ENERGY 2020 Documentation

Volume 1

Overview 2020

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Table of Contents

1. INTRODUCTION **1**

1.1. Organization of this Document 2
1.2. Other ENERGY 2020 Resources Available 2

2. ENERGY 2020 OVERVIEW **3**

2.1. Demand Sector Characteristics 5
2.2. Supply Module Characteristics 6
2.3. Modeling Approach 7
2.4. Incorporating Technology Innovation 8
2.5. Sensitivity Analysis 10
2.6. Inputs and Outputs by Sector 11
2.7. Order of Model Execution 14

3. DEMAND MODULE **17**

3.1. Demand Mechanics Overview 18
3.2. Tracking Capital Stock 20
3.3. Efficiency Choice Curve 21
3.4. Fuel Market Share Calculation 24
3.1. Cogeneration Energy Demand (including Direct Self-Generation) 25
3.2. Feedstock Energy Demand 26
3.3. Demand Sector Calibration 27

4. SUPPLY MODULE **30**

4.1. Methodology Overview 30
4.2. Electric Supply Sector 32
4.3. Oil and Gas Production 36
4.4. Oil Refinery Sector 38
4.5. Biofuel Production 41
4.6. Coal and Steam Production 43
4.7. Supply Sector Calibration 44

5. EMISSIONS TRACKING **46**

5.1. Sources and Types of Pollutants 46
5.2. Calculating Emissions 47
5.3. Emissions Reduction Mechanisms 47
5.4. Structures in Place to Define Emissions Prices or Cap-and-Trade 52

6. MACROECONOMIC INTEGRATION **55**

6.1. Current Interface Linking to Canadian Macroeconomic Model 55
6.2. Data Transfers 56

7. POLICY ANALYSIS USING ENERGY 2020 .... **59**

7.1. Advantages of using ENERGY 2020 for Policy Analysis 59
7.2. Process of Policy Analysis 61
7.3. Policy Files to Modify Model Variables 62

8. MODEL SOURCE CODE **64**

9. INPUT DATA AND ASSUMPTIONS **69**

APPENDIX 1. U.S. REGIONS DEFINED BY STATE **1**
APPENDIX 2. FUELS AND END-USE TECHNOLOGIES **2**
APPENDIX 3. TECHNOLOGY INNOVATION ASSUMPTIONS **5**
APPENDIX 4. ECONOMIC DRIVERS **7**
APPENDIX 5. CONSUMER CHOICE THEORY OVERVIEW **10**
APPENDIX 6: CALCULATING EMISSIONS COEFFICIENTS **13**

Table of Tables

TABLE 1. ECONOMIC CATEGORIES REPRESENTED IN ENERGY 2020 5
TABLE 2. CHARACTERISTICS OF ENERGY 2020 DEMAND SECTORS 6
TABLE 3. CHARACTERISTICS OF ENERGY 2020 SUPPLY SECTORS 7
TABLE 4. DEMAND SECTOR INPUTS AND OUTPUTS 11
TABLE 5. SUPPLY SECTOR INPUTS AND OUTPUTS 12
TABLE 6. KEY DEMAND CALIBRATION VARIABLES 27
TABLE 7. AUTOMATED OPTIONS FOR PROJECTING CALIBRATION VARIABLES 28
TABLE 8. CALIBRATION VARIABLES - INITIAL PROJECTION METHODS AND ADJUSTMENT FILES 29
TABLE 9. SUPPLY SECTOR METHODOLOGY AT-A-GLANCE 31
TABLE 10. PLANT TYPES REPRESENTED IN ENERGY 2020 34
TABLE 11. PRODUCTION PROCESSES OF OIL AND GAS PLAYS 37
TABLE 12. OIL AND GAS PRODUCTION ALGORITHMS 38
TABLE 13. OIL REFINERY LOCATIONS (NODES) 40
TABLE 14. TYPES OF CRUDE OIL INPUTS AND REFINED PETROLEUM PRODUCTS OUTPUTS 40
TABLE 15. SUPPLY MODULE CALIBRATION VARIABLES 44
TABLE 16. POLLUTANTS REPRESENTED IN ENERGY 2020 46
TABLE 17. INDUSTRIES AND POLLUTANTS IMPACTED BY OFFSETS AND REDUCTION COST CURVES 50
TABLE 18. POLLUTANTS REDUCED BY OIL AND GAS INDUSTRY WORK PRACTICES 52
TABLE 19. NAMING CONVENTIONS – PREFIXES ON SOURCE CODE FILE NAMES 64
TABLE 20. DEMAND SECTOR CODE FILE NAMES 65
TABLE 21. ELECTRIC SUPPLY SECTOR CODE FILE NAMES 66
TABLE 22. NON-ELECTRIC SUPPLY CODE FILE NAMES (OIL, GAS, REFINERY, BIOFUEL, COAL) 67
TABLE 23. MACROECONOMIC SOURCE CODE FILE NAMES 68
TABLE 24. MISCELLANEOUS SOURCE CODE FILE NAMES 68
TABLE 25. DETAILED FUEL TYPES REPRESENTED IN ENERGY 2020 2
TABLE 26. END-USE TECHNOLOGIES BY SECTOR 2
TABLE 27. TECHNOLOGY INNOVATION BY 2040 – RESIDENTIAL EFFICIENCY 5
TABLE 28. TECHNOLOGY INNOVATION BY 2040 – COMMERCIAL EFFICIENCY 5
TABLE 29. TECHNOLOGY INNOVATION BY 2040 – INDUSTRIAL EFFICIENCY 6
TABLE 30. TECHNOLOGY INNOVATION LEARNING RATES – ELECTRIC SECTOR CONSTRUCTION COSTS 6
TABLE 31. ECONOMIC DRIVERS FOR CANADA, U.S., AND MEXICO ENERGY DEMAND 7

Table of Figures

Figure 1. ENERGY 2020 Model Structure 3
Figure 2. Default Demand Areas in ENERGY 2020 4
Figure 3. ENERGY 2020 Flow Diagram 14
Figure 4. Demand Sector Methodology Diagram 18
Figure 5. Efficiency/Capital Cost Trade-Off Curve 22
Figure 6. Capital Cost Trade-Off Curve 22
Figure 7. Efficiency Curve Exception Based on CO2 Price 24
Figure 8. Market Share Mechanics 25
Figure 9. Default Transmission Nodes 33
Figure 10. Sample Policy Analysis Capabilities by Sector 59
Figure 11. Steps to Creating a Policy Simulation 61

1. Introduction

ENERGY 2020 is an integrated, all-fuel, end-use, energy and emissions model that simulates the North American energy supply and demand market on an annual basis through 2050 and beyond. The model is used to forecast energy and emissions as well as to perform energy and emissions-related policy analyses. Projections include energy consumption, efficiency, investments, production, imports, exports, and fuel prices given a variety of assumptions regarding factors such as economic indicators, consumer preferences, characteristics of energy technologies, resource availability and costs, transmission constraints, and the regulatory environment. Projections also include energy and non-energy related emissions across eighteen greenhouse gas pollutants and criteria air contaminants. ENERGY 2020 is able to be dynamically linked to a macroeconomic model to create a powerful fully integrated energy-emissions-economy modeling system.

ENERGY 2020's methodologies make it an ideal use for policy analysis. The model is designed with a bottom-up, causal approach simulating a detailed, integrated energy system. Principles of consumer choice theory are applied to provide realistic simulation of consumer decisions, and principles from system dynamics are applied to track capital stock turnover. With this approach, detailed policies are able to be simulated showing impacts of feedback effects across sectors and fuels and interaction effects of running multiples policies simultaneously. Some examples of the types of policies analyzed using ENERGY 2020 are listed below.

Policy examples able to be analyzed using ENERGY 2020:

- Energy and emission taxes and incentives
- Carbon cap-and-trade systems
- Clean air standards
- Energy efficiency measures
- Appliance and building standards
- Landfill gas regulations
- Vehicle emissions regulations
- Clean fuel standards
- Renewable energy requirements
- Industrial generation

ENERGY 2020 is proprietary software maintained by Systematic Solutions, Inc. and is used by government agencies, climate action groups, and utilities to develop long-range energy and emissions projections and to conduct energy and emissions-related policy analyses.

The ENERGY 2020 framework is customizable and can be calibrated and/or modified to represent any particular energy source or geographical area. Additionally, the end-uses and economic sectors in the model are able to be customized and can be as detailed as the user can accommodate. This documentation describes the model configuration in the 2019 default version of the model.

1.1. Organization of this Document

This Overview documentation provides a summary of the overall design, structure, and methodologies used within ENERGY 2020. The sections contained in this model overview are: 1) Introduction; 2) ENERGY 2020 Overview; 3) Demand Module; 4) Supply Module; 5) Emissions Tracking; 6) Macroeconomic Integration; 7) Policy Analysis; and 8) Model Source Code.

For specifics on how execute the model to obtain a reference case forecast and policy scenarios as well as how to view model outputs, and basic mechanics of the programming language, please refer to *ENERGY 2020 Procedures Manual and Appendix April 2017*.

1.2. Other ENERGY 2020 Resources Available

For further detail on ENERGY 2020 modules, refer to the list of available documentation below. The model documentation covers details of each module, specifics on conducting policy analysis, an assumptions book, and a procedures manual which describes the mechanics of running the model.

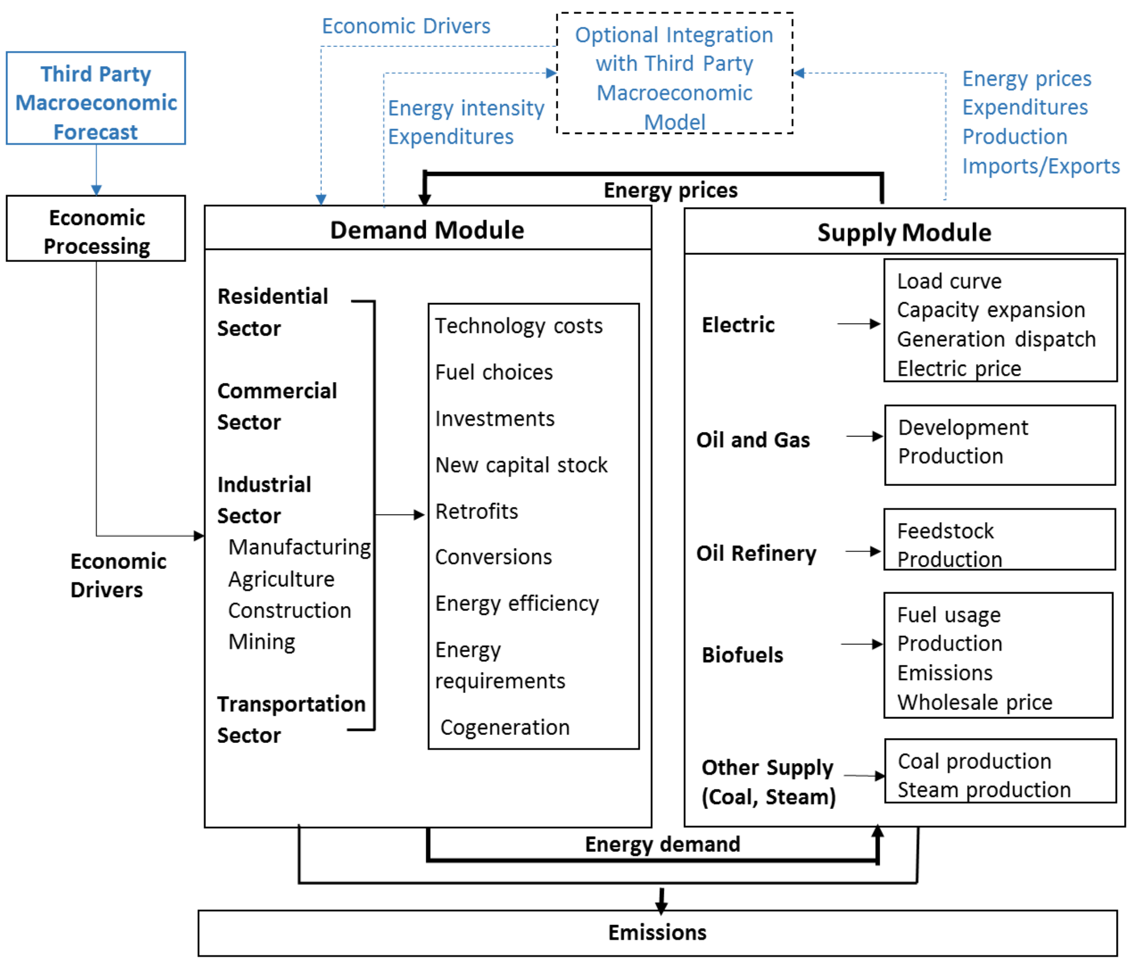
ENERGY 2020 Documentation Available:

- Volume 1: ENERGY 2020: An Overview
- Volume 2: Demand Sector Structure and Code
- Volume 3: Demand Sector Theoretical Derivation
- Volume 4: Electricity Supply
- Volume 5: Oil, Gas, and Other Supply
- Volume 6: Policy Analysis
- Volume 7: Input Data and Assumptions
- Volume 8: Data Dictionary
- ENERGY 2020 Procedures Manual

2. ENERGY 2020 Overview

ENERGY 2020 is an integrated regional, multi-sector energy analysis system that simulates energy supply, price and demand across twenty-five detailed fuel types (Table 25 in *Appendix 2. Fuels and End-Use Technologies*). It uses economic drivers to drive energy demand which must be met by energy supplies (local or imports). Figure 1 illustrates the overall structural design of ENERGY 2020. The energy demand module consists of four sectors (residential, commercial, industrial, and transportation). Energy demands are calculated and sent as input to the supply module consisting of six energy producing sectors – electricity, oil and gas, refinery, biofuels, coal, and steam. The supply module produces the energy required to meet the energy demand, calculates energy prices, and sends energy prices back as feedback to the demand sector. Both energy and non-energy related emissions are tracked covering eighteen separate greenhouse gas (GHG) pollutants and criteria air contaminants (CAC) plus water usage.

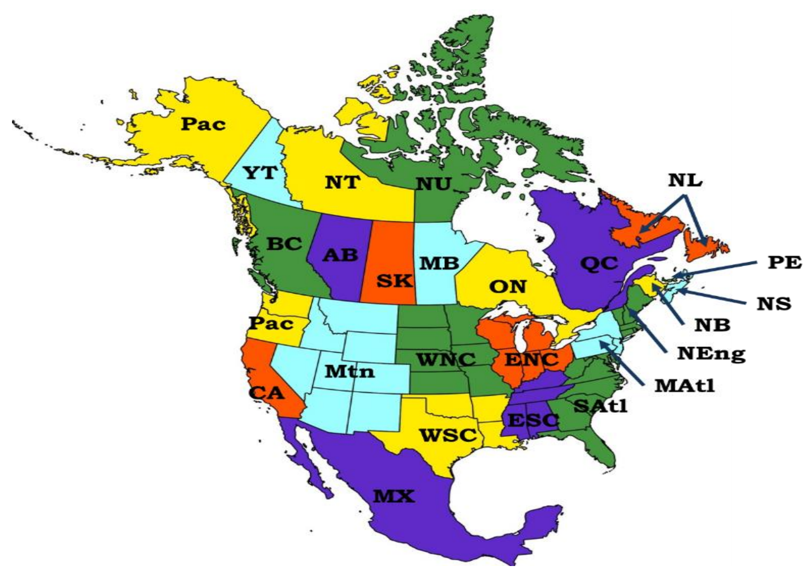
Figure 1. ENERGY 2020 Model Structure



Shown with dashed lines, Figure 1 illustrates the optional integration with a third-party macroeconomic model. ENERGY 2020 is able to be dynamically linked to a macroeconomic model resulting in a fully integrated energy-emissions-economic (E3) modeling system. In this "integrated" case, the energy supply and demand sectors feed policy impacts to the macroeconomic model which then sends economic impacts the demand sector. Indirect impacts from the macroeconomic model are sent to the supply sector through changes in energy demand. This process iterates up to five times each forecast year until convergence is met based on a specified tolerance level. See *Section 6*. *Macroeconomic Integration* for more detail on integration with a macroeconomic model. If a third-party macroeconomic model is not linked to ENERGY 2020, then ENERGY 2020 inputs static economic drivers from an exogenous macroeconomic forecast. The economic forecast in this "non-integrated" case remains constant regardless of policy.

The currently-defined areas in the model are shown on the map in Figure 2. Each U.S. state is simulated individually within the model; however, the current configuration aggregates the states into ten U.S. regions (matching the census divisions reported by the U.S. Energy Information Administration) with California being split out from the Pacific region (for purposes of modeling the Western Climate Initiative's cap-and-trade system). See *Appendix 1. U.S. Regions Defined by State* for a list of the U.S. states assigned to each of the U.S. census division areas. For Canada, each province and territory is represented individually, and Mexico is represented at an aggregate national level.

Figure 2. Default Demand Areas in ENERGY 2020



The specific economic categories, or types of consumers, represented in the model are able to be customized; however, the default version currently splits out three (3) residential and twelve (12) commercial classes, forty-three (43) industries, and eight (8) transportation economic categories in addition to several miscellaneous categories (see Table 1). The miscellaneous categories include three (3) used to hold fuel demands from suppliers not otherwise accounted for in the industrial sector - electric utility generation, biofuel production, and steam generation (where steam generation category simulates the facilities which are operated to sell steam to other sectors). Miscellaneous categories also include eight (8) that are specific to tracking non-combustion related emissions (solid waste, waste water, incineration, land use, road dust, agriculture open sources, forest fires, and Biogenics).

Table 1. Economic Categories Represented in ENERGY 2020

Residential	Commercial	
Single Family	Wholesale Trade	Health Care and Social Assistance
Multi-Family	Retail Trade	Arts, Accommodation, Food, Other
Other Family	Warehousing and Storage	Natural Gas Distribution
	Information and Cultural Industries	Oil Pipelines
	Offices	Natural Gas Pipelines
	Educational Services	Street Lighting

Industrial			
Food & Tobacco	Rubber	Iron Ore Mining	Conventional Gas production
Textiles Apparel & Leather	Cement	Other Metal Mining	Sweet Gas Processing
Lumber	Glass	Non-Metal Mining	Unconventional Gas Production
Furniture	Lime & Gypsum	Light Oil Mining	Sour Gas Processing
Pulp and Paper Mills	Other Non-Metallic	Heavy Oil Mining	LNG production
Converted Paper	Iron & Steel	Frontier Oil Mining	Coal Mining
Petrochemicals	Aluminum	Primary Oil Sands	Construction
Industrial Gas	Other Nonferrous Metal	SAGD Oil Sands	Forestry
Other Chemicals	Transport Equipment	CSS Oil Sands	
Fertilizer	Other Manufacturing	Oil Sands Mining	
Petroleum Products		Oil Sands Upgraders	

Transportation		Other Miscellaneous Categories		
Passenger	Foreign Passenger	Miscellaneous	Solid Waste	Road Dust
Freight	Foreign Freight	Electric Resale	Wastewater	Agriculture Open Sources
Air Passenger	Residential Off-Road	Utility Electric Generation	Incineration	Forest Fires
Air Freight	Commercial Off-Road	Biofuel Production	Land Use	Biogenics
		Steam Generation		

2.1. Demand Sector Characteristics

The demand module provides long-range projections of total energy demand (end-use, cogeneration, and feedstock), emissions, energy efficiency, and investments for each of the residential, commercial, industrial, and transportation sectors. Energy demands are projected for all economic categories (household types, building types, industry types, and transportation modes), end-use technologies, and areas represented in the model. The economic drivers chosen to drive energy demands for each of Canada, U.S., and Mexico areas of the model are identified in Table 31 of *Appendix 4. Economic Drivers.*

Table 2 below summarizes the structural characteristics represented in ENERGY 2020's current default configuration within each of the four demand sectors.

Table 2. Characteristics of ENERGY 2020 Demand Sectors

<table>
<tr><th>Energy Sector</th><th>Categories Represented
(Default)</th><th>Regional Representation
(Default)</th></tr>
<tr><td>Residential Demand Sector</td><td>• Three housing types
• Seven end-uses (space heating, water heating, other substitutables, refrigeration, lighting, air conditioning, other non-substitutables)
• Nine technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal)</td><td rowspan="4">Demand Sector Areas:
• U.S. – 10 demand regions consisting of 9 EIA-defined census divisions plus California split out
• Canada – 14 provinces and territories (with Newfoundland and Labrador split)
• Mexico – 1 nation</td></tr>
<tr><td>Commercial Demand Sector</td><td>• Twelve commercial sectors
• Seven end-uses (Space heating, water heating, other substitutables, refrigeration, lighting, air conditioning, other non-substitutables)
• Nine technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal)</td></tr>
<tr><td>Industrial Demand Sector</td><td>• Forty-three industrial sectors
• Seven end-uses (process Heat, motors, other substitutables, miscellaneous, off-road, excess steam)
• Ten technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal, off-road)</td></tr>
<tr><td>Transportation Demand Sector</td><td>• Eight transportation economic categories (Passenger, Freight, Air Passenger, Air Freight, Foreign Passenger, Foreign Freight, Off Road Passenger, Off Road Commercial)
• Forty-five technology types (eight light duty vehicle and eight light duty truck types, motorcycle, buses, trains, air planes, marine, and 16 heavy duty vehicle categories)</td></tr>
</table>

2.2. Supply Module Characteristics

ENERGY 2020's supply module produces electricity, crude oil, natural gas, biofuels, refined petroleum products, coal, and steam to meet the fuel demands required by the residential, commercial, industrial, transportation, and miscellaneous demand sectors. The model has the capability to produce an endogenous forecast for each of these sectors, use an exogenous forecast, or a combination of both depending on model switches set by the user. Table 3 summarizes the characteristics of each supply sector, including the plant types, generating units, production processes, regions, and electric transmission nodes represented in the current default configuration of the model.

Table 3. Characteristics of ENERGY 2020 Supply Sectors

<table>
<tr><th>Energy Sector</th><th>Categories Represented
(Default)</th><th>Regional Representation
(Default)</th></tr>
<tr><td>Electricity Supply Sector</td><td>Capability for individual generating unit representation:
• 930 aggregated electric generating units in U.S.
• 1,485 individual generating units in Canada
Twenty-four plant types:
• Nine conventional plant types; twelve renewable types; and three other.
• Minimizes costs to meets demand (from all residential, commercial, industrial, and transportation demand sectors)</td><td>Electric transmission Nodes:
• U.S. - 22 electric supply nodes
• Canada - 14 nodes, one for each province and territory plus Labrador
• Mexico - 1 node</td></tr>
<tr><td>Oil and Gas Supply Sector</td><td>• Fourteen production processes (Light Oil, Heavy Oil, Frontier Oil Mining; Oil Sands – Primary, CSS, SAGD, Mining, Upgraders – Conventional Gas, Unconventional Gas, Sweet Gas Processing, Sour Gas Processing, Pentanes Plus, Condensates, and LNG production)
• Oil and gas “plays” from U.S, Canada, and Mexico</td><td rowspan="4">Oil and gas, refinery, biofuel, and coal supply regions:
• U.S. – 10 regions
• Canada – 13 provinces and territories
• Mexico – 1 nation</td></tr>
<tr><td>Oil Refining Supply Sector</td><td>• Twelve refined petroleum products (asphalt, aviation gas, diesel, heavy fuel oil, jet fuel, kerosene, light fuel oil, LPG, lubricants, Naphtha, other non-energy, and other oil products)
• Meets North America demand (refines based on minimizing costs)</td></tr>
<tr><td>Biofuels Supply Sector</td><td>• Two biofuels produced (Ethanol and Biodiesel)
• Five feedstocks (Corn, Wheat, Cellulosic for Ethanol, and Rapeseed and Other for Biodiesel)
• Production, imports and exports to meet demand (most demands from transportation sector)</td></tr>
<tr><td>Coal and Steam Supply Sectors</td><td>• No special structures were created to simulate the coal and steam supply sectors.
• Production, imports and exports to meet demand</td></tr>
</table>

2.3. Modeling Approach

ENERGY 2020’s modeling approach is designed to make model results understandable and realistic, establishing a one-to-one relationship between the model and the real world. ENERGY 2020 uses algorithms that simulate a realistic decision-making process for each economic actor and associated real-world factors. For instance, in the real world, utilities dispatch electricity to minimize system costs with the help of a linear program. The algorithms within ENERGY 2020 mimic this process when simulating the dispatch for plants into the future. Consumers making decisions regarding purchasing a new appliance or car, however, generally do not act optimally, but rather make decisions based on limited information available combined with personal preferences. ENERGY 2020 reproduces the consumers’ decision-making process by simulating actual (rather than optimized) responses, allowing it to capture the nuances of technology selections that a standard optimization model is likely to miss. See *Section 3. Demand Module* and *Section 4. Supply Module* for descriptions of specific methodologies used to simulate the demand and supply sectors. By stressing causality, the methodology allows for rational explanations of how policies impact the real world. See *Section 7. Policy Analysis using ENERGY 2020* for more detail on the benefits of ENERGY 2020's methodology for policy analysis.

Demand Module Methodology: A Snapshot

ENERGY 2020 uses the same modeling approach and methodology across each of the residential, commercial, industrial, and transportation sectors building up energy demand from the energy requirements within the energy system. ENERGY 2020 tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases in which consumers and businesses make sequential acquisitions with limited foresight about the future. Principles from consumer choice theory (using multinomial logistic functions incorporating price and non-price factors related to consumer perceptions of utility) are used to simulate how consumers make decisions of new technology purchases impacting energy efficiency levels and fuel market shares.

Supply Sector Methodology: A Snapshot

Within the supply module, the electric sector uses optimization to dispatch individual electric generating units to minimize system costs while meeting electricity demand. The oil, gas, refinery, and biofuel supply modules, can optionally accept exogenous forecasts from third party sources as input or calculate endogenous projections based on a user switch. When an exogenous forecast is input to the oil and gas module, a price response mechanism is added to allow policies to impact oil and gas production. Endogenous projections are able to be selected for any one or all of the supply sectors. The oil and gas supply sector routines simulate production for an aggregate set of oil and gas plays using fuel prices and the characteristics of each play including capital, O&M, and fuel costs, taxes and royalties, and reserves. The biofuels sector assumes production equals demand and uses consumer choice theory to simulate which production processes (feedstock-fuel combinations) are used by the suppliers. Oil refineries produce RPPs based on a linear program that selects the optimal type, amount, and transportation flows of RPP production which minimizes costs. The coal sector production is assumed to match the level of coal demand plus exports where exports from coal producing regions are determined by local coal prices relative to export market coal prices.

2.4. Incorporating Technology Innovation

Energy demand and supply technologies evolve over time due to invention, innovation, and learning through experience which results in lower costs and higher efficiencies. These technology innovations impact future energy demand and supply requirements therefore are incorporated into several of ENERGY 2020's demand and supply sector technologies. The specific method used to simulate technology innovation is dependent on whether a specified technology's innovation is thought to be based on global (world-wide) or local (Canada and U.S.) experience. For technologies whose innovation is thought to be based on a global experience, global trends in efficiency and capitals costs are assumed from external sources and directly input to the model. For technologies whose innovation is thought to be based on a local base of experience, a learning curve is added to the model. The sections below summarize the technology innovation incorporated into ENERGY 2020. For a more detailed methodology description, see *Volume 8 (Input Data and Assumptions)*.

Demand Sector Technology Innovation Based on Global Experience

Technologies in the residential, commercial, and industrial demand sectors currently are assumed to have a global base of experience across all building and industry types. That is, in order for innovation shifts to occur with demand sector technologies (represented by end-use technologies in ENERGY 2020, such as furnaces, water heaters, process heaters), it is assumed that a base of experience larger than the North American areas represented in the model needs to be considered. To obtain estimates of global trends of endogenous technological change for these technologies, efficiency projections were derived from those reported in the U.S. EIA's *2014 Annual Energy Outlook*. Where technology trends were available, ENERGY 2020's efficiency curves were shifted upward such that, for a given price point, higher efficiency levels would be chosen in the future with no significant increase in capital cost. Efficiency trends are input for the residential, commercial, and industrial demand sectors for certain appliances and equipment (heating, cooling, water heating, refrigeration, and lighting devices). Incorporating technology trends for transportation have not yet been added to the model; however, are expected to be added in the next update cycle. Table 27, Table 28, and Table 29 (*Appendix 3. Technology Innovation Assumptions*) lists the global-experience based efficiency increases incorporated into the model by residential, commercial, and industrial sector respectively for specific devices (appliances/equipment) where data was available from EIA. For technologies in ENERGY 2020 where global trends were not found (such as with process, or building shell, efficiency), trends in efficiency improvements were estimated from historical data and projected through the forecast period.

Electric Sector Technology Innovation Based on Local Experience

Technology innovation within the electric supply sector of ENERGY 2020 is assumed to be a function of local experience (based on development within both Canada and the U.S.). For the technologies which are expected to improve efficiency or reduce costs as the electric utility industry gains experience, endogenous technological change learning curve parameters are incorporated. As Canada or the U.S. invests in new electric generating technologies (like solar and wind) the cost of those technologies will drop (and/or efficiencies improve). Learning curve parameters are derived from learning rates reported in EIA's 2014 NEMS model documentation[1] and listed in Table 30 in *Appendix 3. Technology Innovation Assumptions*. Where technology innovation learning rates are not available, an assumed "rule-of-thumb" is used such that that as the installed capacity doubles, the costs are reduced by 20%.

2.5. Sensitivity Analysis

Sensitivity analysis can be performed using a formal approach, such as the Latin-Hypercube sampling approach, or an informal approach by varying values of the key input assumptions.

The Latin-Hypercube quantifies the impacts of uncertainty (such as price of electricity, capacity requirements, or energy costs per consumer unit). A set of variables are identified for which to test uncertainty. Each of these variables is assigned a probability distribution, then the input parameters are varied simultaneously to capture the more realistic "all-else-not-equal" conditions. The following steps are performed when conducting Latin-Hypercube approach to uncertainty analysis:

1) Identify the key inputs (independent variables)
2) Identify the key outputs (dependent variables)
3) Develop a probability distribution for each independent variable
4) Generate a Latin Hypercube sample of values for the independent variable
5) Execute ENERGY 2020 using the samples' values
6) Analyze the model results to generate sensitivity and uncertainty information on the dependent variables (model outputs)

The number of independent variables is often restricted by the work required to develop the probability distributions. However, the distributions can initially be specified with a wide variance, and the initial results would then provide information on the benefit of refining the distributions.

Another technique which is simpler, but generates less statistical information, is to vary each independent variable one-at-a-time, execute the model, and analyze the results. This

[1] U.S. Energy Information Administration, "The Electricity Market Module of the National Energy Modeling System: Model Documentation 2014", August 2014 http://www.eia.gov/forecasts/aeo/nems/documentation/electricity/pdf/m068(2014).pdf

technique provides a measure of the importance of each independent variable and can assist in determining which are "key" variable and thus deserve additional attention.

2.6. Inputs and Outputs by Sector

As was shown in Figure 1, the primary data transfers between the demand and supply modules are energy demand and energy prices. Table 4 provides a snapshot view showing more specific detail of the demand sector's key inputs and outputs. All demand sectors share the same methodology; however, transportation sector has different types of input data definitions being slightly different from the others. Table 5 lists the key inputs and outputs to the supply sector. The inputs listed do not make up an exhaustive list, but rather highlight some key inputs.

Table 4. Demand Sector Inputs and Outputs

Sector	Outputs	Inputs from ENERGY 2020	Exogenous Inputs
Residential Demand Commercial Demand Industrial Demand	Energy demand (end-use, cogeneration, feedstock) by economic category, enduse, fuel, and area Emissions (from end-use, cogeneration, and feedstock demand) by pollutant Energy efficiency and capital costs of process energy (building shell and industrial processes) for historical and forecast period Energy efficiency and capital costs of devices/equipment for historical and forecast period Investments in processes (building shell) and devices (appliances) Spending on fuel expenditures and emissions reduction permits	Production capacity by vintage (residential and commercial floor space, industrial output) Energy prices from supply modules (electricity, oil, gas, RPP, and coal prices from prior year) Oil and natural gas production from prior year (driver for commercial pipelines, NG distribution and gas and industrial oil and gas mining) RPP and coal production from prior year (to drive petroleum products, and coal mining industries)	Macroeconomic (residential and commercial floorspace, households, industrial gross output, GDP, inflation index, exchange rate) Process (building shell or industrial process) and device (equipment) characteristics - Energy efficiency & capital costs for initialization year, where available - Energy efficiency maximums, physical lifetimes Existing building codes, energy efficiency standards, regulations Feedstock efficiency by industry Cogeneration characteristics (potential, heat rate) Emissions coefficients or inventories Technology innovation assumptions Emissions coefficients, inventories Emissions caps or reduction requirements

Sector	Outputs	Inputs from ENERGY 2020	Exogenous Inputs
Transportation Demand	Energy demand for all passenger, freight, and off-road vehicle types (45 modes) Transportation-related emissions Energy efficiency and capital costs of transportation processes and devices/vehicles Investments in transportation processes and devices/vehicles Spending on fuel expenditures and emissions reduction permits	Production capacity (people transported) Fuel prices from supply modules (biofuels and refined petroleum product prices, such as gasoline, diesel from prior year) Emissions caps or reduction requirements	Economic drivers (population, personal income, GDP) Existing and new vehicle characteristics (efficiency and capital costs for initialization year, lifetimes) Vehicle safety and emissions regulations Emissions coefficients or inventories Emissions caps or reduction requirements

Table 5. Supply Sector Inputs and Outputs

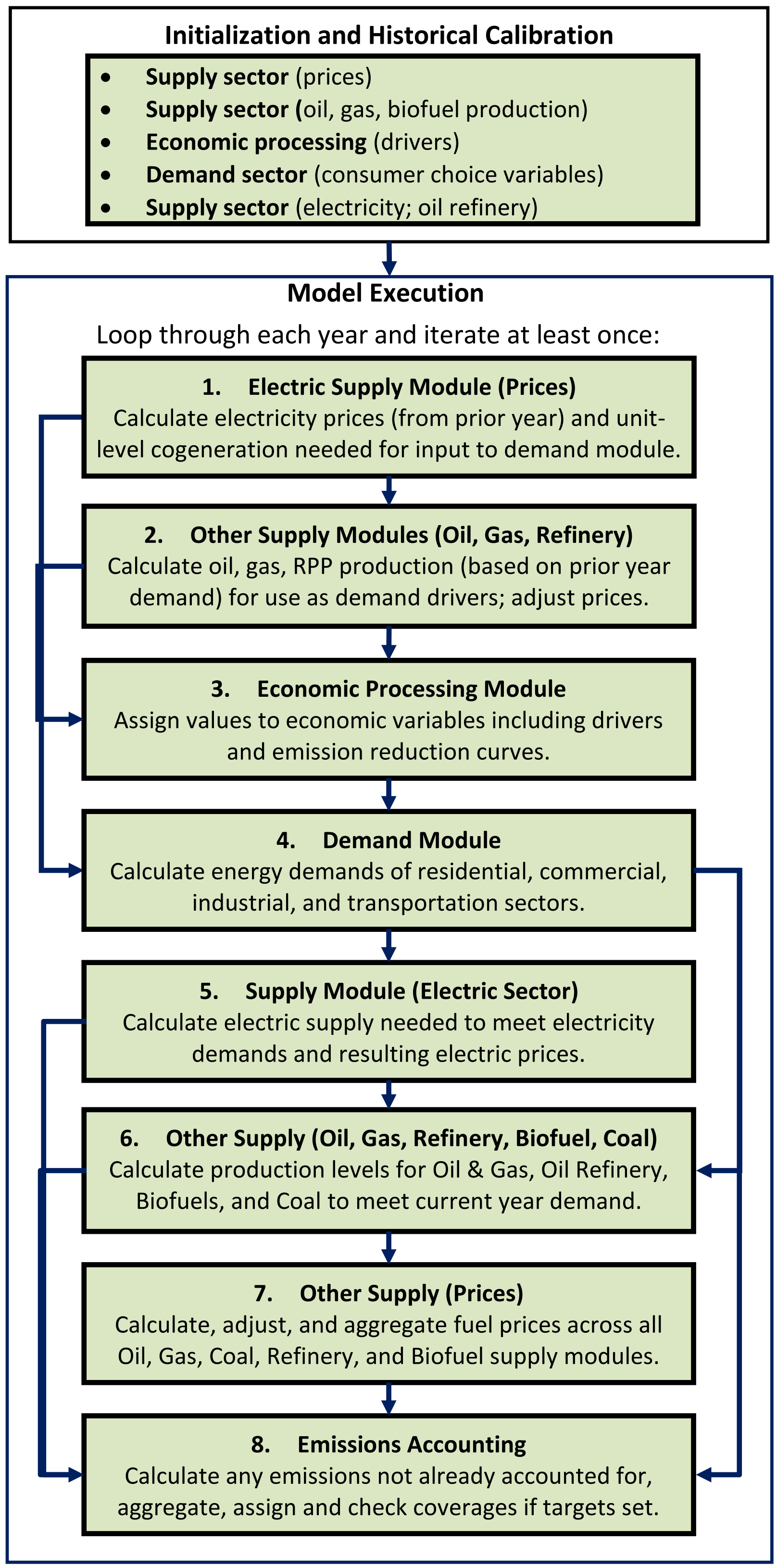
Sector	Outputs	Inputs from ENERGY 2020	Exogenous Inputs
Electricity Supply	Electricity capacity, generation, transmission flows, imports and exports Fuel usage required to generate electricity (energy demand for Electric Utility Generation industry) Emissions from electric generation Electricity prices Spending on fuel expenditures and emissions reduction permits	Consumer demand for electricity (residential, commercial, industrial, transportation) Peak, average, minimum load by season and time period	Existing and new plant characteristics (location, capacity, plant type, costs, etc.) Technology innovation curves Emissions coefficients or inventories Emissions caps or reduction requirements
Oil and Gas Supply	Crude oil and natural gas production	Demand for oil and gas fuels from residential, commercial, industrial, transportation demand sectors and electric utility supply sector	Development rate assumptions Wholesale price of oil and gas Financial input data (capital costs, O&M costs, return on investment, production costs) Depletion and learning curves Tax policies, environment regulations Emissions caps or reduction requirements
Oil Refinery Supply	Production of twelve refined petroleum products Amount of crude oil used as feedstock	Demand for refined petroleum products (from Petroleum Products industry) Delivered price of refined petroleum products	Costs of oil refining Wholesale prices Characteristics of refineries (refinery capacity, yields, maximum and minimum output per barrel of crude input) Transportation limits and costs

Sector	Outputs	Inputs from ENERGY 2020	Exogenous Inputs
Biofuel Supply	Biofuel (ethanol and biodiesel) production Feedstocks required to produce biofuels Emissions generated during biofuel production Wholesale price of ethanol and biodiesel Fuel usage to produce biofuels (energy demand for Biofuel Production industry)	Demand for ethanol and biodiesel (primarily from transportation sector)	Characteristics of biofuel production (physical lifetime, energy efficiency, biofuel production as fraction of national demand) Costs of producing ethanol and biodiesel Feedstock prices and yields Emissions coefficients Assumptions of price and non-price factors for consumer choice market share equations used until historical data are available
Coal Supply	Coal production Coal imports and exports Delivered price of coal	Demand for coal (from demands sectors and electric utility sector)	Local coal prices Export market coal price Emission taxes

2.7. Order of Model Execution

Figure 3 illustrates the order in which ENERGY 2020 modules are executed for each forecast year in relationship to each other. First ENERGY 2020 initializes the model by assigning values to model variables for a historical initialization year (typically 1985), then it calibrates model equations to the historical input data obtaining calibration variables to be used in making projections. The model initialization and calibration steps are executed for all sectors within the demand and supply modules. After initialization and calibration, ENERGY 2020 is ready to execute model equations used to forecast long-range annual projections of the energy demand and supply system. Model execution first is performed for the historical period to obtain model outputs back through history. Next, the model execution is run over the projection period during which ENERGY 2020 loops through each forecast year and performs the operations in the order shown in the flow diagram (Figure 3).

Figure 3. ENERGY 2020 Flow Diagram



Model Execution Steps 1 and 2. Electric Supply Module (Prices); Other Supply Modules (Oil, Gas, Refinery): The initial two steps of model execution run portions of the supply module to gather and prepare supply sector variables required for input to the demand module, specifically fuel prices, unit-level industrial cogeneration, and production levels used to drive energy demands for certain industries, such as oil and gas mining. Because the demand module requires energy prices and production levels as inputs, yet the supply module has not yet been executed, the prior year's values are brought in for use as initial estimates. Additionally, whereas industrial cogeneration is calculated within the demand sector, optional unit-level representation of industrial generators are able to be specified and calculated in the electric sector for input to the demand module. This unit-level cogeneration is determined before the demand module is executed.

Step 3. Economic Processing Module: Step three, economic processing, translates macroeconomic indicators obtained from an external macroeconomic forecast into economic drivers of energy demand. The economic processing module also calculates non-energy related emissions, such as process emissions, due to economic activity and assigns values to parameters of any potential emission reduction curves that have been activated.

Step 4. Demand Sector Module: Using inputs of energy prices and economic drivers together with initialization and calibration values, the demand sector module code calculates enduse, cogeneration, and feedstock energy demands for each of residential, commercial, industrial, and transportation sectors. Each of the residential, commercial, industrial, and transportation sectors is executed sequentially – first calculating annual energy demands then translating those demands into load curves (by season/month and peak, minimum, and average day types) for input to the electric supply module. Other outputs include projections of emissions, energy efficiency and capital costs, investments, and expenditures.

Step 5. Supply Module (Electric Sector): The load curves output from the demand module are used as input to the supply module's electric supply sector which builds new generating capacity, if required, and dispatches individual generating units to meet the demands while minimizing system costs (subject to a set of constraints). The fuel used to generate electricity by the electric utility industry is then calculated along with resulting emissions from electricity generation and delivered price of electricity.

Step 6. Other Supply (Oil, Gas, Refinery, Biofuel, and Coal): The remaining supply sector modules (oil and gas, oil refinery, biofuels, and coal) are executed to calculate production levels given energy demands calculated in the demand module. The production forecasts are able to be input exogenously or calculated endogenously based on a user-selected switch (see *Section*

4. Supply Module Overview for more details). Outputs from these supply sectors include production, imports, and exports, costs of production, and emissions from production.

Step 7. Other Supply (Prices): Energy prices resulting from the costs of production determined in Steps 5 and 6 are calculated and aggregated as part of step seven. Prices are adjusted for pollution costs where applicable.

Step 8. Emissions Accounting: During the emissions accounting step, all of the emissions that have not already been calculated within the demand and supply modules are accounted for and added to the total emissions. These types of emissions include unit-level industrial cogeneration as well as non-energy related process emissions. Emissions from each of the economic categories (energy-related and non-energy related) are aggregated for the current year.

These eight model execution steps occur for each year with at least one iteration. The second iteration is run to allow price feedback from the first iteration's supply module's results to be incorporated into a second round of demand module calculations and vice versa. During the second iteration, energy prices from the first iteration are able to be used as input to the demand module during the second iteration rather than prices from the prior year. Typically, no more than two iterations are performed with the exception of policy runs where emissions limits are set. In those instances, each year iterates (with increased pressure for emission reduction, such as increased fossil fuel costs) until the emissions are reduced to targeted levels.

The following section provides an overview of the general methodology and calculations performed to simulate the residential, commercial, industrial, and transportation energy demand sectors within the demand module. *Section 4. Supply Module* then provides an overview of the specific methodologies used within each of the supply sectors simulated in the supply module.

3. Demand Module

Outputs from ENERGY 2020's demand module include energy demand, emissions, energy efficiency, capital cost, investment, and expenditures. These outputs are detailed by type of consumer, fuel, end-use, and area as well as accounting for each type of fuel demand (end-use, cogeneration, and feedstock) and for each of the residential, commercial, industrial, and transportation sectors. Primary inputs to the demand module include economic drivers, energy prices, and technology characteristics.

This section provides a general overview of the methodology used in the demand module. More detailed descriptions can be found in subsequent volumes of ENERGY 2020 documentation: *Volume 2 (Demand Sector Structure and Code) and Volume 4 (Demand Sector Theoretical Derivation)*.

ENERGY 2020 models the energy demand system by defining the causal relationships among fuel prices, the economy, and energy demand. The interactions of price, the economy, and energy demand are highly dependent on energy efficiencies within the system (both process and device) as well as fuel market shares. If prices are high and the economy is growing, there will be a quick turnover of capital stock with increasing efficiency (assuming efficiency of new stock is greater than old). If economic growth is low, there will be less investment and a smaller turnover in capital stock and fewer changes in energy efficiency and other variables. ENERGY 2020 incorporates all the structure and detail necessary to capture these interactions within the energy system.

The same modeling approach and methodology is used to simulate each of the residential, commercial, industrial, and transportation sectors building up energy demand from the energy requirements within the energy system. As a technology vintage model, ENERGY 2020 tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases in which consumers and businesses make sequential acquisitions with limited foresight about the future. Principles from consumer choice theory are used to simulate how consumers make decisions of new technology purchases impacting energy efficiency levels and fuel market shares. To understand how ENERGY 2020 simulates energy demand, it is important to become familiar with three key methodologies that form the basis of the demand sector projections:

1. Tracking capital stock;
2. Modeling energy efficiency through trade-off curves; and
3. Determining fuel market shares.

3.1. Demand Mechanics Overview

Energy demand is assumed to be a consequence of consumers using capital stock (which requires energy) in the production of output. For example, the residential sector requires housing to provide sustained living services; the commercial sector requires buildings to provide services; and the industrial sector requires factories to produce output. In each of these cases, consumers use capital stock (building/factory) in the production of the sector's output (sustained living, commercial services, industrial output). The buildings require energy for heating, cooling, and electromechanical uses. The energy requirements of the building must be met by energy-using devices (appliances or equipment), such as furnaces, air conditioners, or motors. Within ENERGY 2020, the energy service requirements of the building are referred to as *process energy requirements*. The energy-using devices (appliances/equipment) required to meet the process energy requirements are referred to as *device energy requirements*. Determining the system's device energy requirements combined with utilization factors (including weather) along with cogeneration and feedstock demands yields total system energy demand.

Figure 4. Demand Sector Methodology Diagram

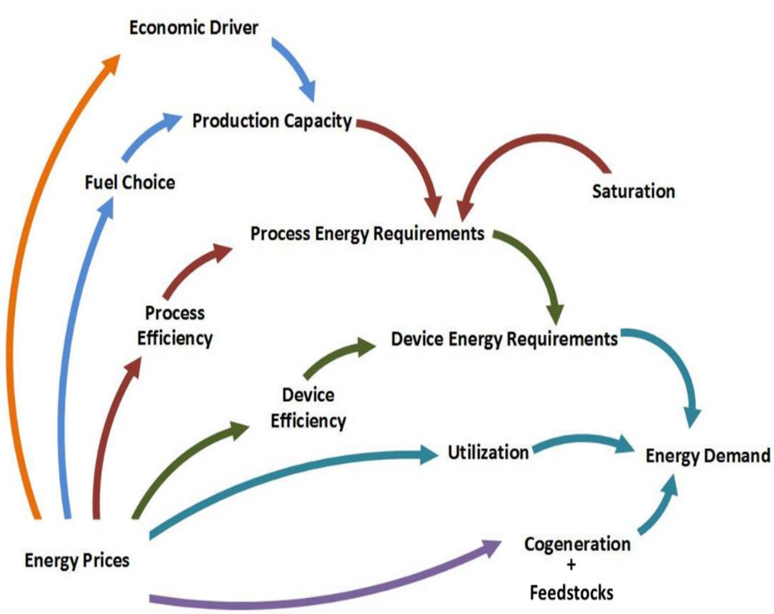


Figure 4 graphically illustrates the mechanisms used to determine energy demand. The diagram shows the causal structures that link energy prices and the economy to energy demand. Economic drivers are translated into production capacity by vintage (old, middle, new) as an indicator of each sector's economic output. For each forecast year, new production capacity is added commensurate with economic growth, and old production capacity is retired and replaced. Changes in production capacity drive changes in the need for process energy which, in turn, drives changes in the need for device energy. For example, the economic driver for Canada's residential energy demand is floorspace. In ENERGY 2020, floorspace is then translated into a production capacity variable. If there is growth in the residential sector, then there will be new construction of homes showing up as new floorspace. This increase in floorspace creates increased process energy requirements, such as for heating and cooling, which drives a need for new energy-using devices, such as furnaces and air conditioners, thereby increasing the device energy requirements.

> **Process and Device Energy**
>
> Process energy represents the energy services from capital stock used to produce output within each sector (housing for sustained living in residential, buildings to provide services in commercial, factories and industrial processes for producing output in industrial, and transportation infrastructure for transporting people in transportation). Process energy represents the building-level energy needs, such as heating and cooling. Process energy efficiency represents the building level efficiency and is impacted by insulation levels as well as consumers' usage patterns.
>
> Device energy represent the energy from specific energy-using equipment used to meet the process energy requirements. For example, a light bulb provides the device energy required by households' lighting or a car provides the device energy required by transporting needs.

The energy requirements of the system depend not only on changes to production capacity, but also on consumer choices of energy efficiency levels and fuel choices for new capital stock. For example, the energy efficiency of a house combined with the conversion efficiency of its furnace (which is dependent on the fuels chosen) are used determine how much energy the house uses to provide the desired warmth.

The energy efficiency of the building is referred to as *process efficiency* and is primarily technological (e.g. insulation levels) but can also be associated with control or life-style changes (e.g. less household energy use because both spouses work outside the home). Process efficiency is measured as unit of economic output per unit of energy input (e.g. $/Btu).

The efficiency of the furnace is referred to as *device efficiency* and represents a measure of thermal efficiency. Device efficiency is measured as unit of energy output per unit of fuel input (e.g. Btu/Btu). In transportation, device efficiency is measured as distance traveled per unit of fuel input (e.g. Km/PJ). Consumers choices of efficiency levels are based on trade-offs between capital costs and efficiency levels and are impacted largely by energy prices.

ENERGY 2020 uses saturation rates for devices to represent the amount of energy services necessary to produce a given level of output. Saturation rates may change over time to reflect changes in standard of living or technological improvements. For example, air conditioning has historically increased with rising disposable incomes. These rates can be specified exogenously or can be defined in relation to other variables within the model (such as disposable income).

In summary, the overall energy system in ENERGY 2020 is represented by production capacity, process energy requirements, device energy requirements which are impacted by fuel choices and efficiency levels (process and device). Device saturation levels indicate the penetration of particular devices in each sector. These factors combined with utilization and cogeneration (and feedstock demand) yield total energy demand. The equation for energy demand is shown below where device energy requirements incorporate all the structures discussed above and utilization factors are obtained from the historical calibration (see *Volume 4. Demand Sector Model Code*).

Energy Demand =
Device Energy Requirements x Utilization Factors x Weather Factors +
Cogeneration Demand + Feedstock Demand

The following sections provide an overview description of each of the key demand-sector methodologies: 1) Tracking capital stock; 2) Energy efficiency; and 3) Fuel market shares.

3.2. Tracking Capital Stock

To build up the system's energy requirements, ENERGY 2020 tracks retirements, replacements, and new additions of capital stock (in terms of energy). The three types of capital stock in the model include production capacity, process energy, and device energy.

The tracking of retirements, replacements and new additions of capital stock allows for tracking changes to the energy requirements of the system. Each year the capital stock levels and characteristics change due to one or more of the following:

- Retirements of capital stock due to wear-out (at end of physical lifetime); replaced with new capital stock (of the same technology type)
- Retirements of capital stock due to economic decline; not replaced
- Retirements of capital stock due to retrofits (before end of physical lifetime); replaced with new capital stock
- Additions of new capital stock due to economic growth

With this vintaging process, new improved capital stock gradually replaces older capital stock over time resulting in the average efficiency of total stock gradually reflecting newer higher levels of efficiency brought into the system. The energy requirement embodied in the capital stock can be changed only by new investments, retirements, or by retrofitting. The size and efficiency of the capital stock, and hence energy demand, change over time as consumers make new investments and retire old equipment. Consumers determine which fuel and technology to use for new investments based on perceptions of cost and utility. Marginal trade-offs between changing fuel costs and efficiency determine the capital cost of the chosen technology. These trade-offs are dependent on perceived energy prices, capital costs, operating costs, risk, access to capital, regulations and other imperfect information.

The key theory that drives the energy efficiency choices and fuel choices of new capital stock is consumer choice theory - particularly two formulations described briefly below.

3.3. Efficiency Choice Curve

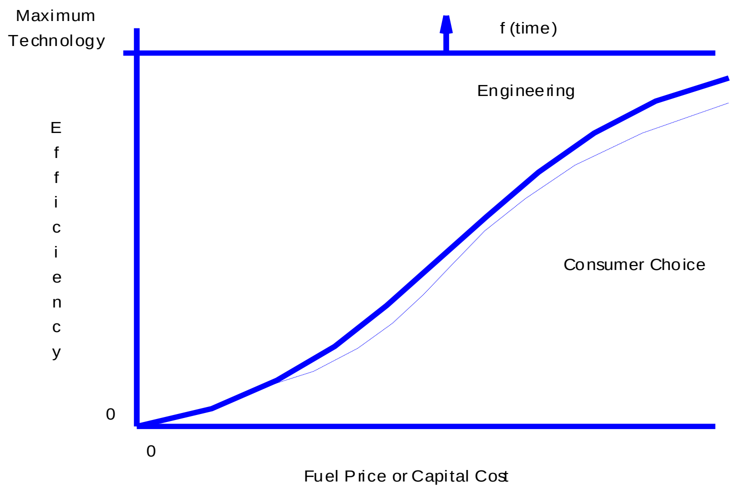
The first consumer choice formulation that is critical to the energy decision making process is the efficiency/capital cost trade-off. This is really a trade-off between high up-front costs and high future costs. If a very high efficiency furnace is purchased, the capital cost will be large, however, the operating costs in the future will be lower than with a lower efficiency furnace. The efficiency of the new capital purchased depends on the consumer's perception of this trade-off. For example, as fuel prices increase, the efficiency consumers choose for a new furnace is increased despite higher capital costs. The amount of the increase in efficiency depends on the perceived price increase and its relevance to the consumer's cash flow.

The standard ENERGY 2020 efficiency trade-off curves are called consumer-preference curves because they are estimated using cross-sectional (historical) data showing the decisions consumers made based on their perception of a choice's value. The efficiency with which the capital uses energy has a limit determined by technological or physical constraints.

Figure 5 illustrates this principal. Either fuel price or capital cost can be used on the horizontal axis. Each price corresponds to two efficiency levels. The engineering curve selects the economically optimal level of efficiency for each capital cost or fuel price. The more realistic curve is the consumer choice curve that shows a less than perfect relationship between efficiency and capital cost. The consumer choice curve reflects the fact that all additional capital cost dollars do not go into the purchase of higher efficiency. Top of the line appliances include many features (some energy using) that lower priced appliances do not. Self-defrosting freezers, ice makers, cold water spigots on the refrigerator door are all examples of the extra, energy using features, of high-end appliances.

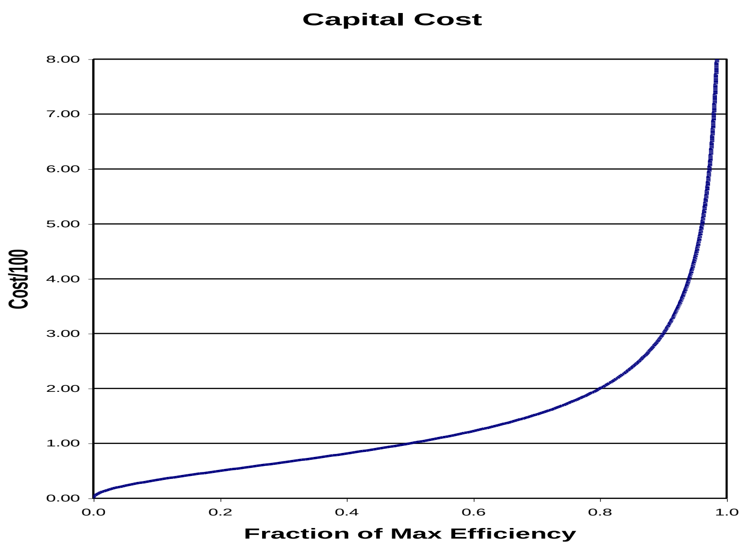
The “S” curves for both the engineering and consumer choice relationships are drawn against a maximum technology curve (a ceiling on efficiency given current technology) which can change over time as technological breakthroughs occur. As the maximum technology line shifts, the engineering and consumer choice curves change as well.

Figure 5. Efficiency/Capital Cost Trade-Off Curve



During model execution, efficiency levels for technologies are determined first, then the associated capital cost is determined based on the efficiency level chosen. Figure 6 illustrates that capital costs increase as the selected average efficiency increases at an increasing rate until the selected efficiency reaches the maximum possible efficiency.

Figure 6. Capital Cost Trade-Off Curve



The coefficients for the energy efficiency/capital cost trade-off curve are calculated from historical data for one initialization year (based on historical relationships of capital cost and efficiency choices at a given fuel price relative to the maximum efficiency and capital cost). These curve parameters can be carried into the future or the curves may be adjusted up or down during calibration. Curve coefficients are developed for both process and device energy efficiency and capital costs. The initial curves are then able to be adjusted upward or downward as a lever to calibrate to historical data, to meet expert predictions, or to simulate technology change for a specific economic sector, fuel type, or end-use. The upward adjustment of the efficiency curve results in an increase in the marginal efficiency selected at each fuel price. The adjustment of the capital cost curve results in a change in the capital cost associated with the selected efficiency.

For further detail on the derivation of the efficiency/capital cost trade-off curves, see ENERGY 2020 Documentation, see Volumes 2 and 3.

Historical Standards Impact Consumer Choice Relationships

During historical calibration, one objective of the model is to identify the consumer selected levels of efficiency given historical inputs of efficiencies and prices. The consumer choice relationship can be distorted by historical efficiency standards being in place (which forces the selected efficiency to be above the typical consumer-selected level). To account for this, a historical standard is sometimes input to the model in which case the model assumes a specified relationship between the standard efficiency and a hypothetical consumer choice level of efficiency. As a default setting, the model assumes the consumer choice efficiency is 70% as efficient as the input standard efficiency. This 70% is a judgement decision until we can find more specific data presumably from a study, if available. If we assume the efficiency standard is higher than what the consumer would have selected without the standard, we know the value is less than 100%. We estimated this value at 70% (so the standards are generally a 30% improvement). This value produced historical efficiencies consistent with our (SSI and ECCC) expectations of historical efficiency.

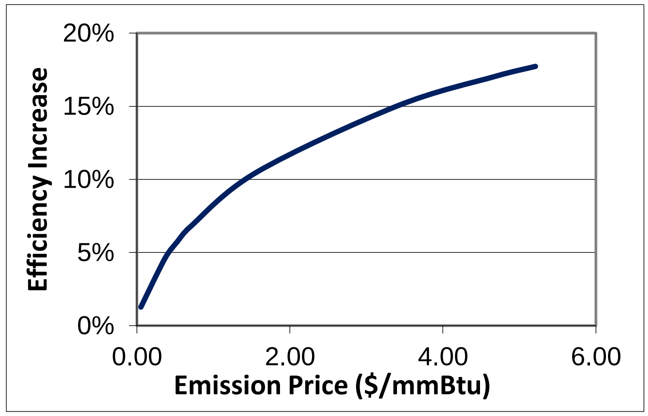
Efficiency Curve Adjustments due to Technology Innovation

Price curves are able to be adjusted and are done so to incorporate the impacts of technological innovation (as discussed in Section 2.4). For those technologies and industries that are thought to improve over time (and capital costs decrease) due to industry experience and/or innovation regardless of fuel price, the efficiency price response curve is adjusted upward or downward.

Exceptions to Efficiency/Capital Cost Trade-Off Curves

Other efficiency curves are able to be incorporated as needed into the model methodology. One example is in oil sands where the marginal efficiency and capital costs of the oil sands are determined based on the price of carbon (CO2). In this case, a model switch is used to select between the fuel price-response curve and a curve based on a carbon price depending on which curve produces a higher level of efficiency. Figure 7 shows an example of an alternative efficiency price response curve used for the oil sands industry. Other specific curves have been developed and used for reductions in fugitive emissions.

Figure 7. Efficiency Curve Exception Based on CO2 Price

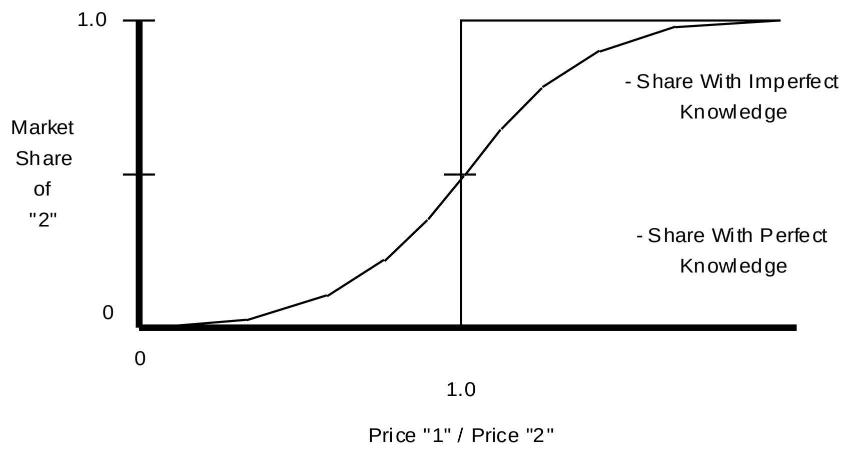


3.4. Fuel Market Share Calculation

The equations used to calculate fuel market shares are described and shown in *Appendix 5. Consumer Choice Theory*, and a description of its theoretical derivation can be found in ENERGY 2020 documentation's *Volume 3 (Demand Sector Theoretical Derivation).*

Figure 8 illustrates the process of fuel choice - trading off one fuel for another on the basis of relative prices. If consumers behaved with perfect economic rationality and had perfect information, the market share curve would look like the share with perfect knowledge illustrated in the diagram. In reality, fuel choice is a less clear-cut process. As the price of one fuel rises relative to another, there will be a gradual shift to the cheaper fuel based on consumer perceptions of the relative prices (often made with imperfect information) as well as the influence of non-price factors. The curve formed by these decisions resembles the S-shaped curve in the diagram - even if price "1" is higher than price "2" some consumers will still choose the more expensive fuel. This can be the result of imperfect information or indifference (if fuel costs are a very small part of the budget) or because of a non-price related factor. For instance, some people choose gas stoves because they prefer to cook with them, not because of price differentials.

Figure 8. Market Share Mechanics



Relative costs of each competing fuel option combined with non-price factors of consumer preference are incorporated within a multinomial logistic function to calculate market shares of the competing fuels. These fuel market shares are determined for new capital stock decisions. Replacements of capital stock are assumed to be replaced with the same fuel type; however, using a switch in the model, replacements can be converted to alternative fuels using the consumer choice equations.

During calibration, historical data are used to determine the non-price factor portion of the market share equation. This non-price factor provides information on the propensity towards or resistance to various technologies when consumers made choices historically for new capital stock. ENERGY 2020 estimates historical marginal market shares from historical data then solves for the non-price factor using the market share equation. Once the historical marginal market share is known, the non-price factor can be calculated given it is the only remaining unknown factor in the marginal market share equation. Once the non-price factor is determined, a decision is made regarding how to project it into the future. Currently, the non-price factor is calculated such that the marginal market share will equal the average market share in the last historical year.

3.1. Cogeneration Energy Demand (including Direct Self-Generation)

Most energy users can meet their electricity requirements either through purchases from a utility or by generating the power themselves. Historically most of the power generated themselves comes from energy users who cogenerate steam and electricity from their boilers. Energy users can also generate electricity directly from hydro, solar PV, or wind facilities. Within ENERGY 2020, self-generation includes direct generation and cogeneration. When the model was originally constructed, cogeneration was the dominant source of self-generation, so the documentation and variables names tend to include the cogeneration descriptor.

Self-generation is represented in two forms in ENERGY 2020. The “unit” self-generation consists of individual units which are represented in the same way as utility units. These units have detailed characteristics, like heat rates and emission factors, which are specific to that unit. This allows for detailed energy forecast and policy analysis. Many policies impact individual units differently; these policies can be precisely analyzed by the model. These self-generation units can be constructed endogenously, but generally are specified as exogenous inputs to the model.

The “sector” self-generation is represented in a more aggregate fashion where each economic sector is assigned a potential for self-generation by type of plant. For example, the single-family sector has an installed capacity of solar PV and a level of solar PV generation. This “sector” self-generation is the source of most of the new self-generating capacity. The expansion of this capacity is based on the relative cost of electricity as compared to the cost of the self-generating technology subject to the capacity potential of the self-generating technology. In the case of cogeneration, the potential is defined as the steam generated. In the case of direct generation, the potential is defined as the electricity demand of each sector (because actual direct generation is not limited, the model allows direct generation to exceed the potential if the economics are strong enough). The fraction of the potential developed (market share) is based on the relative cost of electricity compared to the cost of the self-generating technology combined with a non-price factor for self-generation (determined during historical calibration).

These two types of self-generation (“unit” and “sector”) are combined to produce the overall forecast of capacity, generation, fuel usage, and emissions.

3.2. Feedstock Energy Demand

Feedstock energy demands represent fuels used as raw material for input to a process, such as for manufacturing. An example of feedstock fuel usage is crude oil input to oil refinery processes in order to produce gasoline.

Feedstock energy demands are determined based on extracting a feedstock process efficiency from historical feedstock demands during calibration. The feedstock efficiency is represented in dollars of economic output per unit of energy and is determined based on the relationship of historical production capacity and feedstock demands. This efficiency level is held constant into the future, and feedstock demand projections are made based on the economic production capacity divided by the historical feedstock efficiency.

3.3. Demand Sector Calibration

Within the demand module, ENERGY 2020 calibrates several key equations to historical energy data. These equations are: marginal fuel market shares, energy demand (enduse, cogeneration, and feedstock), and energy efficiency (device and process). The calibration variables are calculated through each year of the historical period (enabling the model's historical output to match historical data) and are listed in Table 6.

Table 6. Key Demand Calibration Variables

Calibration Variable	Calibration Variable Description
Used in marginal fuel market share equations (enduse and cogeneration):	
MMSM0	Marginal Market Share Multiplier (Non-Price Factor)
CgMSM0	Cogeneration Marginal Market Share Multiplier (Non-Price Factor)
Used in energy demand equations (enduse, cogeneration, feedstock):	
CERSM	Capital Energy Requirement Multiplier (Lifestyle Multiplier)
CUF	Capacity Utilization Factor
CgCUF	Cogen. Capacity Utilization Factor
FsPEE	Feedstock Process Efficiency
Used in energy efficiency equations (device and process):	
DEMM	Maximum Device Efficiency Multiplier
PEMM	Maximum Process Efficiency Multiplier

Process of Projecting Calibration Variables to Generate a Forecast

The process of generating a forecast using ENERGY 2020 involves reviewing, analyzing, and determining the best method of projecting the calibration variables. An initial set of projection methods is chosen as the starting point of the process. Experience generating energy forecasts with the model has enabled refinement of the initial projection methods chosen; however, each year these methods are considered starting points for the full process of developing the forecasted calibration values. A multitude of automated forecasting methodologies are built into the model, and other methods are developed as needed on a case by case basis. The initial projection method is assigned for each variable (by area, industry, fuel, and enduse) and stored in a set of calibration control variables. Table 7 provides a list of the currently defined automated methods for projecting the calibration variables along with calibration control variables that store the method selection.

Table 7. Automated Options for Projecting Calibration Variables

Control Variables	User-Set Value	Methodology Automated Options Of Projecting Calibration Variable into Future
YMMSM YCgMSM YCERSM YCUF YCgCUF YFsPEE YDEMM YPEMM	=1	Trend future values to an exogenous values
	=2	Assign future values equal to exogenous values scaled to the last historical year's value
	=3	Assign future values equal to last historical year's value
	=4	Assign future values equal to the mean of the historical values
	=5	Trend the future values toward an exogenous value
	=6	Develop a trend line from the historical values
	=7	Develop an exponential trend line from the historical values
	=8	Estimate a full asymptotic line from the historical values
	=9	Estimate a partial asymptotic line from the historical values
	=11	Develop projections based on maximum likelihood estimation
	=16	Set future marginal value equal to last historical average value using last historical year input values
	=17	Set future marginal value equal to last historical average value using trended input values.
	=18	Set future marginal value equal to an exogenous value.

Given model results from the initial projection methods, analysis is performed (combined with expert knowledge or expectations of the future energy market) to determine the best methods for projecting the calibration variables. Analysts review and analyze the historical values of the calibration variables, the impact of the historical energy data on the calibration variables, and the impact of the initial values on the forecast. Modifications to the methods used may be made for specific areas, industries, fuels, or enduses by creating adjustment files which overwrite the initial methodology assigned.

For a typical reference forecast, the initial projection methodology assignments are listed in Table 8. These initial methods are used across all dimensions (areas, industries, fuels, enduses) to project the calibration variables, then adjustments may be made for specific industries, areas, fuels during forecast review.

Table 8. Calibration Variables - Initial Projection Methods and Adjustment Files

Calibration Variable	Calibration Variable Description	Initial Projection Methodology
MMSM0	Marginal Market Share Multiplier (Non-Price Factor)	YMMSMM=16
CERSM	Capital Energy Requirement Multiplier (Lifestyle Multiplier)	YCERSM=3
CUF	Capacity Utilization Factor	YCUF=1
DEMM	Maximum Device Efficiency Multiplier	YDEMM=3
PEMM	Maximum Process Efficiency Multiplier	YPEMM=3
FsPEE	Feedstock Process Efficiency	YFsPEE=3
CgCUF	Cogen. Capacity Utilization Factor	YCgCUF=3
CgMSM0	Cogeneration Marginal Market Share Multiplier (Non-Price Factor)	YCgMSM=3

The model is recalibrated when there are changes to model structure or as new data becomes available. The calibration process is automated so the only manual effort is to review and resolve the issues introduced by new model structure or new data.

In the current version of ENERGY 2020, the U.S. forecast is calibrated into the future to the U.S. EIA's Annual Energy Outlook (AEO) forecast. Historical U.S. data are input from U.S. government sources (SEDS, SEPER, Form 860, etc.).

4. Supply Module

4.1. Methodology Overview

The supply module produces electricity, crude oil, natural gas, refined petroleum products, biofuels, coal, and steam to meet total North America system energy demands.

The electric supply sector in ENERGY 2020 is the most complex of the supply sector simulations with representation and dispatch of close to 2,000 individual electric generating units. The endogenous projections within the electric supply sector use optimization routines to dispatch individual electric generating units to minimize system costs while meeting system-wide electricity demand. Crude oil and natural gas supply is simulated based on the profitability of production for individual oil and gas plays. The oil and gas module allows for flexibility of using different projection algorithms for each of the plays. Endogenous projections within the oil refinery sector uses optimization, minimizing costs, to determine the type, amount, and transportation flows of RPP production. ENERGY 2020's biofuels production is determined by meeting biofuel demands with consumer choice theory to applied to the feedstock-fuel process producers choose to use in production. Finally, coal sector production is assumed to match the level of coal demand plus coal exports where exports from coal producing regions are determined by local coal prices relative to export market coal prices. Simulation of the transportation of natural gas by pipelines is currently under construction in ENERGY 2020.

Energy Demand from Energy Suppliers

The fuel demands of energy suppliers, other than electric utilities and biofuel producers, is simulated within the industrial demand sector. These energy suppliers consist of the following industries: petroleum products, coal mining, light oil mining, heavy oil mining, frontier oil mining, primary oil sands, SAGD oil sands, CSS oil sands, conventional gas production, unconventional gas production, sweet gas processing, and sour gas processing. The two exceptions (suppliers not represented in the industrial demand sector) are electric utilities and biofuel producers. Fuel usage of electric utility generators and biofuel producers are calculated in the supply module, and their fuel demands are stored in the miscellaneous economic categories of Electric Utility Generation and Biofuel Production.

Methodology descriptions of each supply sector are summarized at an at-a-glance view in Table 9.

Table 9. Supply Sector Methodology At-A-Glance

Supply Sector	Methodology Snapshot
Electric utility generation	Electricity generation is simulated by dispatching individual generating units to meet system energy demand while minimizing system costs subject to generating capacity and transmission constraints.
Oil and gas production	The oil and gas production forecast can optionally 1) accept as input an exogenous forecast with an endogenous price response built in for policy analysis, or 2) use model algorithms to simulate oil and gas production of an aggregate set of oil and gas plays across Canada based on profitability criteria determined by fuel prices, costs and reserves associated with each play.
Oil refinery production	The production, imports, and exports of refined petroleum products (RPPs) can optionally 1) be exogenously specified or 2) be endogenously determined based on a linear programming (LP) algorithm that minimizes costs while meeting North American RPP demand subject to constraints of refinery capacities, yields, and transportation limits for pipelines, train, marine, and trucks.
Biofuel production	Biofuel (ethanol and biodiesel) production can be exogenously specified or calculated as biofuel demand plus exports less imports, where imports and exports are determined based on historical fractions. The market share of the types of production processes (feedstock and fuel combination) the biofuel producers choose is based on consumer choice logic.
Coal production	Coal production is calculated as demand for coal plus exports minus imports. Demand for coal is determined in the demand sectors and 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.

Supply Sector	Methodology Snapshot
Steam generation	Most steam generation is simulated inside the demand sector which utilizes the steam. The "steam generation sector" simulates the facilities that sell steam to other sectors. As such the steam generated is the steam purchased by other sectors, and outputs include fuel use and emissions required to generate the steam sold.

Subsequent sections provide a broad overview of the structure and methodologies available within each of the supply sectors in the following order: electricity, oil and gas, oil refinery, biofuels, and coal production. For more in-depth documentation of the supply module, including variable names and equations, see ENERGY 2020 documentation *Volume 5 (Supply Sector – Electric Generation)* and *Volume 6 (Supply Sector – Oil, Gas, Refinery, and Biofuel Production)*.

4.2. Electric Supply Sector

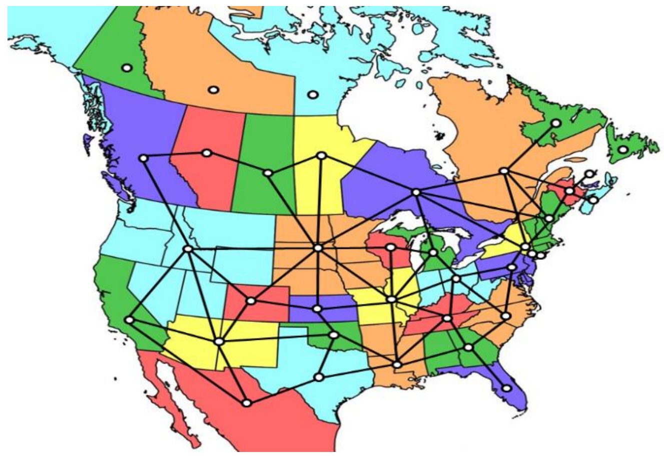
The electric supply sector is simulated with individual electric generating units sending electricity over transmission lines connected by a set of electricity nodes. Inputs such as total electricity demand, generating unit characteristics, transmission costs and constraints are used find an optimal solution (minimizing costs) of generation dispatch. Outputs include projections of future capacity, generation, flows including imports and exports, and the resulting nodal prices. The entire geographic area of the model is dispatched as a single system. Generating units are dispatched by month (or season) across six time periods (from low load hours up to one peak hour) and for three representative day types in the month (peak, minimum, and average).

Imports and exports are endogenously determined from the dispatch routine; however, users are able to specify contract amounts that force the flow of electricity between specific nodes if there are known minimum contracted flows in or out of specific regions.

Structure of Electric System

The structure of the electricity supply module contains several building blocks including a customizable transmission network, individual representation of generating units with the ability to aggregate or disaggregate to desired levels, twenty-four (24) plant types, and a representation of generating companies and retail companies (or load serving entities LSEs).

Figure 9. Default Transmission Nodes



Transmission network: The transmission network consists of a set of nodes connected by transmission lines which are able to be customized. The standard version of the model has thirty-seven (37) nodes represented across North America. These nodes consist of twenty-two (22) nodes in the U.S. (matching EIA's Electricity Market Module regions), fourteen (14) nodes in Canada (one for each province and territory with Newfoundland and Labrador split), and one node in Mexico. Figure 9 illustrates the typical transmission network represented in ENERGY 2020. Transmission lines are defined by assigning a capacity, transmission efficiency, and wheeling costs between two nodes.

Electric generating units: Each node is assigned its own specified demand (obtained from the demand module), which is met by a pool of resources consisting of electric generating units. The current model configuration simulates 930 aggregate U.S. generating units and 1,485 mostly disaggregate units in Canada. Generating units are specified by defining characteristics, include a name, the node in which they are located, the type of plant, the heat rate, the online and retirement years of the unit, its generating capacity, and fixed and variable costs. These units may be flagged as "industrial" meaning its primary purpose is providing electricity for the industrial facility. Units may also be flagged as "must run", meaning the unit always runs.

Electric Generating Unit$_{(i)}$ Sample Key Characteristics
Unit code, Name, Generating company
Location - Area, Node
Plant type, Generating capacity
Heat rate, outage rate
Fixed costs, variable costs
Industrial unit flag, Must-run flag

Plant types: Each of the individual generating units is assigned one of twenty-four (24) plant types represented in the model consisting of conventional, renewable, and other plant types (shown in Table 10).

Table 10. Plant Types Represented in ENERGY 2020

Conventional	Renewable	Other
Gas/Oil Peaking	Pumped Hydro	CHP/Other
Gas/Oil Combined Cycle	Small Hydro	Fuel Cells
Small OGCC	Biomass	Other Storage
Gas/Oil Steam	Biogas	
Coal	Waste	
Coal with CCS	Onshore Wind	
Nuclear	Offshore Wind	
Base Hydro	Solar PV	
Peak Hydro	Solar Thermal	
	Geothermal	
	Wave	
	Tidal	

Retail and Generating Companies: ENERGY 2020 simulates both generating and retail (load serving entities) companies. The number of companies represented varies by model implementation but range from 10 to 40. The current model configuration defines generating and retail companies as a one-to-one correspondence with the areas in the model. Each generating company is assigned a set of generating units, a capacity expansion strategy, a bidding strategy, and contracts with retail companies. Retail companies have contracts with generating companies, sales to demand areas, and a retail cost structure.

Electric Sector Methodology

The electric supply module transforms electricity demand (calculated in the demand module) into load curves for typical peak, average, and minimum hours by season or month, then builds new capacity as required based on reserve margins or wholesale prices, creates contracts between retail companies and generation companies, dispatches electric generating plants to meet the demand based on minimizing system costs subject to specified constraints, and calculates the resulting emissions and price of electricity. Key outputs from this module include generation, transmission flows, imports, and exports, emissions, and electricity prices.

Electric prices obtained from the electric supply model are sent back to the demand module, and energy demands are recalculated based on these new electricity prices, thereby obtaining a feedback effect from electricity prices.

The electric supply sector performs five key functions: 1) calculates load curves, 2) determines capacity expansion, 3) dispatches electric generating units, 4) calculates pollution, and 5) calculates electric prices. Each of these functions is summarized below.

1. **Load Curves**: Turns sector electricity demands into electric load curves by time of day, season, and node.
2. **Capacity Expansion**: Determines construction of new generating plants based on meeting a reserve margin and/or based on wholesale prices.
3. **Generation Dispatch:** Dispatches the available generating capacity using pre-specified dispatch assumptions and minimizing the overall cost to the system. Outputs include generation dispatched, transmission flows, wholesale prices, imports, and exports, as well as electric utility fuel usage.
4. **Pollution:** Calculates the emissions based on the fuel usage of the electric generators.
5. **Electric Prices:** Calculates electricity prices based on the cost of purchased power, delivery charge and other adjustments.

The heart of the electricity module is the unit dispatch routine simulated using a linear program (LP) where the objective function minimizes the cost of production subject to the constraints of meeting demand using available capacity within the limits of the transmission system. The cost of production includes the bid price of the units and the cost of moving power across the transmission network. Most units are bid at their marginal costs although other options are available. Some units (nuclear) may have a reported fuel cost which overstates their marginal costs. These units can be bid at less than their marginal costs. Bids can vary by time period, and market bids can be set to maximize generating company income. Generating companies modify their bids (up and down) and monitor their net revenue. If net revenues go up, then the generating company continues to modify their bids.

Transmission flows are a function of the dispatch algorithm; however exogenous "contract flows" can be added to force the flow of electricity between specific nodes. This may be needed when significant amount of storage hydro is available since the allocation of the water includes consideration of "contract flows".

Further details on the electric supply sector methodology and code can be found in ENERGY 2020 documentation, *Volume 5 (Supply Sector Electricity).*

4.3. 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 development and production for an aggregate set of oil and gas plays across North America. In either case, the production is independent of the oil and gas demand calculated in ENERGY 2020's demand sector. It is assumed that the oil and gas sector will produce to its potential as long as it is economical to do so. The production methodology is selected through the use of a model switch.

Growth projections of production from the oil and gas supply sector are sent as input to the demand module to drive energy demand for oil pipelines, all oil mining industries, conventional and unconventional gas production, and sweet and sour gas processing industries.

This section provides an overview of the methodologies used to forecast endogenous oil and gas production. See *Volume 6: Supply Sector Oil, Gas, Refinery, and Biofuel* for a more detailed description of the oil and gas supply sector structures, methodology, and code.

Oil and Gas Sector Methodology

The current default methodology of simulating oil and gas production calibrates to an exogenous forecast for each model area with direct price impacts. This exogenous-with-direct-price-impacts method develops a baseline forecast matching an exogenous forecast at an assumed level of exogenous prices. Policy scenarios are able to directly or indirectly alter price factors in the forecast, producing an endogenous response for oil and gas production compared to the baseline. Forecasts of oil and gas imports and exports are also exogenously input, and model switches allow the capability of imports and exports to grow with demand for refined petroleum products. Imports and exports are then adjusted to ensure production, demand, exports, and imports balance. The fuel demands of the oil and gas suppliers in this case is also an exogenous input to the model for the reference case.

Oil and Gas Sector Methodology Options

ENERGY 2020 forecasts long-term oil and gas production for a representative set of oil and gas plays, or units, within Canada, the United States, and Mexico. Overall, the structure of this module is generic, approaching each oil and gas play in a similar fashion. It is also flexible allowing the simulation of unique aspects of each play. It is assumed that each oil and gas unit will produce the maximum level it is capable of producing as long as it is cost effective to do so. The long-term oil and gas production forecast is based on 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, development, and production costs, tax policies, and environmental constraints.

Oil and Gas production Plays/Units(i) Sample Key Characteristics
Unit code, Name
Location - Area
Production process
Fuel type
Industry represented

Oil and Gas Plays: A set of oil and gas plays is input to the model each having a set of unique characteristics. Each oil and gas play produces a specific type of oil or gas and uses a specific type of production process. The current representation of individual oil and gas plays is at an aggregate, regional level and are represented in the model by a set called *OGUnit*. The exact set of individual plays ultimately to be included in the model is still under review. 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 type of industry (by economic category) the oil and gas play is (for example, light oil mining, conventional gas production, etc.). The list of production processes in the current representation are shown in Table 11.

Table 11. Production Processes of Oil and Gas Plays

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

Oil and Gas Production Algorithms: It is assumed that each oil and gas unit will produce the maximum level it is capable of producing as long as it is cost effective to do so. Production is based on 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, development, and production costs, tax policies, and environmental constraints.

The oil and gas production algorithms within ENERGY 2020 consist of the set of equations used to calculate rates and levels of development and production. These algorithms are designed to facilitate the generation of a long-term forecast, sensitivity analysis, as well as policy analysis and are flexible so changes to the basic algorithm are easily incorporated into the model. For each of the specific oil and gas plays, the method used to compute development and production can be different. The different algorithms can be mixed or matched to best simulate each individual play. Oil and natural gas are produced from the developed reserves. Production rates are calculated as the amount of production divided by developed reserves.

Table 12 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 12. Oil and Gas Production Algorithms

Algorithm Options	Description of Method
Direct Input	If we *know* it, then just input the value. This method could apply to any of future discoveries, development, and production rates or levels.
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.

Depletion and Learning Curves: Two mechanisms, depletion and learning curve, have an impact on oil and gas production costs and production 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 both development and production.

Imports and Exports: Forecasts of oil and gas imports and exports are exogenously input with model switches allowing the capability of imports and exports to grow with demand for refined petroleum products. Imports and exports are then adjusted to ensure production, demand, exports, and imports balance.

4.4. Oil Refinery Sector

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).

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

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 13. 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 14 identifies the types of crude oil used as input to the refineries and the fuels considered to be refined petroleum products.

Table 14. 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	Non-Energy Petroleum
Crude Bitumen (Domestic)	Jet Fuel	Petrochemical Feedstock
Condensates/C5 (Domestic)	Kerosene	Petroleum Coke
Other Material Charged	Light Fuel Oil	Still Gas

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.

For more detailed description of the oil refinery supply sector, refer to ENERGY 2020 documentation *Volume 6 (Supply Sector – Oil, Gas, Refinery, and Biofuel Production)*.

4.5. 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 will come from the transportation sector, the model allows for potential demand from any sector. Biofuel production is determined based on ethanol and biodiesel demands (determined in the demand module) plus exports less imports.

Biofuel Supply Sector Structures

Biofuel production requires energy from a variety of fuels and feedstocks. The main crops used to produce ethanol include corn, corn stover (by-product of corn, such as stalk, leaves, sheaths, husks, and cobs), and less frequently other grains, such as sugar cane, sorghum, wheat, and barley. Biodiesel is a fuel made from vegetable oils, fats, or greases—such as recycled restaurant grease. The crops used to produce biodiesel include rapeseed oil and other high-oil content crops.

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 below.

Biofuel Production Feedstocks and Energy Sources

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

Methodology

Total biofuel production is calculated to meet the ethanol and biodiesel demands from the demand module. Imports and exports are determined based on historical relationships of imports and exports to historical demands. Production within each area then is the demand plus imports minus exports. To determine which type of production processes biofuel suppliers will choose, consumer choice market share equations are applied to the various feedstock-fuel options. Market shares for each of the ethanol and biodiesel production processes are calculated based on the relative levelized costs of each production option in combination with a non-price factor indicating propensity toward or barrier to each type of production process. ENERGY 2020 then applies the resulting market shares to the total expected biofuel production. Canada's biofuel production capacity is allocated to areas based on historical data.

Activating Endogenous Biofuel Supply

Using the endogenous production algorithms is options, and activated by way of setting a switch (*BiofuelSwitch=1*). Additionally, input data assumptions need to be assigned and are currently assigned values in a text file named *SpBiofuel_Data.txt* housed in the *2020Model* subdirectory.

Key Outputs

Outputs from the biofuel sector include production, energy demand for production processes, feedstock demands, emissions, and prices. The energy demand and feedstock demand of the biofuel producers are calculated within the supply module and are added to the demand sector totals in the miscellaneous economic category of "Biofuel Production". The key input and output variables of the biofuel supply sector are written to a file named *SpBiofuel.dta* during model execution. The key output variables are listed below:

- Biofuel production
- Energy used to produce biofuels
- Biofuel feedstock required for production
- Emissions generated during biofuel production
- Wholesale price of biofuel

4.6. Coal and Steam Production

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.

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.

4.7. Supply Sector Calibration

Within the supply module, a set of variables is used to calibrate model equations for electricity peak, minimum, and average loads, electricity generation, fuel prices, and oil refinery production to historical values. Electric generation is calibrated using an outage rate variable, and electricity price are calibrated through a delivery charge variable. Oil refinery production is calibrated based on an outage rate and the maximum amount of crude. Table 15 summarizes the calibration variables used in each of the key supply module equations and identifies the location of the source code.

Table 15. Supply Module Calibration Variables

Equation to be Calibrated	Calibration Variable	Source Code Location
Electricity average, peak, and minimum load (MonOut, PkLoad, MinLd)	- BaseAdj(Day,Month,Area,Year) - Adjustment Factor (MW/MW)	- SCalib.src
Electric generating capacity dispatched by unit (UnGCD)	- UnOOR(Unit,Year) - Operational Outage Rate (MW/MW)	- EGCalib.src

Equation to be Calibrated	Calibration Variable	Source Code Location
Electricity retail price (PE)	- PEDC(ECC,ReCo,Year) - Electricity Delivery Charge ($/MWh)	- ElectricPriceCalib.txt
Oil, gas, and coal fuel price (FP)	- FPDChg(Prices,Area,Year) - Fuel Delivery Charge ($/mmBtu)	- SCalib.src
Oil refinery production (RfProd)	- RfOOR(RfUnit,Fuel,Year) - Refinery Unit Operational Outage Rate (Btu/Btu) - RfMaxCrude(RfUnit,Crude,Year) - Refinery Maximum Input of Crude Types (TBtu/Yr)	- SpRefCalib.src *Procedure CalibrateProduction*

For more detailed description of calibration in the supply sectors, see *Volume 6 (Supply Sector Oil Gas Refining and Biofuel)*.

5. Emissions Tracking

Emissions resulting from energy consumption by the demand sector and supply sector are tracked by source of emissions and type of pollutant. The sources of emissions come from both energy-related (combustion and non-combustion) and non-energy related sources.

5.1. Sources and Types of Pollutants

The four sources of emissions tracked in ENERGY 2020 are categorized by method by which the pollutant is created and are listed below.

- Energy emissions: Emissions from combustion of fuels.
- Process emissions: Emissions from economic activity.
- Feedstock emissions: Emissions from non-combusted fuels used as raw material input to processes.
- Fugitive emissions: Emissions from leaks of gases into the air (venting, flaring, and other fugitives).

Nineteen types of pollutants are represented in the model, including seven greenhouse gases (GH), eleven criteria air contaminants (CAC), and one other category consisting of water usage as shown in Table 16.

Table 16. Pollutants Represented in ENERGY 2020

Pollutants Represented in ENERGY 2020	
Greenhouse Gases	
Nitrous Oxide (N2O)	Perfluorocarbon (PFC)
Carbon Dioxide (CO2)	Hydrofluorocarbon (HFC)
Methane (CH4)	Nitrogen Trifluoride (NF3)
Sulphur-Hexafluoride (SF6)	
Criteria Air Contaminants	
Sulphur Oxides (SOX)	Particulate Matter 10 (PM10)
Nitrogen Oxides (NOX)	Black Carbon (BC)
Particulate Matter Total (PMT)	Mercury (Hg)
Volatile Org Comp. (VOC)	Ammonia (NH3)
Carbon Monoxide (COX)	Ozone (O3)
Particulate Matter 2.5 (PM25)	
Other	
Water Use (H2O)	

5.2. Calculating Emissions

Emissions coefficients are used to project emissions into the future for each type of pollutant. The definition of the emission coefficients varies based on the source of emissions. For emissions caused by combustion of fuels, the coefficients are defined as unit of emissions produced per unit of energy combusted. For other sources of emissions, coefficients are defined as the unit of emissions produced per unit of economic activity (for process emissions), per unit of raw fuel use (for feedstock emissions), or per unit of gas leakage (for fugitive emissions). Total emissions are calculated by multiplying the respective emissions coefficients times the amount of energy consumed for energy-related emissions, the amount of economic activity for process emissions, the of raw fuel used as feedstock for feedstock emissions, and the amount of gas leaked for fugitive emissions.

Emissions coefficients for each type of pollutant (by area, economic category, enduse, technology, and fuel if relevant) are needed in order to project future emissions. For GHG emissions coefficients, these coefficients known energy-related engineering calculations. In this case, historical coefficients are directly input to the model, and total emissions are a simple calculation of energy use multiplied by the emissions coefficient. However, the CAC coefficients contain more complexity and are not so easily obtained. As a result, an implied coefficient is calculated based on historical inventories of CAC emissions. The coefficient is calculated from the inventory using several different methods. See *Appendix 6: Calculating Emissions Coefficients* for a summary of the various methods used.

5.3. Emissions Reduction Mechanisms

Several mechanisms are in place to simulate the energy suppliers and consumers taking specific measures designed to directly mitigate emissions in response to price signals, such as increased prices due to carbon taxes or cap-and-trade systems.

The types of emissions-reducing mechanisms in place consist of offsets and reduction curves, implementing generic energy efficiency improvements, and improving work practices in the oil and gas industry. Electric utilities additionally will respond to increased emissions prices and/or targets by switching to lower-emitting fuel sources of generation, such as natural gas and renewables.

Offsets and Reduction Curves

Given an increased carbon price, three mechanisms are in place to reduce emissions based on reduction cost curves: 1) offset reductions from agriculture, forestry, and waste; 2) carbon capture and storage sequestering (CCS); and 3) improvements to industrial processes.

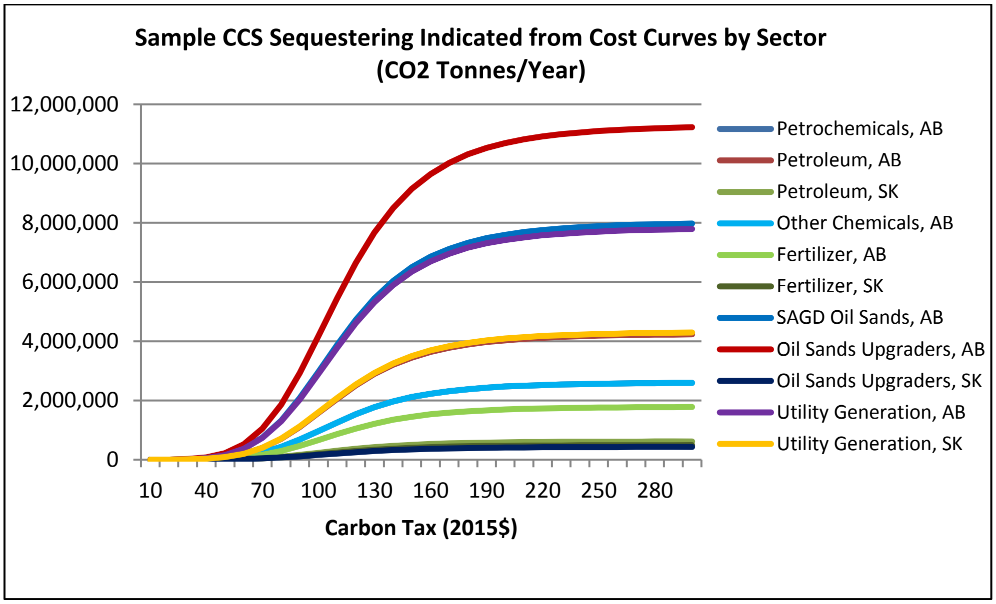
Offsets from Agriculture, Forestry, and Waste

There are currently seven types of offsets represented in ENERGY 2020. Each of the offsets is mapped to an economic category (ECC) in ENERGY 2020 and to a Pollutant. The offset mapping is listed below.

Offset		ECC		Pollutant
Landfill Gas Capture Solid Waste (LFG)	→	Solid Waste	→	CH4
Anaerobic Wastewater Treatment (WWT)	→	Wastewater	→	CH4
Aerobic Composting Solid Waste (AC)	→	Solid Waste	→	CH4
Nitrous Oxide Agriculture (NERA)	→	Crop production	→	N2O
Anaerobic Decomposition Agriculture (AD)	→	Animal production	→	CH4
Wood Biomass Agriculture (WB)	→	Crop production	→	CH4
Forestry	→	Forestry	→	CO2

Carbon capture and storage (CCS) sequestering

The amount of carbon capture and storage sequestering implemented is determined based on a carbon cost curve whose parameters are model inputs. CCS is represented in the Chemical, Oil Sands, and Electric Utility sectors within Alberta and Saskatchewan. An exogenous amount of sequestering also could be input to the model to indicate government developed CCS. The exogenous level of sequestering serves as the minimum amount of sequestering developed. A sample of the reduction cost curves represented in the model by type of gas and industry is shown in the figure below. Curve parameters are input through the policy file named *GHG_CCSCurves.txp* and stored in the 2020Model subdirectory.



Improvements to Industrial Processes: Industrial processes emission non-CO2 reduction cost curves are represented in the model. The figure below illustrates the fraction of emissions reduced at various levels of carbon taxes by economic sector.

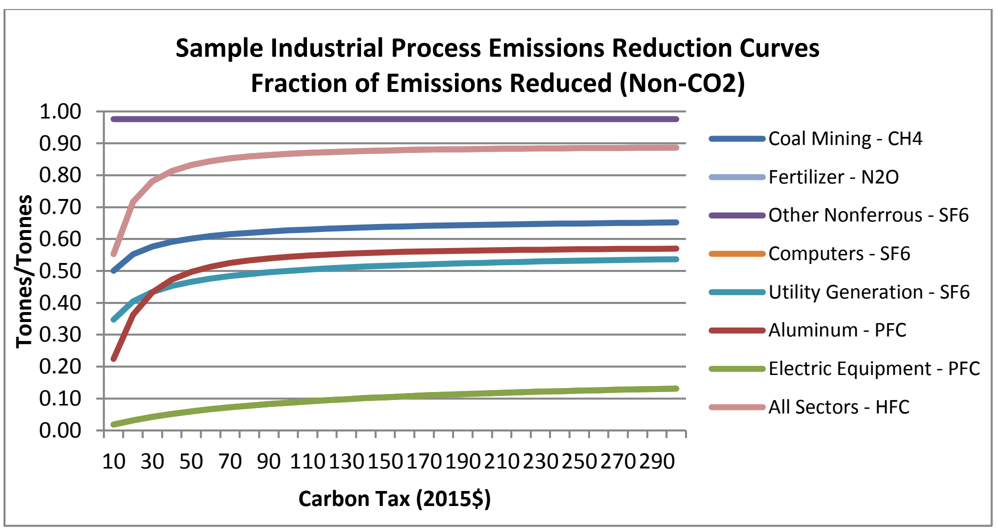


Table 17 identifies which pollutants are reduced by the emissions-reduction curves initiated by carbon prices. These curves are able to be set as active or non-active with the use of a model switch.

Table 17. Industries and Pollutants Impacted by Offsets and Reduction Cost Curves

	Industrial Sector	Industrial Processes	CCS	Agriculture, Forestry, Waste Offsets
1	Food & Tobacco	HFC	-	-
2	Textiles	HFC	-	-
3	Apparel	HFC	-	-
4	Lumber	HFC	-	-
5	Furniture	HFC	-	-
6	Pulp and Paper Mills	HFC	-	-
7	Converted Paper	HFC	-	-
8	Printing	HFC	-	-
9	Petrochemicals	HFC	CO2	-
10	Industrial Gas	HFC	-	-
11	Other Chemicals	HFC	CO2	-
12	Fertilizer	N2O, HFC	CO2	-
13	Petroleum Products	HFC	CO2	-
14	Rubber	HFC	-	-
15	Leather	HFC	-	-
16	Cement	HFC	-	-
17	Glass	HFC	-	-
18	Lime & Gypsum	HFC	-	-
19	Other Non-Metallic	HFC	-	-
20	Iron & Steel	HFC	-	-
21	Aluminum	PFC, HFC	-	-
22	Other Nonferrous Metal	SF6, HFC	-	-
23	Fabricated Metals	HFC	-	-
24	Machines	HFC	-	-
25	Computers	SF6, HFC	-	-
26	Electric Equipment	PFC, HFC	-	-
27	Transport Equipment	HFC	-	-
28	Other Manufacturing	HFC	-	-
29	Iron Ore Mining	HFC	-	-
30	Other Metal Mining	HFC	-	-
31	Non-Metal Mining	HFC	-	-
32	Light Oil Mining	HFC	-	-
33	Heavy Oil Mining	HFC	-	-
34	Frontier Oil Mining	HFC	-	-
35	Primary Oil Sands	HFC	-	-
36	SAGD Oil Sands	HFC	CO2	-
37	CSS Oil Sands	HFC	-	-
38	Oil Sands Mining	HFC	-	-
39	Oil Sands Upgraders	HFC	CO2	-
40	Sweet Gas production	HFC	-	-
41	Sweet Gas Processing	HFC	-	-
42	Sour Gas production	HFC	-	-
43	Sour Gas Processing	HFC	-	-
44	LNG production	HFC	-	-
45	Coal Mining	CH4, HFC	-	-
46	Construction	HFC	-	-

	Industrial Sector	Industrial Processes	CCS	Agriculture, Forestry, Waste Offsets
47	Forestry	HFC	-	CO_2
48	On Farm Fuel Use	HFC	-	-
49	Crop production	HFC	-	N_2O, CH_4
50	Animal production	HFC	-	CH_4
51	Utility Generation	SF_6, HFC	CO_2	-
52	Solid Waste	-	-	CH_4
53	Waste Water	-	-	CH_4

Generic Energy Efficiency Improvements

Code is in place which allows the industrial sectors to activate improvements to device and process efficiency curves. Additionally, generic device and process efficiency improvements are introduced to the model across the residential, commercial, and industrial sectors. The level of improvements is exogenously set.

Oil and Gas Industry Work Practices

Emission-reduction measures within the oil and gas industry ("work practices") are incorporated into the model based on increases to carbon prices and include reductions from the following five areas:

- Venting emissions reductions
- Flaring emission reductions of CO_2 from Reduced Emission Completion (REC) programs which capture gas from hydraulic fracturing
- Sequestering of formation CO_2 - natural gas processing industry sequestering of formation CO_2.
- Fugitive emission reductions from pneumatic device improvements
- Fugitive emission reductions from Leak Detection and Repair (LDAR) programs
- Other fugitive emission reductions CH_4 – sets a minimum level based on an overall 45% target

A summary of the industries and pollutants impacted by the oil and gas work practices is listed in Table 18.

Table 18. Pollutants Reduced by Oil and Gas Industry Work Practices

ENERGY 2020 Sectors Impacted by Oil and Gas Industry Work Practices						
Industrial Sector	Venting	RECs Flaring	Formation CO2 Sequestering	Pneumatic Devices Fugitives	LDAR Fugitives	Other Fugitives
Light Oil Mining	CH_4 (+CO_2, VOC)			CH_4		CH_4
Heavy Oil Mining	CH_4 (+CO_2, VOC)			CH_4		CH_4
Frontier Oil Mining				CH_4		CH_4
Primary Oil Sands	CH_4 (+CO_2, VOC)					CH_4
SAGD Oil Sands						CH_4
CSS Oil Sands						CH_4
Oil Sands Mining						CH_4
Oil Sands Upgraders						CH_4
Sweet Gas production		CO_2			CO_2, CH_4, VOC	CH_4
Sweet Gas Processing			CO_2	CH_4		CH_4
Sour Gas production		CO_2			CO_2, CH_4, VOC	CH_4
Sour Gas Processing			CO_2			CH_4

5.4. Structures in Place to Define Emissions Prices or Cap-and-Trade

ENERGY 2020 simulates all aspects that may be specified in a cap-and-trade system design. The structures that are able to be specified include:

- Emissions coverage criteria;
- Allocated allowances;
- Offsets;
- Allowance reserves;
- Banking and borrowing allowances;
- Allowance revenues; and
- Macroeconomic feedback.

Emissions Coverage: Emissions coverage identifies the geographic areas, economic sectors, and emissions included in the cap-and trade system. Through the use of model switches, ENERGY 2020 is designed to assign any set of areas (state, province, or territory), economic sectors, fuels, and pollutants to be included or excluded as part of a cap-and-trade system. The coverages are specified with a single variable which ranges between 0 (not covered) and 1.0 (100% covered). Values in between are often used to simulate systems which cover only facilities which exceed a certain level of emissions (for example facilities which emit more than 25,000 tonnes). These values can change over time as more sectors, areas or pollutants are incorporated into the cap-and-trade system.

Allocated Allowances: Allocated allowances are determined based on the emissions goal - the number of emission allowances is equal to the emission goal. These allowances are either allocated to participants or sold and traded in the market. Generally, some of the allowances are allocated freely to participants (gratis allowances) to reduce the economic impact of the program on the participants. Allowances can be allocated in many different ways including historical, forecast, and intensity based. The allocated allowance formulas may contain any number of factors including the age of the participants (new or old facility), the type of fuel being burned (special allowance for renewable fuels or waste fuels), or the type of operations (industrial generation of electricity). The allocated allowances are often reduced over time, so initially 80% of allowances may be allocated, but by 2025 only 15% are allocated freely, with the remainder being purchased at auction in the market.

Offsets: Sectors that often are not included in the cap-and-trade systems, such as agriculture and forestry are available for offsets. Offsets are intended to provide flexibility (and thus lower costs) in meeting the GHG goals, and their availability and price are defined in the cap-and-trade simulation. The offsets in ENERGY 2020 generally are simulated with an offset curve. This curve has the GHG allowance price ($/tonne) as an input, while the output is the level of GHG reductions (tonne/year). Offsets, however, can have a more complicated simulation. The landfill gas offset results in the construction of electric generating capacity which burns landfill gas, methane, to produce electricity. Any excess methane, not used in electric generation, is flared. In both cases, the landfill gas, methane, is burned to reduce methane but increase CO2.

Allowance Reserves: Allowance reserves are a pool of allowances controlled by the regulatory authority that are released into the market to attempt to moderate prices. ENERGY 2020 adds allowances to the market when the price thresholds are reached. These extra allowances will mitigate the upward pressure on prices and result in a lower price to meet goals.

Banking and Borrowing Allowances: In order to provide flexibility (and thus reduce the financial burden) participants may be allowed to bank and borrow allowances. Banking consists of storing allocated or purchased allowances. Participants may bank allowances when prices are low or during periods when they are easily able to reduce emissions. ENERGY 2020 uses banking and borrowing when the GHG allowance price iteration involves an entire price series (a price for every year of the analysis period). When the model is run with a single price series, some years meet the goal some years exceed the goal, and some years fall short of the goal. The model assigns banking and borrowing to carry excess or shortfalls across years and thereby determine if the emissions meet the overall, multi-year goals of the system.

Allowance Revenues: Any allowances which the regulatory authority sells in an auction will generate revenue. The regulatory authority must decide what to do with this revenue. Options include rebates to the participants, tax reductions, lowering national debt, direct reduction of GHG, investments in energy efficiency, investments in GHG reducing technologies, or any other purpose deemed beneficial. ENERGY 2020 computes these revenues then passes them to the macroeconomic model, if available, or the other ENERGY 2020 sectors. The macroeconomic impact of recycling is dependent on the detail of the linked macroeconomic model.

Macroeconomic Feedback: The cap-and-trade system will have an impact on the economic growth, employment, and personal income of the area being regulated. These impacts will come from the requirement to purchase permits, the investments in new energy and emission reduction technologies, the increases in energy prices, and the method of utilization of the allowance revenues. ENERGY 2020 passes the cost impacts to the macroeconomic model which processes the impact on the economy.

6. Macroeconomic Integration

ENERGY 2020 is able to be dynamically linked to a macroeconomic model to obtain a fully-integrated energy-environment-economy (E3) system. The model integration is performed using an interface between the two models written as a control program which, for each year of simulation, calls ENERGY 2020, passes energy model results to the macroeconomic model, executes the macroeconomic model, then passes those results back to ENERGY 2020. This process is iterated up to five times each year until a set of convergence criteria is met. Model runs are then able to made stand-alone (non-integrated) or linked to the macroeconomic model (integrated).

6.1. Current Interface Linking to Canadian Macroeconomic Model

An interface currently exists which was written specifically to integrate ENERGY 2020 to Environment and Climate Change Canada's Canadian macroeconomic model (TIM). This interface is written in Visual Basic and is called using the executable, *Inf_RunTandem.exe*. Environment and Climate Change Canada is in the process of identifying alternative macroeconomic models, therefore the current interface will likely to change by 2018. Whereas the specific interface will be different, the principles of linking the models will remain the same.

The process of integrating ENERGY 2020 with a macroeconomic model involves executing and transferring data between both models automatically (no manual steps). This data transfer can be done through reading databases directly, passing text files, or some other method. In the policy cases, impacts on the energy system will come from ENERGY 2020 with the macroeconomic model responding to these changes.

In the case of the existing interface, data transfers and mappings between variables are defined in an Excel spreadsheet called E2020_TIM_Config.xls. The E2020_TIM_Config.xls is stored in the \Informetrica\TIMFCST\F1601_EC\ folder. During execution, the *Inf_RunTandem* Visual Basic program reads the E2020_TIM_Config.xls spreadsheet to identify which variables to transfer based on a prefix identifier in each of the sheet names. Any sheet with a prefix of "TIM_" is read by the interface and contains information on which variables to transfer. Inside the sheet, the variable names are listed, the mappings between industries, and whether this is an output array (from TIM to ENERGY 2020) or an input array (from ENERGY 2020 to TIM). For example, the sheet name TIM_GO0 contains the variable names and industry mappings of the gross output variable and is an output array to be read from TIM and sent to ENERGY 2020. Sheets without the "TIM_" prefix are not read by the program.

6.2. Data Transfers

Transfers from ENERGY 2020 to Macroeconomic Model

The section below lists data outputs from ENERGY 2020 that are typically sent to a macroeconomic model for each iteration of an integrated run. Each category listed is anticipated to produce an impact in the linked macroeconomic model.

- **Energy production by Fuel Type and Province/Territory (PJ per year)** – Annual production of natural gas, oil, coal, and electricity.
- **Consumption of Energy by Fuel Type and Province/Territory (PJ per year)** – Total annual crude oil, electricity, natural gas, coal, and refined petroleum products consumption.
- **Volume of Canadian Energy Exports by Fuel Type (PJ per year)** – Annual exports of crude oil, electricity, natural gas, coal, and refined petroleum products from Canada.
- **Volume of Canadian Energy Imports by Fuel Type (PJ per year)** – Annual imports of crude oil, electricity, natural gas, coal, and refined petroleum products to Canada.
- **Wholesale Canadian Energy Price by Fuel Type ($CN per GJ per year)** – Annual prices for crude oil, natural gas, coal, and electricity at the point of production. This data can be considered similar to wellhead natural gas, WTI oil, and other wholesale energy market prices. Electric prices are a weighted average of the ENERGY 2020 nodal wholesale electric prices.
- **Delivered Canadian Energy Price by Fuel Type ($CN per GJ per year)** – Annual prices for crude oil, natural gas, coal, and electricity at the point of consumption. Delivered prices include delivery charges and any sales, excise, and pollution taxes.
- **Device Investment by Economic Category (Billion $CN per year)** – Annual total expenditure of each economic category on energy related devices. In ENERGY 2020, a device refers to machinery that is used to fulfill the production needs of the process for each given economic category. For example, a residential house requires space heating which can be met by installing a furnace or a factory might require steam which is produced via a boiler. In ENERGY 2020, both the furnace and boiler are devices, which are purchased, aged, retired, and replaced.
- **Process Investment by Economic Category (Billion $CN per year)** – Annual total expenditure of each economic category on process additions or improvements. Process investments would include new buildings or facilities to meet growth in the economy or to replace aging existing stock. Investments also include spending in process improvements would be related towards decreasing the energy intensity of economic activity for each category. For example, investing in insulating a house would decrease

the total heating and cooling process energy intensity since the home's furnace and air conditioning would have to run less to regulate the temperature.

- **Emission Permit Expenditures by Economic Category (Million $CN per year)** – Annual purchases of emissions permits from a regulatory authority.

Data Transfers from Macroeconomic Model to ENERGY 2020

ENERGY 2020 uses macroeconomic data to drive energy demands in the residential, commercial, industrial, and transportation sectors. Data from the macroeconomic model is used to initialize interactions in ENERGY 2020 during the historical period. Currently, the model receives energy input data beginning in 1985 and requires corresponding historical macroeconomic data starting from that year.

The current linkages between ENERGY 2020 and the macroeconomic model allow for simulation of the real-time impact of energy and environmental concerns on the economy and vice versa. This variables listed below are typically read in from the macroeconomic model to ENERGY 2020. How each of those variables is used within ENERGY 2020 is described for each.

- **Residential Housing Stock by Type and Province/Territory**
  ENERGY 2020 uses growth in housing stock as an indicator of growth in energy demand for the residential sector. The change in housing stock contributes to the estimate of the rate of new construction, which is used in conjunction with marginal fuel choices, process efficiencies, and device efficiencies to determine energy usage. The housing stock is broken out into single family, multi-family, and other family types.
- **Commercial and Residential Floor Space by Economic Sector and Province/Territory**
  Within the commercial and residential sectors, ENERGY 2020 uses floor space by type of building as an indicator of energy demand. The change in floor space contributes to the estimate of the rate of new construction, which is used in conjunction with marginal fuel choices, process efficiencies, and device efficiencies to determine energy usage. The commercial floor space is specified for each commercial sector while residential floor space is specified by housing type.
- **Real Gross Output by Industry by Province/Territory**
  Gross output by industry type and province is passed from the macroeconomic model to ENERGY 2020 and used to drive the growth in the industrial sector. The change in industrial gross output contributes to the estimate of the rate of new factory construction, which is used in conjunction with marginal fuel choices, process efficiencies, and device efficiencies to determine energy usage. Gross output is

specified for each relevant industrial sector, as well as, mining, construction, forestry, and agriculture.

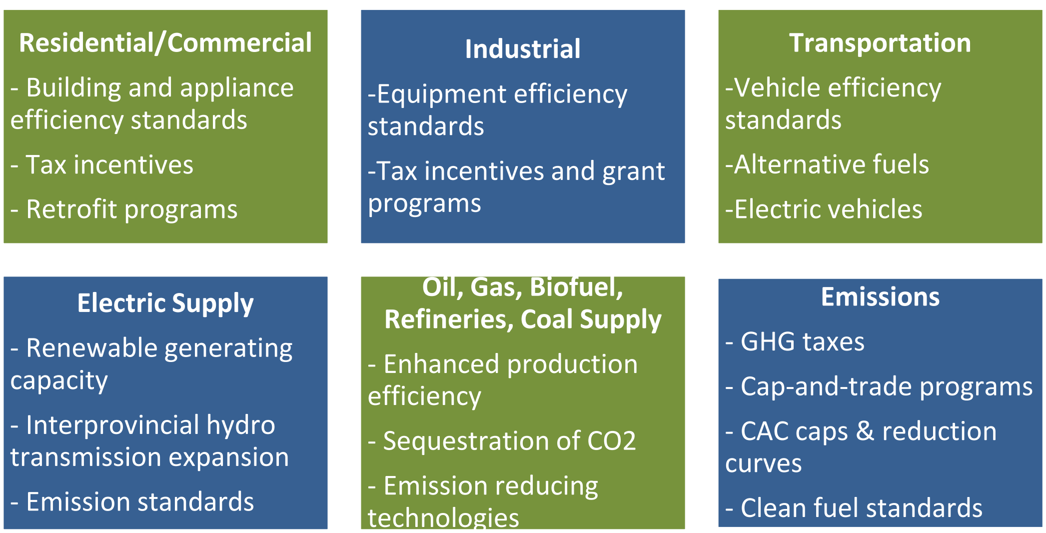
- **Real GDP by Province/Territory**
  ENERGY 2020 uses gross domestic product as a driver for energy demand within several transportation categories, such as freight and off-road. Gross Domestic Product is used as a surrogate for increases in the demand for transportation by these sectors.
- **GDP Deflator at the National Level**
  ENERGY 2020 uses the GDP deflator from the macroeconomic model as an indicator of the inflation rate.
- **Canada-US Exchange Rate**
  Within ENERGY 2020, all data are converted to US dollars and converted back to Canadian dollars on the output side. ENERGY 2020 uses the Canada-US exchange rate from the macroeconomic model to do these conversions.
- **Population by Province/Territory**
  Population is used to calculate total households, the economic driver for passenger transportation energy demands, and is used to compute per capita outputs.
- **Personal Income by Province/Territory**
  ENERGY 2020 uses personal income as an indicator of demands within the air passenger industry.
- **Employment by Province/Territory**
  Employment is not used directly for the energy calculations in ENERGY 2020, but is used as an output and to generate energy use per employee ratios.

7. Policy Analysis using ENERGY 2020

ENERGY 2020 is a powerful analysis tool for simulating a wide variety of policies which impact the energy system across energy demand, energy supply, and emissions. Policies are designed to test impacts of changes made to the energy system in relation to a business-as-usual, or reference case, scenario. Examples of policies include building codes, efficiency standards and regulations, energy efficiency programs, incentives promoting fuel switching, addition or retirement of specific types of electric generating capacity (such as coal, nuclear, wind, solar), taxes on greenhouse gas emissions, and cap-and-trade programs.

Figure 10 provides a sample of the types of policies ENERGY 2020 is able to simulate across each of the residential, commercial, industrial, and transportation demand sectors, electricity, oil, gas, biofuels, refineries, and coal supply sectors as well as emissions-related policies crossing both demand and supply sectors.

Figure 10. Sample Policy Analysis Capabilities by Sector



7.1. Advantages of using ENERGY 2020 for Policy Analysis

Decision Making Behavior – ENERGY 2020 is focused on the behavior of the energy system decision makers. It simulates how energy consumers and suppliers actually make decisions rather than what decisions are optimal. Policies are intended to influence how energy consumers or producers make decisions. Because ENERGY 2020 is a behavioral model, simulating the decision-making process of consumers and producers, it enables policies to be modelled with realistic impacts. For example, if a policy encourages industries to develop cogeneration by offering emission credits, ENERGY 2020 behavior equations combine cost factors (capital costs, fuel costs, emission costs or credits) with non-cost factors (industrial preferences, distributional impacts) to enable policy-makers to better predict the impact of a policy.

Detailed Representation - ENERGY 2020 simulates the energy and emission system in significant detail; therefore, policies are able to be simulated to the specific level of detail defined in actual policies (such as to specific regions, industries, end uses, technology, fuels, generating units, and pollutants). Without a detailed representation, simulating detailed policies would require scaling policy parameters up to an aggregated level. As an example, ENERGY 2020 is able to simulate the details of a policy specifically applied to heavy fuel oil cogeneration in Alberta's fertilizer industry rather than requiring a scaled version of the policy applied to the entire chemical sector in Canada.

Annual Dynamics - ENERGY 2020 executes on an annual basis allowing analysts to examine impacts for each year of the policy. Policy makers often are interested in the annual pattern of policy impacts in addition to its long-term impact. For instance, the variability of a cap-and-trade price may be as significant an impact as the price in the final year. Another example would be in the development of renewable resources. Rapid development leads to higher emission reductions long term, but policy makers must determine if the rapid development is affordable and reasonable. Annual results allow users to review short term results and help decision makers decide if short term impacts are a tolerable to meet the long term goals.

Flexibility and Short Development Time - ENERGY 2020 has been designed for the development of new and unique policies in a short time. Decision-makers often need time-critical analysis of newly conceptualized policies. Before finalizing the policies, they need to know impacts of subtle changes to the policy. ENERGY 2020 is easily revised to include the extra variables needed to simulate these subtle differences in policies.

Tracking Vintage of Capital Stock – Most decisions in the energy sector are made when capital stock is replaced either due to economic expansion or capital stock retirements. Policies are generally geared toward having an impact on these decisions. The impact of a policy depends on impact on the decision, but also on how many decisions are made each year. The number of decisions made depends on the amount of new capital stock which, again, is based on the economic expansion and the capitol stock retirements. An industrial without significant economic growth will only have new capital stock as their old capitol stock retires. ENERGY 2020 also simulates the retrofitting of capital stock, but recognizes the added cost of replacing capitol stock before the end of its useful lifetime.

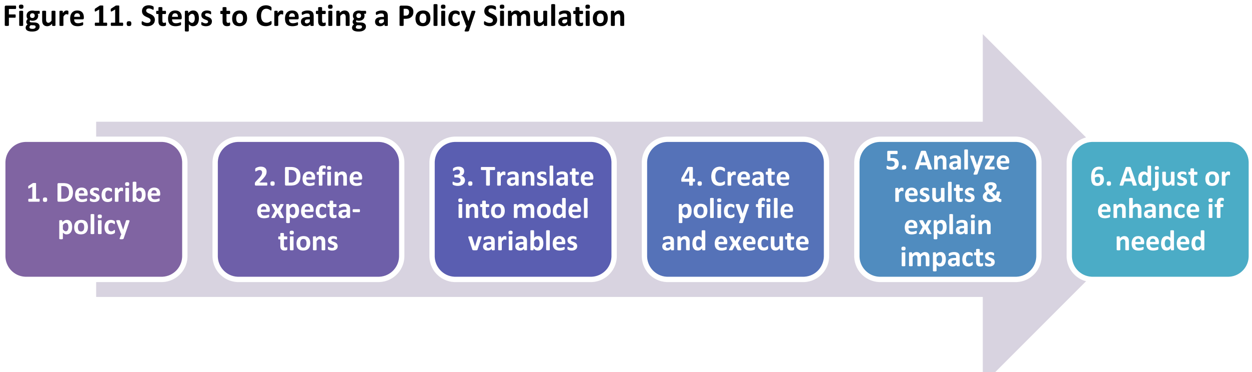
Process and Device Efficiency – ENERGY 2020 simulates both the process energy efficiency (economic output produced per unit of service energy) and the device energy efficiency (service energy per unit of fuel inputs) to compute energy demands. This is important for a number of reasons:

- The lifetime of a factory, commercial building or residential home is longer than the lifetime of a device (motor, furnace, refrigerator), so tracking the age of process capital stock is different from tracking the age of device capital stock.
- The process efficiency may be decreasing while the device efficiency is increasing; for example, there may be less economic output per lumens in a grocery store (the grocery store is brighter) while the light fixtures are producing more lumens per unit of electricity.
- Policies will generally be directed at either process or device efficiency, so the model needs to be able distinguish between a process and a device policy to accurately model the policy.
- Two policies (one for process and one for device efficiency) will interact, so to calculate the interaction both process and device must be modeled.

7.2. Process of Policy Analysis

Policy analysis begins with describing the policy in detail and defining expectations of policy impacts. Then the policy definitions need to be translated into ENERGY 2020 model variables. The changes to model variables are made by developing a "policy file" then executing the model. Finally results are analyzed by explaining model relationships and determining whether any adjustments to the policy are required. The steps involved in creating a policy simulation in ENERGY 2020 are summarized in Figure 11.

Figure 11. Steps to Creating a Policy Simulation



Identifying the ENERGY 2020 model variables to modify for a policy simulation is the key to creating policies in ENERGY 2020. Identification of model variables is not covered in this overview; however, please refer to ENERGY 2020 documentation *Volume 7 (Policy Analysis)* for descriptions of variables and methodologies used to simulate common demand sector and electric sector policies.

7.3. Policy Files to Modify Model Variables

Policy files in ENERGY 2020 are written as text files that contain code written in Promula language and, by convention, are saved with a ".txp". They modify values of input or policy variables used in key ENERGY 2020 model equations. Policy files are executed in ENERGY 2020 using batch files. A batch file is a separate file, with a ".bat" extension, consisting of a set of operating system commands to execute the model. Each policy is represented as its own policy file or set of policy files. Multiple policies can be combined by creating multiple policy files and executed together to define a scenario.

What are Policy files?

- Text files that contain code written in Promula language.
- Saved with a *.txp .extension ("policy text file")
- Modify values of input variables.
- May execute multiple policy files together to define a scenario.
- Are executed through ENERGY 2020 using batch files.

Existing Policy Files

The easiest method of creating a new policy file is to modify the values within an already existing policy file. Values can be specified by direct input, an equation, or a set of equations. Equations allow the values to be specified as a fraction of an existing model variable, including a percent change from a base case or reference case. Setting values of a policy variable in relation an existing model variable greatly facilitates and improves the accuracy of the representation of complex policies.

To simulate the impact of single policy in the forecast, a policy file is developed that makes changes to all the relevant model variables. An appropriate base line or reference scenario is identified and a new model run is executed with the new policy added on top of the forecast that it is being compared to. The impact of the policy is the difference in the model results between the two cases. A portfolio of policies can be individually tested then added together to develop entire forecast scenarios.

New Policy Files

To translate a policy into model variables and equations requires an understanding of the model structure and may require assistance. ENERGY 2020 has been designed to be flexible and to facilitate the addition of new polices; however, often times a policy is new and unique and requires revisions to the model (for example, adding a new policy variable into model equations that simulate the energy consumers' or suppliers' decision-making process). Revising the model variables or structure generally requires assistance from Systematic Solutions, Inc. (SSI). Recent examples where SSI revised model code to incorporate a new policy include: 1) creating the ability to allow for differences between various cap-and-trade proposals; and 2) restructuring the electric generation module as part of simulating the Alberta Clean Air Strategic Alliance (CASA) program to retire units when the cost of emission reduction retrofits is expected to exceed revenues

8. Model Source Code

ENERGY 2020's model source code with model equations are primarily found in the model's Engine subdirectory and are written in Promula language in script files having a ".src" file extension. Parallel coding structures are defined for each of the residential, commercial, industrial, and transportation sectors. The prefix of the source code file names indicates which module is associated with the procedures contained within the file based on conventions shown in Table 19. For example, files beginning with 'R' represent residential demand files; whereas, files beginning with 'C' represent commercial demand files, and the same is true for Industrial ('I') and Transportation ('T').

Table 19. Naming Conventions – Prefixes on Source Code File Names

Demand Sector	Prefix	Economic Sector	Prefix	Supply Sector	Prefix
Residential	'R'	Macroeconomic	'M'	Supply aggregate	'S'
Commercial	'C'			Electricity	'E' or 'EG'
Industrial	'I'			Oil and gas	'SpO' 'SpG' 'SpOG'
Transportation	'T'			Coal	'SpCoal'
				Refinery	'SpRef'
				Biofuel	'SpBiofuel'

When reading ENERGY 2020 source code files, it is helpful to know that each file contains a set of procedures (subroutines), and the control procedure that calls those procedures is located at the bottom of the file. As part of PROMULA coding rules procedures must be defined above the location in the file where it is being called resulting in code being called from the bottom-up.

Demand Sector Code

Table 20 summarizes the naming conventions of the different types of demand module source code files. Model equations across the residential, commercial, industrial, and transportation demand sectors are similar, if not exact, and variable names also are identical across each segment. For example, a separate energy demand variable, named *Dmd*, exists within each of the residential, commercial, industrial, and transportation segments. Each of the separate *Dmd* variables is dimensioned by the sectors' respective levels of granularity for economic categories, end uses, fuels/technologies, and areas. The variable name with its dimensions is specified as: Dmd(Enduse,Tech,EC,Area,Year).

The ENERGY 2020 source code files are named based on the task they perform, such as model initialization files, demand calibration files, and demand module execution files. All variables in the model are defined in a set of files whose names specify whether the variables are *inputs*, *calibration variables*, or *outputs* (named *Input.src, *CalDB.src, and *Output.src respectively).

Note that the '*' represents a placeholder for indicating whether the file is residential, commercial, industrial, or transportation. For example, actual names are RInput.src, CInput.src, IInput.src, and TInput.src.

Table 20. Demand Sector Code File Names

Demand Sector Source Code	File Name
Input variable definitions for demand sector Residential, Commercial, Industrial, Transportation	RInput.src, CInput.src IInput.src, TInput.src
Calibration variable definitions for demand sector Residential, Commercial, Industrial, Transportation	RCalDB.src, CCalDB.src ICalDB.src, TCalDB.src
Output variable definitions for demand sector Residential, Commercial, Industrial, Transportation	ROutput.src, COutput.src IOutput.src, TOutput.src
Input data (demand sector) Assigns values to constants, assumptions, and model structures, such as names of fuel types. The data in these files typically do not need annual updates. Input data that require updating annually are input through Access database or text files.	RData.src, CData.src IData.src, TData.src
Initialization (demand sector) Code to initialize demand-related variables. 1985 is default initialization year; some variables use 1993 or 2000 as initialization year.	RInitial.src, CInitial.src IInitial.src, TInitial.src
Calibration equations Contains code to calibrate equations to historical data.	RCalib.src, CCalib.src ICalib.src, TCalib.src
Calibration parameter future projections Contains code to project calibration parameters through the forecast years based on user-selected methodology.	RFuture.src, CFuture.src IFuture.src, TFuture.src
Demand sector execution Contains equations for demand projections.	RDemand.src, CDemand.src IDemand.src, TDemand.src
Demand sector load translation: Contains equations to translate electric and natural gas annual demands into loads by month and day type (peak, minimum, average) for input to the supply module.	RLoad.src, CLoad.src ILoad.src, TLoad.src

Supply Sector Model Code

Table 21 identifies the types of the files and file names within the electric supply sector. Table 22 identifies the names of all other supply-related model code. As was true with the demand sector code, the files within the supply module are split by function.

Table 21. Electric Supply Sector Code File Names

Electric Supply Sector Source Code	File Name
Variable definitions for electric sector	
Electric sector input variables	EInput.src
Electric sector output variables	EOutput.src
Electric retail company input variables	ERInput.src
Electric retail company output variables	EROutput.src
Electric generating company Input variables	EGInput.src
Electric generating company output variables	EGOutput.src
Electric calibration	
Much of the electric calibration code now exists in text files in the 2020Model subdirectory	ECalDB.src EGCalDB.src EGCalib.src
Input Data (electric sector) Assigns values to constants, assumptions, and model structures such as names of plant types. The data in these files typically do not need annual updates. Input data that require updating annually are input through Access database or text files.	EData.src ERData.src
Electricity supply These files make up the submodules of the electric supply sector. They calculate load curves, set up contracts, build capacity if required, dispatch electric units, calculates fuel usage, pollution and resulting delivered price for electricity.	ELoadCurve.src ERetailPurchases.src EContractDevelopment.src ECapacityExpansion.src EDispatch.src EDispatchLP.src EFuelUse.src EPollution.src ERetailPowerCosts.src ElectricPrice.src

Table 22. Non-Electric Supply Code File Names (Oil, Gas, Refinery, Biofuel, Coal)

Other Supply (Non-Electric) Source Code	File Name
Variable definitions for supply sector (oil, gas, refinery, biofuel)	
Generic supply input variables	SInput.src
Generic supply output variables	SOutput.src
Supply production input variables	SpInput.src
Supply production output variables	SpOutput.src
Supply sector initialization and calibration	
Supply calibration database creation file	SCalDB.src
Alternative energy supply sector calibration	SCalib.src
Supply constants and initial values	SInitial.src
Projects calibration parameters into forecast period	SFuture.src
Refinery Module	
Petroleum refining (current methodology)	SpRef.src
Refineries calibration	SpRefCalib.src
Refineries calibration	SpRefCalib_Fuel.src
Refineries calibration	SPRefCalib_Nation.src
Petroleum refining (pre-2017 version)	SpRefinery.src
Linear program for petroleum refining	SpRefLP.src
Energy supply Sector	
Alternate fuel energy supply sector	Supply.src
Biofuels supply	SpBiofuels.src
Coal supply	SpCoal.src
Ethanol supply	SpEthanol.src
Natural gas supply	SpGas.src
Natural gas transmission	SpGTrans.src
Linear program for natural gas transmission	SpGTrLP.src
Endogenous oil and gas production	SpOGProd.src
Oil production	SpOProd.src
Summary Pollution Calculations	SuPollution.src

Table 23 provides a listing of the macroeconomic processing-related code, and Table 24 contains miscellaneous other files used for defining model structures, controlling routines for all of the sectors, and defining the input variables read are read in from the Access databases using a visual basic routine (*VBInput.exe*).

Table 23. Macroeconomic Source Code File Names

Macroeconomic Processing Source Code	File Name
Variable Definitions for Macro Economy	
Macroeconomic input variables	MInput.src
Macroeconomic output variables	MOutput.src
Macroeconomic emissions input variables	MEInput.src
Macroeconomic emissions output variables	MEOutput.src
Macroeconomic calibration	
Creates databases for Macroeconomic calibration	MCalDB.src
Calculates historical growth rates	MCalib.src
Initialization of economic related variables	MInitial.src
Projects calibration parameters into forecast period	MFuture.src
Input Data (Macro Economy)	MData.src
Assigns values to constants, assumptions, and model structures. The data in these files typically do not need annual updates. Input data that require updating annually are input through Access database or text files.	MEData.src
Macroeconomic Processing Code	MEconomy.src
Macroeconomic Pollution	
Process pollution, pollution related to economic activity	MPollution.src
Pollution Reductions	MReductions.src

Table 24. Miscellaneous Source Code File Names

Source Code Function	File Name
Main Segment Model Definitions	2020.src
Defines sets, variables, and keys for global variables which can be used throughout all segments the model.	2020DB.src
Controls execution of code within:	
Macroeconomic segment	MControl.src
Supply segment	SControl.src
Electricity generation segment	EControl.src
Electricity generation segment #2	EGContro.src
Residential demand segment	RControl.src
Commercial demand segment	CControl.src
Industrial demand segment	IControl.src
Transportation demand segment	TControl.src
Variable Definitions for Input Data Read in from Access	
Definitions of input variables from Canadian Access databases (vData.accdb, vData_CAC.accdb, vData_ElectricUnits_CN.accdb.	VBInput.src
Definitions of input variables from U.S. electric unit database (vData_ElectricUnits.accdb)	vData_ElectricUnits.src

9. Input Data and Assumptions

ENERGY 2020 can be calibrated to any service area or region with publicly-available data. Its internal national and state databases contain historical economic, price, and demand data by economic sector, fuel, and end-use. Any data the user does not enter or is not already in the database will be provided "synthetically." The default databases contain not only generic data, but also regional data that is modified to be compatible with the data provided by the user. For example, if the user only knows the system peak and annual customer class sales, the input routines will generate estimated end-use load shapes by class by appropriately scaling detailed state or regional data. As the user adds more data, less "default" data is synthetically created. The data set evolves as better data is added to it. ENERGY 2020 is often used for analyses where the user-specific data is limited but answers are critically needed.

Data Requirements

As a multi-sector analytical tool, ENERGY 2020 requires data and assumptions covering a broad range of economic sectors and their interactions. Input data are required in the eight areas listed below:[2]

1. Economic and demographic
2. Fuel prices
3. Energy use and consumption
4. Technology characteristics
5. Financial
6. Emissions and air regulations
7. Electricity sector
8. Oil, gas, coal, steam, oil refinery, and biofuel production

Data within each of these areas are required for each region simulated in the model – Canada (by province and territory), U.S. (by state or EIA census divisions), and Mexico (national-level). ENERGY 2020 requires both historical data and projections to calibrate and generate forward-looking projections. Historical data are input for the period 1985 through the last year for which detailed sector and end-use data are available. Projections through 2050 are input for economic drivers as well as any specific sectors for which exogenous projections are to be calibrated.

[2] “Data” here refers to both historical data and assumptions and projections of future inputs.

Data Sources

In most cases, the necessary data – both historical and projected – are available from public sources. Data specific to Canada are populated by Environment and Climate Change Canada from a variety of data sources with a large portion of data obtained from Statistic Canada. Data specific to the U.S. are populated from U.S. federal sources, primarily from the U.S. Department of Energy. Mexico's data are obtained from the International Monetary Fund's World Economic Outlook database and the World Bank database.

Input Data Location

Canada input data that are updated annually are housed in Access databases (named vData.accdb and vData_Electricity_CN.accdb) and populated by Environment and Climate Change Canada staff.

U.S. input data on electric generating units is gathered from the U.S. Department of Energy's EIA database and are input to the model through an Access database, vData_Electricity_US.accdb. Other U.S. input data are input to the model through text files and housed in the model's Superset subdirectory.

See *Volume 8: Input Data and Assumptions* for further details on ENERGY 2020's data requirements and sources.

Appendix 1. U.S. Regions Defined by State

U.S. Area	Key Name	States
New England	NEng	Connecticut Massachusetts Maine New Hampshire Rhode Island Vermont
Middle Atlantic	MAtl	New York New Jersey Pennsylvania
East North Central	ENC	Illinois Indiana Michigan Ohio Wisconsin
West North Central	WNC	Iowa Minnesota North Dakota Nebraska South Dakota Kansas Missouri
West South Central	WSC	Arkansas Louisiana Oklahoma Texas

U.S. Area	Key Name	States
South Atlantic	SAtl	Delaware Maryland West Virginia Florida Georgia North Carolina South Carolina Virginia
East South Central	ESC	Kentucky Mississippi Tennessee
Mountain	Mtn	Arizona Colorado Idaho Montana Nevada Utah Wyoming
Pacific	Pac	Oregon Alaska Hawaii Washington
California	CA	California

Appendix 2. Fuels and End-Use Technologies

Thirty-nine (39) detailed fuels are represented in ENERGY 2020 (Table 25). Demand sector end-use technologies are represented by an end-use and fuel combinations at a more aggregated fuel level. The end-use technologies represented for each of the residential, commercial, industrial and transportation sectors is shown in Table 26.

Table 25. Detailed Fuel Types Represented in ENERGY 2020

Fuel Types Represented in ENERGY 2020			
Asphalt	Diesel	Kerosene	Petrochemical Feedstocks
Asphaltines	Electric	Light Crude Oil	Petroleum Coke
Aviation Gasoline	Ethanol	Light Fuel Oil	Renewable Natural Gas
Biodiesel	Gasoline	LPG	Solar
Biogas	Geothermal	Lubricants	Steam
Biojet	Heavy Crude Oil	Naphtha Specialties	Still Gas
Biomass	Heavy Fuel Oil	Natural Gas	Waste
Coal	Hydro	Natural Gas Raw	Wave
Coke	Hydrogen	Nuclear	Wind
Coke Oven Gas	Jet Fuel	Other Non-Energy Products	

Table 26. End-Use Technologies by Sector

Residential and Commercial		Industrial	
Space Heating Water Heating Other Substitutables Refrigeration Lighting Air Conditioning Other Non-Substitutables	Electric Gas Coal Oil Biomass Solar LPG Geothermal Heat Pumps	Process Heat Motors Other Substitutables Miscellaneous Off Road Excess Steam	Electric Gas Coal Oil Biomass Solar LPG Steam Off Road

Transportation Technologies				
Light Duty Vehicles Light Duty Trucks	Gasoline Diesel Electric Natural Gas Propane Ethanol Hybrid Fuel Cell	Buses Gasoline Diesel Electric Natural Gas Propane Motorcycles Trains Diesel Electric Planes Jet Fuel Gasoline	Heavy Duty Vehicles Class 2B Class 3 Class 4 Class 5 Class 6 Class 7 Class 8A Class 8B Marine Heavy Light Off-Road	Gasoline Diesel

The table below identifies combinations of sector, technology and fuel types represented within the transportation sector.

Transportation Technology and Fuel Combinations – Air, Off-Road, Foreign					
Sector	**Technology**	**Fuel**	**Sector**	**Technology**	**Fuel**
Air Freight	Plane Gasoline	Aviation Gasoline	Foreign Freight	Marine Heavy	Heavy Fuel Oil
	Plane Jet Fuel	Jet Fuel		Marine Light	Biodiesel
Air Passenger	Off-Road	Biodiesel			Diesel
		Diesel			Ethanol
		Ethanol			Gasoline
		Gasoline		Plane Gasoline	Aviation Gasoline
	Plane Gasoline	Aviation Gasoline		Plane Jet Fuel	Jet Fuel
	Plane Jet Fuel	Jet Fuel			
Commercial Off-Road & Residential Off-Road	Off-Road	Biodiesel	Foreign Passenger	Plane Gasoline	Aviation Gasoline
		Diesel		Plane Jet Fuel	Jet Fuel
		Ethanol			
		Gasoline			
		LPG			
		Natural Gas			

Table 2: Freight and Passenger Transportation Technologies in ENERGY 2020

Transportation Technology and Fuel Combinations Freight and Passenger Sectors		
Sector	**Technology**	**Fuel**
Freight	HDV2B Diesel	Biodiesel Diesel
	HDV3 Diesel	
	HDV4 Diesel	
	HDV5 Diesel	
	HDV6 Diesel	
	HDV7 Diesel	
	HDV8A Diesel	
	HDV8B Diesel	
	HDV2B Gasoline	Ethanol Gasoline
	HDV3 Gasoline	
	HDV4 Gasoline	
	HDV5 Gasoline	
	HDV6 Gasoline	
	HDV7 Gasoline	
	HDV8A Gasoline	
	HDV8B Gasoline	

Transportation Technology and Fuel Combinations Freight and Passenger Sectors		
Sector	**Technology**	**Fuel**
	Marine Heavy	Heavy Fuel Oil
	Marine Light	Biodiesel Diesel Ethanol Gasoline Kerosene Light Fuel Oil
	Train Diesel	Biodiesel Diesel
Passenger	Bus Diesel	Biodiesel Diesel
	Bus Electric	Electric
	Bus Natural Gas	Natural Gas
	Bus Propane	LPG
	LDT Diesel LDV Diesel Train Diesel	Biodiesel Diesel
	LDT Electric LDV Electric	Electric
	LDT Gasoline LDV Gasoline Motorcycle	Ethanol Gasoline
	LDT Hybrid LDV Hybrid	Electric Ethanol Gasoline
	LDT Natural Gas LDV Natural Gas	Natural Gas
	LDT Propane LDV Propane	LPG

Appendix 3. Technology Innovation Assumptions

Technological change trends in the following tables are based on stock efficiency values from the 2015 Annual Energy Outlook Reference Case produced by the EIA. Table 27 illustrates the increase in device efficiency incorporated into the model due to residential technological change by 2040. The residential technological improvements vary across single family, multi-family and other family. Increases in device efficiency due to commercial technological change by 2040 are shown in Table 28. These commercial increases in efficiency are assumed to be the same across all commercial buildings.

Table 27. Technology Innovation by 2040 – Residential Efficiency

Residential Increase in Device Efficiency from Technological Innovation by 2040 (AEO 2014)			
	Single Family	Multi-Family	Other Family
Space Heating			
Electric	24.4%	37.9%	56.7%
Geothermal	29.2%	0.0%	0.0%
LPG	5.2%	34.4%	6.2%
Natural Gas	3.8%	4.5%	8.0%
Oil	2.5%	0.2%	3.2%
Wood	7.7%	16.3%	7.7%
Water Heating			
Electric	8.1%	7.9%	8.1%
Natural Gas	2.4%	5.4%	5.0%
Air Conditioning			
Electric	16.3%	16.3%	16.3%
Geothermal	69.5%	0.0%	0.0%
Natural Gas	16.7%	16.7%	0.0%
Lighting	215.8%	227.1%	204.1%
Refrigeration	8.4%	8.4%	8.4%

Table 28. Technology Innovation by 2040 – Commercial Efficiency

Commercial Device Increase in Efficiency due to Technology Innovation by 2040 (AEO 2014)			
	Electricity	Natural Gas	Oil
Space Heating	32.0%	3.0%	1.0%
Water Heating	14.0%	17.0%	1.0%
Air Conditioning	21.0%	18.0%	-
Refrigeration	56.0%	-	-
Lighting	54.0%	-	-
Other Substitutables	2.0%	1.0%	-
Other Non-Substitutables	7.0%	-	-

Annual efficiency improvements due to technological change in the industrial sector are shown in Table 29.

Table 29. Technology Innovation by 2040 – Industrial Efficiency

Annual Improvement to Industrial Processes due to Technology Innovation (AEO 2014)						
	Electric	Gas	Oil	LPG	Coal	Steam
Crop Production	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%
On Farm Fuel Use	0.60%	0.60%	0.60%	0.60%	0.00%	0.60%
Coal Mining	0.60%	1.20%	0.60%	0.60%	0.60%	0.60%
Light Oil Mining	0.60%	1.20%	0.60%	0.60%	0.60%	0.60%
Iron Ore Mining	0.60%	1.20%	0.60%	0.60%	0.60%	0.60%
Construction	0.60%	1.20%	0.60%	0.60%	0.60%	0.60%
Food	0.39%	0.39%	0.39%	0.39%	0.39%	0.78%
Pulp Paper Mills	0.13%	0.13%	0.13%	0.13%	0.13%	0.26%
Petrochemicals	0.42%	0.42%	0.42%	0.42%	0.42%	0.84%
Glass	0.05%	0.05%	0.05%	0.05%	0.05%	0.09%
Cement	0.36%	0.36%	0.36%	0.36%	0.36%	0.36%
Iron Steel	2.58%	2.58%	2.58%	2.58%	2.58%	5.16%
Aluminum	0.47%	0.47%	0.47%	0.47%	0.47%	0.47%
Fabricated Metals	1.68%	1.68%	1.68%	1.68%	1.68%	3.36%
Machines	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%
Computers	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%
Transp. Equipment	0.67%	0.67%	0.67%	0.67%	0.67%	1.34%
Electric Equipment	0.84%	0.84%	0.84%	0.84%	0.84%	1.68%
Rubber	0.84%	0.84%	0.84%	0.84%	0.84%	1.68%
Other Manufacturing	0.67%	0.67%	0.67%	0.67%	0.67%	1.34%

Table 30 lists the learning rates assumed for construction costs within ENERGY 2020's electric sector due to technology innovation.

Table 30. Technology Innovation Learning Rates – Electric Sector Construction Costs

Learning Rates Assumed for Construction Costs by Technology			
ENERGY 2020 Plant Type	Learning Rate	ENERGY 2020 Plant Type	Learning Rate
Gas/Oil Peaking	10%	Wind	10%
Gas/Oil Combined Cycle	10%	Solar	20%
Gas/Oil Steam	1%	Fuel Cells	20%
Coal	1%	Pumped Hydro	1%
Advanced Coal	10%	Small Hydro	1%
Nuclear	5%	Wave	20%
Base Hydro	1%	Geothermal	8%
Peak Hydro	1%	Other Storage	1%
CHP/Other Generation	1%	Coal with CCS	20%
Biomass	1%	Biogas	10%
Landfill Gas/Waste	1%	Trash	1%

Appendix 4. Economic Drivers

The drivers for energy demand vary by nation. Canada economic drivers are selected by Environment and Climate Change Canada; U.S. drivers are chosen to align with the U.S. EIA's economic drivers used to produce the U.S. projections reported in the *Annual Energy Outlook*; Mexico's economic drivers are chosen based on the availability of publicly available data. Table 31 compares the economic drivers of Canada, U.S., and Mexico for each economic category within the residential, commercial, industrial, and transportation sectors.

Table 31. Economic Drivers for Canada, U.S., and Mexico Energy Demand

Sector	Canada	U.S.	Mexico
Residential			
Single Family	Floor Space	Households	Population
Multi Family	Floor Space	Households	Population
Other Residential	Floor Space	Households	Population
Commercial			
Wholesale Trade	Floor Space	Gross Output	Services Gross Output
Retail Trade	Floor Space	Gross Output	Services Gross Output
Warehousing and Storage	Floor Space	GRP	Services Gross Output
Info. and Cultural Industries	Floor Space	Gross Output	Services Gross Output
Offices	Floor Space	Gross Output	Services Gross Output
Educational Services	Floor Space	Gross Output	Services Gross Output
Health Care & Social Assist.	Floor Space	Gross Output	Services Gross Output
Arts, Accom., Food, Other	Floor Space	Gross Output	Services Gross Output
Natural Gas Distribution	NG Demand	Gross Output	Industry Gross Output
Oil Pipelines	National Oil Production	Gross Output	Industry Gross Output
Natural Gas Pipelines	NG Demand Local Gas Prod. (BC, AB)	Gross Output	Industry Gross Output
Street Lighting	GRP	GRP	GRP
Industrial			
Food & Tobacco	Gross Output	Gross Output	Gross Output
Textiles Apparel & Leather	Gross Output	Gross Output	Textiles & Clothing GO
Lumber	Gross Output	Gross Output	Other Mfg. GO
Furniture	Gross Output	Gross Output	Other Mfg. GO
Pulp and Paper Mills	Gross Output	Gross Output	Other Mfg. GO
Converted Paper	Gross Output	Gross Output	Other Mfg. GO
Petrochemicals	Gross Output	Gross Output	Chemicals Gross Output
Industrial Gas	Gross Output	Gross Output	Chemicals Gross Output
Other Chemicals	Gross Output	GRP	Chemicals Gross Output
Fertilizer	Gross Output	Gross Output	Chemicals Gross Output
Petroleum Products	National RPP Production	Gross Output	Other Mfg. GO
Rubber	Gross Output	Gross Output	Other Mfg. GO
Cement	Gross Output	GRP	Other Mfg. GO

Sector	Canada	U.S.	Mexico
Glass	Gross Output	Gross Output	Other Mfg. GO
Lime & Gypsum	Gross Output	Gross Output	Other Mfg. GO
Other Non-Metallic	Gross Output	Gross Output	Other Mfg. GO
Iron & Steel	Gross Output	GRP	Other Mfg. GO
Aluminum	Gross Output	GRP	Other Mfg. GO
Other Nonferrous Metal	Gross Output	Gross Output	Other Mfg. GO
Transport Equipment	Gross Output	Gross Output	Mach.&Trans. Equip. GO
Other Manufacturing	Gross Output	Gross Output	Other Mfg. GO
Iron Ore Mining	Gross Output	Gross Output	Industry Gross Output
Other Metal Mining	Gross Output	Gross Output	Industry Gross Output
Non-Metal Mining	Gross Output	Gross Output	Industry Gross Output
Light Oil Mining	Local Oil Production	Local Oil Production	N/A
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	Industry Gross Output
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
LNG Production	Local LNG Production	Local LNG Production	Industry Gross Output
Coal Mining	Gross Output	GRP	Industry Gross Output
Construction	Gross Output	Gross Output	Industry Gross Output
Forestry	Gross Output	Gross Output	Agriculture Gross Output
On Farm Fuel Use	Gross Output	Gross Output	Agriculture Gross Output
Crop Production	Gross Output	Gross Output	N/A
Animal Production	Gross Output	Gross Output	N/A
Transportation			
Passenger	Population	Personal Income	Personal Income
Freight	GRP	GRP	GRP
Air Passenger	Personal Income	Personal Income	Personal Income
Air Freight	GRP	GRP	GRP
Foreign Passenger	GRP	GRP	GRP
Foreign Freight	GRP	GRP	GRP
Residential Off-Road	GRP	GRP	GRP
Commercial Off-Road	GRP	GRP	GRP
Miscellaneous Sectors (not used)			
Miscellaneous	N/A	N/A	N/A
Electric Resale	N/A	N/A	N/A
Miscellaneous Sectors (used to hold Energy Demands from Suppliers)			

Sector	Canada	U.S.	Mexico
Utility Electric Generation	Electric Utility Gen.	Electric Utility Gen.	Electric Utility Gen.
Biofuel Production	Biofuel Production	Biofuel Production	N/A
Steam Generation	Steam Generation	Steam Generation	N/A
Miscellaneous Sectors (used for Emissions Accounting Only)			
Solid Waste	Total Households	Gross Output	N/A
Wastewater	Total Households	Gross Output	N/A
Incineration	Total Households	Gross Output	N/A
Land Use	Land Acres	Gross Output	N/A
Road Dust	Freight Miles	Gross Output	N/A
Agriculture Open Sources	Farm Gross Output	Gross Output	N/A
Forest Fires	Land Acres	Gross Output	N/A
Biogenics	Land Acres	Gross Output	N/A

Appendix 5. Consumer Choice Theory Overview

The decision of residential consumers to choose among a set of is a qualitative choice situation and can be modeled as such. A qualitative choice situation is one in which a decision-maker faces a choice among a set of alternatives where the number of alternatives is finite. Qualitative Choice models calculate the probability that a decision-maker will choose a particular alternative from a particular set of alternatives. Qualitative choice methods capture the behavioral choice process that trades-off efficiency with other cost components and preferences.

According to consumer choice theory, consumers will make purchasing decisions based on perceptions of cost and utility. Marginal trade-offs between changing fuel costs and efficiency determine the capital cost of the chosen technology. These trade-offs are dependent on perceived energy prices, capital costs, operating costs, risk, access to capital, promotions/advertising, regulations, values, perceptions, and other imperfect information. Given even limited historical data on only analogous choices, historical usage has shown that Qualitative Choice Theory generates a robust estimation of behavioral responses.

A qualitative choice situation is one in which a decision maker faces a choice among a set of options that meet the following criteria:

1) The number of alternatives is **finite**.
2) The alternatives are **mutually exclusive**.
3) The set of alternatives is **exhaustive**.

Typically a choice can be portrayed as a selection among a spectrum of alternatives. Faced with the selection options, a particular or discrete choice is made based on the preference of the consumer. The mathematical characterization of this choice process is called discrete choice analysis. The preferences are a function of observable quantities such as price and unobservable quantities such as style or taste. Additionally, consumer uncertainty in both the observable and unobservable portions of the individual's preference function means that the mathematical formulation of the choice process must be based on an estimation process, as are those estimations performed for more common econometric representations.

The probability of a consumer making a particular choice can be determined with the use of a multinomial logit (MNL).

$$P_n(i) = \frac{e^{V_{in}}}{\sum_{j=1}^{N} e^{V_{jn}}}$$

Where V_i is the utility of option i.

This model (or equivalent variants of it) can be derived in a great number of ways. Its original formulation is due to Luce (1959), a mathematical psychologist. He derived the form of the [above] equation by making assumptions about the choice probabilities rather than the disturbances.

The utility function is often written clearly, for example, as a simple function of price (Pi) with the constant (non-price, a_i) term. [3]

$$V_i = a_i + b^*P_i$$

In ENERGY 2020, the log-linear form is used:

$$V_i = a_i + b^*\ln(P_i)$$

An implication of this form is that the consumers are more sensitive to the proportional (percent) differences in costs than in absolute ($) differences. This means a one dollar difference is less important in a thousand dollar furnace decision than it is in a three dollar light-bulb decision.

The market share equation that we use in ENERGY 2020 and the spreadsheet model, then, is:

*V (i) = Non-Price Factor + VarianceFactor*Ln(Price(i)/Price(k))*

$$\mathrm{MarketShare}_n(\mathrm{i}) = \frac{e^{(\mathrm{NonPriceFactor}+\mathrm{VF}*\mathrm{Ln}(\mathrm{Price(i)}/\mathrm{Price(k)}))_{in}}}{\sum_{j=1}^{N} e^{(\mathrm{NonPriceFactor}+\mathrm{VF}*\mathrm{Ln}(\mathrm{Price(i)}/\mathrm{Price(k)}))_{in\,jn}}}$$

Where,

- MSF(i) - Marginal Market Share Fraction for Option i ($/$)
- V(i) - Utility Of Choice I (also referred to as marginal allocation weight)
- Price(i) - Levelized Lifecycle Cost Of Option I ($/mmBtu)
- Price(k) – Levelized Lifecycle Cost of Option Used as Reference ($/mmBtu).

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[3] Train, K., *Discrete Choice Methods with Simulation*, Cambridge University Press, 2009.

- Variance Factor - Price Coefficient ($/$)
- Non-Price Factor(i) - Non-price coefficient for option I ($/$)

To summarize, the market share fraction equation incorporates both price and non-price factors. The fraction of each type of fuel chosen will be affected by the relative marginal cost of energy, the efficiency, and non-price factors, such as propensity toward a specified technology due to environmental benefits or a resistance to a specified technology due to perceived barriers.

Appendix 6: Calculating Emissions Coefficients

Energy-related CAC emissions from demand sector

For the demand sector energy-related CAC emissions, an emissions coefficient is first calculated from the known historical CAC emissions (emissions divided by energy consumed). There are sectors in which historical CAC emissions for a particular fuel exist where no historical fuel demand exists. In those instances, the historical emissions are categorized as process emissions. Cogeneration coefficient is set equal to the energy coefficient due to a lack of specific data. The feedstock coefficient, which sets values for non-combustions emissions, is currently set to zero to avoid double-counting issues since its historical inventories are also found in the process inputs. The code described above can be found in the following 2020Model files: CAC_Industrial.txt, CAC_Commercial.txt, CAC_Residential.txt, CAC_Transportation.txt.

Process Emissions CACs

Several sectors that produce CAC emissions aren't modeled in detail by ENERGY 2020 and have no input fuel demands. These sectors are given energy and process emissions coefficients in CAC_Macroeconomy.txt based on their historical inventories and corresponding economic driver in order to account for their expected emissions in the model forecast. Some sectors, such as Forest Fires, have a constant value set for the driver so the model assumes that we will generally have the same amount of emissions from these sources in the future as we have had historically.

Electric Utility CACs

Generating electric utility coefficients is more complex compared to the demand sectors since ENERGY 2020 simulates electric generation, fuel consumption, and emissions at the unit level. Since there are two separate sources of data for Utility Generation emissions, sector-wide inventories across each area (XEnFPol) and NPRI data containing unit-level emissions (vUnPol), the CAC_ElectricGeneration.txt file contains code developed to both. Units are initialized with the same energy and process coefficient across a given area by dividing the sum of all unit fuel usage (UnDmd) in a given area by the corresponding inventory (XEnFPol). The inventory is re-calculated using the new coefficient (UnPOCX) and any differences between the calculated and historical inventories are placed into process.

If a unit contains data from NPRI then the coefficients are adjusted using the NPRI data. Other units not included in the NPRI data have their emissions coefficients recalculated in order to match the sector-wide inventory. In practice, the NPRI data and sector-wide inventories often do not agree completely so it is difficult to match both inputs at once. As a compromise, the code is designed to iterate between adjusting based on the NPRI data and the sector-wide inventories ten times in order balance between the two data sources and create the most reasonable estimate possible.

Emissions-Related Input Data

Input data differs by the type of the pollutant (GHG vs. CAC) and the method by which the pollutant is created (Combustion, Process, etc.). ENERGY 2020 reads in emissions-related coefficients and inventories as input data through the Access database, vData.accdb. The following lists the emissions-related variables that are in the Access database along with a short description of each:

- vPOCX: Energy emissions coefficients (GHG)
- vFsPOCX: Feedstock emissions coefficients (GHG)
- vEUPOCX: Electric Utility energy emissions coefficients (GHG)
- vTrEnFPOCX: Transportation energy emissions coefficients (GHG)
- vTrFsPOCX: Transportation feedstock emissions coefficients (GHG)
- vEnFPol: Energy emissions inventories (CAC)
- vMEPol: Process emissions inventories
- vOREnFPol: Off-road emissions inventories (CAC)
- vTrEnFPol: Transportation energy emissions (CAC)
- vTrMEPol: Transportation process emissions
- vFlPol: Flaring emissions inventories
- vFuPol: Fugitive emissions inventories
- vVnPol: Venting emissions inventories
- vUnPol: NPRI utility emissions inventories
- vNPRICode: NPRI data unit identification data