

# ENERGY 2100 Documentation

# Volume **1**

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## Overview

April 2026

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## 1. INTRODUCTION

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ENERGY 2100 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 with capabilities to project through the year 2100 and beyond. The model is used to forecast energy and emissions as well as to perform 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 18 greenhouse gas pollutants and air pollutants. ENERGY 2100 uses techniques from discrete choice economic consumer theory and system dynamics to develop a partial equilibrium, which when linked iteratively with an economic model, arrives at a general equilibrium and creates a powerful fully integrated energy-emissions-economy modeling system.

ENERGY 2100's methodologies make it an ideal use for policy analysis given its bottom-up, causal approach. Principles of consumer choice theory provide realistic simulation of consumer decisions, and principles from system dynamics track capital stock turnover. With this approach, detailed policies are able to be simulated capturing feedback effects across sectors and fuels and interaction effects of implementing multiple policies simultaneously. Some examples of the types of policies analyzed using ENERGY 2100 are listed below.

*Policy examples able to be analyzed using ENERGY 2100:*

- Energy and emission taxes and incentives
- Cap-and-Trade Systems
- Clean air standards
- Energy efficiency measures
- Appliance and building standards
- Landfill gas regulations
- Vehicle emissions regulations
- Clean Fuel Regulations
- Clean Electricity Regulations
- Renewable energy requirements
- Industrial generation
- Direct air capture

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ENERGY 2100 is proprietary software maintained by Systematic Solutions, Inc. (SSI) and has been 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 modeling 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.

### 1.1. Organization of this Document

This document provides a summary of the overall design, structure, and methodologies used within ENERGY 2100. The sections covered consist of: 1) [Introduction](#); 2) [ENERGY 2100 Overview](#); 3) [Demand Module](#); 4) [Supply Module](#); 5) [Emissions Tracking](#); 6) [Macroeconomic Integration](#); 7) [Policy Analysis](#); 8) [Model Source Code](#); 9) [Input Data and Assumptions](#).

For specifics on how to generate a reference case forecast and build policy scenarios as well as how to view model outputs, and basic mechanics of the programming language, please refer to ENERGY 2100 model documentation, *Volume 1 - ENERGY 2100 User Manual*.

### 1.2. Other ENERGY 2100 Resources Available

For further details on ENERGY 2100 modules, refer to the list of available documentation below. The model documentation covers a user manual providing instructions on the mechanics of running the model and building policies, theoretical derivations of methodologies and key equations within each module, and model assumptions and input data.

*ENERGY 2100  
Documentation  
Available:*

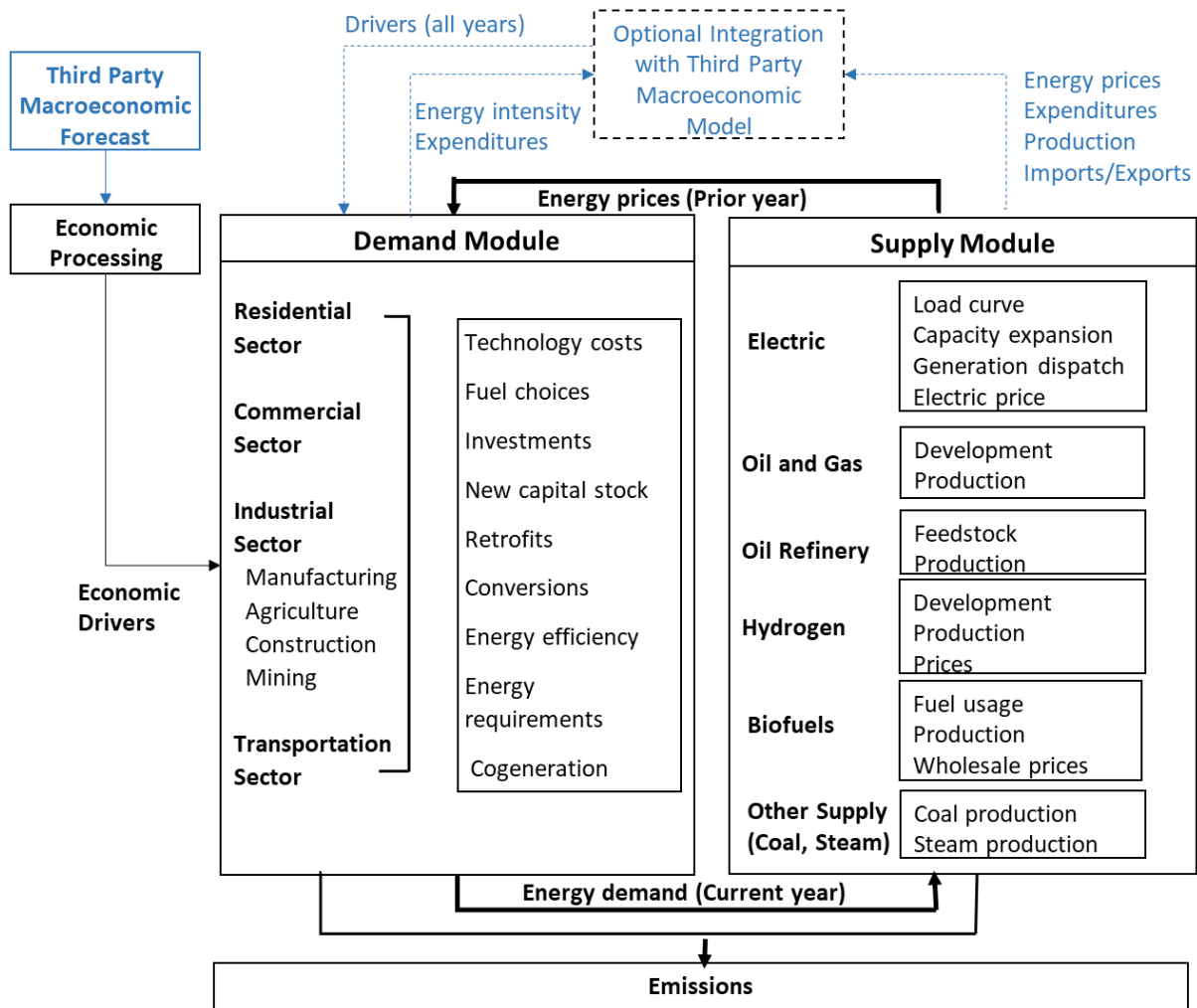
- Volume 1: ENERGY 2100 User Manual
- Volume 2: Overview
- Volume 3: Demand Module
- Volume 4: Electricity Supply Module
- Volume 5: Oil and Gas Supply Module
- Volume 6: Refineries, Hydrogen, and Other Supply Modules
- Volume 7: Input Data and Assumptions

## 2. ENERGY 2100 OVERVIEW

ENERGY 2100 is an integrated regional, multi-sector energy simulation model. Energy supply, prices, and demands are simulated across forty-one detailed fuel types (Table 25 in *Appendix 2. Fuels, End-UseS, and Technologies*).

ENERGY 2100 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 2100. The energy demand module consists of four sectors (residential, commercial, industrial, and transportation).

**Figure 1. ENERGY 2100 Model Structure**



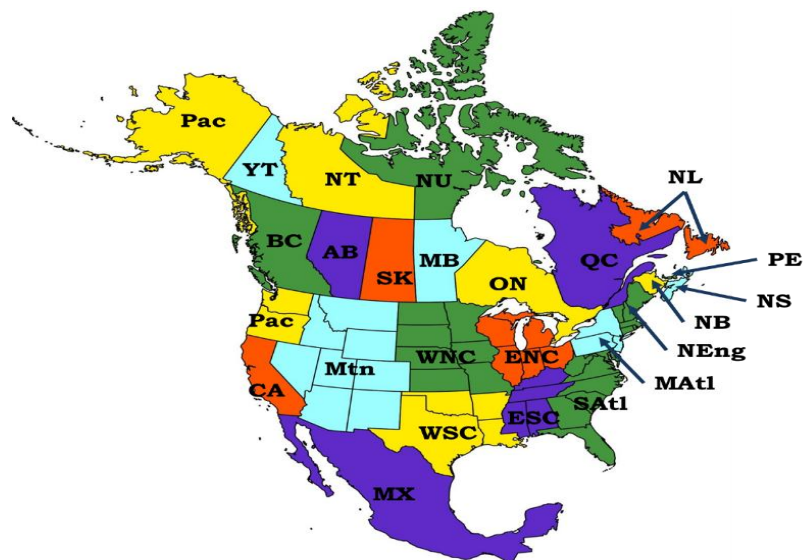
Energy demands are calculated and sent as input to the supply module consisting of 7 energy producing sectors – electricity, oil and gas, refinery, biofuels, coal, hydrogen, and steam. The supply module produces the energy required to meet the energy demand, calculates energy prices, and sends energy prices back as feedback to the demand sector. Both energy and non-energy related emissions are tracked covering 18 possible greenhouse gas (GHG) pollutants and air pollutants plus water usage.

Shown with dashed lines, Figure 1 illustrates the optional integration with a third-party macroeconomic model. In this fully integrated energy-emissions-economy case, the energy supply and demand sectors feed policy impacts to the macroeconomic model which then sends back revised economic drivers the demand sector. Indirect impacts from the macroeconomic model are sent to the supply sector through changes in energy demand. This process is iterated to reach convergence. 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 2100, then ENERGY 2100 inputs static economic drivers from an exogenous macroeconomic forecast. The economic forecast in this “non-integrated” case remains constant regardless of policy. With the linkage to an economic model, ENERGY 2100 and that economic model iterate until prices, demands, and supplies are fixed, reaching a general equilibrium. As such, both models together make up a general equilibrium model. ENERGY 2100, in providing half of that process is classified as a partial equilibrium model, holding the values from the economic model as fixed.

The currently-defined areas in the model are shown on the map in Figure 2. The U.S. states are aggregated states into ten regions (matching the census divisions reported by the U.S. Energy Information Administration) with California being split out from the Pacific region. Each province and territory of Canada is represented individually. Mexico is represented at an aggregate national level (See *Appendix 1.* for a complete list of areas as well as how states are mapped to regions.

**Figure 2. Default Demand Areas in ENERGY 2100**



The economic categories in the model are able to be customized; however, the default version specifies 4 residential and 12 commercial/institutional classes, 42 industries, and 8 modes of transportation in addition to several miscellaneous categories (see Table 1). The miscellaneous categories include 4 used to hold fuel demands from suppliers not otherwise accounted for in the industrial sector - electric utility generation, biofuel production, hydrogen production, and steam generation (where steam generation category simulates the facilities that sell steam to other sectors). The miscellaneous categories also include 9 that are specific to tracking other emissions not directly related to energy supply or consumption (solid waste, waste water, incineration, land use, road dust, agriculture open sources, forest fires, biogenic emissions, and miscellaneous) and simulation of Direct Air Capture (DAC) devices.

**Table 1. Economic Categories Represented in ENERGY 2100**

Residential		Commercial/Institutional		
Single Family Detached		Wholesale Trade	Health Care and Social Assistance	
Single Family Attached		Retail Trade	Arts, Accommodation, Food, Other	
Multi-Family		Warehousing and Storage	Natural Gas Distribution	
Other Family		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	
Petrochemicals	Iron & Steel	Frontier Oil Mining	Coal Mining	
Industrial Gas	Aluminum	Primary Oil Sands	Construction	
Other Chemicals	Other Nonferrous Metal	SAGD Oil Sands	Forestry	
Fertilizer	Transport Equipment	CSS Oil Sands		
Petroleum Products	Other Manufacturing	Oil Sands Mining		
		Oil Sands Upgraders		
Transportation		Other Miscellaneous Categories		
Passenger	Foreign Passenger	Miscellaneous	Direct Air Capture	Road Dust
Freight	Foreign Freight	Hydrogen Production	Solid Waste	Agriculture Open Sources
Air Passenger	Residential Off-Road	Utility Electric Gen.	Wastewater	Forest Fires
Air Freight	Commercial Off-Road	Biofuel Production	Incineration	Biogenics
		Steam Generation	Land Use	

## 2.1. Demand Sector Characteristics

The demand module provides long-range projections of total energy demand (end-use, self-generation, and feedstock), emissions, energy efficiency, and investments for each of the

sectors. The economic drivers chosen to drive energy demands for each of Canada, U.S., and Mexico areas of the model are identified in Table 29 of *Appendix 3. Economic Drivers*.

Table 2 below summarizes the structural characteristics represented in ENERGY 2100’s default configuration within each of the four demand sectors.

**Table 2. Characteristics of ENERGY 2100 Demand Sectors**

Energy Sector	Categories Represented (Default)	Regional Representation (Default)
Residential Demand Sector	<ul style="list-style-type: none"> <li>• Four housing types</li> <li>• Seven end-uses (space heating, water heating, other substitutables<sup>1</sup> that can use various fuels, refrigeration, lighting, air conditioning, other non-substitutables<sup>2</sup>)</li> <li>• Twelve technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal, heat pump, dual heat pump, fuel cell)</li> </ul>	Demand Sector Areas: <ul style="list-style-type: none"> <li>• U.S. – 10 demand regions consisting of 9 EIA-defined census divisions plus California</li> <li>• Canada – 13 provinces and territories</li> <li>• Mexico – 1 nation</li> <li>• Rest of World (1)</li> </ul>
Commercial Demand Sector	<ul style="list-style-type: none"> <li>• Twelve commercial/institutional sectors</li> <li>• Seven end-uses (Space heating, water heating, other substitutables, refrigeration, lighting, air conditioning, other non-substitutables)</li> <li>• Twelve technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal, heat pump, dual heat pump, fuel cell)</li> </ul>	
Industrial Demand Sector	<ul style="list-style-type: none"> <li>• Forty-two industrial sectors</li> <li>• Six end-uses (process Heat, motors, other substitutables, miscellaneous, off-road, excess steam)</li> <li>• Twelve technology types (electric, gas, coal, oil, biomass, solar, LPG, steam, geothermal, off-road, heat pump, fuel cell, battery storage)</li> </ul>	
Transportation Demand Sector	<ul style="list-style-type: none"> <li>• Eight transportation economic categories (Passenger, Freight, Air Passenger, Air Freight, Foreign Passenger, Foreign Freight, Off Road Passenger, Off Road Commercial)</li> <li>• Fifty-seven technology types (eight light duty vehicle and eight light duty truck types, motorcycle, buses, trains, air planes, marine, and 24 heavy duty vehicle categories)</li> </ul>	

## 2.2. Supply Module Characteristics

ENERGY 2100’s supply module produces electricity, crude oil, natural gas, biofuels, refined petroleum products, coal, hydrogen, and steam to meet the fuel demands required by the residential, commercial, industrial, transportation, and miscellaneous demand sectors. The

<sup>1</sup> Substitutables are devices (e.g. ranges, dryers, pipeline compressors) that can use various fuels.

<sup>2</sup> Non-substitutables are miscellaneous electrical devices (e.g. computers, TVs).

model has the capability for users to produce endogenous forecasts for each of these sectors, calibrate to exogenous forecasts, or a combination of both depending on activated model switches. 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 default configuration of the model.

**Table 3. Characteristics of ENERGY 2100 Supply Sectors**

Energy Sector	Categories Represented (Default)	Regional Representation (Default)
Electricity Supply Sector	<p>Capability for individual generating unit representation:</p> <ul style="list-style-type: none"> <li>• Aggregated electric generating units in U.S. (634)</li> <li>• Individual generating units in Canada (2044)</li> <li>• Twenty-four plant types: 9 conventional; 12 renewable; and 3 other types.</li> <li>• Minimizes costs to meet demand (from residential, commercial, industrial, and transportation sectors)</li> </ul>	<p>Electric transmission Nodes:</p> <ul style="list-style-type: none"> <li>• U.S. - 22 electric supply nodes</li> <li>• Canada - 14 nodes, one for each province and territory plus Labrador</li> <li>• Mexico - 1 node</li> </ul>
Oil and Gas Supply Sector	<ul style="list-style-type: none"> <li>• 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)</li> <li>• Oil and gas “plays” from U.S, Canada, and Mexico</li> </ul>	<p>Oil and gas, refinery, biofuel, hydrogen, and coal supply regions:</p> <ul style="list-style-type: none"> <li>• U.S. – 10 regions</li> <li>• Canada – 13 provinces and territories</li> <li>• Mexico – 1 nation</li> </ul>
Oil Refining Supply Sector	<ul style="list-style-type: none"> <li>• 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)</li> <li>• Meets North America demand (refines based on minimizing costs)</li> </ul>	
Biofuels Supply Sector	<ul style="list-style-type: none"> <li>• Two biofuels produced (Ethanol and Biodiesel)</li> <li>• Five feedstocks (Corn, Wheat, Cellulosic for Ethanol, and Rapeseed and Other for Biodiesel)</li> <li>• Production, imports and exports to meet demand (most demands from transportation sector)</li> </ul>	
Coal and Steam Supply Sectors	<ul style="list-style-type: none"> <li>• No special structures were created to simulate the coal and steam supply sectors.</li> <li>• Production, imports and exports to meet demand</li> </ul>	
Hydrogen/Ammonia Supply Sector	<ul style="list-style-type: none"> <li>• Twelve production technologies (Grid Electrolysis, Onshore Wind Electrolysis, Solar PV Electrolysis, Interruptible Electrolysis, SMR NG, SMR NG with CCS, ATR NG with CCS, Biomass, Biomass with CCS, SMNR, Methane Pyrolysis, and Other)</li> </ul>	

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### 2.3. Modeling Approach

ENERGY 2100'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. Algorithms 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 2100 mimic this process when simulating the dispatch of generating units 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 2100 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. By stressing causality, the methodologies allows for rational explanations of how policies impact the real world.

#### **Demand Module Methodology: A Snapshot**

Each demand sector – residential, commercial, industrial, and transportation – is modeled the same way by building up energy demand from the energy requirements within the energy system. The evolution of capital stocks are tracked 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 users' perceptions of utility) are applied to simulate how consumers make decisions about new technology purchases impacting energy efficiency levels and fuel market shares.

#### **Supply Sector Methodology: A Snapshot**

Within the supply module, the electric sector optimizes the dispatch of individual electric generating units to minimize system costs while meeting electricity demand. The oil and gas, refinery, hydrogen, and biofuel supply modules, can either be calibrated to exogenous forecasts or calculate endogenous projections based on a user switch. When an exogenous forecast is used for the reference case, the forecasts respond to changes in wholesale energy prices and oil and gas policies within any scenario cases run.

Endogenous projections are able to be selected for any one or all of the supply sectors. The oil and gas supply sector module simulates 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. Biofuel and hydrogen/ammonia production are determined by demand, imports, exports, and wholesale prices and use consumer choice theory to simulate

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which production processes (feedstock-fuel combinations) are used by the suppliers. Oil refineries produce refined petroleum products (RPPs) to match demand for RPPs after accounting for import and export flows. Similarly, coal is produced to meet demand for coal after accounting for coal trade flows.

## 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 technological evolutions impact future energy demand and supply requirements and can be incorporated into several of ENERGY 2100's demand and supply sector technologies as the user desires. The specific method used to capture technology innovation in ENERGY 2100 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.

Some technologies can be assumed to experience cost and efficiency gains based on world-wide, global experience. In these cases, local experience does not have much impact on the overall efficiency or cost improvements of a technology. An example of local vs global base of experience can be seen with people learning how to site solar panels and hook them up to the grid. When solar was first introduced, there was a lot of local learning, such as finding south facing slopes with appropriate access. As developers got better at selecting and developing sites, the cost of installation went down. Over time, solar developers no longer experience significant gains from learning more about what makes a good site for solar panels. Rather, technology improvements are now driven by widely (globally) available innovations in solar panel design.

**Incorporating Technology Improvements Based on Local Experience:** For technologies that we assume improve based on local experience, users assign a learning curve based local usage of the technology (for example, efficiency and/or costs of solar might improve as installed capacity in Canada increases). Learning curve parameters are obtained from learning rates reported by external sources, such as by the U.S. Energy Information Administration. Where technology innovation learning rates are not available, an assumed "rule-of-thumb" can be used, such as when the installed capacity doubles, the costs are reduced by 20%.

**Incorporating Technology Improvements Based on Global Experience:** Some technologies, such as furnaces, water heaters, and process heater, may experience improvements in cost and efficiencies over time based on a global base of experience regardless of usage in local areas. To incorporate technology innovation where a global base of experience drives the innovations,

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users can input exogenous world-wide rates of efficiency and/or capital cost improvements obtained from external sources.

## **2.5. Sensitivity Analysis**

Sensitivity analysis is conducted by observing the impact of varying key input variables. These variations can be approached systematically when a set of input variables are assigned a multidimensional probability distribution. Using Latin-Hypercube sampling, the input parameters are varied simultaneously to capture the more realistic "all-else-not-equal" conditions and probabilistic confidence intervals over output variables.

Scenarios can also be run while varying each input variable one-at-a-time. This technique provides a measure of the importance of each input and can assist in determining which are "key" variable and thus deserve additional attention.

## 2.6. Inputs and Outputs by Sector

Table 4 provides the demand sector’s key inputs and outputs. Whereas all demand sectors share the same methodologies, input data definitions for the transportation sector vary slightly from the other sectors. Table 5 lists the key inputs to and outputs from the supply sector.

A majority of the input data are input through text files (stored with a .dat extension). See **Section 9. Input Data and Assumptions** for a list of demand and supply input data files entered to the model.

**Table 4. Demand Sector Inputs and Outputs**

Sector	Outputs	Inputs from ENERGY 2100	Exogenous Inputs
Residential Demand	Energy demand (end-use, self-generation, feedstock) by economic category, enduse, fuel, and area	Production capacity by vintage (residential and commercial floorspace, industrial output)	Macroeconomic (residential and commercial floorspace, households, industrial gross output, GDP, inflation index, exchange rate)
Commercial Demand	Emissions (from end-use, self-generation, and feedstock demand) by pollutant	Energy prices from supply modules (electricity, oil, gas, RPP, and coal prices)	Process (building shell or industrial process) and device (equipment) characteristics
Industrial Demand	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	Emission prices Oil and natural gas production (driver for commercial pipelines, NG distribution and gas and industrial oil and gas mining) RPP and coal production (to drive petroleum products, and coal mining industries)	<ul style="list-style-type: none"> <li>- Energy efficiency &amp; capital costs for initialization year, where available</li> <li>- Energy efficiency maximums, physical survival rates</li> </ul> Existing building codes, energy efficiency standards, regulations Feedstock efficiency by industry Self-generation characteristics (potential, heat rate) Emissions coefficients or inventories Technology innovation assumptions Emissions coefficients, inventories Emissions caps or reduction requirements
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 and diesel) Emission prices Emissions caps or reduction requirements	Economic drivers (population, personal income, GDP) Existing and new vehicle characteristics (efficiency and capital costs for initialization year, vehicle scrappage rates) Vehicle safety and emissions regulations Emissions coefficients or inventories Emissions caps or reduction requirements

**Table 5. Supply Sector Inputs and Outputs**

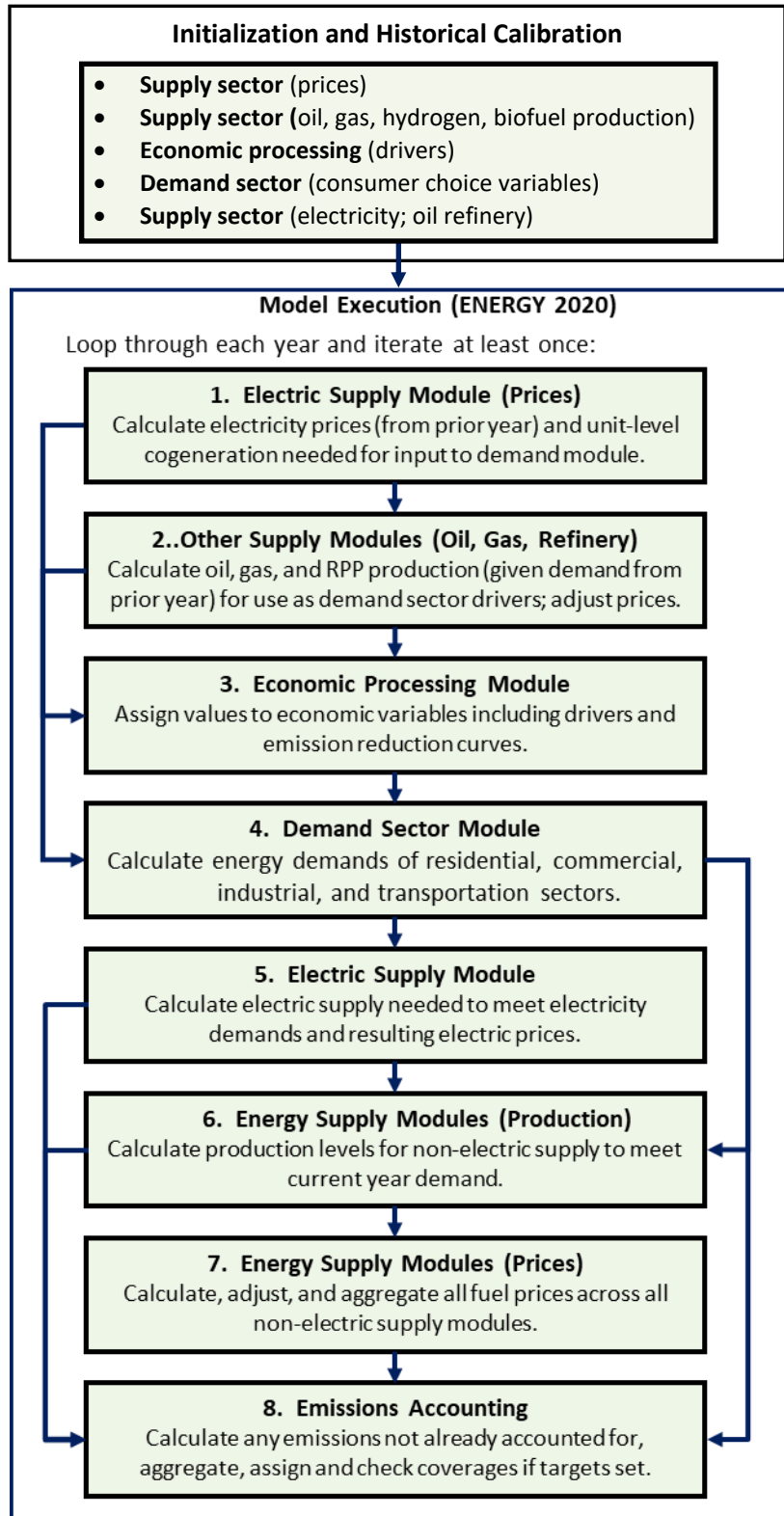
Sector	Outputs	Inputs from ENERGY 2100	Exogenous Inputs
Electricity Supply	Electricity capacity, generation, transmission flows, imports and exports Fuel usage required to generate electricity (energy demand for Electric Utility Generation industry) Emissions from electric generation Electricity prices 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 Emission prices	Existing and new plant characteristics (location, capacity, plant type, costs, etc.) Technology innovation curves Power generation and fuel demand for historical years Emissions coefficients or inventories Emissions caps or reduction requirements
Oil and Gas Supply	Crude oil and natural gas production	Fuel prices from supply modules Emission costs Capital costs	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
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) Emission prices	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 demand and electric utility sectors)	Local coal prices Export market coal price Emission taxes
Hydrogen Supply	Hydrogen and ammonia production Imports and exports Hydrogen prices	Demand for hydrogen and ammonia Emission prices	Hydrogen and ammonia demands Historical price data
Steam Supply	Steam production	Demand for steam	Historical steam demands

## 2.7. Steps of Model Execution

Figure 3 illustrates the general order in which ENERGY 2100 modules are executed for each forecast year in relationship to each other. First ENERGY 2100 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 2100 is ready to execute model equations used to forecast long-range annual projections of the energy demand and supply system. The model execution is run over the projection period during which ENERGY 2100 loops through each forecast year and performs the operations generally in the order shown in the flow diagram.

**Model Execution Steps 1 and 2. Electric Supply Module (Prices) and Other Supply Modules:** The initial two steps

**Figure 3. ENERGY 2100 Flow Diagram**



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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 self-generation, 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, unit-level self-generation is determined before the demand module is executed.

**Step 3. Economic Processing Module:** The economic processing module 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 the residential, commercial, industrial, and transportation sectors. Each of the sectors is executed sequentially – first calculating annual energy demands then translating the electric 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. Electric Supply Module:** 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. Energy Supply Modules (Production):** The remaining supply sectors are executed to calculate production levels given energy demands. The production forecasts are able to be input exogenously or calculated endogenously based on a user-selected switch. Outputs from these supply sectors include production, imports and exports, costs of production, and emissions from production.

**Step 7. Energy Supply Modules (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.

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**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 self-generation 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.

**Iterations to Meet Emissions Caps:** These eight model execution steps occur for each year with at least one iteration. The first iteration is used to calculate the emissions without an emissions cap in order to know the fractional reduction needed to meet the cap. This fractional reduction is then used in the second iteration. 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 sections provide more detailed descriptions of methodologies used to simulate the demand sectors ([3. Demand Module](#)) and the supply sectors ([4. Supply Module](#)).

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### 3. DEMAND MODULE

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This section provides more specifics on methodologies used to simulate the demand sectors. Three categories of fuel demands are simulated: 1) fuel used for end-use consumption, 2) fuel used for self-generation, and 3) fuel used as feedstocks.

Outputs from ENERGY 2100'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, self-generation, and feedstock). Primary inputs to the demand module include economic drivers, energy prices, and technology characteristics.

ENERGY 2100 projects energy demand 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 demand is built up from the energy requirements within the energy system. As a technology vintage model, ENERGY 2100 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 on new technology purchases impacting energy efficiency levels and fuel market shares. To understand how ENERGY 2100 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 Methodology 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. 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.

### Process and Device Energy

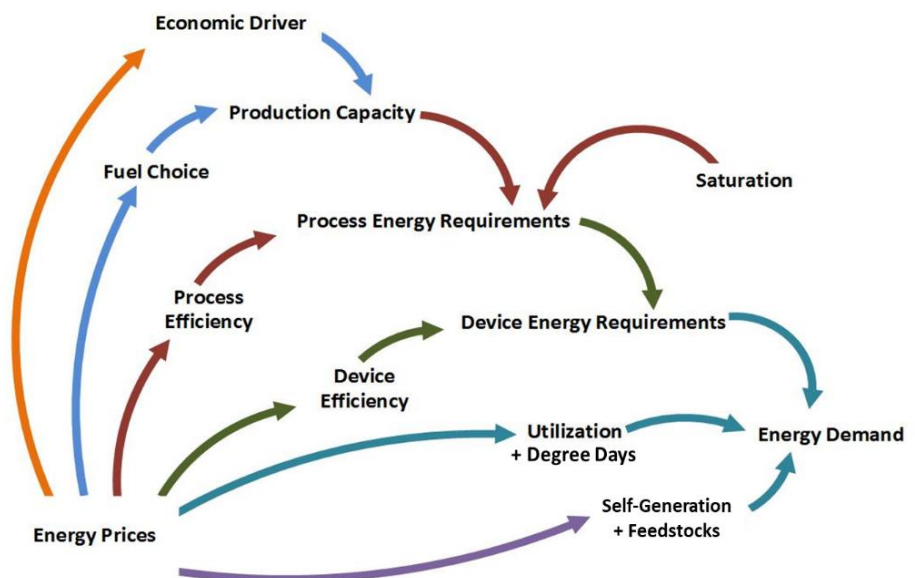
**Process energy** represents the energy services from capital stock used to produce output within each sector (housing for sustained living in residential, buildings to provide services in commercial, factories and industrial processes for producing output in industrial, and transportation infrastructure 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.

Figure 4 graphically illustrates the mechanisms used to determine total energy demand. The diagram shows the causal structures that link energy prices (bottom left) and the economic driver (top) ultimately to energy demand (bottom right).

Economic drivers by sector 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

**Figure 4. Demand Sector Methodology Diagram**



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production capacity drive changes in the need for process energy which, in turn, drives changes in the need for device energy. For example, if the economic driver for residential energy demand is floorspace in square feet, floorspace is translated into a production capacity variable. Given growth in the residential sector, new homes will be constructed 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.

The energy requirements of the system depend not only on changes to production capacity, but also on **fuel choices** for new capital stock as well as consumer choices of **energy efficiency** levels. 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 to determine how much energy the house uses to provide the desired warmth.

The energy efficiency of the building (**process efficiency**) 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 all residents work outside the home). Process efficiency is measured as unit of economic output per unit of energy output (e.g. floorspace or \$/Btu).

The efficiency of the furnace (**device efficiency**) 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.

**Saturation** rates of devices also impact energy requirements. Saturation rates represent the amount of energy services necessary to produce a given level of output. These 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. Saturation rates can be specified exogenously or can be defined in relation to other variables within the model (such as disposable income).

All the factors described above make up the device energy requirements of consumers' end-use demands. Combining the device energy requirements with utilization factors (obtained from historical calibration) and degree days, self-generation, and feedstock fuel demands yields the total consumer energy demand. Utilization factors are extracted from historical data during the calibration and are able to be modified by the user (see *Section 3.7 Calibration of Demand Sector Equations*). The equation for energy demand is shown in Figure 5.

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**Figure 5. Energy Demand Equation**

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$$\text{Energy Demand} = \text{Device Energy Requirements} * \text{Utilization Factors} * (\text{Temperature Sensitive Load} * \text{Degree Days}) + \text{Self-Generation Demand} + \text{Feedstock Demand}$$

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The following sections provide further detail on each of the key demand-sector concepts:

- 3.2. *Tracking Capital Stock*
- 3.3. *Energy Efficiency*
- 3.4. *Fuel Market Shares*
- 3.5. *Self-Generation/Cogeneration*
- 3.6. *Feedstocks*
- 3.7. *Calibration of Demand Sector Equations*

### **3.2. Tracking Capital Stock**

To build up the system's energy requirements, ENERGY 2100 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. Stocks for production capacity and process energy are tracked by three age types – new, middle, and old. Stock for device energy (such as vehicles, furnaces, boilers, etc.) are tracked at a more detailed vintage level based on years. The more detailed vintaging of device energy allows for the model to utilize scrappage rates by age to allow for older devices to retire at greater rates than newer devices.

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 wear-out (at end of physical lifetime); converted to capital stock of any fuel type
- Retirements of capital stock due to economic decline; not replaced

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- 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.

### 3.3. Energy Efficiency

Consumer choices of efficiency levels of new technologies are made based on an efficiency/capital cost trade-off. This trade-off is 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.

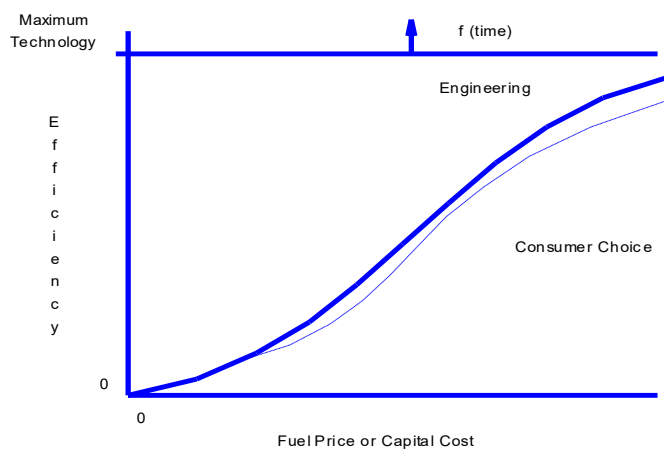
The standard ENERGY 2100 efficiency tradeoff curves are called consumer preference curves because they are estimated using cross-sectional (historical) data showing the decisions consumers made based on their perception of a choice's value. The efficiency with which the capital uses energy has a limit determined by technological or physical constraints.

Figure 6 illustrates this principle. 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.

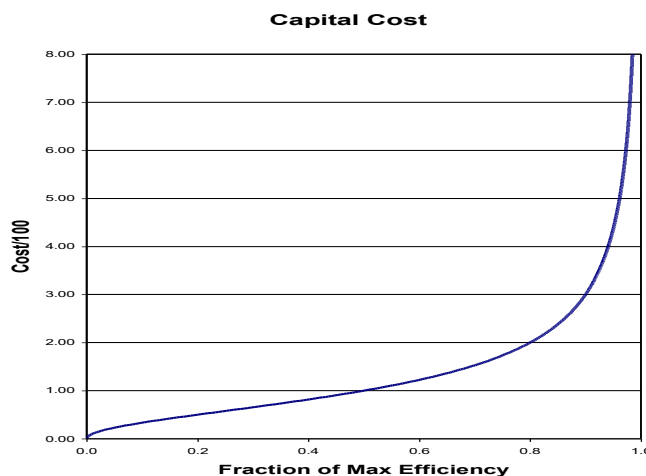
The “S” curves for both the engineering and consumer choice relationships are drawn against a maximum technology curve (a ceiling on efficiency given current technology) which can change over time as technological breakthroughs occur. As the maximum technology line shifts, the engineering and consumer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

**Figure 6. 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 7 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 7. Capital Cost Trade-Off Curve**



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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 2100 Documentation, *Volume 3 (Demand Module)*.

### **Impact of Historical Efficiency Standards**

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%. This value produced historical efficiencies consistent with our 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.

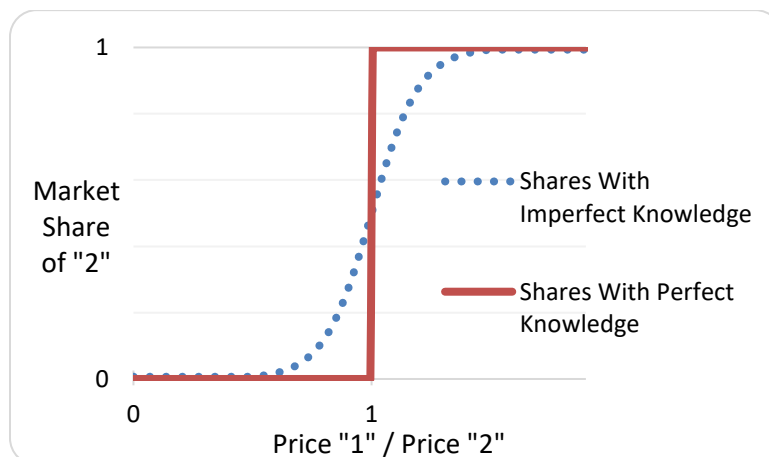
### Exceptions to Efficiency/Capital Cost Trade-Off Curves

Other efficiency curves are able to be incorporated as needed into the model methodology. One example is in the Iron and Steel sector, where the marginal efficiency and capital costs are determined based on curve parameters developed from an outside study of expected technological change. In this case, a model switch is used to select the output of an equation using these parameters in place of the existing assumptions in the model. Other specific curves have been developed and used for reductions in fugitive emissions and levels of carbon sequestration.

### 3.4. Fuel Market Shares

Qualitative choice methods are used to capture a consumer's fuel choice process that trades-off efficiency with other cost components and preferences. 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**



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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 2100 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.

Market share equations are provided in *Appendix 5. Consumer Choice Theory*, and a description of its theoretical derivation can be found in ENERGY 2100 documentation's *Volume 2 (Demand Module)*.

### **3.5. Self-Generation/Cogeneration**

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 2100, self-generation includes both 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 at the “unit” level and is designed to be similar to the electric generation segment. Individual self-generating units are constructed in a similar manner as utility units assigning detailed characteristics, such as heat rates and emission factors specific to that unit. Modeling individual self-generating units allows for detailed policy analysis in which policies may impact individual units differently. Self-generation units can be constructed endogenously or can be specified as exogenous inputs to the model.

### 3.6. Feedstocks

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 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.

### 3.7. Calibration of Demand Sector Equations

#### Demand Calibration

ENERGY 2100 calibrates three demand module concepts to historical energy data: marginal fuel market shares, energy demand (enduse, self-generation, and feedstock), and energy efficiency (device and process). 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
<b>Used in marginal fuel market share equations (enduse and self-generation):</b>	
MMSM0	Marginal Market Share Multiplier (Non-Price Factor)
CgMMSM0	Self-Generation/Cogeneration Marginal Market Share Multiplier (Non-Price Factor)
<b>Used in energy demand equations (enduse, self-generation, feedstock):</b>	
CERSM	Capital Energy Requirement Multiplier (Lifestyle Multiplier)
CUF	Capacity Utilization Factor
CgCUF	Self-Generation/Cogeneration Capacity Utilization Factor
FsPEE	Feedstock Process Efficiency
<b>Used in energy efficiency equations (device and process):</b>	
DEMM	Maximum Device Efficiency Multiplier
PEMM	Maximum Process Efficiency Multiplier

More information on how these variables are calculated can be found in *Volume 3. Demand Module*.

## Projecting Calibration Variables into the Future

The process of generating a forecast using ENERGY 2100 involves reviewing, analyzing, and determining the best method of projecting the calibration variables. An initial set of projection methods is set up as a default. 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. The initial, default projection method assigned for each variable (by area, industry, fuel, and enduse) are listed in Table 7.

**Table 7. Default Projection Methods of Calibration Variables**

Variables	Projecting Calibration Variable into Future Default Methods
MMSMO Non-Price Factor	<ul style="list-style-type: none"> <li>• Use average historical market share value (Res/Com/Ind)</li> <li>• Use average historical non-price factor (Trans)</li> </ul>
CERSM Lifestyle Multiplier	<ul style="list-style-type: none"> <li>• Assign future values equal to exogenous values scaled to the last historical year's value</li> </ul>
CUF Capacity Utilization	<ul style="list-style-type: none"> <li>• Trend future values to an exogenous value</li> </ul>
FsPEE Feedstock Process Efficiency	<ul style="list-style-type: none"> <li>• Assign future values equal to exogenous values scaled to the last historical year's value</li> </ul>
DEMM Maximum Device Efficiency Multiplier	<ul style="list-style-type: none"> <li>• Assign future values equal to exogenous values scaled to the last historical year's value</li> </ul>
PEMM Maximum Process Efficiency Multiplier	<ul style="list-style-type: none"> <li>• Assign future values equal to exogenous values scaled to the last historical year's value</li> </ul>

Given model results from the default projection methods, users can conduct an analysis (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.

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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 2100, the demand equations for the U.S. forecast are calibrated to match 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.). Mexico's data are obtained from public sources where available – energy data is primarily from Mexico's Secretariat of Energy (SENER)<sup>3</sup>, and economic data is from International Monetary Fund's World Economic Outlook Database and World Bank.

The demand equations for Canada are calibrated throughout the historical period, and the calibration variables are projected using the default methods above, with further adjustments as desired by analysts.

For more detail on calculation of demand module calibration variables and selecting alternative methods for projecting these variables into the future, see *Volume 3. Demand Module*.

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<sup>3</sup> <https://sie.energia.gob.mx/inicio/#/>

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## 4. SUPPLY MODULE

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### 4.1. Supply Methodology Overview

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

The electricity module is the most complex of the supply sector simulations with representation and dispatch of over 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 use optimization - minimizing costs - to determine the type, amount, and transportation flows of RPP production.

ENERGY 2100's biofuel and hydrogen/ammonia production are determined by meeting demands by way of suppliers choosing the type of production method using principles of consumer choice theory.

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. Finally, 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.

Summaries of the methodologies used to simulate each of the supply sectors are provided at an at-a-glance view in Table 8.

#### Energy Demand from Energy Suppliers

The fuel demands of energy suppliers, other than electric utilities, hydrogen, 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. Fuel usage of electric utilities, hydrogen, and biofuel producers is calculated in the supply module, and their fuel demands are stored in their corresponding miscellaneous economic categories.

**Table 8. Supply Sector Methodology At-A-Glance**

<b>Supply Sector</b>	<b>Methodology Snapshot</b>
Electricity 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.
Hydrogen and ammonia production	The Hydrogen Module outputs both hydrogen and ammonia production for energy uses. Total hydrogen production is calculated to meet local hydrogen demand plus any hydrogen required as feedstock to produce ammonia. Total ammonia production meets local ammonia demand plus international exports. Exports are exogenously input and are assumed to be exclusively ammonia as ammonia is the most cost effective way to transport hydrogen energy.

Supply Sector	Methodology Snapshot
Coal production	Coal production is assumed to meet demand for coal plus exports minus imports. Demand for coal is determined in the demand sectors and electric utility supply sector. For active coal-producing regions, coal exports from North America to the rest of the world are based on the local coal price relative to the export market coal price. Coal imports are used to balance demand, production, and exports for areas with limited production.
Steam generation	Most steam generation is simulated inside the 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 more details of the structure and methodologies used within each of the supply sectors: [electricity](#), [oil and gas](#), [oil refinery](#), [biofuels](#), [hydrogen](#), and [coal and steam](#) production. For more in-depth documentation of the supply module, including variable names and equations, see ENERGY 2100 documentation *Volume 3 (Supply Sector – Electric Generation)*, *Volume 4 (Oil and Gas Supply)*, and *Volume 5 (Other Supply - Refinery, Hydrogen, and Biofuel Production)*.

## 4.2. Electricity Supply

The electric supply sector is simulated with individual electric generating units sending electricity to nodes over transmission lines. Inputs such as total electricity demand, generating unit characteristics, transmission costs and constraints are used to 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 peak load hours).

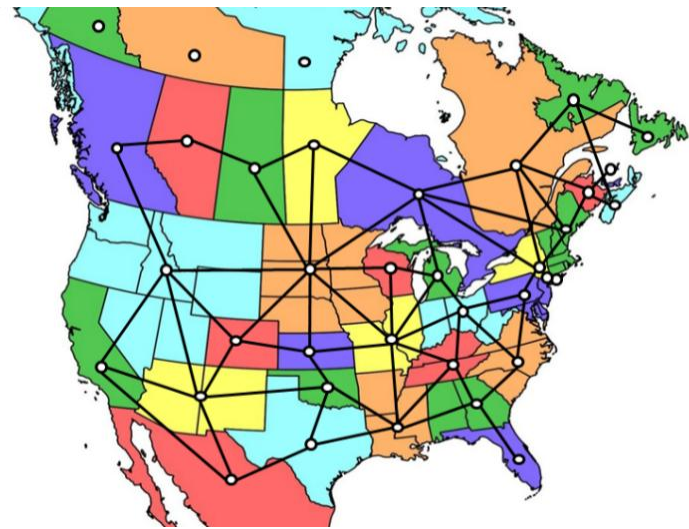
Imports and exports are endogenously determined from the dispatch routine; however, users are able to specify contract amounts that force the flow of electricity between specific nodes if there are known minimum contracted flows between regions.

## 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, 27 plant types, and a representation of generating companies.

*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 40 nodes represented across North America. These nodes consist of 25 nodes in the U.S. (matching EIA's Electricity Market Module regions), 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 2100. Transmission lines are defined by assigning a capacity, transmission efficiency, and wheeling costs between two nodes.

**Figure 9. Default Transmission 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 over two thousand individual generating units. 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.

<b>Electric Generating Unit<sub>(i)</sub> Sample Key Characteristics</b>
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 1 of 24 plant types represented in the model consisting of fossil fuel, renewable, and other plant types (shown in Table 9).

**Table 9. Plant Types Represented in ENERGY 2100**

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

*Retail and Generating Companies:* ENERGY 2100 simulates both generating and retail (load serving entities) companies. Each geographic area in the model contains one retail company and one generation company. 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 and/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.

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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 2100 documentation, *Volume 3 (Supply Sector Electricity)*.

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### 4.3. Oil and Gas Production

ENERGY 2100 projects oil and gas production either by 1) incorporating an exogenous forecast and adding a direct price response or by 2) simulating oil and gas production endogenously through projections of 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 2100's demand sector. It is assumed that the oil and gas sector will produce to its potential if it is economical to do so. The production methodology is selected with a model switch.

Growth projections of production from the oil and gas supply sector are sent as an 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 oil and gas production. See *Volume 5: Oil and Gas Supply* for a more detailed description of the oil and gas supply sector structures, methodology, and code.

#### Structure of Oil and Gas Sector

##### *Submodules*

The oil and gas supply sector consists of several integrated Julia modules that work together to simulate the full supply chain:

- **SpOGProd.jl** - Endogenous Oil and Gas Production with development and production economics
- **SpOProd.jl** - Oil Production, Imports, and Exports balancing
- **SpGas.jl** - Natural Gas Production, Processing, and Pricing
- **SpGTrans.jl** - Natural Gas Transmission Network with pipeline optimization
- **SpImportsExports.jl** - International and Interprovincial/Interstate Trade Flows

##### *Oil and Gas Production Processes*

ENERGY 2100 simulates 16 distinct oil and gas production processes across North America (see Table 10). Each process is represented as an oil and gas “unit” or “play” with unique characteristics including location, production technology, fuel type, and economic attributes.

**Table 10. Production Processes of Oil and Gas Plays**

Process Descriptors	Type of Production
Light Oil Mining	Oil Production
Heavy Oil Mining	Oil Production
Frontier Oil Mining	Oil Production
Primary Oil Sands	Oil Production
SAGD Oil Sands	Oil Production
CSS Oil Sands	Oil Production
Oil Sands Mining	Oil Production
Oil Sands Upgraders	Oil Processing
Conventional Gas Production	Gas Production
Unconventional Gas Production	Gas Production
Associated Gas Production	Gas Production*
Sweet Gas Processing	Gas Processing
Sour Gas Processing	Gas Processing
Pentanes Plus	Oil/NGL Production**
Condensates	Oil/NGL Production**
LNG Production	Gas Processing

\* Associated Gas Production is driven by oil production from Light Oil Mining and Frontier Oil Mining plays.

\*\* Pentanes Plus and Condensates are oil/NGL production driven by gas production from Conventional and Unconventional Gas plays.

### ***Interdependencies Between Oil and Gas***

The model captures important linkages between oil and gas production. Associated gas is produced as a byproduct of light and frontier oil extraction, with volumes proportional to oil production. Conversely, pentanes plus and condensates are natural gas liquids extracted during gas processing, representing oil production driven by gas plays.

Natural gas requires processing before entering the transmission system. The gas is allocated between sweet and sour processing facilities based on the sulfur content characteristics of each play, with sour gas requiring additional processing to remove hydrogen sulfide.

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## Oil and Gas Sector Methodology

### ***Endogenous Production Methodology***

When operating in endogenous mode, the model simulates development and production decisions separately for each oil and gas play. This two-stage approach allows the model to distinguish between the capital-intensive development phase and the lower-cost production phase, which is particularly important for oil sands and other resource plays with high upfront development costs.

### ***Development and Production as Separate Decisions***

Each play can be modeled endogenously at either the **development stage** (adding new reserves) or the **production stage** (extracting from existing reserves), or both. This flexibility is critical for representing realistic producer behavior:

- **Development decisions** are based on forward-looking economics, including expected prices, development costs, and return on investment compared to industry benchmarks
- **Production decisions** are based on current prices relative to marginal production costs

This separation allows the model to capture an important industry dynamic: once capital-intensive development has occurred (particularly for oil sands projects), production can continue even when prices are low, if prices cover the relatively low marginal operating costs. In contrast, new development requires prices high enough to justify the large upfront capital investment.

### ***Cost Dynamics***

The model incorporates several cost adjustment mechanisms:

- **Depletion effects** increase costs as the most favorable resources are developed first
- **Learning curves** reduce costs as the industry gains experience with a particular technology or play
- **Infrastructure sharing** reduces costs for subsequent developments that can leverage existing pipelines and facilities
- **Demand-driven multipliers** link oil and gas development costs to broader trends in capital costs

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### ***Royalty Regimes***

The model supports both gross revenue royalties (based on production value) and net revenue royalties (based on revenues after costs are deducted). Royalty rates can vary with prices, typically increasing when commodity prices are high.

### ***Oil and Gas Trade***

The model balances domestic oil and gas production with refinery demand and end-use consumption through imports and exports. For Canada, the model assumes the country is a price taker for world oil and gas prices, with production and trade responding to international price signals rather than influencing them.

Crude oil imports and exports are calculated to balance production with refinery demand, subject to minimum import/export constraints. The minimum import/export constraints are often based on the last historical year. Natural gas trade includes both pipeline flows to the United States and LNG exports to international markets.

### ***Economic Linkages***

Oil and gas production drives energy demand in related economic sectors including pipeline transportation, oil and gas extraction services, and gas processing facilities. Production growth forecasts are passed to the demand module through gross output multipliers, which adjust energy demand in these sectors proportionally to changes in oil and gas production.

Changes in oil and gas production also affect regional GDP, employment, government revenues from royalties and taxes, and export earnings - impacts that are captured through linkages to the macroeconomic model.

### ***Model Configuration Options***

The oil and gas sector can operate in several modes:

- **Exogenous Production Mode:** Uses external production forecasts with direct price elasticity responses. This mode is simpler to calibrate and useful when matching specific industry or government forecasts.
- **Endogenous Production Mode:** Calculates development and production from economic fundamentals based on return on investment, resource depletion, and learning curves. This mode provides fuller responses to policy changes and technology shifts.

- 
- **Price Responses:** Supply price multipliers can be enabled to allow wholesale prices to respond to changes in production volumes.

## References

For detailed technical specifications, algorithms, and data sources, see:

- **Volume 4: Oil and Gas Supply** - Comprehensive documentation of oil and gas sector structures and methodology
- **Julia module source files:** SpOGProd.jl, SpOProd.jl, SpGas.jl, SpGTrans.jl, SpImportsExports.jl

### 4.4. Oil Refinery Sector

Given refined petroleum product (RPP) demand, ENERGY 2100 calculates RPP production, imports, exports, flows, and crude oil processed by U.S., Canada, and Mexico oil refineries. Two options are built into the model for simulating the oil refineries. The first option calculates RPP production and flows based on RPP demands with a mixture of endogenous and exogenous inputs and outputs depending on a user-specified switch (*RPPSw*). The second option determines production based on a linear programming (LP) algorithm to minimize the cost of supplying all the RPP demands in North America.

Each method is described below. The first method is the default used in the current model version. The second LP method can be activated once specific refinery input data is available.

#### Methodology 1 – Production Based on Demands (Default Method)

The default method calculates RPP production, exports, and imports based on demand for RPPs from the demand modules and the value of a user-defined switch (*RPPSw*) that selects from a range of options. Options include:

- Option 0: Exogenous production and imports. Exports are production less demand plus imports
- Option 1: Exogenous production. Imports are a function of RPP demand growth. Exports are production less demand plus imports
- Option 2: Imports and exports are a function RPP demand growth. Production is RPP demand plus exports minus imports.

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## Methodology 2 – Production Based on Linear Program to Minimize Costs

A linear program (LP) algorithm can be activated to determine RPP production based on 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 of Refinery Linear Program***

Inputs to the refinery supply sector include characteristics of the refineries based on type of crude oil input. Outputs include RPP production by refinery and quantities of crude oil feedstock.

The key inputs to the oil refinery supply sector when optimizing based on cost 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 of Refinery Linear Program***

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 as having refinery capacity.

**Table 11. Oil Refinery Locations (RfNode)**

Oil Refinery Locations		
Ontario	California	Mountain
Quebec	Middle Atlantic	Pacific
British Columbia	East North Central	Mexico
Alberta	West North Central	
Saskatchewan	South Atlantic	
New Brunswick	East South Central	
Newfoundland	West South Central	

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

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

Crude Oil Inputs to Refinery Process	Fuels Defined as Refined Petroleum Products	
Conventional Light Foreign	Asphalt	LPG
Conventional Light Domestic	Aviation Gasoline	Lubricants
Conventional Heavy Foreign	Diesel	Naphtha Specialties
Conventional Heavy Domestic	Gasoline	Other Non-Energy Products
Synthetic Light (Domestic)	Heavy Fuel Oil	Petrochemical Feedstock
Crude Bitumen (Domestic)	Jet Fuel	Petroleum Coke
Condensates/C5 (Domestic)	Kerosene	Still Gas
Other Material Charged	Light Fuel Oil	

***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 is 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 2100 documentation *Volume 5 (Other Supply – Refinery, Hydrogen, and Biofuel Production)*.

#### **4.5. Biofuel Production**

ENERGY 2100's biofuel module simulates the production of liquid biofuels – ethanol and biodiesel – used primarily for transportation, but also used in any sector using liquid fuels for electric generation or off-road use. While in practice nearly all liquid biofuel 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 2100, 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 are shown in the table below.

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

## Biofuel Production 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 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 2100 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.

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## Activating Endogenous Biofuel Supply

Using the endogenous production algorithms is optional and activated by setting a switch (*BiofuelSwitch* = 1). The switch is activated within a Julia script file, *BiofuelSwitch.jl*. Input data assumptions are also assigned values via a Julia script file, *\Calibration\EthanolBiodiesel.jl*.

## Key Outputs of Biofuel Module

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 output variables of the biofuel supply sector 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. Hydrogen Supply

ENERGY 2100’s Hydrogen Supply Module simulates the production of hydrogen as well as ammonia used for generating power across multiple sectors including transportation, industry, and electricity generation.

**Hydrogen (H<sub>2</sub>)** can generate power through fuel cells or direct combustion. Hydrogen is primarily produced through industrial methods that extract it from other compounds. The two most common methods are via **steam methane reforming (SMR)** of natural gas and **electrolysis**, which splits water into hydrogen and oxygen using electricity<sup>4</sup>.

**Ammonia (NH<sub>3</sub>)** production is integrated into the Hydrogen Supply Module, as ammonia can serve as an efficient way to transport and store hydrogen. Ammonia can also be burned directly, such as for maritime shipping. Ammonia is produced using a two-step process – the first step is to produce hydrogen, and the second is to use a **Haber-Bosch process** combining the hydrogen with nitrogen to create ammonia<sup>5</sup>. ENERGY 2100 only simulates ammonia used

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<sup>4</sup> U.S. Energy Information Administration, “Hydrogen Explained”, June 23, 2023. <https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php>

<sup>5</sup> Hochman G., Goldman G., and Felder F., “Chapter 14: Alternative ammonia production processes and the use of renewables,” *Biomass, Biofuels, Biochemicals*, 2022. DOI: <https://doi.org/10.1016/B978-0-12-819242-9.00007-5>

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for energy and does not simulate any legacy ammonia production used for fertilizer or other uses.

International **exports** of hydrogen/ammonia consist of green ammonia (ammonia in which the hydrogen component was produced from green sources, such as wind). The international exports of green ammonia are exogenous inputs to the model.

**Ammonia demand** is assumed to be the sum of ammonia demands from sectors in the demand module plus international exports of green ammonia. **Hydrogen demand** is the sum of hydrogen demand from the demand module plus the hydrogen required as feedstock to produce total ammonia demand. **Hydrogen and ammonia production** are then assumed to meet demand.

### Hydrogen Module Structures

Hydrogen production requires energy from a variety of fuels and feedstocks, with different production pathways offering varying levels of efficiency and emissions intensity. Within ENERGY 2100, a set of twelve hydrogen production technologies are introduced and stored as a set, named **H2Tech**. The hydrogen-producing technologies are chosen using principles of consumer choice theory. Hydrogen produced in a given area is used for local hydrogen demand, and the remainder is used as a feedstock for Ammonia and exported.

The model represents 12 distinct hydrogen production pathways (H2Techs), each with unique characteristics for energy input, feedstock requirements, and emissions profiles:

- **Electrolysis Technologies:** Water electrolysis technologies that split water into hydrogen and oxygen using electricity
  - **Grid Electrolysis (Grid):** Uses electricity from the grid mix, with emissions dependent on the electricity generation portfolio
  - **Onshore Wind Electrolysis (OnshoreWind):** Uses dedicated onshore wind electricity for near-zero emission hydrogen production
  - **Solar PV Electrolysis (SolarPV):** Uses dedicated solar photovoltaic electricity for near-zero emission hydrogen production
  - **Interruptible Electrolysis (Interruptible):** Uses interruptible or curtailed electricity at lower costs, providing grid flexibility
- **Natural Gas Reforming Technologies:**
  - **SMR NG (NG):** Steam methane reforming using natural gas as both feedstock and fuel source, the most common current production method

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- **SMR NG with CCS (NGCCS):** Steam methane reforming with carbon capture and sequestration, producing “blue hydrogen” with significantly reduced emissions
  - **ATR NG with CCS (ATRNGCCS):** Autothermal reforming with carbon capture and sequestration, using oxygen in addition to steam for improved efficiency and easier carbon capture integration
  - **Biomass-Based Technologies:**
    - **Biomass (Biomass):** Gasification or reforming of biomass feedstocks to produce hydrogen
    - **Biomass with CCS (BiomassCCS):** Biomass gasification or reforming with carbon capture and sequestration, potentially achieving negative emissions
  - **Advanced Technologies:**
    - **Small Modular Nuclear Reactor (SMNR):** Uses nuclear heat and/or electricity for hydrogen production through high-temperature electrolysis or thermochemical water splitting
    - **Methane Pyrolysis (MP):** Thermal decomposition of methane into hydrogen and solid carbon, avoiding direct CO<sub>2</sub> emissions
    - **Other (Other):** Placeholder for emerging or alternative hydrogen production technologies

## Hydrogen Module Methodology

To determine which production technologies hydrogen suppliers will choose, consumer choice market share equations are applied to the various technology options. Market shares for each of the hydrogen production processes are calculated based on the relative levelized marginal costs of each production option in combination with a non-price factor indicating propensity toward or barrier to each type of production process.

## Cost Components

The levelized marginal cost (H2MCE) for each hydrogen production technology includes:

1. **Capital Costs:** The overnight construction cost of production facilities (H2CCN - normal capital cost, adjusted by H2CCM - capital cost multiplier, yielding H2CC), converted to an annual basis using capital charge rates (H2CCR) and capacity utilization factors (H2CUF)
2. **Fixed Operating and Maintenance (O&M) Costs:** Annual fixed costs for facility operation (H2FOF - O&M cost factor, yielding H2FOMCost)
3. **Variable O&M Costs:** Per-unit production costs (H2UOMC - unit O&M costs, yielding H2VOMCost)

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4. **Fuel Costs:** Cost of energy inputs (H2ECP - fuel prices for hydrogen production, calculated from delivered fuel prices weighted by fuel fractions H2DmFrac, yielding H2FuelCost)
  5. **Feedstock Costs:** Cost of feedstock materials where applicable (H2FsPrice - feedstock price, weighted by H2FsFrac - feedstock fraction)
  6. **Emissions Costs:** Carbon pricing and other emissions-related costs (H2EmissionCost and H2DmdEmissionCost) based on the production technology's emission intensity (H2EI - total emission intensity, composed of H2EIDmd - combustion emissions and H2EIFs - feedstock emissions)

### Capacity Planning and Expansion

The module tracks hydrogen and ammonia production capacity by technology and area. Parallel variables and methods are used for both hydrogen and ammonia. The production capacity variables include the following:

- **Indicated Capacity (H2CapI, NH3CapI):** The capacity needed to meet production targets
- **Construction Completion (H2CapCR, NH3CapCR):** New capacity additions with construction delay periods (H2CD)
- **Retirements (H2CapRR, NH3CapRR):** Capacity retirement based on facility lifetime
- **Installed Capacity (H2Cap, NH3Cap):** Total hydrogen production capacity by technology and area
- **Capacity Utilization (H2CUF, NH3CUF):** Actual production relative to installed capacity, planned using H2CUFP/NH3CUFP (planning capacity utilization factor) subject to H2CUFMax/NH3CUFMax (maximum capacity utilization factor)

Production capacity expands endogenously based on demand growth, with construction delay factors and planning capacity utilization factors determining the timing and scale of new capacity additions.

### Market Share Allocation

ENERGY 2100 applies multinomial logit equations to calculate market shares for competing hydrogen production technologies. The non-price factors are calibrated from historical data and can be projected forward to represent technology preferences, barriers to entry, infrastructure availability, or policy influences that affect technology adoption beyond pure economics.

### Emissions Tracking

The hydrogen supply module calculates greenhouse gas emissions from:

- 
1. **Combustion Emissions:** Direct emissions from fuel burned in the production process
  2. **Feedstock Emissions:** Emissions associated with feedstock production and processing
  3. **Upstream Emissions:** Life-cycle emissions from electricity generation or natural gas extraction

Emission intensities are calculated in tonnes of CO<sub>2</sub>-equivalent per TBtu of hydrogen produced and vary significantly by technology.

## Pricing

**Wholesale Prices:** The wholesale hydrogen price is calculated as a production-weighted average of the levelized marginal costs across all production technologies in each nation. This reflects the market-clearing price needed to incentivize sufficient production.

**Retail Prices:** Delivered hydrogen prices include: - Wholesale price - Distribution and delivery charges - Distributor margins - Fuel taxes - Pollution taxes (carbon pricing) - Sales taxes

Separate pricing is calculated for different end-use sectors (industrial, transportation, etc.) to reflect different delivery requirements and tax structures.

## Activating Endogenous Hydrogen Supply Equations

The hydrogen supply module algorithms can operate endogenously or exogenously. Endogenous production is activated by setting a model switch (HydrogenSwitch = 1). When operating endogenously, the module:

1. Calculates production requirements from demand
2. Determines optimal technology mix through market share equations
3. Builds new capacity as needed with construction delays
4. Dispatches production to minimize system costs
5. Calculates resulting emissions and prices

Input data assumptions for hydrogen production are stored in the model database including:

- Technology capital costs (H2CCN, NH3CCN)
- Energy efficiency by technology (H2Eff, NH3Eff)
- Fixed and variable O&M costs (H2OF, H2UOMC, NH3OF, NH3UOMC)
- Non-price market share factors (H2MSM0, NH3MSM0)
- Capacity utilization factors (H2CUFP, H2CUFMax, NH3CUFP, NH3CUFMax)
- Construction delay periods (H2CD)

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## Hydrogen Supply Module Key Outputs

Outputs from the Hydrogen Supply Module include production, capacity, energy demand for production processes, feedstock demands, emissions, and prices for both hydrogen and ammonia. The energy demand and feedstock demand of hydrogen producers are calculated within the supply module and are added to the demand sector totals in the miscellaneous economic category of “Hydrogen Production”.

The key output variables of the hydrogen supply sector include:

- **H2Prod/NH3Prod:** Hydrogen/ammonia production by technology and area (TBtu/Yr)
- **H2Cap/NH3Cap:** Hydrogen/ammonia production capacity by technology and area (TBtu/Yr)
- **H2Demand/NH3Demand:** Energy used to produce hydrogen by fuel, technology, and area (TBtu/Yr)
- **H2EI:** Hydrogen production GHG emission intensity by technology and area (Tonnes eCO<sub>2</sub>/TBtu H<sub>2</sub>)
- **H2ENPN/NH3ENPN:** Hydrogen/ammonia wholesale price by nation (\$/mmBtu)
- **H2MCE/NH3MCE:** Hydrogen/ammonia levelized marginal cost by technology and area (\$/mmBtu)
- **H2MSF/NH3MSF:** Hydrogen/ammonia technology market share by technology and area (fraction)
- **NH3Exports/NH3Imports:** Green ammonia trade flows by nation (TBtu/Yr)

These outputs enable detailed analysis of the hydrogen economy including:

- Technology deployment patterns
- Regional production and consumption balances
- Emission intensities and total emissions
- Economic costs and price evolution
- Infrastructure requirements and investment needs

The module’s integration with other ENERGY 2100 sectors allows for comprehensive analysis of hydrogen’s role in decarbonization scenarios, including its use in hard-to-abate industrial sectors, heavy-duty transportation, and as seasonal energy storage for electricity systems.

## 4.7. 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 model 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 model simulates the fuel use and emissions required to generate steam sold to other sectors.

### 4.8. Calibration of Supply Sector Equations

Within the supply module, a set of variables is used to calibrate model equations to historical values for electric loads, electric generation, electric prices, non-electric fuel prices, oil and gas development rate, oil and gas production rate, and oil refinery production. The calibration variables for each of these supply equations is listed in Table 13.

**Table 13. Supply Module Calibration Variables**

Equation Calibrated	Calibration Variable	Variable Title
<b>Electric Loads</b> (MonOut, PkLoad, MinLd)	BaseAdj [Day,Month,Area,Year]	Adjustment Factor (MW/MW)
<b>Electric generating capacity</b> (UnGCD)	UnOOR [Unit,Year]	Operational Outage Rate (MW/MW)

Equation Calibrated	Calibration Variable	Variable Title
<b>Electric retail price</b> (PE)	PEDC [ECC,ReCo,Year]	Electricity Delivery Charge (\$/MWh)
<b>Non-electric fuel prices</b> (FPF)	FPDChg [Prices,Area,Year]	Fuel Delivery Charge (\$/mmBtu)
<b>Oil-gas development rate</b> (DvRateM)	DevVF [OGUnit,Year]	Development Rate Variance Factor for ROI (Btu/Btu)
<b>Oil-gas production rate</b> (PdRateM)	PdVF [OGUnit,Year]	Production Rate Variance Factor for ROI (Btu/Btu)
<b>Oil refinery production</b> (RfProd)	RfOOR[RfUnit,Fuel,Year]	Refinery Unit Operational Outage Rate (Btu/Btu)
	RfMaxCrude[RfUnit,Crude,Year]	Refinery Maximum Input of Crude Types (TBtu/Yr)

For more detailed description of calibration in the supply sectors, see *Volume 3 (Electricity Supply)*, *Volume 4 (Oil and Gas Supply)*, and *Volume 5 (Other Supply – Refining, Hydrogen, and Biofuel)*.

## 5. EMISSIONS TRACKING

Emissions resulting from activity in the demand and supply sectors 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 2100 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. For example, emissions from cattle or industrial processes.
- 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 (GHGs), eleven air pollutants, and one other category consisting of water usage as shown in Table 14.

**Table 14. Pollutants Represented in ENERGY 2100**

Pollutants Represented in ENERGY 2100	
<b>Greenhouse Gases</b>	
Nitrous Oxide (N <sub>2</sub> O)	Perfluorocarbon (PFC)
Carbon Dioxide (CO <sub>2</sub> )	Hydrofluorocarbon (HFC)
Methane (CH <sub>4</sub> )	Nitrogen Trifluoride (NF <sub>3</sub> )
Sulphur-Hexafluoride (SF <sub>6</sub> )	
<b>Air pollutants</b>	
Sulphur Oxides (SOX)	Particulate Matter 10 (PM <sub>10</sub> )
Nitrogen Oxides (NOX)	Black Carbon (BC)
Particulate Matter Total (PMT)	Mercury (Hg)
Volatile Org Comp. (VOC)	Ammonia (NH <sub>3</sub> )
Carbon Monoxide (COX)	Ozone (O <sub>3</sub> )
Particulate Matter 2.5 (PM <sub>2.5</sub> )	
<b>Other</b>	
Water Use (H <sub>2</sub> O)	

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## 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. Total emissions are calculated by multiplying the respective emissions coefficients times the amount of energy consumed for energy-related emissions and the amount of economic activity for process emissions, feedstock emissions, and fugitive emissions.

Emissions coefficients for each type of pollutant (by area, economic category, enduse, technology, and fuel if relevant) are needed to project future emissions. GHG emissions coefficients are taken from 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 air pollutant coefficients contain more complexity and are not so easily obtained. As a result, an implied coefficient is calculated based on historical inventories of air pollutant 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.

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### **Offsets from Agriculture, Forestry, and Waste**

There are currently seven types of offsets represented in ENERGY 2100. Each of the offsets is mapped to an economic category (ECC) in ENERGY 2100 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
CO2 Pipeline	→	Light Oil Mining	→	CH4

Curve parameters are input through script files for each type of offset (e.g. *Offsets\_Forestry.jl*), located in the *Calibration* subdirectory.

### **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 curves are currently input for the following industries: Pulp and Paper Mills, Petrochemicals, Other Chemicals, Fertilizer, Petroleum, Cement, Iron and Steel, Aluminum, Other Nonferrous, Heavy Oil Mining, Light Oil Mining, SAGD Oil Sands, CSS Oil Sands, Oil Sands Mining, OilSandsUpgraders, Sweet Gas Processing, Unconventional Gas Production, Sour Gas Processing, Utility Generation, and Industrial Gas. 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. CCS curve parameters are input through script files located in the *Policy* subdirectory (e.g. *GHG\_CCSCurves.jl*).

**Improvements to Industrial Processes:** Industrial processes emission non-CO<sub>2</sub> reduction cost curves are represented in the model. The curve input to the model indicates the fraction of non-CO<sub>2</sub> emissions reduced at various levels of carbon taxes by economic sector. Industrial process emission reduction curve parameters are input through script files located in the *Policy* subdirectory (e.g. *GHG\_Ind\_ProcessReductionCurves.jl*).

### **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

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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 of CO<sub>2</sub> from the venting emission reductions.

### 5.4. Direct Air Capture

The Direct Air Capture (DAC) Module was developed to simulate the energy demands of DAC facilities that capture and sequester CO<sub>2</sub> directly from the atmosphere and the subsequent impacts on annual carbon emission inventories. Various DAC technologies are incorporated to allow for specific characteristics for each modeled technology.

**Table 15. Direct Air Capture Technologies**

DAC Technologies	
KOH-Ca Looping	Liquid H2
KOH BPMED	Liquid NG
Solid Sorbent	Solid H2
MgO Ambient Weathering	Solid NG

Code for this module is in *DirectAirCapture.jl* in the *Engine* subdirectory. Input data required for operating the DAC module is currently read into the model using a Julia script file, *CarbonRemoval.jl*, in the *Calibration* subdirectory.

The inputs include assumptions for values across DAC devices and specific inputs that vary by DAC technology. Key inputs include:

- Device lifetimes and construction delay
- Capital, variable, and O&M costs by technology
- Utilization factors
- Energy usage fractions and energy efficiency by technology
- Default available technologies (DACMSM0 = 0.0)
- Sequestration fractions and energy penalties by technology
- Capture carbon transportation prices

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There are several different options for how the DAC module initiates direct air capture, which is controlled by the value of a switch, *DACSw*:

- DAC deployments meets an emission goal
- DAC deployment meets an emission goal or an exogenous level (whichever is higher)
- DAC deployment meets a national goal, with production split by exogenous weights
- DAC deployment is determined in response to carbon price
- DAC deployment is exogenously specified (*xDACDem*)

DAC devices are then initiated for each modeled year as needed specified by the options above. The technologies are selected using consumer choice theory given the cost related inputs, fuel prices, and the technologies available for use (*DACMSM0* = 0.0). Devices are initiated and constructed after a specified construction delay.

Annual energy usage, emissions produced and amount of carbon captured is estimated by the model. Outputs for the sector energy usage, emissions, investments, and other data are written to the *DirectAirCapture* supply sector for output and review. Total GHG inventories in the model output are adjusted by the net emissions from *DirectAirCapture*.

## 5.5. Carbon Markets

ENERGY 2100 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. Definitions for each of these concepts are included in *Appendix 7: Glossary of Carbon Market Structures*.

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## 6. MACROECONOMIC INTEGRATION

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ENERGY 2100 can be dynamically linked to a macroeconomic model to obtain a fully-integrated energy-environment-economy (E3) system. The model integration is performed using a controlling module which, for each year of simulation, 1) calls ENERGY 2100, 2) passes energy model results to the macroeconomic model, 3) executes the macroeconomic model, then 4) passes those results back to ENERGY 2100. This process is iterated for convergence. Model runs can be made stand-alone (non-integrated) or linked to the macroeconomic model (integrated).

### 6.1. Current Interface Linking to Macroeconomic Model

An interface currently exists to automate the linkage between ENERGY 2100 and TOM, a version of Oxford Economics' Global Economic Model that has been customized for Environment and Climate Change Canada. The TOM macroeconomic model simulates the economies of both Canada and the United States.

See the *ENERGY 2100 User Manual* for guidance on how to specify data transfers and mappings between the ENERGY 2100 and TOM. The sections below provide a broad overview of the typical transfers made between the models.

### 6.2. Data Transfers

#### ***Transfers from ENERGY 2100 to Macroeconomic Model***

The list below identifies variables that are typically sent from the energy model to a macroeconomic model during integrated runs.

- **Energy Production by Fuel Type and Province/Territory (PJ per year)** – Annual production of natural gas, oil, coal, electricity, and alternative fuels.
- **Emissions Intensity by Fuel Type and Province/Territory (PJ per year)** – Energy intensity of crude oil, electricity, natural gas, coal, and refined petroleum products.
- **Amount 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.
- **Amount 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 like wellhead natural gas, WTI oil, and other wholesale energy market prices. Electric prices are a weighted average of the ENERGY 2100 nodal wholesale electric prices.

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- **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 2100, a device refers to machinery and equipment 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 2100, 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-related permits from a regulatory authority.

### ***Transfers from Macroeconomic Model to ENERGY 2100***

ENERGY 2100 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 2100 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 2100 and the macroeconomic model allow for simulation of the real-time impact of energy and environmental concerns on the economy and vice versa. The list below identifies economic variables sent to ENERGY 2100.

- **Residential Housing Stock by Type and Province/Territory**  
ENERGY 2100 uses growth in housing stock as an indicator of growth in energy demand for the Waste sector.
- **Commercial and Residential Floorspace by Economic Sector and Province/Territory**

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Within the commercial and residential sectors, ENERGY 2100 uses floorspace by type of building as an indicator of energy demand. The change in floorspace 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 floorspace is specified for each commercial sector while residential floorspace 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 2100 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 economic category, including mining, construction, forestry, and agriculture.

- **Real GDP by Province/Territory**

ENERGY 2100 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 2100 uses the GDP deflator from the macroeconomic model as an indicator of the inflation rate.

- **Canada-US Exchange Rate**

Within ENERGY 2100, data are converted to local dollars, and 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 2100 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 2100 but is used as an output and to generate energy use per employee ratios.

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## 7. POLICY ANALYSIS

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ENERGY 2100 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 2100 can 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**

<b>Residential/Commercial</b> <ul style="list-style-type: none"><li>- Building and appliance efficiency standards</li><li>- Tax incentives</li><li>- Retrofit programs</li></ul>	<b>Industrial</b> <ul style="list-style-type: none"><li>- Equipment efficiency standards</li><li>- Tax incentives and grant programs</li></ul>	<b>Transportation</b> <ul style="list-style-type: none"><li>- Vehicle efficiency standards</li><li>- Alternative fuels</li><li>- Electric vehicles</li></ul>
<b>Electric Supply</b> <ul style="list-style-type: none"><li>- Renewable generating capacity</li><li>- Interprovincial hydro transmission expansion</li><li>- Emission standards</li></ul>	<b>Oil, Gas, Biofuel, Refineries, Coal Supply</b> <ul style="list-style-type: none"><li>- Enhanced production efficiency</li><li>- Sequestration of CO<sub>2</sub></li><li>- Emission reducing technologies</li></ul>	<b>Emissions</b> <ul style="list-style-type: none"><li>- GHG taxes</li><li>- Cap-and-trade programs</li><li>- CAC caps &amp; reduction curves</li><li>- Clean fuel standards</li></ul>

### 7.1. Advantages of using ENERGY 2100 for Policy Analysis

**Decision Making Behavior** – ENERGY 2100 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 2100 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 2100 behavior equations combine cost

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factors (capital costs, fuel costs, emission costs or credits) with non-cost factors (industrial preferences, distributional impacts) to enable policymakers to better predict the impact of a policy.

**Detailed Representation** - ENERGY 2100 simulates the energy and emission system in significant detail; therefore, policies can 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 2100 simulates 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 2100 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 2100 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 2100 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 economic expansion and the capital stock retirements. An industry without significant economic growth will only have new capital stock as their old capital stock retires. ENERGY 2100 also simulates the retrofitting of capital stock but recognizes the added cost of replacing capital stock before the end of its useful lifetime.

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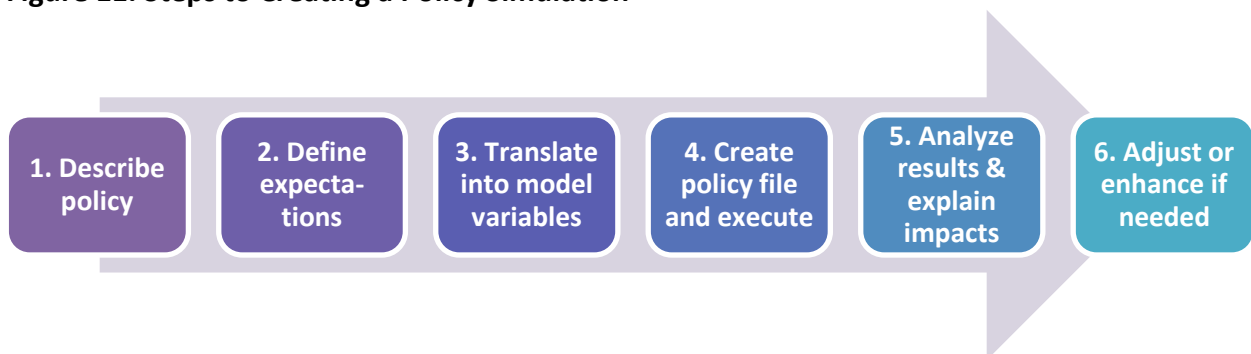
**Process and Device Efficiency** – ENERGY 2100 simulates both the process energy efficiency (economic output produced per unit of service energy) and the device energy efficiency (service energy per unit of fuel inputs) to compute energy demands. This is important for a number of reasons:

- 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. Mechanics 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 2100 model variables. The changes to model variables are made by developing a “policy file” then executing the model with that file. 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 2100 are summarized in Figure 11.

**Figure 11. Steps to Creating a Policy Simulation**



Identifying the ENERGY 2100 model variables to modify for a policy simulation is the key to creating policies in ENERGY 2100. Identification of model variables is not covered in this

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overview; however, please refer to the *ENERGY 2100 User Manual* for descriptions of variables and methodologies used to simulate common demand sector and supply sector policies.

### ***Policy Files to Modify Model Variables***

Policy files in ENERGY 2100 are written as script files that contain code written in the Julia language and, by convention, are saved in the Policy subdirectory. They modify values of input or policy variables used in key ENERGY 2100 model equations. 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. See the *ENERGY 2100 User Manual* for specific instructions on how to create policies.

#### **What are Policy files?**

- Script files that contain code written in the Julia language.
- Saved with a \*.jl extension into the Policy subdirectory
- Modify values of input or calibration variables.
- May execute multiple policy files together to define a scenario.

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## 8. MODEL SOURCE CODE

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The vast majority of ENERGY 2100's code is written in the Julia programming language using script files containing a “.jl” file extension. This code is organized into subdirectories under the root model directory grouped by the intent of each group of script files.

### 8.1. Model Folders

A description of the types of files in each of these folders is listed below.

**\2020Model** - Stores batch files used to execute the model and the batch file to initiate the user interface

**\2020TOM** - Houses the Oxford Economics macroeconomic model, TOM, and the economic forecast files (TOMInitial.db)

**\Calibration** – These are script files which make calculations in preparation for the historical calibration (including historical policies), execute the historical calibration, and make post-calibration adjustments.

**\Core** – These are Julia utility functions which define functions like “ReadDisk” and “WriteDisk”. These are in essence an extension of the Julia language.

**\Database** – Contains files that define the model variables and how they are partitioned on the HDF5 database as well as the set definitions. Set definitions are stored as csv files under \Database\Sets.

**\Economic Transfers** - Stores code that maps ENERGY 2100 variables to TOM

**\Engine** - Model source code

**\Input** - Stores data input through script files; contains mappings of TOM variables to ENERGY 2100 variables; contains maps of TOM sectors and fuels to ENERGY 2100 sectors and fuels

**\InputData** - Stores user input data stored in .dat files. Eventually this subdirectory will be moved inside \Input.

**\Output** - Stores Julia script files that write customized output files in both Excel and Access-friendly formats.

**\Policy** - Stores Julia script files that modify policy variables; also stores the groupings of policy files that make up the reference case and scenario cases.

**\src** – This is a required Julia subdirectory which must be named “src”

**\Test** – This folder contains test Julia files which individual modelers have constructed. The model does not need these to execute.

**\VBInput** – Visual Basic program to read .dat input data files and to create TOM-related .csv files that pass data to/from the TOM macroeconomic model.

## 8.2. Organization of Engine Source Code

Variable and set definitions are housed in the \Database subdirectory, and model source code is housed in the \Engine subdirectory. Variables are stored on an HDF5 database which is partitioned by model segments, such as residential demand, commercial demand, industrial demand, transportation demand, electric supply, non-electric supply, macroeconomic, etc. The prefix of the source code file names generally indicates which module is associated with the procedures contained within the file based on conventions shown in Table 16. 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 16. Naming Conventions – Prefixes on Source Code File Names**

Demand Sector	Prefix	Economic Sector	Prefix	Supply Sector	Prefix
Residential	‘R’	Macroeconomic	‘M’	Supply aggregate	‘S’ or ‘Sp’
Commercial	‘C’			Electricity	‘E’ or ‘EG’
Industrial	‘I’				
Transportation	‘T’				

When reading ENERGY 2100 source code files, it is helpful to know that each file contains a set of functions (subroutines), and the control procedure that calls those procedures is located at the bottom of the file.

### Demand Sector Code

Table 17 summarizes the naming conventions of the different types of demand module source code files. Parallel coding structures are defined for each of the residential, commercial, industrial, and transportation demand sectors, and variable names are identical across the sectors. 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 2100 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 located in the Database subdirectory whose names specify whether the variables are *inputs*, *calibration variables*, or *outputs* (named \*Input.jl, \*CalDB.jl, and \*Output.jl respectively). Note that the '\*' represents a placeholder for indicating whether the file is residential, commercial, industrial, or transportation. For example, actual names are RInput.jl, CInput.jl, IInput.jl, and TInput.jl.

**Table 17. Demand Sector Code File Names**

Demand Sector Source Code	File Name
Input variable definitions for demand sector Residential, Commercial, Industrial, Transportation	/Database/ RInput.jl, CInput.jl IInput.jl, TInput.jl
Calibration variable definitions for demand sector Residential, Commercial, Industrial, Transportation	/Database/ RCalDB.jl, CCalDB.jl ICalDB.jl, TCalDB.jl
Output variable definitions for demand sector Residential, Commercial, Industrial, Transportation	/Database/ ROutput.jl, COutput.jl IOutput.jl, TOutput.jl
Input data (demand sector) Assigns values to constants and assumptions. The data in these files typically do not need annual updates.	/Input/Scripts/ RData.jl, CData.jl IData.jl, TData.jl
Initialization (demand sector) Code to initialize demand-related variables.	/Engine/ RInitial.jl, CInitial.jl IInitial.jl, TInitial.jl
Calibration equations Contains code to calibrate equations to historical data.	/Engine/ RCalib.jl, CCalib.jl ICalib.jl, TCalib.jl
Calibration parameter future projections Contains code to project calibration parameters through the forecast years based on user-selected methodology.	/Engine/ RFuture.jl, CFuture.jl IFuture.jl, TFuture.jl
Demand sector execution Contains equations for demand projections.	/Engine/ RDemand.jl, CDemand.jl IDemand.jl, TDemand.jl
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.	/Engine/ RLoad.jl, CLoad.jl ILoad.jl, TLoad.jl

## Supply Sector Model Code

Table 18 identifies the types of the files and file names within the electric supply sector. Table 19 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 18. Electric Supply Sector Code File Names**

Electric Supply Sector Source Code	File Name
Variable definitions for electric sector Electric sector input variables Electric sector output variables Electric generating company Input variables Electric generating company output variables	/Database/ EInput.jl EOutput.jl EGInput.jl EGOutput.jl
Electric calibration Much of the electric calibration code now exists in text files in the 2020Model subdirectory	/Database/ ECalDB.jl EGCalDB.jl
Input Data (electric sector) Assigns values to constants, assumptions, and model structures, such as names of plant types, that typically do not need annual updates.	/Input/Scripts/ EData.jl EGData.jl
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.	/Engine/ ECapacityExpansion.jl EContractDevelopment.jl ECosts.jl EDispatch.jl EDispatchCg.jl EDispatchLP.jl EFlows.jl EFuelUsage.jl EGenerationSummary.jl ElectricPrice.jl ELoadCurve.jl EPeakHydro.jl EPollution.jl ERetailPowerCosts.jl ERetailPurchases.jl

**Table 19. Non-Electric Supply Code File Names**

Other Supply (Non-Electric) Source Code	File Name
Variable definitions for supply sector (oil, gas, refinery, biofuel) Generic supply calibration variables Generic supply input variables Generic supply output variables Supply production input variables Supply production output variables	/Database/ SCalDB.jl SInput.jl SOutput.jl SpInput.jl SpOutput.jl
Supply sector initialization and calibration Alternative energy supply sector calibration Supply constants and initial values Projects calibration parameters into forecast period	/Database/ SCalib.jl SInitial.jl SFuture.jl
Input Data Assigns values to constants, assumptions, and model structures	/Input/Scripts/ SData.jl SpData.jl
Refinery Module Petroleum refining (current methodology) Refineries calibration Petroleum refining (pre-2017 version) Linear program for petroleum refining	/Engine/ SpRef.jl SpRefCalib.jl SpRefinery.jl SpRefLP.jl
Energy supply Sector Direct Air Capture Module Alternate fuel energy supply sector Biofuels supply Coal supply Ethanol supply Fuel supply curve equations Natural gas supply Natural gas transmission Endogenous oil and gas production Oil production Thermal supply	/Engine/ DirectAirCapture.jl Supply.jl SpBiofuels.jl SpCoal.jl SpEthanol.jl SpFuelSupplyCurve.jl SpGas.jl SpGTrans.jl SpOGProd.jl SpOProd.jl SpThermal.jl
Pollution Calculations Supply emissions summary Clean Fuel Standard equations Emission intensity equations Emissions market equations OGEC equations	/Engine/ SuPollution.jl SuPollutionCFS.jl SuPollutionEI.jl SuPollutionMarket.jl SuPollutionOGEC.jl

Table 20 provides a listing of the macroeconomic processing-related code, and Table 21 contains other miscellaneous files used for defining model structures, controlling routines for all of the sectors, and defining the variables used during the data input process.

**Table 20. Macroeconomic Source Code File Names**

Macroeconomic Processing Source Code	File Name
Variable Definitions for Macro Economy Macroeconomic calibration variables Macroeconomic input variables Macroeconomic output variables Macroeconomic emissions input variables Macroeconomic emissions output variables	/Database/ MCalDB.jl MInput.jl MOutput.jl MEInput.jl MEOutput.jl
Macroeconomic calibration Calculates historical growth rates Initialization of economic related variables Projects calibration parameters into forecast period	/Engine/ MCalib.jl MInitial.jl MFuture.jl
Input Data (Macro Economy) Assigns values to constants, assumptions, and model structures. The data in these files typically do not need annual updates.	/Input/Scripts/ MData.jl MEData.jl
Macroeconomic Processing Code	/Engine/ MEconomy.jl MEconomyTOM.jl
Macroeconomic Pollution Process pollution, pollution related to economic activity Pollution Reductions Waste emissions module	/Engine/ MPollution.jl MReductions.jl MEWaste.jl

**Table 21. Miscellaneous Source Code File Names**

Source Code Function	File Name
Main Segment Model Definitions Defines sets, variables, and keys for global variables which can be used throughout all segments of the model.	/Database/ MainDB.jl
Controls execution of code within: Model execution order for each year Model constants Macroeconomic segment Supply segment Electricity generation segment Electricity generation segment #2 Residential demand segment Commercial demand segment Industrial demand segment Transportation demand segment	/Engine/ E2020.jl E2020_Constants.jl MControl.jl SControl.jl EControl.jl EGContro.jl RControl.jl CControl.jl IControl.jl TControl.jl
Variable Definitions for Input Data Read in from Access Definitions of input variables from input data sets	/Database/ VBInput.jl vData_ElectricUnits.jl

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## 9. INPUT DATA AND ASSUMPTIONS

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ENERGY 2100 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 2100 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 2100 requires data and assumptions covering a broad range of economic sectors and their interactions. Input data are required in the eight areas listed below:<sup>6</sup>

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, hydrogen, 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 2100 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.

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<sup>6</sup> "Data" here refers to both historical data and assumptions and projections of future inputs.

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## 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 the *\InputData* subdirectory in text files saved with .dat file extensions. Canada-specific data files are populated and maintained by Environment and Climate Change Canada staff. Input data for the U.S. and Mexico input data is also housed in the *\InputData* subdirectory. These datasets are regularly updated by Systematic Solutions, Inc. staff.

The exogenous Canada, U.S., and Mexico input data stored as .dat files in the *\InputData* folder are identified in *Appendix 7: List of Exogenous Input Data (.DAT) Files*.

## Demand-Related Input Data

Primary inputs to the demand module consist of economic drivers (some of which come from an exogenously input macroeconomic forecast and others calculated in the supply module), delivered and wholesale fuel prices from the supply modules, technology characteristics (for processes and devices), such as physical lifetimes and costs), and inputs from the demand calibration. Table 22 lists exogenous inputs to the demand module.

ENERGY 2100 reads in input data for the Demand Module through data files stored in the *\InputData* subfolder.

**Table 22. Exogenous Inputs Required for Demand Module**

Description	Variable Name and Definition
Historical energy demand (TBtu/Yr) <ul style="list-style-type: none"><li>- End-use</li><li>- Feedstock</li><li>- Steam generation</li></ul>	xDmd(Enduse,Tech,EC,Area,Year) xFsDmd(Tech,EC,Area,Year) xStDmd(FuelEP,Area,Year)
Prices (Historical and Future) <ul style="list-style-type: none"><li>- Wholesale Fuel Price (\$/mmBtu)</li><li>- Delivered Fuel Price (\$/mmBtu)</li></ul>	xENPN(Fuel,Nation,Year) xFP(Prices,Area,Year)

Description	Variable Name and Definition
Emissions coefficients (Tonnes/TBtu) <ul style="list-style-type: none"> <li>- Energy-related</li> <li>- Cogeneration</li> <li>- Feedstock</li> </ul>	POCX(Enduse,FuelEP,EC,Poll,Area) CgPOCX(FuelEP,EC,Poll,Area,Year) FsPOCX(Fuel,Tech,EC,Poll,Area,Year)
Device characteristics (in one initialization year) <ul style="list-style-type: none"> <li>- Historical Physical Life of Equipment (Yrs)</li> <li>- Device Capital Cost (\$/mmBtu/Yr)</li> <li>- Historical Device Efficiency (Btu/Btu)</li> <li>- Maximum Device Efficiency (Btu/Btu)</li> <li>- Device Efficiency Standards (Btu/Btu)</li> </ul>	xDPL(Enduse,Tech,EC,Area,Year) xDCC(Enduse,Tech,EC,Area,Year) xDEE(Enduse,Tech,EC,Area,Year) DEM(Enduse,Tech,EC,Area) DEStd(Enduse,Tech,EC,Area,Year)
Process characteristics (in one initialization year) <ul style="list-style-type: none"> <li>- Process Energy Capital Cost (\$/(\$/yr))</li> <li>- Maximum Process Efficiency (\$/mmBtu)</li> <li>- Process Efficiency Standards (\$/Btu)</li> </ul>	xPCC(Enduse,Tech,EC,Area,Year) PEM(Enduse,EC,Area) PESTD(Enduse,Tech,EC,Area,Year)

## Supply-Related Input Data

### 9.1. Electric Generating Units

#### Electric Generating Characteristics

Characteristics for Canadian units are regularly updated by ECCC using the input Canadian electric unit database (vData\_ElectricUnits\_CN.accdb). Each unit is automatically assigned a unit code (UnCode) based on the value of the Unit column in the vUnArea table.

US unit data is maintained and regularly updated by SSI using the input US electric unit database (vData\_ElectricUnits\_US.accdb). US units are aggregated by plant type and US area based on EIA data.

**Table 23. Electric Generating Unit Characteristics**

Generating Unit Characteristic	Variable Name	Description
Area	vUnArea(Unit)	Location of unit
Nation	vUnNation(Unit)	Country of unit
Name	vUnName(Unit)	Name of generating unit
Owner	vUnOwner(Unit)	Owner of generating unit
Generating Company	vUnGenCo(Unit)	Model generating company (GenCo) of the unit. The model has the capability to simulate specific generating companies if input data is available. The current version assigns a single company to each model area.
Node	vUnNode(Unit)	Electric node where unit is located.
Plant Type	vUnPlant(Unit)	Plant type assigned from list of ENERGY 2100 plant types.

Online Date	vUnOnline(Unit)	First year of operation.
Retirement Data	vUnRetire(Unit)	Last year of operation.
Industrial Cogeneration Switch	vUnCogen(Unit)	Switch indicating if unit is industrial cogeneration. '0' is used if the unit is solely for electric generation. '1' is used if the unit is cogeneration.
Economic Sector	vUnSector(Unit)	Assignment of economic sector if unit is industrial cogeneration unit. Non-cogeneration units are generally assigned the 'UtilityGen' sector.
Facility	vUnFacility(Unit).	Facility name if the unit is part of a facility. Used for emissions policies that enact regulation at the facility level.
Primary Fuel Type	vUnF1(Unit)	The primary fuel used by the unit.
Emissions Indicator	vUnEmit(Unit)	Switch indicating if unit produces emissions ('0' no emissions; '1' unit emits).
'Must Run' Status	vUnMustRun(Unit)	Switch to indicate the unit must always be dispatched if generation is needed regardless of market price. '1' signifies that the unit is must run.

### Electric Generating Unit Historical Data

Historical data for Canadian units are regularly updated by ECCC using the input Canadian electric unit database (vData\_ElectricUnits\_CN.acddb). Forecast values can optionally be read in for use by the model to match projections of future operation at each unit.

**Table 24. Electric Generating Unit Historical Input Data Requirements**

Unit Data	Variable	Description
Capacity	vUnGC	Generating capacity in megawatts of each unit for each year
Generation	vUnEGA	Total annual generation in gigawatt hours for each unit.
Energy Demand	vUnDmd	Annual gigajoules of energy consumption of each unit for each fuel type.
Heat Rate	vUnHrt	Annual ratio of Btu input per kilowatt hour output for each unit
Fuel Fraction	vUnFIFr	Annual ratio of amount of fuel type consumed over total fuel consumption.
Energy Availability Factor	vUnEAF	Availability factor for each unit by model month and year.
Outage Rate	vUnOR	Outage rate of each unit by year. '1' reflects that the unit was offline the entire year.
Capital Cost	vUnGCCC	Overnight capital costs for each unit in fixed dollars per kW of constructed capacity.
CAC Emissions Inventory	vUnPol	Annual tonnes or kilograms of emissions by fuel type per unit by pollutant.
Emissions Reduction O&M Cost	vUnROCF	Cost factor of operating emissions reduction devices per unit.
Sequestration Fraction	vUnSqFr	Percentage of sequestered emissions of total emissions per unit.

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## 9.2. Aggregated Electric Sector Input Data

The input data listed below are required to simulate the electric generation system as a whole. This data primarily influences the flow of electricity across electric nodes during the electric unit dispatch.

### ***GHG Emissions Coefficients***

GHG emissions coefficients for Canadian electric units by pollutant type, fuel consumed, plant type, and area are provided by ECCC. US GHG coefficients are provided by SSI based on available data.

### ***Electric Sales***

Total gigawatt hour sales for Canadian areas by model month are provided by ECCC through the Electric fuel type in the input demand variables. This value is converted from annual to months using the input peak load data. US sales by state uses data from the EIA's Form EIA-826, converted to fit the model's months and areas.

### ***Electric Exports***

Gigawatt hours exported to other Canadian areas (vAreaSales) and the US (vExpSales) are provided for Canadian areas by ECCC.

### ***Electric Imports***

Gigawatt hours imported from other Canadian areas (vAreaPurchases) and the US (vExpPurchases) are provided for Canadian areas by ECCC.

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## APPENDIX 1. MODEL DEFINED DEMAND AREAS

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The current configuration of ENERGY 2100 defines the following demand areas. These areas are defined in the model file, *Area.csv*, stored in the \Database\Sets subdirectory:

No.	Area	Area Key	No.	Area	Area Key
1	Ontario	ON	14	California	CA
2	Quebec	QC	15	New England	NEng
3	British Columbia	BC	16	Middle Atlantic	MAtl
4	Alberta	AB	17	East North Central	ENC
5	Manitoba	MB	18	West North Central	WNC
6	Saskatchewan	SK	19	South Atlantic	SATl
7	New Brunswick	NB	20	East South Central	ESC
8	Nova Scotia	NS	21	West South Central	WSC
9	Newfoundland	NL	22	Mountain	Mtn
10	Prince Edward Island	PE	23	Pacific	Pac
11	Yukon Territory	YT	24	Mexico	MX
12	Northwest Territory	NT	25	Rest of World	ROW
13	Nunavut	NU			

### States Mapped to U.S. Regions

The U.S. regions can be mapped to states as follows:

- **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
- **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, Hawaii, Alaska, Washington
- **California (CA):** California

## APPENDIX 2. FUELS, END-USES, AND TECHNOLOGIES

All sets in ENERGY 2100 are defined in .csv files in the \Database\Sets subdirectory. The list of fuels, enduses, and technologies are listed in the tables below.

**Table 25. Detailed Fuel Types Represented in ENERGY 2100 (Fuel Set)**

Fuel Types Represented in ENERGY 2100			
Ammonia	Diesel	Light Crude Oil	Renewable Natural Gas
Asphalt	Electric	Light Fuel Oil	Solar
Asphaltines	Ethanol	LPG	Steam
Aviation Gasoline	Gasoline	Lubricants	Still Gas
Biodiesel	Geothermal	Naphtha Specialties	Thermal Energy Storage
Biogas	Heavy Crude Oil	Natural Gas	Waste
Biojet	Heavy Fuel Oil	Natural Gas Raw	Wave
Biomass	Hydro	Nuclear	Wind
Coal	Hydrogen	Other Non-Energy Products	
Coke	Jet Fuel	Petrochemical Feedstocks	
Coke Oven Gas	Kerosene	Petroleum Coke	

**Table 26. End-Uses by Sector (Enduse Set)**

Residential and Commercial	Industrial	Transportation
Space Heating	Process Heat	Carriage
Water Heating	Motors	
Other Substitutables	Other Substitutables	
Refrigeration	Miscellaneous	
Lighting	Off Road	
Air Conditioning	Excess Steam	
Other Non-substitutables		

**Table 27. Residential, Commercial, and Industrial Technologies (Tech Set)**

Residential and Commercial	Industrial
Electric	Electric
Gas	Gas
Coal	Coal
Oil	Oil
Biomass	Biomass
Solar	Solar
LPG	LPG
Geothermal	Steam
Heat Pumps	Off Road
Dual Heat Pumps	Heat Pump
Fuel Cell	Fuel Cell
	Storage

**Table 28. Transportation Technologies (Tech Set)**

Transportation Technologies		
LDV Gasoline	Bus Gasoline	HDV67 Gasoline
LDV Diesel	Bus Diesel	HDV45 Gasoline
LDV Electric	Bus Electric	HDV45 Diesel
LDV Natural Gas	Bus Natural Gas	HDV45 Electric
LDV Propane	Bus Propane	HDV45 Natural Gas
LDV Ethanol	Bus FuelCell	HDV45 Propane
LDV Hybrid	Train Diesel	HDV45 FuelCell
LDV FuelCell	Train Electric	HDV67 Diesel
LDT Gasoline	Train FuelCell	HDV67 Electric
LDT Diesel	Plane Jet Fuel	HDV67 Natural Gas
LDT Electric	Plane Gasoline	HDV67 FuelCell
LDT Natural Gas	Plane FuelCell	HDV8 Gasoline
LDT Propane	HDV2B3 Gasoline	HDV8 Diesel
LDT Ethanol	HDV2B3 Diesel	HDV8 Electric
LDT Hybrid	HDV2B3 Electric	HDV8 Natural Gas
LDT FuelCell	HDV2B3 Natural Gas	HDV8 Propane
Motorcycle	HDV2B3 Propane	HDV8 FuelCell
	HDV2B3 FuelCell	Marine Heavy
		Marine Light
		Marine FuelCell
		Off-Road

## APPENDIX 3. 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 reported in the *Annual Energy Outlook*; Mexico's economic drivers are chosen based on the availability of publicly available data. Table 29 compares the economic drivers of Canada, U.S., and Mexico for each economic category modeled.

**Table 29. Economic Drivers for Canada, U.S., and Mexico Energy Demand**

Sector	Canada	U.S.	Mexico
<b>Residential</b>			
Single Family Detached	Floorspace	Households	Population
Single Family Attached	Floorspace	Households	Population
Multi Family	Floorspace	Households	Population
Other Residential	Floorspace	Households	Population
<b>Commercial</b>			
Wholesale Trade	Floorspace	Gross Output	Services Gross Output
Retail Trade	Floorspace	Gross Output	Services Gross Output
Warehousing and Storage	Floorspace	GRP	Services Gross Output
Info. and Cultural Industries	Floorspace	Gross Output	Services Gross Output
Offices	Floorspace	Gross Output	Services Gross Output
Educational Services	Floorspace	Gross Output	Services Gross Output
Health Care & Social Assist.	Floorspace	Gross Output	Services Gross Output
Arts, Accom., Food, Other	Floorspace	Gross Output	Services Gross Output
Natural Gas Distribution	NG Demand	NG Demand	Industry Gross Output
Oil Pipelines	National Oil Production	Gross Output	Industry Gross Output
Natural Gas Pipelines	BC, AB -> National Gas Prod. NB, NS -> NS Gas Prod. Rest of Areas -> NG Demand	NG Demand	Industry Gross Output
Street Lighting	GRP	GRP	GRP
<b>Industrial</b>			
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 GO
Other Chemicals	Gross Output	GRP	Chemicals GO
Fertilizer	Gross Output	Gross Output	Chemicals GO
Petroleum Products	Local RPP Production	Gross Output	Other Mfg. GO
Rubber	Gross Output	Gross Output	Other Mfg. GO

Sector	Canada	U.S.	Mexico
Cement	Gross Output	GRP	Other Mfg. GO
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	Transp. 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 Prod	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 Prod	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 Prod	Industry Gross Output
Coal Mining	Coal Production	Coal Production	Industry Gross Output
Construction	Gross Output	Gross Output	Industry Gross Output
Forestry	Gross Output	Gross Output	Agriculture GO
On Farm Fuel Use	Gross Output	Gross Output	Agriculture GO
Crop Production	Gross Output	Gross Output	N/A
Animal Production	Gross Output	Gross Output	N/A
<b>Transportation</b>			
Passenger	Vehicle Stock	Vehicle Stock	Vehicle Stock
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
<b>Miscellaneous Sectors (not used)</b>			
Miscellaneous	N/A	N/A	N/A
<b>Miscellaneous Sectors (used to hold Energy Demands from Suppliers)</b>			

Sector	Canada	U.S.	Mexico
Utility Electric Generation	Electric Utility Gen.	Electric Util Gen.	Electric Utility Gen.
Biofuel Production	Biofuel Production	Biofuel Prod	N/A
Hydrogen Production	Hydrogen Demands	Hydrogen Dmd	N/A
Steam Generation	Steam Generation	Steam Generation	N/A
Direct Air Capture	Demand for DAC	Demand for DAC	N/A
<b>Miscellaneous Sectors (used for Emissions Accounting Only)</b>			
Solid Waste	Total Households	Total Households	N/A
Wastewater	Total Households	Total Households	N/A
Incineration	Total Households	Total Households	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

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## APPENDIX 5. CONSUMER CHOICE THEORY OVERVIEW

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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 ( $P_i$ ) with the constant (non-price,  $a_i$ ) term.<sup>7</sup>

$$V_i = a_i + b * P_i$$

In ENERGY 2100, 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 2100 is:

$$V(i) = \text{Non-Price Factor}(i) + \text{Variance Factor} * \ln(\text{Price}(i)/\text{Price}(k))$$

$$\text{MarketShare}_n(i) = \frac{e^{(\text{NonPriceF actor} + \text{VF} * \ln(\text{Price}(i)/\text{Price}(k)))_{in}}}{\sum_{j=1}^N e^{(\text{NonPriceF actor} + \text{VF} * \ln(\text{Price}(i)/\text{Price}(k)))_{in,jn}}}$$

Where,

- MarketShare – Stored as MMSF (Marginal Market Share Fraction) in ENERGY 2100 for Option  $i$  (\$/\$)
- $V(i)$  - Utility of Choice  $i$  (also referred to as marginal allocation weight)
- $\text{Price}(i)$  - Levelized Lifecycle Cost of Option  $i$  (\$/mmBtu)

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<sup>7</sup>Train, K., *Discrete Choice Methods with Simulation*, Cambridge University Press, 2009.

- 
- Price(k) – Levelized Lifecycle Cost of Option Used as Reference (\$/mmBtu).
  - 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.

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## APPENDIX 6: CALCULATING EMISSIONS COEFFICIENTS

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### Energy-related air pollution emissions from demand sector

For the demand sector energy-related air pollutant emissions, an emissions coefficient is first calculated from the known historical air pollutant emissions (emissions divided by energy consumed). There are sectors in which historical air pollutant 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 *Calibration* files: CAC\_Industrial.jl, CAC\_Commercial.jl, CAC\_Residential.jl, CAC\_Transportation.jl.

### Process Emissions Air Pollutants

Several sectors that produce CAC emissions aren't modeled in detail by ENERGY 2100 and have no input fuel demands. These sectors are given energy and process emissions coefficients in CAC\_Macroeconomy.jl 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 to produce the same amount of emissions from these sources in the future as we have had historically.

### Electric Utility Air Pollutants

Generating electric utility coefficients is more complex compared to the demand sectors since ENERGY 2100 simulates electric generation, fuel consumption, and emissions at the unit level. Data at this level of granularity can have issues, especially when trying to pair historical inventories (vUnPol) with historical demands (vUnDmd). As an assumption, where there are input inventories for a unit without matching fuel demands then the inventory is classified as 'Process' and a process coefficient (UnMECX) is created to match the historical inventory value.

The air pollutant inventories for cogeneration units come from two different data sources, unit-level NPRI data (vUnPol) and sector level (vCogFPol). These units are differentiated using the 'xUnPolSw' variable in the model code. The air pollutant calibration files include code to assign the appropriate unit level value to the NPRI units and create a coefficient for cogeneration units without specific data assigned. This code can be simplified once all input inventories are available at the unit-level.

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## Emissions-Related Input Data

Input data differs by the type of the pollutant (GHG vs. air pollutants) and the method by which the pollutant is created (Combustion, Process, etc.). ENERGY 2100 reads in emissions-related coefficients and inventories as input data through data files in the *InputData* subfolder. GHG input are typically found in *vData* and air pollutant files are stored in *vData\_CAC*. The following lists the emissions-related variables that are in this subfolder along with a short description of each:

- vPOCX: Energy emissions coefficients (GHG)
- vFsPOCX: Feedstock emissions coefficients (GHG)
- vEUPOCX: Electric Utility energy emissions coefficients (GHG)
- vTrFsPOCX: Transportation feedstock emissions coefficients (GHG)
- vTrPOCX: Transportation energy emissions coefficients (GHG)
- vCogFPol: Sector-level cogeneration inventories (air pollutants)
- vEnFPol: Energy emissions inventories (air pollutants)
- vMEPol: Process emissions inventories
- vOREnFPol: Off-road emissions inventories (air pollutants)
- vTrEnFPol: Transportation energy emissions (air pollutants)
- vTrMEPol: Transportation process emissions
- vFIPol: Flaring emissions inventories
- vFuPol: Fugitive emissions inventories
- vVnPol: Venting emissions inventories
- vUnPol: NPRI utility emissions inventories

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## APPENDIX 7: GLOSSARY OF CARBON MARKET STRUCTURES

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**Emissions Coverage:** Emissions coverage identifies the geographic areas, economic sectors, and emissions included in the cap-and-trade system. Using model switches, ENERGY 2100 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 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 2100 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 CO<sub>2</sub>.

**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 2100 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.

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**Banking and Borrowing Allowances:** 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 2100 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 2100 computes these revenues then passes them to the macroeconomic model, if available, or the other ENERGY 2100 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 2100 passes the cost impacts to the macroeconomic model which processes the impact on the economy.

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## APPENDIX 7: LIST OF EXOGENOUS INPUT DATA (.DAT) FILES

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Exogenous input data files are stored in \InputData under one of the following subfolders:

- vData – Generic input data, mostly for Canada
- vData\_US – Generic input data for the U.S.
- vData\_MX – Generic input data for Mexico
- vData\_CAC – Air pollutant-related input data
- vData\_NGTransmission – Natural gas transmission data
- vData\_OGUnits – Input data and characteristics of oil and gas plays
- vData\_OilRefinery – Data on oil refineries
- vData\_CoalSupply – Coal trade flows
- vData\_ElectricUnits\_CN – Electric unit data for Canada
- vData\_ElectricUnits\_US – Electric unit data for the U.S.
- vData\_Macro – Macroeconomic input data
- vData\_2020Model – Input data that used to be stored in text files in \2020Model

The specific data files and the variables it populates are categorized and listed in the tables that follow:

- [Demand Module Input Data](#)
- [Prices Input Data](#)
- [Self-Generation/Cogeneration Input Data](#)
- [Emissions-Related \(GHG\) Input Data](#)
- [Air Pollutant \(CAC\) Related Input Data](#)
- [Trade Flows Input Data](#)
- [Miscellaneous Input Data \(Built from 2020Model Text Files\)](#)
- [Electric Supply Input Data Files](#)
- [Electric Generating Unit Input Data Files \(Canada\)](#)
- [Natural Gas Transmission Input Data Files](#)
- [Oil Refinery Input Data Files](#)
- [U.S. Input Data Files](#)
- [Waste Module Input Data](#)
- [Coal Supply Input Data Files](#)
- [Mexico Input Data Files](#)
- [Input Data Files for Oil and Gas Plays](#)

## Demand Module Input Data

\InputData\vData		
File Name	Variable (Sets)	Title
vDCC.dat	vDCC[vEnduse,vTech,ECC,Area,Year]	Device Capital Cost (Local 1985\\$/mmBtu/Yr)
vDDay.dat	vDDay[vEnduse,Area,Year]	Degree days(Degree Days)
vDDayNorm.dat	vDDayNorm[vEnduse,Area]	Normal Annual Degree days(Degree Days)
vDEE.dat	vDEE[vEnduse,vTech,ECC,Area,Year]	Historical Device Efficiency (Btu/Btu)
vDEETrend.dat	vDEETrend [vEnduse,TechRes,ECRes,vArea,Year]	Trend (Trend)
vDEM.dat	vDEM[vEnduse,vTech,ECC,Area,Year]	Maximum Device Efficiency (Btu/Btu)
vDEStd.dat	vDEStd[vEnduse,vTech,ECC,Area,Year]	Device Efficiency Standards (Btu/Btu)
vDmd.dat	vDmd[vEnduse,Fuel,ECC,Area,Year]	Enduse Demands (TBtu/Yr)
vDmd_OG.dat	vDmd_OG	
vDOCF.dat	vDOCF[vEnduse,vTech,ECC,Year]	Device Operating Cost Fraction (\\$/\\$/)
vDPL.dat	vDPL[vEnduse,vTech,ECC,Year]	Physical Life of Equipment (Years)
vDST.dat	vDST[vEnduse,ECC,Area,Year]	Device Saturation (Btu/Btu)
vEUDmd.dat	vEUDmd[Fuel,Area,Year]	Electric Utility Demands (TBtu/Yr)
vFsDmd.dat	vFsDmd[Fuel,ECC,Area,Year]	Feedstock Demands (TBtu/Yr)
vFSUnit.dat	vFSUnit[ECC,vArea,Year]	Floorspace per Unit (Sq Units/Building)
vStDmd.dat	vStDmd[FuelEP,Area,Year]	Steam Generation Fuel Demands (TBtu/Yr)
vTrDAct.dat	vTrDAct[TechTrans,ECTrans,vArea,Year]	Device Activity Level (Ton-Miles/Vehicle-Mile)
vTrDCC.dat	vTrDCC[TechTrans,ECTrans,vArea,Year]	Device Capital Cost (Real \\$/mmBtu/Yr)
vTrDCMM.dat	vTrDCMM [TechTrans,ECTrans,vArea,Year]	Capital Cost Maximum Multiplier (1=2008)
vTrDEE.dat	vTrDEE[TechTrans,ECTrans,vArea,Year]	Device Efficiency (miles/mmBtu)
vTrDEE_Default.dat	vTrDEE[TechTrans,ECTrans,vArea,Year]	Device Efficiency (miles/mmBtu)
vTrDEM.dat	vTrDEM[TechTrans,ECTrans,vArea,Year]	Maximum Device Efficiency (miles/mmBtu)
vTrDmd.dat	vTrDmd [Fuel,TechTrans,ECTrans,Area,Year]	Transportation Enduse Demand (TBtu/Yr)
vTrDPConv.dat	vTrDPConv [TechTrans,ECTrans,vArea,Year]	Device Process Conversion (Vehicle Mile/Passenger Mile)
vTrDST.dat	vTrDST[ECTrans,Area,Year]	Transportation Device Saturation (Btu/Btu)
vTrFsDmd.dat	vTrFsDmd [FuelFs,TechTrans,ECTrans,Area,Year]	Transportation Feedstock Demands (TBtu/Yr)

## Prices Input Data

\InputData\vData		
File Name	Variable (Sets)	Title
vENPN.dat	vENPN[Fuel,Nation,Year]	Wholesale Price (Real \\$/mmBtu)
vFPBaseF.dat	vFPBaseF[Fuel,ES,vArea,Year]	Delivered Fuel Price without Taxes (Real \\$/mmBtu)
vFPSMF.dat	vFPSMF[Fuel,ES,vArea,Year]	Energy Sales Tax (CN\\$/CN\\$)
vFPTaxF.dat	vFPTaxF[Fuel,ES,vArea,Year]	Fuel Tax (Real \\$/mmBtu)
vGAProd.dat	vGAProd[Process,Area,Year]	Natural Gas Production (TBtu/Yr)

## Self-Generation/Cogeneration Input Data

\InputData\vData		
File Name	Variable (Sets)	Title
vCgFIFrNew_CN.dat	vCgFIFrNew[FuelEP,Plant,Area,Year]	Fuel Fraction for New Plants (Btu/Btu)
vCgFIFrNew_US_MX.dat	vCgFIFrNew[FuelEP,Plant,Area,Year]	Fuel Fraction for New Plants (Btu/Btu)
vCgGen.dat	vCgGen[Fuel,ECC,vArea,Year]	Cogeneration Generation (GWh/Yr)
vCgORNew_CN.dat	vCgORNew[Plant,Area,Year]	Outage Rate for New Plants (MW/MW)
vCgORNew_US_MX.dat	vCgORNew[Plant,Area,Year]	Outage Rate for New Plants (MW/MW)

## Emissions-Related (GHG) Input Data

\InputData\vData		
File Name	Variable (Sets)	Title
vEUPOCX.dat	vEUPOCX[FuelEP,Plant,Poll,vArea,Year]	Electric Utility Pollution Coefficient (Tonnes/TBtu)
vFIPol.dat	vFIPol[ECC,Poll,vArea,Year]	Fugitive Flaring Emissions (Tonnes/Yr)
vFsPOCX.dat	vFsPOCX[Fuel,ECC,Poll,vArea,Year]	Feedstock Pollution Coefficient (Tonnes/TBtu)
vFuPol.dat	vFuPol[ECC,Poll,vArea,Year]	Fugitive Emissions (Tonnes/Yr)
vMEPol.dat	vMEPol[ECC,Poll,vArea,Year]	Non-Energy Pollution (Tonnes/Yr)
vPOCX.dat	vPOCX[FuelEP,ECC,Poll,vArea,Year]	Enduse Pollution Coefficient (Tonnes/TBtu)
vTrFsPOCX.dat	vTrFsPOCX [FuelFs,TechTrans,ECTrans,Poll,vArea,Year]	Transportation Feedstock Pollution Coefficient (Tonnes/TBtu)
vTrMEPol.dat	vTrMEPol [TechTrans,ECTrans,Poll,vArea,Year]	Non-Energy Trans Pollution (Tonnes/Yr)
vTrPOCX.dat	vTrPOCX [FuelEP,TechTrans,ECTrans,Poll,vArea,Year]	Transportation Pollution Coefficient (Tonnes/TBtu)
vVnPol.dat	vVnPol[ECC,Poll,vArea,Year]	Fugitive Venting Emissions (Tonnes/Yr)

## Air Pollutants/CAC Input Data Files

InputData\\vData_CAC		
File Name	Variable (Sets)	Title
vCogFPol.dat	vCogFPol[FuelEP,ECC,Poll,vArea,Year]	Cogeneration Pollution (Tonnes/Yr)
vEnFPol.dat	vEnFPol[FuelEP,ECC,Poll,vArea,Year]	Enduse Energy Pollution (Tonnes/Yr)
vEUPCostN.dat	vEUPCostN[FuelEP,Plant,Poll,Area,Year]	Pollution Reduction Cost Normal (Local 1985\\$/Tonne)
vEUPOCX.dat	vEUPOCX[FuelEP,Plant,Poll,vArea,Year]	Electric Utility Pollution Coefficient (Tonnes/TBtu)
vEUPVF.dat	vEUPVF[FuelEP,Plant,Poll,Area,Year]	Pollution Reduction Variance Factor (\\$/\)
vEURPCSw.dat	vEURPCSw[Plant,Poll,Area,Year]	Pollution Reduction Curve Switch (Switch)
vFIPol.dat	vFIPol[ECC,Poll,vArea,Year]	Fugitive Flaring Emissions (Tonnes/Yr)
vFuPol.dat	vFuPol[ECC,Poll,vArea,Year]	Fugitive Emissions (Tonnes/Yr)
vMEPCstN.dat	vMEPCstN[ECC,Poll,Area,Year]	Pollution Reduction Cost Normal (Local 1985\\$/Tonne)
vMEPol.dat	vMEPol[ECC,Poll,vArea,Year]	Non-Energy Pollution (Tonnes/Yr)
vMEPVF.dat	vMEPVF[ECC,Poll,Area,Year]	Pollution Reduction Variance Factor (\\$/\)
vMERCSw.dat	vMERCSw[ECC,Poll,Area,Year]	Pollution Reduction Curve Switch (Switch)
vOREnFPol.dat	vOREnFPol[FuelEP,ECC,Poll,vArea,Year]	Off Road Energy Pollution (Tonnes/Yr)
vPCostN.dat	vPCostN[FuelEP,ECC,Poll,Area,Year]	Pollution Reduction Cost Normal (Local 1985\\$/Tonne)
vPVF.dat	vPVF[FuelEP,ECC,Poll,Area,Year]	Pollution Reduction Variance Factor (\\$/\)
vRPCSw.dat	vRPCSw[ECC,Poll,Area,Year]	Pollution Reduction Curve Switch (Switch)
vTrEnFPol.dat	vTrEnFPol [FuelEP,TechTrans,ECTrans,Poll,vArea,Year]	Transportation Pollution (Tonnes/Yr)
vTrMEPol.dat	vTrMEPol [TechTrans,ECTrans,Poll,vArea,Year]	Non-Energy Trans Pollution (Tonnes/Yr)
vTrPCostN.dat	vTrPCostN [TechTrans,ECTrans,Poll,Area,Year]	Pollution Reduction Cost Normal (Local 1985\\$/Tonne)
vTrPVF.dat	vTrPVF[TechTrans,ECTrans,Poll,Area,Year]	Pollution Reduction Variance Factor (\\$/\)
vTrRPCSw.dat	vTrRPCSw[ECTrans,Poll,Area,Year]	Pollution Reduction Curve Switch (Switch)

vVnPol.dat	vVnPol[ECC,Poll,vArea,Year]	Fugitive Venting Emissions (Tonnes/Yr)
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### Trade Flows Input Data

File Name	Variable (Sets)	Title
vExports.dat	vExports[FuelEP,Nation,Year]	Primary Energy Exports (TBtu/Yr)
vExportsFraction.dat	vExportsFraction[Fuel,vArea,Year]	Exports Fraction (Btu/Btu)
vFlow.dat	vFlow[Fuel,Area,AreaX,Year]	Historical Energy Flow to Area from AreaX (TBtu/Yr)
vFlowNation.dat	vFlowNation[Fuel,Nation,NationX,Year]	Historical Energy Flow to Nation from NationX (TBtu/Yr)
vImports.dat	vImports[FuelEP,Nation,Year]	Primary Energy Imports (TBtu/Yr)
vImportsFraction.dat	vImportsFraction[Fuel,vArea,Year]	Imports Fraction (Btu/Btu)
vInflowFraction.dat	vInflowFraction[Fuel,vArea,Year]	Domestic Inflow Fraction (Btu/Btu)
vLNGAProd.dat	vLNGAProd[Area,Year]	LNG Production (TBtu/Yr)
vOAProd.dat	vOAProd[Process,Area,Year]	Primary Oil Production (TBtu/Yr)
vOutflowFraction.dat	vOutflowFraction[Fuel,vArea,Year]	Domestic Outflow Fraction (Btu/Btu)
vRPPAProd.dat	vRPPAProd[vArea,Year]	Refined Petroleum Products Production (TBtu/Yr)
vRPPExports.dat	vRPPExports[Nation,Year]	Refined Petroleum Products Exports (TBtu/Yr)
vRPPIimports.dat	vRPPIimports[Nation,Year]	Refined Petroleum Products Imports (TBtu/Yr)

### Miscellaneous Input Data (Built from 2020Model Text Files)

File Name	Variable (Sets)	Title
vDDCoefficient.dat	vDDCoefficient[vEnduse,Area,Year]	Annual Energy Degree Day Coefficient (DD/DD)
vDDay.dat	vDDay[vEnduse,Area,Year]	Degree days(Degree Days)
vDDayMonthly.dat	vDDayMonthly [vEnduse,Month,Area,Year]	Monthly Degree Days (Degree Days)
vDDayNorm.dat	vDDayNorm[vEnduse,Area]	Normal Annual Degree days(Degree Days)
vEUPOCX.dat	vEUPOCX [FuelEP,Plant,Poll,vArea,Year]	Electric Utility Pollution Coefficient (Tonnes/TBtu)
vGCPot.dat	vGCPot[Plant,Node,Area,Year]	Exogenous Maximum Potential Generation Capacity (MW)
vPOCX.dat	vPOCX[FuelEP,ECC,Poll,vArea,Year]	Enduse Pollution Coefficient (Tonnes/TBtu)
vVehiclesPerPerson.dat	vVehiclesPerPerson[Area,Year]	Average Vehicle Stock Per Person (Vehicles/Person)

vVehicleStock.dat	vVehicleStock[TechTrans,Area,Year]	Stock of Vehicles (Vehicles)
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### Electric Supply Input Data Files

File Name	Variable [Sets]	Title
vAreaPurchases.dat	vAreaPurchases[Area,Year]	Historical Purchases from Areas in the same Country (GWh/Yr)
vAreaSales.dat	vAreaSales[Area,Year]	Historical Sales to Areas in the same Country (GWh/Yr)
vCD.dat	vCD[Plant,Year]	Construction Delay (Years)
vDesHr_CN.dat	vDesHr [Plant,Power,Area,Year]	Design Hours (Hours)
vDesHr_US_MX.dat	vDesHr[Plant,Power,Area,Year]	Design Hours (Hours)
vEAF_CN.dat	vEAF[Plant,Area,Month,Year]	Energy Availability Factor (MWh/MWh)
vEAF_US_MX.dat	vEAF[Plant,Area,Month,Year]	Energy Availability Factor (MWh/MWh)
vEGFA.dat	vEGFA[Fuel,vArea,Year]	Electricity Generated (GWh/Yr)
vExpPurchases.dat	vExpPurchases[Area,Year]	Historical Purchases from Areas in a different Country (GWh/Yr)
vExpSales.dat	vExpSales[Area,Year]	Historical Sales to Areas in a different Country (GWh/Yr)
vECF.dat	vECF[Fuel,Area,Year]	Energy Conversion Factors (GJ/Various)
vFIFrNew_CN.dat	vFIFrNew[FuelEP,Plant,Area,Year]	Fuel Fraction for New Plants (Btu/Btu)
vFIFrNew_US_MX.dat	vFIFrNew[FuelEP,Plant,Area,Year]	Fuel Fraction for New Plants (Btu/Btu)
vGCCCN.dat	vGCCCN[Plant,vArea,Year]	Overnight Construction Costs (Real \\$/Kw)
vGCPot_CN.dat	vGCPot[Plant,Node,Area,Year]	Exogenous Maximum Potential Generation Capacity (MW)
vGCPot_US_MX.dat	vGCPot[Plant,Node,Area,Year]	Exogenous Maximum Potential Generation Capacity (MW)
vHDXLoad.dat	vHDXLoad [Node,NodeX,TimeP,Month,Year]	Exogenous Loading on Transmission Lines (MW)
vHRtM.dat	vHRtM[Plant,Area,Year]	Marginal Heat Rate (Btu/KWh)
vHRtM_CN.dat	vHRtM[Plant,Area,Year]	Marginal Heat Rate (Btu/KWh)
vHRtM_US_MX.dat	vHRtM[Plant,Area,Year]	Marginal Heat Rate (Btu/KWh)
vLLMax.dat	vLLMax [Node,NodeX,TimeP,Month,Year]	Maximum Loading on Transmission Lines (MW)
vLLVC.dat	vLLVC[Node,NodeX,Year]	Transmission rate (Real US Dollars/MWh)
vUFOMC.dat	vUFOMC[Plant,vArea,Year]	Unit Fixed O&M Costs (Real \\$/Kw/Yr)
vORNew_CN.dat	vORNew[Plant,Area,Year]	Outage Rate for New Plants (MW/MW)
vORNew_US_MX.dat	vORNew[Plant,Area,Year]	Outage Rate for New Plants (MW/MW)
vUOMC.dat	vUOMC[Plant,vArea,Year]	Variable O&M Costs (Real \\$/MWh)

### Electric Generating Unit Input Data Files (Canada)

\vData_ElectricUnits_CN
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<b>File Name</b>	<b>Variable (Sets)</b>	<b>Title</b>
vUnArea.dat	vUnArea	
vUnCogen.dat	vUnCogen[Unit]	Industrial Generation Switch (Switch) (1=Industrial Generation)
vUnDmd.dat	vUnDmd[Unit,FuelEP,Year]	Energy Demands (Tbtu/Yr)
vUnEAF.dat	vUnEAF[Unit,Month,Year]	Energy Availability Factor (GWh/GWh)
vUnEffStorage.dat	vUnEffStorage[Unit]	Storage Efficiency (GWH/GWH)
vUnEGA.dat	vUnEGA[Unit,Year]	Generation (GWh/Yr)
vUnEmit.dat	vUnEmit[Unit]	Does this Unit Emit Pollution (Switch) (1=Yes)
vUnF1.dat	vUnF1	
vUnFacility.dat	vUnFacility	
vUnFIFr.dat	vUnFIFr[Unit,FuelEP,Year]	Fuel Fraction (Btu/Btu)
vUnGC.dat	vUnGC[Unit,Year]	Generating Capacity (MW/Yr)
vUnGCCC.dat	vUnGCCC[Unit,Year]	Generating Unit Capital Cost (Real \\$/Kw)
vUnGenCo.dat	vUnGenCo	
vUnHRT.dat	vUnHRT[Unit,Year]	Heat Rate (BTU/KWh)
vUnLimited.dat	vUnLimited[Unit,Year]	Limited Energy Units Switch (Switch) (1=Limited Energy Unit)
vUnMustRun.dat	vUnMustRun[Unit]	Must Run (Switch) (1=Must Run)
vUnName.dat	vUnName	
vUnNation.dat	vUnNation	
vUnNode.dat	vUnNode	
vUnOnLine.dat	vUnOnLine[Unit]	On-Line Date (Year)
vUnOR.dat	vUnOR[Unit,TimeP,Month,Year]	Outage Rate (MW/MW)
vUnOUREG.dat	vUnOUREG[Unit,Year]	Own Use Rate for Generation (MW/MW)
vUnOURGC.dat	vUnOURGC[Unit,Year]	Own Use Rate for Generating Capacity (MW/MW)
vUnOwner.dat	vUnOwner	
vUnPlant.dat	vUnPlant	
vUnPol.dat	vUnPol[Unit,FuelEP,Poll,Year]	Electric Unit Pollution (Tonnes/Yr)
vUnRetire.dat	vUnRetire[Unit]	Retirement Date (Year)
vUnSector.dat	vUnSector	
vUnSource.dat	vUnSource[Unit]	Source (Switch) (1=Endogenous, 0=Exogenous)
vUnSqFr.dat	vUnSqFr[Unit,Poll,Year]	Sequestered Pollution Fraction (Tonne/Tonne)
vUnStorage.dat	vUnStorage[Unit]	Storage (Switch) (1=Storage, 0=Non- storage)
vUnUFOMC.dat	vUnUFOMC[Unit,Year]	Fixed O&M Costs (Real \\$/Kw/Yr)
vUnUOMC.dat	vUnUOMC[Unit,Year]	Variable O&M Costs (Real \\$/MWh)

## Electric Generating Unit Input Data Files (US)

vData_ElectricUnits_US		
File Name	Variable (Sets)	Title
vUnArea.dat	vUnArea	
vUnCogen.dat	vUnCogen[Unit]	Industrial Generation Switch (Switch) (1=Industrial Generation)
vUnDmd.dat	vUnDmd[Unit,FueEP,Year]	Energy Demands (TBtu/Yr)
vUnEAF.dat	vUnEAF[Unit,Month,Year]	Energy Availability Factor (GWh/GWh)
vUnEGA.dat	vUnEGA[Unit,Year]	Generation (GWh/Yr)
vUnEmit.dat	vUnEmit[Unit]	Does this Unit Emit Pollution (Switch) (1=Yes)
vUnF1.dat	vUnF1	
vUnFacility.dat	vUnFacility	
vUnFIFr.dat	vUnFIFr[Unit,FueEP,Year]	Fuel Fraction (Btu/Btu)
vUnGC.dat	vUnGC[Unit,Year]	Generating Capacity (MW/Yr)
vUnGCCC.dat	vUnGCCC[Unit,Year]	Generating Unit Capital Cost (Real \\$/Kw)
vUnGenCo.dat	vUnGenCo	
vUnHRT.dat	vUnHRT[Unit,Year]	Heat Rate (BTU/KWh)
vUnMustRun.dat	vUnMustRun[Unit]	Must Run (Switch) (1=Must Run)
vUnName.dat	vUnName	
vUnNation.dat	vUnNation	
vUnNode.dat	vUnNode	
vUnOnLine.dat	vUnOnLine[Unit]	On-Line Date (Year)
vUnOR.dat	vUnOR[Unit,TimeP,Month,Year]	Outage Rate (MW/MW)
vUnOwner.dat	vUnOwner	
vUnPlant.dat	vUnPlant	
vUnRetire.dat	vUnRetire[Unit]	Retirement Date (Year)
vUnSector.dat	vUnSector	
vUnSource.dat	vUnSource[Unit]	Source (Switch) (1=Endogenous, 0=Exogenous)
vUnUFOMC.dat	vUnUFOMC[Unit,Year]	Fixed O&M Costs (Real \\$/Kw/Yr)
vUnUOMC.dat	vUnUOMC[Unit,Year]	Variable O&M Costs (Real \\$/MWh)

vData_Macro		
File Name	Variable (Sets)	Title
vECUF.dat	vECUF[ECC,Area,Year]	Capital Utilization Fraction (\\$/\%)
vFloorspaceAEO.dat	vFloorspaceAEO[ECC,Area,Year]	Floorspace from AEO (Million Sq Ft)
vGOAEO.dat	vGOAEO[ECC,Area,Year]	Gross Output from AEO (2012 M\\$/Yr)
vGRPAEO.dat	vGRPAEO[Area,Year]	US Gross Regional Product from AEO (Real M\\$/Yr)
vHHS AEO.dat	vHHS AEO[ECC,Area,Year]	Households from AEO (Households)
vHSize.dat	vHSize[ECC,Area,Year]	Household Size (People/Household)

vMWDecayTime.dat	vMWDecayTime[Area]	Municipal Waste Decay Time (Years)
vPCPL.dat	vPCPL[ECC,Area,Year]	Physical Life of Production Capacity (Years)
vPopAEO.dat	vPopAEO[ECC,Area,Year]	Population by Household Type (Millions)
vPopTAE0.dat	vPopTAE0[Area,Year]	Population (Millions)
vRPIAEO.dat	vRPIAEO[Area,Year]	Total Personal Income (2017 M\\$/Yr)
vVehicleSalesRatio.dat	vVehicleSalesRatio [Fleet,ECCTOM,AreaTOM,Year]	Transportation Investments as Fraction of Gross Output (Btu/Btu)

### Natural Gas Transmission Input Data Files

vData_NGTransmission		
File Name	Variable (Sets)	Title
vGAvFrLNG.dat	vGAvFrLNG[GNode,Month,Year]	LNG Gas Available for Dispatch (Btu/Btu)
vGAvFrProd.dat	vGAvFrProd[GNode,Month,Year]	Production Gas Available for Dispatch (Btu/Btu)
vGAvFrStorage.dat	vGAvFrStorage[GNode,Month,Year]	Storage Gas Available for Dispatch (Btu/Btu)
vGFillFrStorage.dat	vGFillFrStorage[GNode,Month,Year]	Fraction of Gas Storage which is Filled (Btu/Btu)
vGLSF.dat	vGLSF[Month,Area,Year]	Natural Gas Load Shape Factor (Btu/Btu)
vGNodeAreaMap.dat	vGNodeAreaMap[GNode,Area]	Natural Gas Node to Area Map (Map)
vGNodeXAreaMap.dat	vGNodeXAreaMap[GNodeX,Area]	Natural Gas Node to Area Map (Map)
vGNodeNationMap.dat	vGNodeNationMap[GNode,Nation]	Natural Gas Node to Nation Map (Map)
vGNodeXNationMap.dat	vGNodeXNationMap[GNodeX,Nation]	Natural Gas Node to Nation Map (Map)
vGLvStorage.dat	vGLvStorage[GNode,Month,Year]	Historical Level of Natural Gas in Storage (TBtu)
vGTrMax.dat	vGTrMax [GNode,GNodeX,Month,Year]	Natural Gas Transmission Capacity (TBtu/Month)
vGTrEff.dat	vGTrEff[GNode,GNodeX,Month,Year]	Natural Gas Transmission Efficiency (TBtu/TBtu)
vGUVStorage.dat	vGUVStorage[GNode,Month,Year]	Unit Non-Fuel Variable Cost from Storage (\\$/mmBtu)
vGCapLNGImports.dat	vGCapLNGImports [GNode,Month,Year]	Exogenous LNG Imports Capacity (TBtu/Yr)
vGCapLNGExports.dat	vGCapLNGExports [GNode,Month,Year]	Exogenous LNG Exports Capacity (TBtu/Yr)
vGCapStorage.dat	vGCapStorage[GNode,Month,Year]	Exogenous Storage Capacity (TBtu/Yr)
vGTrVC.dat	vGTrVC[GNode,GNodeX,Month,Year]	Natural Gas Transmission Variable Cost (\\$/mmBtu)
vGTrFlow.dat	vGTrFlow [GNode,GNodeX,Month,Year]	Natural Gas Transmission Flow (TBtu/Month)

vGVCLNG.dat	vGVCLNG[GNode,Month,Year]	Historical Natural Gas Variable Cost from LNG (\\$/mmBtu)
vGVCPProd.dat	vGVCPProd[GNode,Month,Year]	Historical Natural Gas Variable Cost from Production (\\$/mmBtu)
vGExpDChg.dat	vGExpDChg[GNode,Month,Year]	World Natural Gas Price Differential (\\$/mmBtu)

## Oil Refinery Input Data Files

vData_OilRefinery		
File Name	Variable (Sets)	Title
vByFrac.dat	vByFrac[OGUnit,Year]	Byproducts Production Fraction (Btu/Btu)
vDevCap.dat	vDevCap[OGUnit,Year]	Exogenous Development Capital Costs (\\$/mmBtu)
vDevDMB0.dat	vDevDMB0[OGUnit,Year]	Development Costs Depletion Multiplier Coefficient (\\$/\\$/)
vDevDpRate.dat	vDevDpRate[OGUnit,Year]	Development Depreciation Rate (\\$/\\$/)
vDevLCMB0.dat	vDevLCMB0[OGUnit,Year]	Development Costs Learning Curve Multiplier Coefficient (\\$/\\$/)
vDilFrac.dat	vDilFrac[OGUnit,Year]	Diluent Fraction (Btu/Btu)
vFkFrac.dat	vFkFrac[OGUnit,Year]	Feedstock Fraction (Btu/Btu)
vGRRMax.dat	vGRRMax[OGUnit,Year]	Maximum Gross Revenue Royalty Rate (\\$/\\$/)
vGRRMin.dat	vGRRMin[OGUnit,Year]	Minimum Gross Revenue Royalty Rate (\\$/\\$/)
vGRRPr.dat	vGRRPr[OGUnit,Year]	Gross Revenue Royalty Rate Slope to Price (\\$/\\$/)
vGRRPr0.dat	vGRRPr0[OGUnit,Year]	Gross Revenue Royalty Rate Intercept (\\$/\\$/)
vMeanEUR.dat	vMeanEUR[OGUnit,Year]	Mean Expected Ultimate Recovery (TBtu/Well)
vNRRMax.dat	vNRRMax[OGUnit,Year]	Maximum Net Revenue Royalty Rate (\\$/\\$/)
vNRRMin.dat	vNRRMin[OGUnit,Year]	Minimum Net Revenue Royalty Rate (\\$/\\$/)
vNRRPr.dat	vNRRPr[OGUnit,Year]	Net Revenue Royalty Rate Slope to Price (\\$/\\$/)
vNRRPr0.dat	vNRRPr0[OGUnit,Year]	Net Revenue Royalty Rate Intercept (\\$/\\$/)
vOGAbCFr.dat	vOGAbCFr[OGUnit,Year]	OG Abandonment Cost Fraction (\\$/\\$/)
vOGArea.dat	vOGArea	
vOGCounter.dat	vOGCounter[Year]	Number of OG Units for this Year (Number)
vOGECC.dat	vOGECC	
vOGFMap.dat	vOGFMap[FuelOG,Fuel]	Map between FuelOG and Fuel (Map)
vOGFPAdd.dat	vOGFPAdd[OGUnit,Year]	Price Adder for Supply Cost Search (\\$/mmBtu)
vOGFPMax.dat	vOGFPMax[OGUnit,Year]	Maximum Price for Supply Cost Search (\\$/mmBtu)
vOGFPMin.dat	vOGFPMin[OGUnit,Year]	Initial Price for Supply Cost Search (\\$/mmBtu)
vOGFPDChg.dat	vOGFPDChg[OGUnit,Year]	Wholesale Price Transportation Charge (\\$/mmBtu)
vOGFuel.dat	vOGFuel	
vOGITxRate.dat	vOGITxRate[OGUnit,Year]	OG Initial Tax Rate (\\$/\\$/)
vOGName.dat	vOGName	
vOGNation.dat	vOGNation	
vOGNode.dat	vOGNode	
vOGOGSw.dat	vOGOGSw	
vOGECC.dat	vOGECC	

vOGProcess.dat	vOGProcess	
vOGOMCosts.dat	vOGOMCosts[OGUnit,Year]	OG O and M Costs (\\$/mmBtu)
vOGROIN.dat	vOGROIN[OGUnit,Year]	Return on Investment (\\$/Yr/\\$)
vOpDMB0.dat	vOpDMB0[OGUnit,Year]	Operating Costs Depletion Multiplier Coefficient (\\$/\\$)
vOpLCMB0.dat	vOpLCMB0[OGUnit,Year]	Operating Costs Learning Curve Multiplier Coefficient (\\$/\\$)
vOWCDays.dat	vOWCDays[OGUnit,Year]	Operating Working Capital Days Payment (Days)
vPdCOOG.dat	vPdCOOG[OGUnit,Year]	Learning Curve Initial Cumulative Production (TBtu)
vROITarget.dat	vROITarget[OGUnit,Year]	ROI Target for Supply Cost Search (\\$/\\$)
vRsD0OG.dat	vRsD0OG[OGUnit,Year]	Learning Curve Initial Developed Resources (TBtu)
vRyLevFactor.dat	vRyLevFactor[OGUnit,Year]	Royalty Levelization Factor (\\$/\\$)
vSusCap.dat	vSusCap[OGUnit,Year]	Exogenous Sustaining Capital Costs (\\$/mmBtu)
vSusDpRate.dat	vSusDpRate[OGUnit,Year]	Sustaining Depreciation Rate (\\$/\\$)

### U.S. Input Data Files

\vData_US		
File Name	Variable (Sets)	Title
vCProd.dat	vCProd[Area,Year]	Coal Production (TBtu/Yr)
vDmd.dat	vDmd[vEnduse,Fuel,ECC,Area,Year]	Enduse Demands (TBtu/Yr)
vDST.dat	vDST[vEnduse,ECC,Area,Year]	Device Saturation (Btu/Btu)
vEUDmd.dat	vEUDmd[Fuel,Area,Year]	Electric Utility Demands (TBtu/Yr)
vExports.dat	vExports[FuelEP,Nation,Year]	Primary Energy Exports (TBtu/Yr)
vFPF.dat	vFPF[Fuel,ES,Area,Year]	Delivered Fuel Price, including Taxes (Real Dollars per mmBtu)
vFsDmd.dat	vFsDmd[Fuel,ECC,Area,Year]	Feedstock Demands (TBtu/Yr)
vGAProd.dat	vGAProd[Process,Area,Year]	Natural Gas Production (TBtu/Yr)
vHDXLoad.dat	vHDXLoad [Node,NodeX,TimeP,Month,Year]	Exogenous Loading on Transmission Lines (MW)
vImports.dat	vImports[FuelEP,Nation,Year]	Primary Energy Imports (TBtu/Yr)
vLLVC.dat	vLLVC[Node,NodeX,Year]	Transmission rate (Real US Dollars/MWh)
vLNGAProd.dat	vLNGAProd[Area,Year]	LNG Production (TBtu/Yr)
vMinLd.dat	vMinLd[Month,Area,Year]	Historical Monthly Minimum Load (MW/Month)
vMonOut.dat	vMonOut[Month,Area,Year]	Historical Monthly Output (GWh/Month)
vOAProd.dat	vOAProd[Process,Area,Year]	Primary Oil Production (TBtu/Yr)
vPkLoad.dat	vPkLoad[Month,Area,Year]	Historical Monthly Peak Load (MW/Month)
vPollImports.dat	vPollImports[Poll,Area,Year]	Reference Case Imported Electricity Emissions (Tonnes/Yr)
vRnImports.dat	vRnImports[Area,Year]	Exogenous Renewable Generation Imports (GWh/Yr)
vRPPExports.dat	vRPPExports[Nation,Year]	Refined Petroleum Products Exports (TBtu/Yr)

vRPPImports.dat	vRPPImports[Nation,Year]	Refined Petroleum Products Imports (TBtu/Yr)
vRPPProd.dat	vRPPProd[Nation,Year]	Refined Petroleum Products Production (TBtu/Yr)
vTrDmd.dat	vTrDmd [Fuel,TechTrans,ECTrans,Area,Year]	Transportation Enduse Demand (TBtu/Yr)
vTrDST.dat	vTrDST[ECTrans,Area,Year]	Transportation Device Saturation (Btu/Btu)
vTrFsDmd.dat	vTrFsDmd [FuelFs,TechTrans,ECTrans,Area,Year]	Transportation Feedstock Demands (TBtu/Yr)

### Waste Module Input Data

\vData		
File Name	Variable [Sets]	Title
vCapture_Rate.dat	vCapture_Rate[Waste,vArea,Year]	CH4 Recovery Fraction (Tonnes/Tonnes)
vDDOCm_accum.dat	vDDOCm_accum[Waste,vArea,Year]	Initial DDOC Accumulation (Tonnes)
vDiversionRate.dat	vDiversionRate[Waste,vArea,Year]	Proportion of Diverted Waste (Tonnes/Tonnes)
vDOCDecomposeFraction.dat	vDOCDecomposeFraction [Waste,vArea,Year]	Fraction of Decomposable DOC (Tonnes/Tonnes)
vDOC.dat	vDOC[Waste,vArea,Year]	Fraction of Degradable Organic Carbon per Waste Landfilled (Tonnes/Tonnes)
vFlaring_Rate.dat	vFlaring_Rate[Waste,vArea,Year]	CH4 Flaring Fraction (Tonnes/Tonnes)
vGenerated_Driver.dat	vGenerated_Driver [Waste,vArea,Year]	Waste per Capita (Tonnes/Driver)
vIncinerated.dat	vIncinerated[Waste,vArea,Year]	Fraction of Waste Incinerated (Tonnes/Tonnes)
vk.dat	vk[Waste,vArea,Year]	CH4 Generation Constant (1/Yr)
vXport.dat	vXport[Waste,vArea,Year]	Fraction of Waste Exported (Tonnes/Tonnes)

### Coal Supply Input Data Files

File Name	Variable [Sets]	Title
vCExports.dat	vCExports[vArea,Year]	Coal Exports (TBtu/Yr)
vCImports.dat	vCImports[vArea,Year]	Coal Imports (TBtu/Yr)
vCProd.dat	vCProd[Area,Year]	Coal Production (TBtu/Yr)

## Mexico Input Data Files

vData_MX		
File Name	Variable (Sets)	Title
vCProd.dat	vCProd[Area,Year]	Coal Production (TBtu/Yr)
vDmd.dat	vDmd[vEnduse,Fuel,ECC,Area,Year]	Enduse Demands (TBtu/Yr)
vDST.dat	vDST[vEnduse,ECC,Area,Year]	Device Saturation (Btu/Btu)
vExports.dat	vExports[FuelEP,Nation,Year]	Primary Energy Exports (TBtu/Yr)
vExpPurchases.dat	vExpPurchases[Area,Year]	Historical Purchases from Areas in a different Country (GWh/Yr)
vExpSales.dat	vExpSales[Area,Year]	Historical Sales to Areas in a different Country (GWh/Yr)
vGAProd.dat	vGAProd[Process,Area,Year]	Natural Gas Production (TBtu/Yr)
vGO.dat	vGO[ECC,Area,Year]	Gross Output (Real 1985 M\\$/Yr)
vGRP.dat	vGRP[Area,Year]	Gross Regional Product (Real 1985 M\\$/Yr)
vImports.dat	vImports[FuelEP,Nation,Year]	Primary Energy Imports (TBtu/Yr)
vMinLd.dat	vMinLd[Month,Area,Year]	Historical Monthly Minimum Load (MW/Month)
vMonOut.dat	vMonOut[Month,Area,Year]	Historical Monthly Output (GWh/Month)
vOAProd.dat	vOAProd[Process,Area,Year]	Primary Oil Production (TBtu/Yr)
vPkLoad.dat	vPkLoad[Month,Area,Year]	Historical Monthly Peak Load (MW/Month)
vPopT.dat	vPopT[Area,Year]	Population (Millions)
vRPI.dat	vRPI[Area,Year]	Total Personal Income (Real 1985 M\\$/Yr)
vRPPExports.dat	vRPPExports[Nation,Year]	Refined Petroleum Products Exports (TBtu/Yr)
vRPPIImports.dat	vRPPIImports[Nation,Year]	Refined Petroleum Products Imports (TBtu/Yr)
vRPPProd.dat	vRPPProd[Nation,Year]	Refined Petroleum Products Production (TBtu/Yr)
vTrDmd.dat	vTrDmd [Fuel,TechTrans,ECTrans,Area,Year]	Transportation Enduse Demand (TBtu/Yr)
vTrDST.dat	vTrDST[ECTrans,Area,Year]	Transportation Device Saturation (Btu/Btu)

## Input Data Files for Oil and Gas Plays

\InputData\vData_OGUnits		
File	Variable [Sets]	Description
vByFrac.dat	vByFrac[OGUnit,Year]	Byproducts Production Fraction (Btu/Btu)
vDevCap.dat	vDevCap[OGUnit,Year]	Exogenous Development Capital Costs (\$/mmBtu)
vDevDMB0.dat	vDevDMB0[OGUnit,Year]	Development Costs Depletion Multiplier Coefficient (\$/\$)

\InputData\vData_OGUnits		
File	Variable [Sets]	Description
vDevDpRate.dat	vDevDpRate[OGUnit,Year]	Development Depreciation Rate (\$/\$)
vDevLCMB0.dat	vDevLCMB0[OGUnit,Year]	Development Costs Learning Curve Multiplier Coefficient (\$/\$)
vDilFrac.dat	vDilFrac[OGUnit,Year]	Diluent Fraction (Btu/Btu)
vFkFrac.dat	vFkFrac[OGUnit,Year]	Feedstock Fraction (Btu/Btu)
vGRRMax.dat	vGRRMax[OGUnit,Year]	Maximum Gross Revenue Royalty Rate (\$/\$)
vGRRMin.dat	vGRRMin[OGUnit,Year]	Minimum Gross Revenue Royalty Rate (\$/\$)
vGRRPr.dat	vGRRPr[OGUnit,Year]	Gross Revenue Royalty Rate Slope to Price (\$/\$)
vGRRPr0.dat	vGRRPr0[OGUnit,Year]	Gross Revenue Royalty Rate Intercept (\$/\$)
vMeanEUR.dat	vMeanEUR[OGUnit,Year]	Mean Expected Ultimate Recovery (TBtu/Well)
vNRRMax.dat	vNRRMax[OGUnit,Year]	Maximum Net Revenue Royalty Rate (\$/\$)
vNRRMin.dat	vNRRMin[OGUnit,Year]	Minimum Net Revenue Royalty Rate (\$/\$)
vNRRPr.dat	vNRRPr[OGUnit,Year]	Net Revenue Royalty Rate Slope to Price (\$/\$)
vNRRPr0.dat	vNRRPr0[OGUnit,Year]	Net Revenue Royalty Rate Intercept (\$/\$)
vOGAbCFr.dat	vOGAbCFr[OGUnit,Year]	OG Abandonment Cost Fraction (\$/\$)
vOGArea.dat	vOGArea[OGUnit]	OG Unit Area (set attribute)
vOGCounter.dat	vOGCounter[Year]	Number of OG Units for this Year (Number)
vOGECC.dat	vOGECC[OGUnit]	OG Exploration Capital Cost (set attribute)
vOGFMap.dat	vOGFMap[FuelOG,Fuel]	Map between FuelOG and Fuel (Map)
vOGFPAdd.dat	vOGFPAdd[OGUnit,Year]	Price Adder for Supply Cost Search (\$/mmBtu)
vOGFPDChg.dat	vOGFPDChg[OGUnit,Year]	Wholesale Price Transportation Charge (\$/mmBtu)
vOGFPMMax.dat	vOGFPMMax[OGUnit,Year]	Maximum Price for Supply Cost Search (\$/mmBtu)
vOGFPMMin.dat	vOGFPMMin[OGUnit,Year]	Initial Price for Supply Cost Search (\$/mmBtu)
vOGFuel.dat	vOGFuel[OGUnit]	OG Unit Fuel (set attribute)
vOGITxRate.dat	vOGITxRate[OGUnit,Year]	OG Initial Tax Rate (\$/\$)
vOGName.dat	vOGName[OGUnit]	OG Unit Name (set attribute)
vOGNation.dat	vOGNation[OGUnit]	OG Unit Nation (set attribute)
vOGNode.dat	vOGNode[OGUnit]	OG Unit Node (set attribute)
vOGOGSw.dat	vOGOGSw[OGUnit]	OG Operational Switch (set attribute)
vOGOMCosts.dat	vOGOMCosts[OGUnit,Year]	OG O and M Costs (\$/mmBtu)
vOGProcess.dat	vOGProcess[OGUnit]	OG Unit Process (set attribute)
vOGROIN.dat	vOGROIN[OGUnit,Year]	Return on Investment (\$/Yr/\$)
vOpDMB0.dat	vOpDMB0[OGUnit,Year]	Operating Costs Depletion Multiplier Coefficient (\$/\$)
vOpLCMB0.dat	vOpLCMB0[OGUnit,Year]	Operating Costs Learning Curve Multiplier Coefficient (\$/\$)
vOWCDays.dat	vOWCDays[OGUnit,Year]	Operating Working Capital Days Payment (Days)

\InputData\vData_OGUnits		
File	Variable [Sets]	Description
vPdCOOG.dat	vPdCOOG[OGUnit,Year]	Learning Curve Initial Cumulative Production (TBtu)
vROITarget.dat	vROITarget[OGUnit,Year]	ROI Target for Supply Cost Search (\$/\$)
vRsDOOG.dat	vRsDOOG[OGUnit,Year]	Learning Curve Initial Developed Resources (TBtu)
vRyLevFactor.dat	vRyLevFactor[OGUnit,Year]	Royalty Levelization Factor (\$/\$)
vSusCap.dat	vSusCap[OGUnit,Year]	Exogenous Sustaining Capital Costs (\$/mmBtu)
vSusDpRate.dat	vSusDpRate[OGUnit,Year]	Sustaining Depreciation Rate (\$/\$)