

Setting up an Endogenous Oil and Gas Production Run

The current version of ENERGY 2020 defaults to using an exogenous oil and gas production forecast. In order to turn on the endogenous oil and gas sector model equations, you will need to set the proper switches and rerun the model. An example of how to set up an endogenous oil and gas production run is shown below.

To activate the endogenous oil and gas sector follow the steps below:

Reference:
How to set up an endogenous oil and gas production run…

1. Activate the endogenous oil and gas production equations using switches OGProdSw and ProcSw(OGProd).
2. Set additional model switches to assign which method will be used to calculate discoveries, development, and production (DisSw, DevSw, and PdSw).
3. Create a policy file, for example having a different fuel price forecast, to create an endogenous policy run for comparison to the endogenous baseline.

As an example, the following policy files can be adjusted and called to set up an endogenous oil and gas production run that is sensitive to prices:

1. Modify OG_Endogenous.txp to set endogenous switches
   - OGProdSw = 1
   - ProcSw(OGProd) - Oil and gas production is endogenous (OAProd and GAProd).

2. Set switches for methods of calculating discovery, development, production
   - DevSw = 2 (Development Rate (DevRate) is adjusted by the ROI of Development (DevROI) relative to the Reference Case)
   - DisSw = 2 (Discovery Rate (DisRate) is adjusted by the ROI of Discovery (DisROI) relative to the Reference Case (DisROIRef)).
   - PdSw = 3 (Production Rate (PdRate) is adjusted by the ROI of Production (PdROI) relative to the Normal ROI (OGROIN))
   - Modify OG_ProductionResponseToPrice.txp
   - OSMSw = 1 (Oil production changes due to changes in oil taxes)
   - GSMSw = 1 (Gas production changes due to changes in gas taxes)

3. Modify Oil50.txp to create policy that adjusts whole sale fuel price

How to Modify a Given Production Algorithm

With the endogenous oil and gas production module active, each oil and gas play will be assigned a default production method as described above. ENERGY 2020 also has the capability to assign methodology changes at the individual play level.

For example, the user might have a specific outside forecast for rate of production for a single play that would be preferable to use over the endogenous value. This can be assigned by developing a text file to select the appropriate play and assigning the switch individually. Oil and gas plays (OGUnit) can be directly selected by name or code using the code example below:

Code Example:
Assign one oil and gas play to use an exogenous forecast…

```
Select OGUnit If OGCode eq "AB_LightOil_0001"
Do If OGCode eq "AB_LightOil_0001"
  PdSw(OGUnit)=0
Write Disk(PdSw)
Select OGUnit*
```

Plays can also be selected as a group via shared unit characteristics. For example, the user has data to support using a different algorithm for all plays within Manitoba. The appropriate plays can be selected similarly to the example below:

Code Example:
Set Manitoba plays to use a different method of calculating rate of development…

```
Select OGUnit If OGArea eq "MB"
Do If OGArea eq "MB"
  DevSw(OGUnit)=0
Write Disk(DevSw)
Select OGUnit*
```

2.7. Oil and Gas Sector Key Input Data, Sources, and Model Variables

Table 7 lists key input data required for input to the oil and gas production module, the input variable name, the source of the data, and the file containing the data in ENERGY 2020.

Table 7. Input Data and Sources for Oil and Gas Supply Sector

Input Data - Variable Name, Input File Name, and Description	Source
Natural gas input data (SpOGResData.txt) • XPdPN(GNode,ProcOG,Year) Natural Gas Production (TBtu/Yr)	AEO 2012, Figure 108
Financial input data (SpOGFinData.txt) • OGAbCFr(OGUnit,Year) OG Abandonment Cost Fraction ($/($/Yr)) • OGITxRate(OGUnit,Year) OG Initial Tax Rate ($/$) • XDevCap(OGUnit,Year) Exogenous Development Capital Costs ($/mmBtu) • XDisCap(OGUnit,Year) Exogenous Discovery Capital Costs ($/mmBtu) • XSusCap(OGUnit,Year) Exogenous Sustaining Capital Costs ($/mmBtu) • XOGOMCosts(OGUnit,Year) OG O&M Costs ($/mmBtu)	2014 CERI Report, Table 3.1 and Table 3.8 and Energy Briefing Note (Nov. 2010), Figure 6
Oil and gas play parameters (SpOGFinData.txt) • OGArea(OGUnit) 'Area' • OGECC(OGUnit) 'Economic Sector' • OGFuel(OGUnit) 'Fuel Type' • OGInitYear(OGUnit) 'Initial Year of Project (Year)' • OGNation(OGUnit) 'Nation' • OGNode(OGUnit) 'Natural Gas Transmission Node' • OGProcess(OGUnit) 'Production Process'	Various sources
Oil Production Costs (OilProdCost.txt) • OPUC(Process,Nation,Year) 'Oil Production Unit Full Cost ($/mmBtu)'	ECCC sources
Price/Cost Variables (vData.accdb) • XENPN(Fuel,Nation,Year) 'Wholesale Energy Prices (1985 US$/mmBtu)' • XFP(Prices,Area,Year) 'Delivered Fuel Price ($/mmBtu)'	ECCC sources

The variables listed in this sector hold data either as part of calculations for the oil and gas production model or as outputs produced. A more comprehensive list of variable names and their use in the model can be found in their respective files in ENERGY 2020. Table 8 identifies the key variables used in the simulation of the discovery, development, and production of oil and gas plays.

Table 8. Oil and Gas Sector Variable Definitions for Simulating Oil and Gas Plays

Endogenous Model Code Model Variables (SpOGProd.src) Key variables produced by the endogenous oil and gas production module
Discovery Variables • DisCap(OGUnit) 'Discovery Capital Costs ($/mmBtu)' • DisDep(OGUnit) 'Discovery Depreciation ($/mmBtu)' • DisExp(OGUnit) 'Discovery Expenses ($/mmBtu)' • DisROI(OGUnit) 'Discoveries Return on Investment ($/$)' • DisRate(OGUnit) 'Discovery Rate (Btu/Btu)' • Dis(OGUnit) 'Discoveries (TBtu/Yr)' • DisRateM(OGUnit) 'Discoveries Rate Multiplier (Btu/Btu)'
Development Variables • DevCap(OGUnit) 'Development Capital Costs ($/mmBtu)' • DevDep(OGUnit) 'Development Depreciation ($/mmBtu)' • DevExp(OGUnit) 'Development Expenses ($/mmBtu)' • DevROI(OGUnit) 'Development Return on Investment ($/$)' • DevRate(OGUnit) 'Reserve Development Fraction (Btu/Btu)' • Dev(OGUnit) 'Development of Reserves (TBtu/Yr)' • DevRateM(OGUnit) 'Development Rate Multiplier (Btu/Btu)'
Production Variables • PdROI(OGUnit) 'Production Return on Investment ($/$)' • PdExp(OGUnit) 'Production Expenses ($/mmBtu)' • PdROI(OGUnit) 'Production Return on Investment ($/$)' • PdRate(OGUnit) 'Production Rate (Btu/Btu)' • Pd(OGUnit) 'Production (TBtu/Yr)' • PdRateM(OGUnit) 'Production Rate Multiplier (Btu/Btu)'
Reserves Variables • RsDev(OGUnit) 'Proven Developed Reserves (TBtu)' • RsUndev(OGUnit) 'Proven Undeveloped Reserves (TBtu)' • RsUnprov(OGUnit) 'Unproven Reserves (TBtu)'
Price/Cost Variables • ByPrice(OGUnit) 'Byproducts Price ($/mmBtu)' • DilPrice(OGUnit) 'Diluent Price ($/mmBtu)' • ENPN(Fuel,Nation) 'Wholesale Price ($/mmBtu)' • FP(Prices,Area) 'Fuel Prices ($/mmBtu)'

Table 9 lists the variables used when calibrating to an exogenous forecast with price impacts and when aggregating the outputs of the oil and gas plays.

Table 9. Oil and Gas Sector Variable Definitions for Exogenous Forecast with Direct Impacts

Aggregate Oil Production Model Code Variables (SpOProd.src) Key variables produced by the summary level oil production code
• OAProd(Process,Area) 'Primary Oil Production (TBtu/Yr)' • O2AProd(Process,Area) 'Endogenous Primary Oil Production (TBtu/Yr)' • XOAProd(Process,Area) 'Exogenous Oil Production (TBtu/Yr)' • Imports(FuelEP,Nation) 'Primary Imports (TBtu/Yr)' • Exports(FuelEP,Nation) 'Primary Exports (TBtu/Yr)' • ENPN(Fuel,Nation) 'Primary Fuel Price ($/mmBtu)' • OPrTax(Process,Nation) 'Oil Production Tax ($/mmBtu)'
Aggregate Gas Production Model Code Variables (SpGProd.src)
• GAProd(Process,Area) 'Primary Gas Production (TBtu/Yr)' • OSM(Process,Nation) 'Oil Supply Multiplier (Btu/Btu)' • GSM(Process,Nation) 'Gas Supply Multiplier from Price Changes' • Imports(FuelEP,Nation) 'Primary Imports (TBtu/Yr)' • Exports(FuelEP,Nation) 'Primary Exports (TBtu/Yr)' • ENPN(Fuel,Nation) 'Primary Fuel Price ($/mmBtu)' • GPrTax(Process,Nation) 'Natural Gas Production Tax ($/mmBtu)'

2.8. Key Oil and Gas Output Files

The files listed below (Table 10) create customized output tables containing model inputs and outputs from the oil and gas supply sector. Several summary level files are produced automatically following each model run. A larger number of specific endogenous production outputs are available by passing the appropriate parameter switch when starting a new scenario run.

Table 10. Oil and Gas Sector Key Output Files

Summary Output Files	Detailed Output Files
• SpGas.txo • SpOil.txo	• OGCostSummary.txo • OGFinanceInputs.txo • OGFinanceOutputs.txo • OGIncomeStatement.txo • OGProductionInputs.txo • OGProdCheck.txo • OG2ProdCheck.txo • OGProductionSummary.txo • OGSummary.txo

3. Oil Refinery Production

The oil refinery module simulates the production of refined petroleum products by oil refineries across North America. Given refined petroleum product (RPP) demand, ENERGY 2020's oil refinery sector determines RPP production, imports, exports, flows, and crude oil processed by U.S., Canada, and Mexico oil refineries. A linear programming (LP) algorithm is used to generate these outputs by minimizing the cost of supplying all the RPP demands in North America subject to the constraints of refinery capacity, yields (maximum and minimum RPP outputs per barrel of crude input), and transportation limits for pipelines, train, marine, and trucks).

3.1. Key Inputs and Outputs

Inputs to the refinery supply sector include characteristics of the refineries based on type of crude oil input, and outputs include RPP production by refinery and quantities of crude oil feedstock. The key inputs to the oil refinery supply sector include:

- RPP demand (net of imports and exports from rest of world)
- Refinery capacity
- Refinery costs and prices (crude oil, RPP, and emergency supply)
- Crude oil maximum and minimum yields
- Crude oil costs and availability
- Transportation costs, capacity, and losses

The key outputs from the oil refinery supply sector include:

- RPP production by refinery
- Crude oil consumed
- RPP imports and exports
- RPP transportation flows and costs
- RPP emergency supply
- RPP nodal prices

Transportation flows of the refined petroleum products include:

- Inside Canada, Canada to US, Mexico, Rest of World
- Inside US, US to Canada, US to Mexico, US to Rest of World
- Mexico to Canada, Mexico to US, Mexico to Rest of World

3.2. Oil Refinery Sector Structures

The oil refinery sector simulates the refined petroleum product production of individual oil refineries, the amount and types of crude oil refined and the area where each refinery's production is sent. Currently, each model area has one aggregate oil refinery represented and located at one node for each area. Transportation between nodes is defined with a set of characteristics (variable costs to move RPPs between two nodes and maximum limits to be transported between any two nodes).

A transportation network is defined to simulate RPP flows between regions. Each refinery is located on a node within each area. The following table lists the oil refinery locations/nodes that are currently defined.

Table 11. Oil Refinery Locations (Nodes)

Oil Refinery Locations	
Ontario	California
Quebec	New England
British Columbia	Middle Atlantic
Alberta	East North Central
Manitoba	West North Central
Saskatchewan	South Atlantic
New Brunswick	East South Central
Nova Scotia	West South Central
Newfoundland	Mountain
Prince Edward Island	Pacific
Yukon Territory	Mexico
Northwest Territory	Alaska
Nunavut	Mexico Baja

The oil refinery supply module creates fourteen different refined petroleum products from seven types of crude oil inputs. Table 12 identifies the types of crude oil used as input to the refineries and the fuels considered to be refined petroleum products.

Table 12. Types of Crude Oil Inputs and Refined Petroleum Products Outputs

Crude Oil Inputs to Refinery Process	Fuels Defined as Refined Petroleum Products	
Conventional Light Foreign	Asphalt	LPG
Conventional Light Domestic	Aviation Gasoline	Lubricants
Conventional Heavy Foreign	Diesel	Naphtha
Conventional Heavy Domestic	Gasoline	Oil
Synthetic Light (Domestic)	Heavy Fuel Oil	NonEnergy
Crude Bitumen (Domestic)	Jet Fuel	PetroFeed
Condensates/C5 (Domestic)	Kerosene	PetroCoke
Other Material Charged	Light Fuel Oil	StillGas

3.3. Oil Refinery Logic (Objective Function of Linear Program)

The objective function of the linear program used to determine oil refinery production is to minimize the cost of supplying RPP products to meet demand in Canada, U.S., and Mexico, net of imports and exports subject to a set of constraints related to refinery, crude oil, and transportation as defined below.

Cost of supplying RPP products are defined by:

- Cost of purchasing crude oil
- Variable production cost
- Transportation cost
- Emergency supply cost

Constraints to RPP production LP include:

- Supply and demand must balance within each area (area's oil refinery production plus transportation flows must meet North America RPP demand). An "emergency supply" factor is introduced to ensure the LP can solve due to capacity or transportation constraints.
- RPP production capacity: RPP production must be less than the effective RPP production capacity
- RPP yields from crude oil (maximum and minimums): RPP production must be less than the maximum yield and greater than the minimum yield for each type of RPP.
- Crude oil production capacity: Crude oil processed at each refinery must be less than the production capacity of each refinery.
- Crude oil maximum availability to refinery: Crude oil processed must be less than the maximum crude oil available to each refinery.
- RPP production balance with crude oil processed: Total RPP production (summed over RPP) must be less than the crude oil processed.
- Transportation capacity: RPP flows are constrained by transportation path capacity.

Flows can include:

- Inside Canada, Canada to US, Mexico, ROW
- Inside US, US to Canada, US to Mexico, US to ROW
- Mexico to Canada, Mexico to US, Mexico to ROW

3.4. Input Data Requirements and Key Variables of Oil Refinery Sector

Historical input data required for the oil refinery includes demand, production, imports, exports, intra-country flows, crude oil processed, oil refinery production capacity. These data are obtained from Environment and Climate Change Canada via the Access database named, vData_OilRefinery.accdb. The input data and variables are listed in Table 13.

Table 13. Historical Oil Refinery Input Data

Historical Input Data Requirement	Variable Definition
RPP production (TBtu/Yr) - By refinery and fuel - By nation and fuel - By area and fuel	 XRfProd(RfUnit,Fuel,Year) XRPPProdNation(Fuel,Nation,Year) XRPPProdArea(Fuel,Area,Year)
RPP Imports (TBtu/Yr) - within North America by fuel - within North America total - to Rest of World	 XRPPImportsNation(Fuel,Nation,Year) XRPPImportsROW(Fuel,Area,Year) XRPPImports(Nation,Year)
RPP Exports (TBtu/Yr) - within North America by fuel - within North America total - from Rest of World	 XRPPExportsNation(Fuel,Nation,Year) XRPPExports(Nation,Year) XRPPExportsROW(Fuel,Area,Year)
Intra-country flows (TBtu/Yr) - Imports - Exports	 XRPPImportsArea(Fuel,Area,Year) XRPPExportsArea(Fuel,Area,Year)
Crude Oil Refined (TBtu/Yr)	XRPPCrude(Crude,Area,Year)
RPP supply adjustments (TBtu/Yr) - by fuel and area - by nation	 XRPPAdjustArea(Fuel,Area,Year) XRPPAdjustments(Nation,Year)
RPP Demands (TBtu/Yr)	XRPPDemandArea(Fuel,Area,Year)
Refining unit production capacity (TBtu/Yr)	XRfCap(RfUnit,Year)

Assumptions regarding prices, costs, transportation limits, and oil refinery yields are required for input to the oil refinery sector and are listed in Table 14. These assumptions are input to the model through a text file stored in the 2020Model subdirectory (RefiningData.txt).

Table 14. Input Data Assumptions Required for Oil Refinery Sector

Input Variable Name	Input Assumption Requirements Description
Oil Refining Prices and Costs	
OilPrRatio(Crude,Nation,Year)	Crude Oil Price Relative to World Oil Price ($/$)
RfVCProd(RfUnit,Fuel,Crude,Year)	Variable Cost of Processing Crude Oil ($/mmBtu)
Oil Refinery Transportation	
RfPathEff(GNode,GNodeX,RfMode,Year)	RPP Transmission Efficiency (Btu/Btu)

Input Variable Name	Input Assumption Requirements Description
RfPathVC(GNode,GNodeX,RfMode,Year)	Variable Cost of Transporting RPP ($/mmBtu)
RfTrMax(GNode,GNodeX,RfMode,Year)	RPP Transmission Capacity (TBtu/Year)
RPP Refining Yields	
RfMaxYield(RfUnit,Fuel,Crude,Year)	Maximum RPP Yield per Crude Oil (Btu/Btu)
RfMinYield(RfUnit,Fuel,Crude,Year)	Minimum RPP Yield per Crude Oil (Btu/Btu)

Table 15 lists the variables used to calibrate model equations to the historical data.

Table 15. Historical Calibration Variables for Oil Refinery Sector

Calibration Variable	Description
RfOOR(RfUnit,Fuel,Year)	Refining Unit Operational Outage Rate (Btu/Btu). Calculate operational outage rate of each refinery from historical calibration to use in projections of RPP production.
RfMaxCrude(RfUnit,Crude,Year)	Refinery Maximum Input Fraction of Crude Types (Btu/Btu) Calibrate crude oil processed using a limit for each type of crude for each refinery.

3.5. Potential Future Enhancements to Refinery Sector

An area for potential future enhancement of the oil refinery sector is to endogenously expand oil refinery capacity as needed based on a set of criteria. Capacity expansion could occur based on the following expansion rules:

1. **Exogenous expansion** - build new capacity according to what experts tell us will be built for refinery expansion.
2. **Reserve margin expansion** - build new capacity when demand exceeds a certain fraction of capacity.
3. **Economic expansion** - build under certain economic conditions (where there is financial incentive), such as a high price of refined petroleum products.

4. Biofuel Production

ENERGY 2020's biofuel module simulates the production of liquid biofuels – ethanol and biodiesel – used primarily for transportation. While in practice nearly all liquid biofuels demand currently come from the transportation sector, the model allows for potential demand from any sector. This document summarizes the key input and output variables from the biofuel module as well as summarizes the methodology used to calculate biofuel production.

The biofuel module determines production, production capacity, imports, exports, fuel demand, feedstock demands, emissions and prices. Emissions from the production of biofuels are assigned to the Biofuel Production economic sector while the emissions from the consumption of biofuels is attributed to the economic sector where the biofuel is consumed.

Biofuel production requires feedstocks and energy to transform the feedstocks. The main crops used to produce ethanol include corn, wheat, cellulosic (by-product of crops, such as stalks, leaves, sheaths, husks, and cobs), and less frequently other grains, such as sugar cane, sorghum, and barley. Corn ethanol is produced through fermenting and distilling in two production processes: wet milling and dry milling.

Biodiesel is a fuel made from vegetable oils, fats, or greases—such as recycled restaurant grease. The production process is called transesterification which converts oils and fats into chemicals. The crops used to produce biodiesel include rapeseed oil and other high-oil content crops.

4.1. Biofuel Supply Sector Structures

Within ENERGY 2020, biofuel production is simulated based on a combination of an energy source and a feedstock. The energy sources, or technologies, represented in the model consist of electricity, gas, oil, coal, biomass, solar, and LPG. The feedstocks currently consist of Corn, Wheat, Cellulosic, Rapeseed oil, and Other. These potential feedstock-technology options for biofuel production represented in ENERGY 2020 are shown in the table to the right.

Biofuel Production Feedstocks and Energy Sources

Biofuel	Feedstock	Potential Technologies	
Ethanol	Corn Wheat Cellulosic	Electric Gas Oil	Coal Biomass Solar LPG
Biodiesel	Rapeseed oil Other	Electric Gas Oil	Coal Biomass Solar LPG

To simulate the biofuel production industry, a new economic sector (ECC) was created, named *Biofuel Production*. This ECC is inserted in the list of ECCs following *Utility Generation*. Additionally, two entirely new sets were created – *Biofuel* and *Feedstock*. The entries in the Biofuel set are Ethanol and Biodiesel, and the entries in the feedstock set are Corn, Wheat, Cellulosic, Rapeseed, and Other. The source code calculating the biofuel production is located in *SpBiofuels.src*. Input and output variables are defined in *SpInput.src* and *SpOutput.src* respectively.

Activating the biofuel module: The biofuel module calculates biofuel production and is activated by setting a switch, *BiofuelSwitch=1*. The biofuel input data are assigned values in a text file housed in \2020Model, *SpBiofuel_Data.txt*, and the source code is contained in \Engine*SpBiofuel.src*.

Biofuel module key outputs: In addition to the amount, type, and location of biofuel production, several other variables are output from the model as a byproduct of production. An output file, *SpBiofuel.dta*, contains most of the input and output variables from the biofuel module. The key output variables are listed below:

- Biofuel production ($BfProd_{(Biofuel,Tech,Feedstock,Area,Year)}$)
- Energy used to produce biofuels ($BfDmd_{(Tech,Area,Year)}$)
- Biofuel feedstock required for production ($BfFsReq_{(Biofuel,Tech,Feedstock,Area)}$)
- Emissions generated during biofuel production ($BfPol_{(FuelEP,Poll,Area,Year)}$)
- Wholesale price of biofuel ($BfENPN_{(Biofuel,Nation,Year)}$)

4.2. Methodology

ENERGY 2020 uses consumer choice logic to determine which of the feedstock-fuel options biofuel producers likely will choose in terms of market shares. These consumer choice market share equations factor in the costs of the various types of production along with assumptions about the impact of non-price factors influencing the propensity toward or resistance to particular types of production processes. ENERGY 2020 then applies the resulting market shares to the total expected biofuel production. Canada biofuel production capacity is allocated to areas based on historical data. The imports and exports are based on historical data and modified as biofuel demands and capacity change. See the Methodology section for further details.

Market share calculation

ENERGY 2020 uses consumer choice equations to estimate market shares for each of the ethanol and biodiesel feedstock-technology options factoring in the levelized costs (BfMCE) of each production option combined with parameters on price (BfVF) and non-price factors (BfMSM0). The equation used to determine the market share (BfMSF) of the various technology options involves calculating a marginal allocation weight (BfMAW) for each of the technology options and a total of the marginal allocation weight (BFTAW).

The market share for each of the technologies is its marginal allocation weight divided by the total allocation weight as shown in the equations below:

$$BfMAW = exp(BfMSM0+BfVF*LN(BfMCE/BfMCE0))$$
$$BfTAW(Bf,Area) = sum(Tech,Fs)(BfMAW(Bf,Tech,Fs,Area))$$
$$BfMSF = BfMAW/BfTAW$$

Biofuel production is then calculated by applying the calculated market shares for each feedstock-technology option to the total ethanol and biodiesel.

The levelized marginal costs of energy (BfMCE) are calculated from input data on fixed cost and variable costs using the following equations:

$$BfVC = (BfCC*BfOF)*Infla+BfECFP*BfEff+BfFsPrice/BfFsYield*1E6$$
$$BfMCE = BfCCR*BfCC/BfCUFP*Infla+BfVC$$

Where:

- $BfVC_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel variable cost ($/mmBtu)
- $BfMCE_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel Levelized Marginal Cost ($/mmBtu)
- $BfCC_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production capital cost ($/mmBtu)
- $BfOF_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production O&M cost factor ($/$/Year)
- $BfECFP_{Tech,Area,Year}$ = Fuel prices for biofuel production ($/mmBtu)
- $BfEFF_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production energy efficiency (Btu/Btu)
- $BfFsPrice_{Feedstock,Area,Year}$ = Biofuel feedstock price ($/Tonne)
- $BfFsYield_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel yield from feedstock (Btu/Tonne)
- $BfCCR_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production capital charge rate ($/$)
- $BfCC_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production capital cost ($/mmBtu)
- $BfCUFP_{Biofuel,Tech,Feedstock,Area,Year}$ = Biofuel production capacity utilization factor for planning (mmBtu/mmBtu)

The values for these input values are shown in *Appendix 2. Key Biofuel Supply Sector Input Data Assumptions*. Parameters on non-price factors (BfMMSM0) are draft estimates which will be revised as data becomes available, and ultimately BfMMSM0 will be calibrated to the historical data. The variance factor, bfVF (or parameter on price), is assumed to be equal to the price parameter used in the industrial sector consumer choice equations (-2.5).

Biofuel Sector Calculations

The model code that simulates biofuel production is called from Procedure *SupplyBiofuel* within *SpBiofuel.src*. The specific calculations performed within the biofuel supply sector are shown in the flow diagram of Figure 3.

Figure 3. Biofuel Supply Flow Diagram

1. Calculate biofuel demands

↓

2. Calculate levelized costs of Biofuel production processes

↓

3. Calculate market shares of Biofuel production processes

↓

4. Calculate biofuel production capacity (Retirements, replacements, new additions)

↓

5. Calculate production to meet biofuel demand

Step 1: Calculate biofuel demand.

Assign ethanol and biodiesel demand to *BfDemNation* variable from demand module in *TotDemand*.

BfDem(Bf,Area)=sum(ECC,Fuel)(TotDemand(Fuel,ECC,Area))
BfDemNation(Bf,Nation)=sum(Area)(BfDem(Bf,Area))

Demand is used to create production targets BfProdTargetN and BfProdTarget for each area based on their historical share of national production BfProdFrac.

BfProdTargetN=BfDemNation-XImports+XExports
*BfProdTarget(Bf,Area)=sum(Nat)(BfProdTargetN(Bf,Nat)*BfProdFrac(Bf,Area,Nat))*

Step 2. Calculate levelized cost of production processes. Calculate levelized marginal cost for ethanol and biodiesel technology (feedstock-technology) option:

*BfVC=(BfCC*BfOF)*Infla+BfECFP*BfEff+BfFsPrice/BfFsYield*1E6*
*BfMCE=BfCCR*BfCC/BfCUFP*Infla+BfVC*

Step 3. Calculate market share for each ethanol and biofuel technology options.

*BfMAW=exp(BfMSM0+BfVF*LN(BfMCE/BfMCE0))*
BfTAW(Bf,Area)=sum(Tech,Fs)(BfMAW(Bf,Tech,Fs,Area))
BfMSF=BfMAW/BfTAW

Step 4. Calculate biofuel production capacity (Retirements, replacements, new additions).

Calculate production capacity, production retired, and new production added for the ethanol and biodiesel technologies:

a. Calculate total production capacity indicated, *BfCapI*. Apply the technology market shares to the ethanol and biodiesel demand-based target production assuming no limit on the amount of production capacity. A capacity utilization factor, BfCUFP, is assumed to be equal to 0.80 indicating that the amount of capacity will be set 20% higher than the amount of demand.

   *BfCapI=BfProdTarget*BfMSF/BfCUFP*

b. Calculate the capacity retired, BfCapRR. The amount retired, BfCapRR, is last year's production capacity divided by the lifetime, BfPL=10 (1/10th will retire each year).

   BfCapRR=BfCapPrior/BfPL

c. The amount of new capacity built in the given year – the capacity completion rate, BfCapCR. The completion rate in the given year is the amount of capacity indicated by the demand, BfCapI, minus the amount of capacity already built, BfCap, plus the amount of capacity retired:

BfCapCR=BfCapI-BfCap+BfCapRR

d. The amount of capacity this year, BfCap, then is the amount of existing capacity plus the amount built this year minus the amount retired:

BfCap=BfCap+BfCapCR-BfCapRR

Step 5. Calculate biofuel production.

a. Total biofuel production is assumed equal to the total biofuel demand. The capacity, BfCap, is used to split the target production by feedstock and technology into production, BfProd:

BfCapTotal(Bf,Area)=sum(Tech,Fs)(BfCap(Bf,Tech,Fs,Area))
*BfProd=xmin(BfCap*BfProdTarget/BfCapTotal,BfCap*BfCUFMax)*
*BfProdNation(Bf,Nation)=sum(Tech,Fs,Area)(BfProd(Bf,Tech,Fs,Area)*ANMap(Area,Nation))*

b. Imports and Exports will fill the differences between production and demand.

Imports=xmax(BfDemNation-BfProdNation+XExports-SupplyAdjustments,0)
Exports=xmax(BfProdNation-BfDemNation+Imports+SupplyAdjustments,0)

Step 6. Calculate summary output variables:

- Capacity utilization, BfCUF
- Energy Usage, BfDmd, EUDemand
- Feedstock Required, BfFsReq
- Production Emissions, BfPol, EnFPol

5. Other Supply (Coal and Steam)

5.1. Coal Production

The coal supply sector is represented by the Coal Mining economic category. Coal production is determined based on demand for coal plus exports minus imports. Demand for coal is input from the demand sector and the electric utility supply sector. For areas identified as able to increase production, coal exports from North America to the rest of the world are based on the local coal price relative to the export market coal price. Coal prices are increased by emission taxes if present. Coal imports are used to balance demand, production, and exports for areas with limited production. Using a switch, any model area's coal production, exports, or imports can be specified exogenously.

Each region's coal production capacity is identified as unlimited, limited, or exogenous using a model switch. If the switch is set equal to exogenous, then production is the maximum of the exogenous production or the demand from the region. Areas with unlimited production have exogenous levels of imports.

Each province or territory's exports are treated uniquely based on the characteristics of their coal industry. Exports being determined based on the local coal price relative to the export price is an option available for areas where this is appropriate. The other areas tend to have a fixed level of exports, if any.

5.2. Steam Production

Most steam generation is simulated inside the sector which utilized the steam. The "steam generation sector" simulates the facilities which are operated to sell steam to other sectors. As such the steam generated is the steam which is purchased by other sectors. The steam generation sector simulates the fuel use and emissions required to generation the steam sold to other sectors.

Appendix 1. Oil and Gas Plays Represented in ENERGY 2020

Table 16. Initial Oil and Gas Plays Represented in ENERGY 2020

OG Name	OGFuel	Economic Category (ECC)	Production Process
Alberta			
Alberta Light Oil	LightOil	LightOilMining	LightOilMining
Alberta Shale Light Oil	LightOil	LightOilMining	ShaleOil
Alberta Heavy Oil	HeavyOil	HeavyOilMining	HeavyOilMining
Alberta Primary Oil Sands	Bitumen	PrimaryOilSands	PrimaryOilSands
Alberta SAGD Oil Sands	Bitumen	SAGDOilSands	SAGDOilSands
Alberta CSS Oil Sands	Bitumen	CSSOilSands	CSSOilSands
Alberta Oil Sands Mining	Bitumen	OilSandsMining	OilSandsMining
Alberta Oil Sands Upgraders	Synthetic	OilSandsUpgraders	OilSandsUpgraders
Alberta Sweet Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Alberta Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Alberta Coalbed Methane	SweetGas	ConventionalGasProduction	Coalbed
Alberta Sour Natural Gas	SourGas	UnconventionalGasProduction	UnconventionalGasProduction
British Columbia			
BC Light Oil	LightOil	LightOilMining	LightOilMining
BC Shale Light Oil	LightOil	LightOilMining	LightOilMining
BC Offshore Light Oil	LightOil	LightOilMining	LightOilMining
BC Sweet Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
BC Sour Natural Gas	SourGas	UnconventionalGasProduction	UnconventionalGasProduction
BC Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Manitoba			
Manitoba Light Oil	LightOil	LightOilMining	LightOilMining
Manitoba Shale Light Oil	LightOil	LightOilMining	ShaleOil
Manitoba Heavy Oil	HeavyOil	HeavyOilMining	HeavyOilMining
New Brunswick			
New Brunswick Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Newfoundland Labrador			
NL Light Oil	LightOil	FrontierOilMining	FrontierOilMining
Hebron	LightOil	FrontierOilMining	FrontierOilMining
Hibernia	LightOil	FrontierOilMining	FrontierOilMining
Terra Nova	LightOil	FrontierOilMining	FrontierOilMining
White Rose	LightOil	FrontierOilMining	FrontierOilMining
NL Sweet Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Nova Scotia			
Nova Scotia Light Oil	LightOil	FrontierOilMining	FrontierOilMining
Nova Scotia Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Deep Panuke	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Glen Chebucto	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Sable Island	SweetGas	ConventionalGasProduction	ConventionalGasProduction

Table 17. Initial Oil and Gas Plays Represented in ENERGY 2020 (Continued)

OG Name	OGFuel	Economic Category (ECC)	Production Process
Nunuvut			
NT Light Oil	LightOil	FrontierOilMining	FrontierOilMining
Arctic Islands Light Oil	LightOil	FrontierOilMining	FrontierOilMining
Mackenzie Delta Light Oil	LightOil	FrontierOilMining	FrontierOilMining
NT Shale Light Oil	LightOil	FrontierOilMining	ShaleOil
NT Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Ontario			
Ontario Light Oil	LightOil	LightOilMining	LightOilMining
Ontario Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Saskatchewan			
Saskatchewan Light Oil	LightOil	LightOilMining	LightOilMining
Saskatchewan Shale Light Oil	LightOil	LightOilMining	ShaleOil
Saskatchewan Heavy Oil	HeavyOil	HeavyOilMining	HeavyOilMining
SK Oil Sands InSitu	Bitumen	SAGDOilSands	SAGDOilSands
SK Oil Sands Upgraders	Synthetic	OilSandsUpgraders	OilSandsUpgraders
SK Sweet Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
SK Sour Natural Gas	SourGas	UnconventionalGasProduction	UnconventionalGasProduction
Yukon Territory			
Yukon Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
United States			
Northeast Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Northeast Other Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Gulf Coast Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Gulf Coast Tight Gas	SweetGas	ConventionalGasProduction	TightGas
Gulf Coast Other Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Midcontinent Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Midcontinent Other Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Rocky Mtn Shale Gas	SweetGas	ConventionalGasProduction	ShaleGas
Rocky Mtn Tight Gas	SweetGas	ConventionalGasProduction	TightGas
Rocky Mtn Coalbed Methane	SweetGas	ConventionalGasProduction	Coalbed
Rocky Mtn Other Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Pacific Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
Alaska Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction
US Crude Oil	LightOil	LightOilMining	LightOilMining
Mexico			
Mexico Natural Gas	SweetGas	ConventionalGasProduction	ConventionalGasProduction

Appendix 2. Key Biofuel Supply Sector Input Data Assumptions

Table 17, Table 18, Table 19, and Table 20 list the assumptions and sources, where relevant, for input requirements of the biofuel supply sector covering general assumptions and those related to financial inputs, cogeneration and feedstocks.

Table 17. Biofuel Supply Sector General Input Data Assumptions and Sources

Description	Variable Name (Set Dimensions)	Value	Source
Biofuel Production Capacity Utilization Factor for Planning (mmBtu/mmBtu)	**BfCUFP** Biofuel,Tech, Feedstock,Area,Year	Value = 0.80	Per Jeff Amlin
Biofuel Production Capacity Utilization Factor Maximum (mmBtu/mmBtu)	**BfCUFMax** Biofuel,Area	Future = 0.90 Historical = 1	Per Jeff Amlin
Biofuel Production Energy Efficiency (Btu/Btu)	**BfEff** Biofuel,Tech, Feedstock,Area,Year	.035 to.033 from 2009 to 2013	ECCC spreadsheet: "Biofuel_Module_Parameters_Rob_05Jan2015.xlsx"
Biofuel Market Share Non-Price Factor (mmBtu/mmBtu)	**BfMSM0** Biofuel,Tech, Feedstock,Area,Year	Electric=-2.4 Gas=0.0 Oil=-3.25	Draft estimates which will be revised and ultimately calibrated once historical data are available.
Biofuel Production as a Fraction of National Demands (Btu/Btu)	**BfProdFrac** Biofuel,Area,Nation		Input based on historical Biofuels production.
Biofuel Production Physical Lifetime (Years)	**BfPL** Year	10 years	Set equal to Industrial Heat lifetime for a preliminary value.
Biofuels to Prices Map (1=Map)	**BfPricesMap** Biofuel,Prices	Equal to 1, based on set selections	We do not have Biodiesel prices; Temporarily using Diesel
Biofuel Pollution Coefficient (Tonnes/TBtu)	**BfPOCX** FuelEP,Poll,Area, Year	Value = 0.0	Preliminary values based on Industrial POCX, EC: Chemicals, Enduse: Heat.
Biofuel Market Share Variance Factor (mmBtu/mmBtu)	**BfVF**; Biofuel,Tech, Feedstock,Area,Year	Value = -2.5	Set same as Industrial XMVF for a preliminary value
Map between Tech and Prices	**TechPricesMap** Tech,Prices	Equal to 1, based on set selections	No specific Biodiesel prices; Temporarily using Diesel

Table 18. Biofuel Supply Sector Input Data Assumptions - Financials

Description	Variable Name	Value	Source
Biofuel Production Capital Cost, Real $/mmBtu	**BfCC** Biofuel,Tech, Feedstock,Area,Year	Value = 0.9661 $CN/Litre Ethanol in 2013	"Biofuel_Module_Parameters _Rob_05Jan2015.xlsx" *With adjustments based on judgment.
Biofuel Production Capital Charge Rate, $/$	**BfCCR** Biofuel,Feedstock, Area	Value = 0.08	Reduced from standard value due to low interest rates per Jeff Amlin.
Biofuel Delivery Charge, Real $/mmBtu	**BfDChg** Prices,Area,Year	Value = 0.0	
Biofuel Production O&M Cost Factor, Real $/$/Yr	**BfOF** Biofuel,Tech, Feedstock,Area,Year	Value = 0.05	Standard value
Biofuel Production Subsidy, $/mmBtu	**BfSubsidy**; Nation,Year	Value = 0.0	
Biofuel Production O&M Costs (Real $/mmBtu)	**BfUOMC** Biofuel,Tech, Feedstock,Area,Year	Value = 0.13 $CN/litre ethanol in 2013	ECCC spreadsheet: "Biofuel_Module_Parameters _Rob_05Jan2015.xlsx"

Table 19. Biofuel Supply Sector Input Data Assumptions - Cogeneration

Description	Variable Name (Set Dimensions)	Value	Source
Cogeneration Capital Cost; $/mmBtu/Yr	**CgCC** Tech,Area,Year	CgCC=ICgCC	From Industrial Database CgCC for Other Chemicals
Cogeneration Capacity Utilization Factor, Btu/Btu	**CgCUF** Tech,Area	Value = 0.894	Same as Industrial database CgCUFP for Other Chemicals
Cogeneration Demands Fuel/Tech Split, Btu/Btu	**CgFrac** Fuel,Tech,Area, Year	CgFrac=ICgFrac	From Industrial database, using CgFrac from Other Chemicals
Cogeneration Market Share; Btu/Btu	**CgMSF** Tech,Area,Year	Value = 0.0	Per J. Amlin
Cogeneration Operation Cost Fraction; $/Yr/$	**CgOF** Tech,Area	Value = 0.05	Standard value
Cogeneration Equipment Lifetime (Years)	**CgPL** Tech,Area.	Value = 25	Industrial Cogeneration physical lifetime for a preliminary value.

Table 20. Biofuel Supply Sector Input Assumptions - Feedstocks

Description	Variable Name	Value	Source
Biofuel Feedstock Price, $/Tonne	**BfFsPrice** Feedstock,Area, Year	Value = 259.02 for 2011; similar prices in other years	ECCC spreadsheet: Biofuel_Module_Parameters_v2.1.xlsx
Biofuels Feedstock Yield, Btu/Tonne	**BfFsYield** Biofuel,Tech, Feedstock,Area, Year	Value = 4978846.621 for 2008	Based on %efficiency from a theoretical maximum of 427 Litres per metric tonne of Corn Stover. Source: http://www.ethanolproducer.com/articles/9658/survey-cellulosic-ethanol-will-be-cost-competitive-by-2016; file Biofuel_Module_Parameters_v2.1.xlsx