

ENERGY 2020 Documentation

Volume 3

Demand Sector Model Code Description

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Demand Sector Model Code Description

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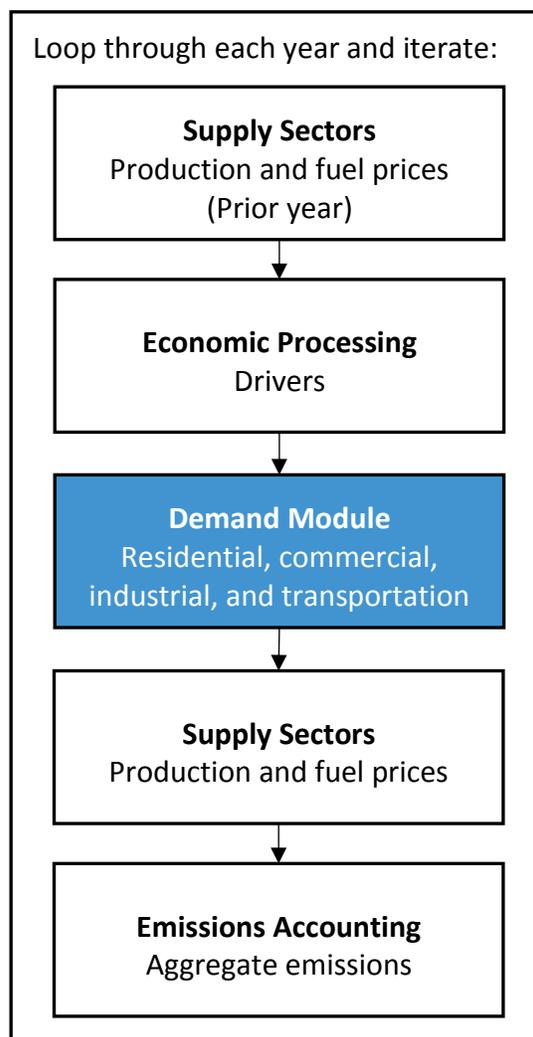
1. Introduction

ENERGY 2020 is an integrated regional, multi-sector energy analysis system that simulates energy supply, price and demand across detailed fuel types. Its energy demand module consists of four sectors (residential, commercial, industrial, and transportation). Energy demands are calculated and sent as input to the supply module consisting of six energy producing sectors – electricity, oil and gas, refinery, biofuels, coal, and steam. The supply module produces the energy required to meet the energy demand, calculates energy prices, and sends energy prices back as feedback to the demand sector. Both energy and non-energy related emissions are tracked covering eighteen separate greenhouse gas (GHG) pollutants and criteria air contaminants (CAC) plus water usage.

1.1. Demand Module Relationship to Rest of Model

For context, a flow diagram of ENERGY 2020's model execution is illustrated in Figure 1 showing the order of execution of the demand module in relationship to the rest of the model (consisting of economic processing and the supply sectors from the supply module (electricity, oil and gas, oil refinery, biofuel, and coal production). For each forecast year, ENERGY 2020 performs the operations in the order shown in the flow diagram. Initially, several supply sectors are run to obtain energy prices and oil, gas, and coal production levels from the prior year. The fuel prices and production are inputs to the demand module. Additionally, economic processing is performed in order to assign drivers for the demand sectors. The demand module then executes each of its sectors separately (residential, commercial, industrial, and transportation) to calculate enduse, cogeneration, and feedstock energy demands for each of the demand sectors. The energy demands are then used as input to the supply modules which calculate energy production required to meet energy demand along with the resulting energy prices. As a final step emissions are aggregated (both energy-related and non-energy). These steps are executed with at least two iterations for each forecast year. The second iteration is run to allow feedback from the first iteration's supply sector results to be incorporated into a second round of demand sector calculations and vice versa. For example, energy prices from the first iteration are updated and input to the demand module during the second iteration.

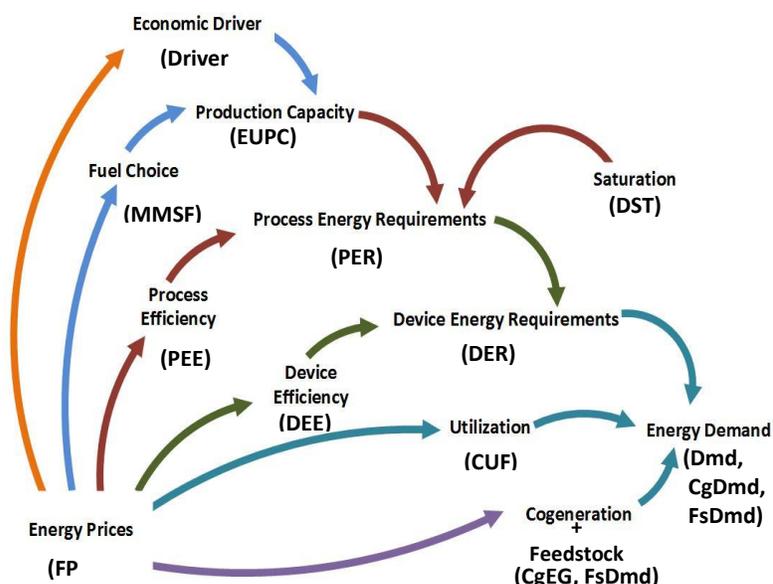
Figure 1. ENERGY 2020 Flow Diagram



1.2. Components of Energy Demand

The primary purpose of the demand module is to make long range projections of energy demand resulting from fuel usage from end-uses, cogeneration, and feedstocks. Figure 2 illustrates the key mechanisms that exist within ENERGY 2020 to simulate the demand sector relationships that go into determining energy demand. Variables names representing each mechanism are listed in parentheses. This diagram shows that ENERGY 2020

Figure 2. Demand mechanisms and key variables in ENERGY 2020



simulates energy demand (enduse, cogeneration, and feedstock) as a function of device energy requirements combined with utilization factors and accounting for cogeneration and feedstocks. Total device energy requirements are determined based on changes in process energy requirements (e.g. building shell) as well as energy efficiency levels of the devices/equipment used to meet the process energy requirements (new and existing). Because ENERGY 2020 tracks vintages of capital stock, changes in device energy requirements and process energy requirements are also due to retirements and replacements of capital stock due to wear-out and/or additions to capital stock from economic growth. Process energy requirements are determined based on changes to production capacity (from retirements, replacement, or additions), process efficiency levels of new and existing stock and device saturations. Changes to production capacity are driven by economic drivers combined with consumers' fuel choices for new capital with energy prices generally influencing all aspects of the energy system.

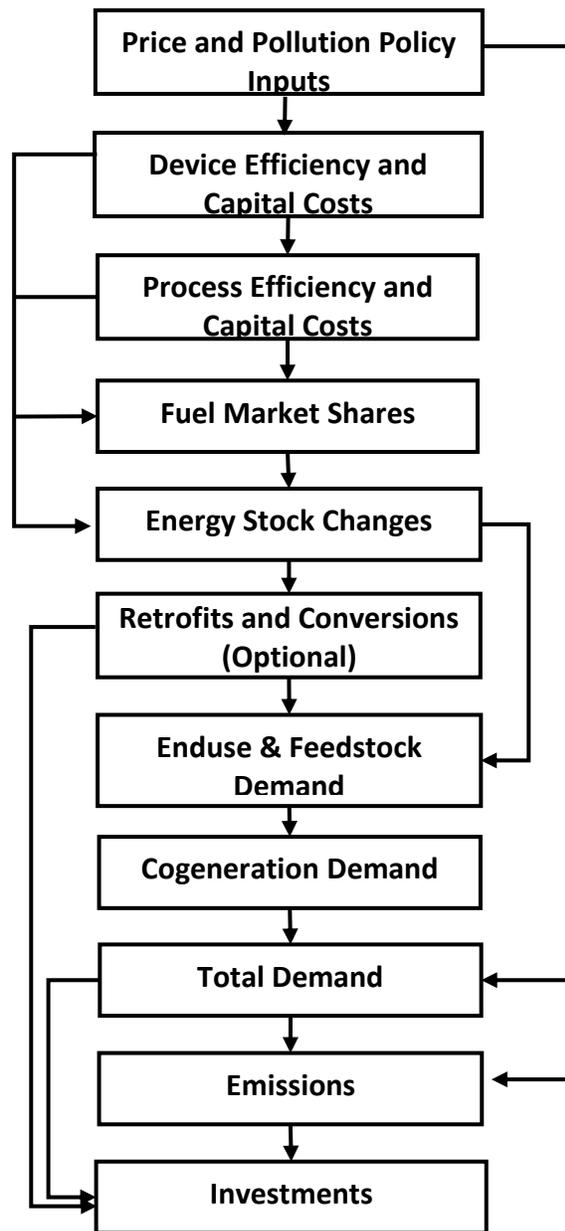
This document summarizes the model code that simulates the relationships shown in Figure 2. The key calculations within the demand sector are related to 1) tracking retirements, replacements, and additions to capital stock in terms of energy; 2) projecting consumers' choices of marginal energy efficiency based on the trade-off between capital costs and efficiency; and 3) projecting consumers' choices of fuel market shares for new capital stock purchases.

Figure 3 provides a flow diagram of the eleven major steps that make up the demand module. Each step represents a set of one or more procedures executed from ENERGY 2020's demand code (called from *Procedure Control*) located within each of RDemand.src, CDemand.src, IDemand.src, and TDemand.src for the residential, commercial, industrial, and transportation sectors respectively.

The objective of each of the eleven major steps is summarized as follows:

1. The **price and pollution policy inputs** procedures process price and pollution input variables for use by other routines.
2. The **device efficiency and capital costs** procedures apply a trade-off curve to determine marginal device efficiencies and device capital costs. These procedures also calculate a marginal cost of fuel use which is used in later routines in the determination of fuel choices.
3. The **process efficiency and capital costs** procedures use a similar methodology to the device efficiency and capital cost routines of applying a trade-off curve to determine marginal process efficiencies and capital costs.
4. The **fuel market shares** procedures apply consumer choice equations to determine fuel market shares for any new purchases made due to economic growth or retirement of capital stock.
5. The **energy stock changes** procedures determine levels of capital stock, device energy requirements, and process energy requirements due to additions and retirements caused by changes in drivers, device saturations, and aging stock.

Figure 3: Demand Module Steps and Linkages



6. The **retrofits and conversions procedures** optionally modify levels of capital stock due to retrofits and allow for consumers to convert stock to alternative fuel types (using consumer choice equations) at the end of the stock's useful life (typically only occurring with new stock additions).
7. The **enduse and feedstock demand** procedures calculate enduse and feedstock energy demands and make optional adjustments due to impacts of energy efficiency programs.
8. The **cogeneration demand** procedures calculate cogeneration energy demands (for both sector-level cogeneration and unit-level cogeneration specified in the electric supply module).
9. The **total demand** procedures create summary demand variables representing total demand (end-use plus feedstock plus cogeneration).
10. The **emissions** procedures calculate energy-related emissions from the end-use, feedstock, and cogeneration demands.
11. The **investments** procedures calculate marginal investments in devices and processes made by the demand sector which can be used to obtain economic impacts when sent to a macroeconomic model.

1.3. Organization of this Document

This volume of ENERGY 2020 documentation summarizes the mechanics of the model source code used to simulate the demand sector. Each of the individual sectors within the demand sector (residential, commercial, industrial, and transportation) is simulated using the same basic methodology – even the variable names are the same. Therefore, model code descriptions, including routines, variables, and equations, apply to all four demand sectors. Note that the terms demand module and demand sector are sometimes used interchangeably to refer to the set of model code in ENERGY 2020 that simulates the energy consuming portion of the energy system (distinguished from energy supplying portion).

The sections that follow are organized based the eleven steps that make up the demand simulation as shown in Figure 3 and described above. An overview of each of each step is provided first, including key input and output variables and a description of the procedures contained within each. Additional sections are provided as a summary of the model initialization and historical calibration process as well as the economic processing module. These sections are important because they provide key inputs to the demand sector simulation.

The final sections of this document consist of details of the specific model equations used in the demand code procedures.

For more information on demand sector structures and theoretical derivation, refer to *Volume 1 (ENERGY 2020 Overview)*, *Volume 2 (Demand Sector Structure Overview)*, and *Volume 4 (Demand Sector Theoretical Derivation)* of ENERGY 2020 documentation for descriptions of ENERGY 2020's demand sector structures and theoretical justification for any particular constructions and functional forms.

2. Source Code

2.1. Naming Conventions

ENERGY 2020 source code is written using Promula simulation language and is located primarily within the Engine subdirectory with a “.src” file extension. The structure of the model files and code are described in more detail in *ENERGY 2020 Procedures Manual and Appendix April 2017*.

A similar code and variable structure exists for each of the residential, commercial, industrial, and transportation sectors (referred to as segments in Promula). Prefixes assigned to the source code files indicate which segment or sector is represented. 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’).

The ENERGY 2020 source code files are named based on the task they perform. All variables in the model are defined in files specifying the type of variable - *inputs, calibration variables, or outputs* (named *Input.src, *CalDB.src, and ROutput.src respectively). Note that the ‘*’ represents a placeholder for indicating whether the file is residential, commercial, industrial, or transportation. Input data that are not updated annually, such as constants, engineering values, conversions and other input assumptions are input through files with a *.Data.src extension (See *Volume 8 Input Data and Assumptions*). Table 1 summarizes the naming conventions of the different types of demand module source code files.

Table 1. Demand Module Source Code File Names

| Demand Source Code Objective | Demand Source Code File Name | | |
|---|--|--|--|
| Defines input variables, calibration variables, and output variables | RInput.src CInput.src IInput.src TInput.src | RCalDB.src CCalDB.src ICalDB.src TCalDB.src | ROutput.src COutput.src IOutput.src TOutput.src |
| Assigns values to constants and model structures, such as names of fuel types | RData.src CData.src | IData.src TData.src | |
| Initializes output variables with value for first historical year (1985) | RInitial.src CInitial.src | IInitial.src TInitial.src | |
| Contains historical calibration equations | RCalib.src CCalib.src | ICalib.src TCalib.src | |
| Contains code to project calibration parameters | RFuture.src CFuture.src | IFuture.src TFuture.src | |
| Contains equations for demand projections | RDemand.src CDemand.src | IDemand.src TDemand.src | |
| Contains equations to translate electric and natural gas demands into loads | RLoad.src CLoad.src | ILoad.src TLoad.src | |

The code that initializes the model output variables for a starting year (typically 1985) are named as *.Initial.src. Calibration model files consist of code that estimates calibration variables from historical data (*.Calib.src) and code that projects the calibration variables into the future (*.Future). Files that contain the key equations that simulate energy demand are named *.Demand.src, and model code that turns energy demands into electric load curves by month/season and day type (peak, minimum, and average) for input to the electric sector are named as *.Load.src.

2.2. Reading Promula Code

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

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

Promula Variables and Sets

Variables in ENERGY 2020 are multi-dimensional arrays. Each dimension is represented by a Promula structure called a "set" where the sets represent the how the energy system is defined, such as areas, economic categories, end-uses, fuels, technologies, and years. For example, "Area" is the name of a set in the residential sector and represents an index of size 24. If a variable representing population were dimensioned by Area, then it would be dimensioned by size 24. In Promula, a set, Area, is defined having size 24 – Area(24). Then each of the 24 indices of the Area set is assigned a key name and descriptor in order to identify what each of those 24 indices represent.

To cut the variable in these different ways, it is necessary to refer specifically to sets and set values. When editing code that extracts output, you need to distinguish between set names, set descriptors, and set keys.

| Set Name | Key | Descriptor |
|----------|---------|--------------------------|
| Enduse | Heat | Space Heating |
| | HW | Water Heating |
| | OthSub | Other Substitutables |
| | Refrig | Refrigeration |
| | Light | Lighting |
| | AC | Air Conditioning |
| | OthNSub | Other Non-Substitutables |

Set name: The set name is simply the name of the set that is referred to when coding output text files. Examples of set names are: Area, EC, and Year. Use this name to refer to the set when writing output text files.

Set descriptor: The set descriptor is a label for each of the set values used for display in output data files. For example, the set descriptors for residential EC set are: *Single Family, Multi Family and Other Residential*.

For most sets, there is a variable that stores all the set descriptors. Its name is typically the set name plus *DS*. For example, for the Area set name, AreaDS is the name of the variable that holds all the descriptors. You will see this set descriptor variable used in the output text files.

Set key: The set key is a name that is used in Promula coding to refer to a specific set value. It is similar to the set descriptor, but it is shorter and cannot contain spaces. For the residential EC set, the set keys are *SingleFamily, MultiFamily and OtherResidential*.

Assigning a population size of 390,000 to Nova Scotia could be done using either of the following two methods of syntax.

- Population(8)=390,000
- Population(NS)=390,000

“Select” statements are also able to be used to make variable assignments, such as:

- Select Area(NS)
- Population(Area)=390,000

With no select statements or set keys, the assignment on the right hand side of the equation is assigned to all set values. So the following assignment assign 390,000 as the population for all areas: Population(Area)=Population(A)=Population(a)=Population(i)=390,000.

It is not necessary to write the subscript:

Population=390,000 is equivalent to Population(A)=390,000.

3. Key Input and Output Variables of the Demand Module

The primary purpose of the demand module is to calculate long term projections of energy demand (for enduse, cogeneration, and feedstock fuel usage). It also forecasts emissions, energy efficiency and capital costs (of processes and devices), investments and expenditures of the demand sector. Energy demands are projected for all economic categories, end uses, fuels, and areas represented in the model. This simulation is done for each of the residential, commercial, industrial, and transportation sectors. Exogenous forecasts are able to be incorporated into the model for specific industries if desired. The key outputs of the demand module are listed in Table 2 along with their associated variable names.

Table 2. Key Output Variables from ENERGY 2020 Demand Module

| Description of Model Output | Variable Name and Definition |
|---|---|
| Energy demand (TBtu/Yr) <ul style="list-style-type: none"> - End-use demand - Cogeneration demand - Feedstock demand - Total (by ECC and fuel) - Total (by energy sector and fuel) | Dmd(Enduse,Tech,EC,Area,Year) CgDmd(Tech,EC,Area,Year) FsDmd(Tech,EC,Area,Year) TotDemand(Fuel,ECC,Area,Year) DmdES(ES,Fuel,Area,Year) |
| Emissions (Tonnes/Yr) <ul style="list-style-type: none"> - End-use - Cogeneration - Feedstock (by fuel) - Feedstock (total) - Total (by ECC and fuel) - Total (by energy sector and fuel) | Polute(Enduse,FuelEP,EC,Poll,Area,Year) CgPol(ECC,Poll,Area,Year) FsPol(Fuel,EC,Poll,Area,Year) NcPol(ECC,Poll,Area,Year) TotFPol(FuelEP,ECC,Poll,Area,Year) TFPol(ES,FuelEP,Poll,Area,Year) |
| Energy efficiency (marginal) <ul style="list-style-type: none"> - Device/equipment (Btu/Btu) - Process/building (\$/Btu) | DEE(Enduse,Tech,EC,Area,Year) PEE(Enduse,Tech,EC,Area,Year) |
| Capital costs <ul style="list-style-type: none"> - Device (\$/mmBtu/Yr) - Process (\$/(\$/Yr)) | DCC(Enduse,Tech,EC,Area,Year) PCC(Enduse,Tech,EC,Area,Year) |
| Investments (M\$/Yr) <ul style="list-style-type: none"> - Device investments - Process investments | DInv(Enduse,Tech,EC,Area,Year) PInv(ECC,Area,Year) |
| Expenditures (M\$/Yr) <ul style="list-style-type: none"> - Fuel expenditures by fuel - Fuel expenditures total - Operating and maintenance | FuelExp(Enduse,Tech,EC,Area,Year) FuelExpenditures(ECC,Area) OMExp(ECC,Area,Year) |

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 3 lists exogenous inputs to the demand module.

Table 3. Exogenous Inputs Required for Demand Module

| Description | Variable Name and Definition |
|---|---|
| Historical energy demand (TBtu/Yr) <ul style="list-style-type: none"> - End-use - Cogeneration - Feedstock - Steam generation | XDmd(Enduse,Tech,EC,Area,Year) XCgDmd(Tech,EC,Area,Year) XFsDmd(Tech,EC,Area,Year) XStDmd(FuelEP,Area,Year) |
| Macroeconomic Indicators (Historical and Future) <ul style="list-style-type: none"> - Gross Output (1985 M\$/Yr) - Gross Regional Product (Real M\$/Yr) - Population (Millions) - Personal Income (Real M\$/Yr) - Households (Number) - Floor Space per Unit (Sq Units/Building) - Inflation Index (\$/\$) | XGO(ECC,Area,Year) XGRP(Area,Year) XPopT(Area,Year) XRPI(Area,Year) XHHS(ECC,Area,Year) FSUnit(ECC,Area,Year) XInfla(Year) |
| Physical life of production capacity (Yrs) | PCPL(ECC,Area,Year) |
| Prices (Historical and Future) <ul style="list-style-type: none"> - Wholesale Fuel Price (\$/mmBtu) - Delivered Fuel Price (\$/mmBtu) | XENPN(Fuel,Nation,Year) XFP(Prices,Area,Year) |
| Emissions coefficients (Tonnes/TBtu) <ul style="list-style-type: none"> - Energy-related - Cogeneration - Feedstock | 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"> - Historical Physical Life of Equipment (Yrs) - Device Capital Cost (\$/mmBtu/Yr) - Historical Device Efficiency (Btu/Btu) - Maximum Device Efficiency (Btu/Btu) - Device Efficiency Standards (Btu/Btu) | 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"> - Process Energy Capital Cost (\$/(\$/yr)) - Maximum Process Efficiency (\$/mmBtu) - Process Efficiency Standards (\$/Btu) | XPCC(Enduse,Tech,EC,Area,Year) PEM(Enduse,EC,Area) PESTD(Enduse,Tech,EC,Area,Year) |

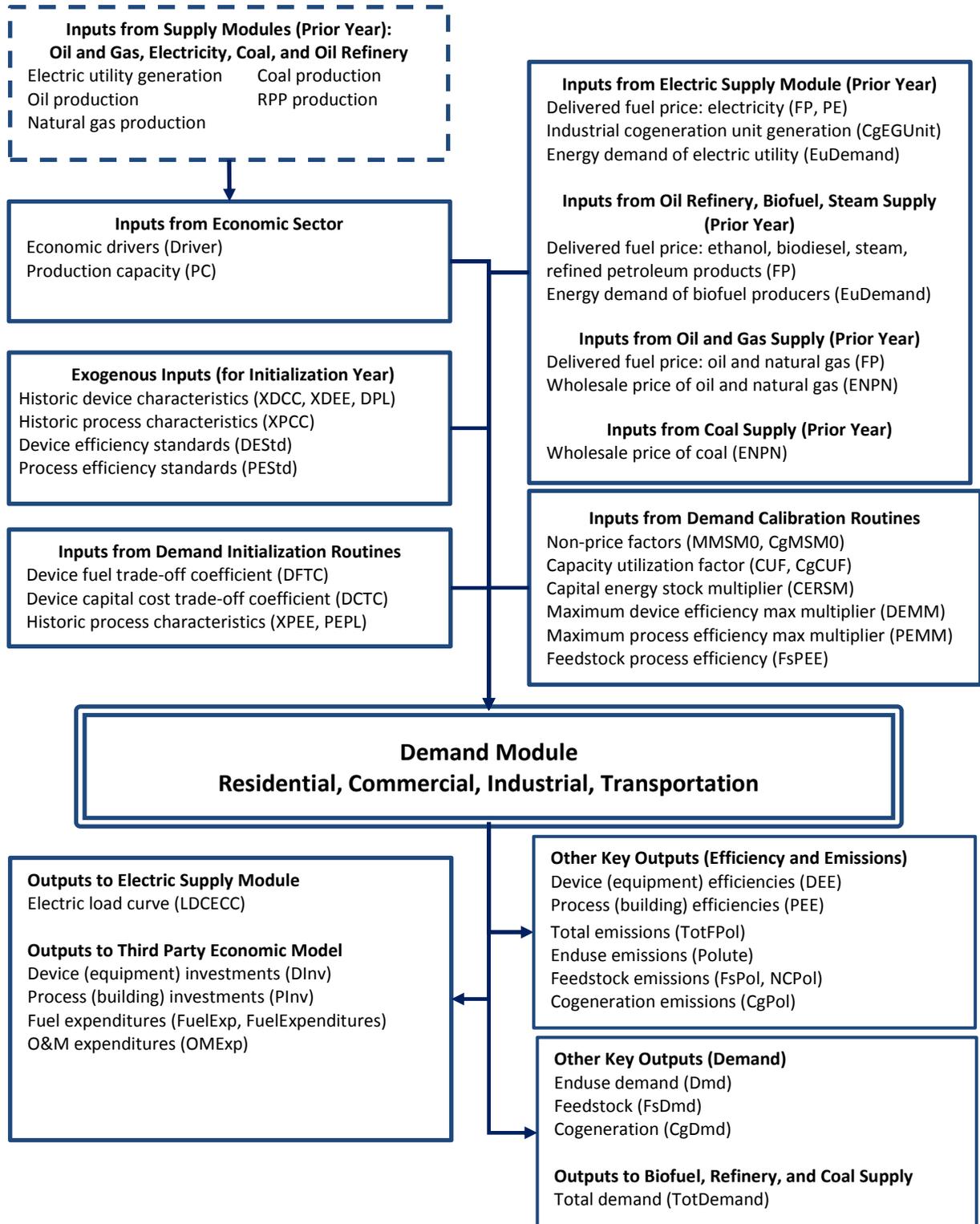
Variables that are calculated during the initialization and historical calibration and used as input to the demand equations are listed in Table 4.

Table 4. Key Inputs from ENERGY 2020

| Description | Variable Name and Definition |
|---|---|
| Key Inputs from Initialization | |
| Process and device characteristics (derived for technologies where values unavailable) <ul style="list-style-type: none"> - Historical Marginal Process Efficiency (\$/Btu) - Historical Marginal Device Efficiency (Btu/Btu) - Physical Life of Process Requirements (Yrs) | XPEE(Enduse,Tech,EC,Area,Year) XDEE(Enduse,Tech,EC,Area,Year) PEPL(Enduse,Tech,EC,Area,Year) |
| Capital cost and fuel trade-off curve coefficients <ul style="list-style-type: none"> - Device Cap. Cost Trade Off Coefficient (DLess) - Process Cap. Cost Trade Off Coefficient (DLess) - Device Fuel Trade Off Coefficient (DLess) - Process Fuel Trade Off Coefficient (DLess) | DCTC(Enduse,Tech,EC,Area,Year) PCTC(Enduse,Tech,EC,Area,Year) DFTC(Enduse,Tech,EC,Area,Year) PFTC(Enduse,Tech,EC,Area,Year) |
| Inputs from Calibration | |
| Calibration variables for energy demand <ul style="list-style-type: none"> - Market Share Non-Price Factors (\$/\$) - Cogeneration Market Share Non-Price Factor (\$/\$) - Capital Utilization Fraction (\$/Yr/\$/Yr) - Cogeneration Capacity Utilization Factor (\$/Yr/\$/Yr) - Capital Energy Requirement Mult. (Btu/Btu) - Feedstock Process Efficiency (\$/mmBtu) | MMSM0(Enduse,Tech,EC,Area,Year) CgMSM0(Tech,EC,Area,Year) CUF(Enduse,Tech,EC,Area,Year) CgCUF(Tech,EC,Area,Year) CERSM(Enduse,EC,Area,Year) FSPEE(Tech,EC,Area,Year) |
| Calibration variables for energy efficiency <ul style="list-style-type: none"> - Process Eff. Max. Multiplier (\$/Btu)/(\$/Btu) - Device Eff. Max Multiplier (Btu/Btu) | PEMM(Enduse,Tech,EC,Area,Year) DEMM(Enduse,Tech,EC,Area,Year) |
| Inputs from Economic Processing Module | |
| <ul style="list-style-type: none"> - Economic Driver (Various Millions/Yr) - Production Capacity (M\$/Yr) - Production Capacity by Enduse and Tech (M\$/Yr) | Driver(ECC,Area,Year) PC(ECC,Area,Year) EUPC(Enduse,Tech,Age,EC,Area,Year) |
| Inputs from Supply Module | |
| <ul style="list-style-type: none"> - Generation from Industrial Units (GWh/Yr) - Primary Oil Production (TBtu/Yr) - Primary Gas Production (TBtu/Yr) - Energy Demand of Electric Utilities (TBtu/Yr) - Energy Demand of Biofuel Producers (TBtu/Yr) | CgEGUnit(Tech,EC,Area,Year) OAProd(Process,Area,Year) GAProd(Process,Area,Year) EuDemand(Fuel,UtilityGen,Area,Y) EuDemand(F,BiofuelProduction,A,Y) |

Figure 5 illustrates the inputs and outputs to the demand module in a diagram.

Figure 4. Diagram Key Inputs and Outputs of Demand Module



4. Summary of Demand Code Procedures

This section provides a summary description of the eleven major steps making up the demand module, providing procedure names, objectives, key inputs, key outputs, and key equations. More detailed descriptions of the specific model code procedures, variables, and equations are provided in *Appendix 1. Demand Procedures and Equation Detail*.

1. The **price and pollution policy inputs** procedures process price and pollution input variables for use by other routines.
2. The **device efficiency and capital costs** procedures apply a trade-off curve to determine marginal device efficiencies and device capital costs. These procedures also calculate a marginal cost of fuel use which is used in later routines in the determination of fuel choices.
3. The **process efficiency and capital costs** procedures use a similar methodology to the device efficiency and capital cost routines of applying a trade-off curve to determine marginal process efficiencies and capital costs.
4. The **fuel market shares** procedures apply consumer choice equations to determine fuel market shares for any new purchases made due to economic growth or retirement of capital stock.
5. The **energy stock changes** procedures determine levels of capital stock, device energy requirements, and process energy requirements due to additions and retirements caused by changes in drivers, device saturations, and aging stock.
6. The **retrofits and conversions procedures** optionally modify levels of capital stock due to retrofits and allow for consumers to convert stock to alternative fuel types (using consumer choice equations) at the end of the stock's useful life (typically only occurring with new stock additions).
7. The **enduse and feedstock demand** procedures calculate enduse and feedstock energy demands and make optional adjustments due to impacts of energy efficiency programs.
8. The **cogeneration demand** procedures calculate cogeneration energy demands (for both sector-level cogeneration and unit-level cogeneration specified in the electric supply module).
9. The **total demand** procedures create summary demand variables representing total demand (end-use plus feedstock plus cogeneration).
10. The **emissions** procedures calculate energy-related emissions from the end-use, feedstock, and cogeneration demands.

11. The **investments** procedures calculate marginal investments in devices and processes made by the demand sector which can be used to obtain economic impacts when sent to a macroeconomic model.

Table 5 identifies the procedure names, objectives, key inputs, key outputs, and key equations to the procedures summarized above.

Table 5. Demand Code Procedures, Key Inputs, and Key Outputs

| Demand Module Code | Key Inputs, Outputs, and Equations |
|--|---|
| 1. PRICE AND POLLUTION POLICY INPUTS | |
| <p>Objective: Procedure TPrice calculates the effective price of energy (ECFP) by combining the fuel price (FP, PE) with any emission charges (PCost).</p> <p>Procedure PRReductions is used with cap and trade policies and calculates emission reductions (RP) and the energy impacts of pollution reductions (RPEI) in response to emission cap and trade policies. The energy impacts of pollution reduction (RPEI) is used to adjust the calculation of energy demand.</p> <p>Related Model Code: <i>Procedure TPrice; Procedure PRReductions</i></p> | |
| Key Inputs | <ul style="list-style-type: none"> • Pollution costs by fuel (PCost) • Pollution coefficient reduction multiplier (RM) • Pollution coefficient (POCX) • End use energy demand (EUDem) • Delivered fuel prices (FP) • Price of electricity (PE) • Production capacity by ECC (PC) |
| Key Outputs | <p>Variable mappings include:</p> <ul style="list-style-type: none"> • Permit cost by technology (PCostTech) • Effective price of fuel (ECFP) • Production capacity (SPC) • Emissions coverage (ECoverage) <p>Pollution-related calculated outputs include:</p> <ul style="list-style-type: none"> • Indicated pollution reduction (IRP) • Pollution reductions (RP) • Energy Impact of Pollution Reduction (RPEI) |
| Key Equations | <ul style="list-style-type: none"> • See procedures for mappings • Pollution reductions are based on cost and stock of reduction devices (dependent on type of emissions cap and trading market) |
| 2. DEVICE EFFICIENCY AND DEVICE CAPITAL COSTS | |
| <p>Objective: <i>Procedure DMarginal</i> calculates the marginal efficiency (DEE) and capital costs of devices (DCC) chosen by consumers as well as the marginal cost of fuel use (MCFU). Device efficiency and capital costs are used in the calculations of device energy requirements which are ultimately needed for end use demand calculations. The marginal</p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|---|--|
| | <p>cost of fuel use (MCFU) is used as input to the consumer choice market share equation in <i>Procedure MShare</i>.</p> <p><i>Procedure DDSM</i> adjusts the device efficiency and capital costs by consumer responses to demand side management programs when they are activated.</p> <p>Related Model Code: <i>Procedure DMarginal; Procedure DDSM</i></p> |
| <p>Key Inputs</p> | <p><u>Inputs from initialization:</u></p> <ul style="list-style-type: none"> • Device fuel trade off coefficient (DFTC) <p><u>Inputs from calibration:</u></p> <ul style="list-style-type: none"> • Maximum device efficiency multiplier (DEMM) <p><u>Other inputs</u></p> <ul style="list-style-type: none"> • Fuel prices (EFCP) • Normalized fuel prices (DFPN) • Device efficiency maximum (DEM) • Multiple financial input variables, such as <ul style="list-style-type: none"> ○ Indirect costs (IdrtCost) ○ return on investment (ROIN), ○ device investment tax credits (DIVTC)) • Methodology switch for calculating DEE and DCC (DEESw, DCCSw) |
| <p>Key Outputs</p> | <p>Intermediate key outputs:</p> <ul style="list-style-type: none"> • Device capital charge rate (DCCR) • Device operating and maintenance cost (DOMC) <p>Final key outputs</p> <ul style="list-style-type: none"> • Marginal cost of fuel use (MCFU) • Device efficiency (DEE) • Device capital costs (DCC) |
| <p>Key Equations</p> | <ul style="list-style-type: none"> • Device efficiency and capital cost calculations can be based on fuel prices alone (DEEPrice, DCCPrice) or based on fuel prices including pollution costs (DEEPoll, DEEPoll) based on the value of DEESw and DCCSw. See procedure for equation details. • $MCFU = DCCR * DCC + DOMC + EFCP / DEE + IdrtCost$ |
| <p>3. PROCESS EFFICIENCY AND PROCESS CAPITAL COSTS</p> | |
| <p>Objective: <i>Procedure CMarginal</i> calculates the marginal efficiency (PEE) and capital costs of processes (PCC). Process efficiency and capital costs are used in the calculations of process energy requirements which are ultimately needed for end use demand calculations.</p> <p>Related Model Code: <i>Procedure CMarginal</i></p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|---|--|
| Key Inputs | <u>Inputs from initialization:</u> <ul style="list-style-type: none"> Process fuel trade off coefficient (PFTC) <u>Inputs from calibration:</u> <ul style="list-style-type: none"> Maximum process efficiency multiplier (PEMM) <u>Other inputs</u> <ul style="list-style-type: none"> Financial variables and costs related to processes Normalized fuel prices (PFPN) Process efficiency maximum (PEM) Methodology switch for calculating PEE and PCC (PEESw, PCCSw) |
| Key Outputs | Process capital charge rate (PCCR) Process efficiency (PEE) Process capital costs (PCC) |
| Key Equations | <ul style="list-style-type: none"> Process efficiency and capital cost calculations can be based on fuel prices alone (PEEPrice, PCCPrice) or based on fuel prices including pollution costs (PEEPoll, PCCPoll) based on the value of PEESw and PCCSw. See procedure for equation details. |
| 4. FUEL MARKET SHARES | |
| <p>Objective: Determines the fuel market share fractions of new devices (marginal market share fractions) using consumer choice equations given price factors and non-price factors calculated during calibration.</p> <p>Related Model Code: <i>Procedure MShare</i></p> | |
| Key Inputs | <u>Inputs from demand calibration:</u> <ul style="list-style-type: none"> Marginal market share multiplier/non-price parameter in consumer choice equation (MMSM0) Marginal variance factor/price parameter (MVF) <u>Inputs from other demand routines:</u> <ul style="list-style-type: none"> Marginal cost of fuel use (MCFU) |
| Key Outputs | Marginal market share factor (MMSF) |
| Key Equations | $\text{Marginal Market Share } (i) = \frac{e^{(\text{Utility of Option } i)}}{\sum_i^j e^{(\text{Utility of Option } j)}}$ <p>where</p> $\text{Marginal Market Share } (i) = \frac{e^{(\text{NonPriceFactor} + \text{VF} * \text{Ln}(\frac{\text{Price}(i)}{\text{Price}(k)})}}{\sum_i^j e^{(\text{NonPriceFactor} + \text{VF} * \text{Ln}(\frac{\text{Price}(i)}{\text{Price}(k)})}}$ $\text{MMSF } (i) = \frac{e^{(\text{MMSM0} + \text{MVF} * \text{Ln}(\frac{\text{MCFU0}(i)}{\text{MCFU}(k)})}}{\sum_i^j e^{(\text{MMSM0} + \text{MVF} * \text{Ln}(\frac{\text{MCFU0}(i)}{\text{MCFU}(k)})}}$ |
| 5. ENERGY STOCK CHANGES | |
| <p>Objective: Tracks marginal additions and retirements of production capacity and the related changes to process and device energy requirements. Additions and retirements are calculated based on changes in device saturation, stock growth or decline (determined from</p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|---|--|
| <p>changes to the economic drivers), and replacements due to normal failures and stock aging. This procedure ultimately calculates the process and device energy requirements variables that are needed to calculate overall energy demands.</p> | |
| <p>Procedures: MStock, TStock</p> | |
| <p>Key Inputs</p> | <p><u>Inputs calculated in economic sector</u></p> <ul style="list-style-type: none"> • Total production capacity (SPC) • Production capacity by end use (EUPC) • Production capacity additions (PCA) <p><u>Inputs calculated in other demand procedures</u></p> <ul style="list-style-type: none"> • Marginal cost of fuel use (MCFU) • Device and process efficiency (DEE, PEE) • Market share fractions for each economic class and fuel (MMSF) <p><u>Other inputs</u></p> <ul style="list-style-type: none"> • Maximum device saturation (DSTM) • Production capacity lifetime (PCPL) |
| <p>Key Outputs</p> | <p>Device saturation (DST)</p> <p>Production capacity</p> <ul style="list-style-type: none"> • Capital stock additions and retirements (EUPCAPC, EUPCRPC) • Total production capacity (EUPC) <p>Device energy requirements</p> <ul style="list-style-type: none"> • Additions and retirements (DERAPC, DERRPC) • Total device energy requirements (DER) <p>Process energy requirements</p> <ul style="list-style-type: none"> • Additions and retirements (PERAPC, PERRPC) • Total process energy requirements (PER) |
| <p>Key Equations</p> | <p>Device saturation (DST) is a fraction of the maximum device saturation (DSTM) determined by the existing level of device saturation modified by changes in the marginal costs of using each fuel.</p> <p>Changes in capital stock, process energy, and device energy requirements are determined from changes in production capacity, changes in device saturation, and changes due to physical lifetimes. Capital stock is retired (EUPCRPC) depending on the lifetime (PCPL) specified. If the lifetime is 30 years, then 1/30 of the capital stock (EUPC) is retired each year. As capital stock is added or retired, those changes also impact process energy and device energy requirements.</p> |
| <p>6. RETROFITS AND CONVERSIONS</p> | |
| <p>Objective: The conversion and retrofit code is optional and chosen by the user using a switch. For conversions, at the end of a device’s useful lifetime, by default in the model, consumers choose a new device having the same technology/fuel type as the one retired. Using the conversion code sets consumer choice equation parameters for conversions to allow the use to switch to alternative technology/fuel types. If the retrofit switch is turned on, values are assigned to retrofit efficiencies and capital costs, and devices are retired early, such as would</p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|--|--|
| <p>be true with a rebate program. Devices and/or processes can be assigned retrofits endogenously or specified exogenously.</p> <p>Related Model Code: <i>Procedure Conversion; Procedure DeviceDynamics; Procedure DRetrofit; Procedure RCPCDynamics; Procedure IniRetrofits; Procedure Retrofit</i></p> | |
| <p>Key Inputs</p> | <p>Fuel prices (ECP) Marginal cost of fuel use (MCFU) Variance factor on perceived prices for conversions (CVF) Non-price factors (CMSM0) Input retrofit device efficiency standard (RDEStd) User specified retrofit device capital cost multiplier (RDCCM) Average device efficiency (DEEA)</p> |
| <p>Key Outputs</p> | <p>Market share fraction for conversions (CMSF) Device retrofit market share fraction (RDMSF) Process Retrofit Market Share Fraction by Device (RPMSF)</p> |
| <p>Key Equations</p> | <p>Conversion market share (CMSF) is determined by price and a variance factor on perceived prices (CVF). Other adjustments to market share come from non-price factors (CMSM0).</p> <p>Retrofit market shares (RDMSF, RPMSF) are determined based on a marginal value of retrofitting determine from the relationship between stock average efficiency and the retrofit marginal efficiency when including the retrofitting cost factors.</p> |
| <p>7. ENDUSE AND FEEDSTOCK DEMAND</p> | |
| <p>Objective: Calculates enduse and feedstock energy demands using consumer choice equations and inputs of price factors and non-price factors from the historical calibration. The temperature sensitive portion of end use demand is adjusted for weather. End use demands are further adjust by the energy impacts from pollution when emissions-reductions policies are in place. Feedstock demand is a simple calculation based on production capacity and feedstock efficiency levels calculated from the historical data.</p> <p>After end use energy demand is calculated, it is adjusted by assumptions of reductions from energy efficiency (EE).</p> <p>Related Model Code: <i>Procedure DmdEnduse; Procedure EECalculation</i></p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|--|--|
| <p style="text-align: center;">Key Inputs</p> | <p><u>Inputs from calibration</u></p> <ul style="list-style-type: none"> • Capacity utilization factor (CUF) • Capital energy requirement multiplier/lifestyle multiplier (CERSM) • Feedstock energy efficiency (FsPEE) <p><u>Exogenous inputs</u></p> <ul style="list-style-type: none"> • Degree day multiplier (DDM) • Temperature sensitive load (value of 1 or 0) (TSLoad) • Fraction of load with energy efficiency (EESat) • Reduction from energy efficiency, Btu/Btu (EEImpact) <p><u>Inputs from other demand routines</u></p> <ul style="list-style-type: none"> • Device energy requirements (DER) • Production capacity (SPC) • Energy impacts from pollution reductions (RPEI) |
| <p style="text-align: center;">Key Outputs</p> | <ul style="list-style-type: none"> • Enduse energy demand (Dmd) • Feedstock energy demand (FsDmd) • Endogenous energy efficiency (EE) |
| <p style="text-align: center;">Key Equations</p> | <ul style="list-style-type: none"> • $Dmd = DER * CUF * CERSM * (DDM * TSLoad + (1 - TSLoad)) * RPEI$ • $FsDmd = SPC / FsPEE$ • $EE = Dmd * EEImpact * EESat$ • $Dmd = Dmd - EE$ |
| 8. COGENERATION DEMAND | |
| <p>Objective: Calculates the amount of cogeneration energy demand within the residential, commercial, and industrial demand sectors. Cogeneration energy demands are calculated within the demand sector module, and are able to be represented also at an individual generating unit level within the electric supply module. Currently, U.S. cogeneration is represented at the aggregate level in the demand sector, and Canada cogeneration is represented at the unit level within the electric supply sector.</p> <p>Related Model Code: <i>Procedure CogenerationSector, Procedure CogenerationTotals</i></p> | |
| <p style="text-align: center;">Key Inputs</p> | <p><u>Inputs from calibration routines:</u></p> <ul style="list-style-type: none"> • Cogeneration capacity utilization factor (CgCUFP) • Cogeneration generating capacity (CgGCSector) <p><u>Other inputs:</u></p> <ul style="list-style-type: none"> • Historical cogeneration demand (XCgDmdSector) • Cogeneration fuel-tech fraction (CgFrac) |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|--|--|
| <p>Key Outputs</p> | <p><u>Sector-level outputs:</u></p> <ul style="list-style-type: none"> • Cogeneration generation (CgEGSector, CgGenSector) • Cogeneration capacity (CgCapSector) • Cogeneration demand (CgDemandSector, CgDmdSector) <p><u>Total cogeneration (sector-level plus generating unit cogeneration):</u></p> <ul style="list-style-type: none"> • Total cogeneration demand (CgDmd, CgDemand) • Total cogeneration generation (CgEG) • Total cogeneration capacity (CgGC) • Total cogeneration by economic category (CgEC) |
| <p>Key Equations</p> | <p><u>Sector level cogeneration</u></p> <ul style="list-style-type: none"> • $CgEGSector = CgGCSector * CgUMS * CgCUPF * WCUF * 8760 / 1E3$ • $CgDmdSector = CgEGSector * CgHRtA / 1E6$ <p><u>Total cogeneration</u></p> <ul style="list-style-type: none"> • $CgDemand = CgDemandSector + CgDemandUnit$ • $CgDmd = CgDmdSector + CgDmdUnit$ • $CgEG = CgEGSector + CgEGUnit$ • $CgGC = CgGCSector + CgGCUnit$ |
| <p>9. TOTAL ENERGY DEMAND</p> | |
| <p>Objective: Creates summary level outputs from the demand and price results from earlier calculations. Total energy demand is the sum of end use demand, feedstock demand and cogeneration demand. The cogeneration demand is the sum of the sector-level cogeneration demand calculated in the demand module plus the unit-level cogeneration demand calculated in the electric supply module.</p> <p>Related Model Code: <i>Procedure EECalculation; Procedure TotalDemand</i></p> | |
| <p>Key Inputs</p> | <p><u>Inputs from other demand module routines:</u></p> <ul style="list-style-type: none"> • End use energy demand (Dmd) • Total cogeneration energy demand (CgDmd) • Feedstock energy demand (FsDmd) • Total cogeneration by economic category (CgEC) |
| <p>Key Outputs</p> | <ul style="list-style-type: none"> • Total energy demand (TotDemand_{Fuel,ECC,Area,Year}) • Energy demands by sector (DmdES_{Sector,Fuel,Area,Year}) • Endogenous energy efficiency (EE) |
| <p>Key Equations</p> | <ul style="list-style-type: none"> • $TotDemand = EuDemand + CgDemand + FSDemand$ With an adjustment for electricity demands: $TotDemand(Electric) = TotDemand(Electric) - Cogeneration$ • $DmdES = sum(ECC)(TotDemand)$ |
| <p>10. EMISSIONS</p> | |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|---|--|
| <p>Objective: Calculates emissions from enduse fuel demands, feedstock fuel demands and cogeneration fuel demands. The emissions calculated in this module are solely those from the demand sector module. Emissions from supplying energy, such as electric generation, are calculated in the Supply Module. Emissions from non-fuel based emissions (MEPol) are calculated in the economic module.</p> <p>Related Model Code: <i>Procedure PollCoefficients; Procedure PollutionGenerated</i></p> | |
| <p>Key Inputs</p> | <ul style="list-style-type: none"> • Emissions coverages, 1=covered (ECoverage, PCCov) • Demand (EuDem, FsDmd, CgDmd), • Marginal emissions coefficient (POCX, CgPOCX), • Policy reductions (RM) • Device additions (DERA) |
| <p>Key Outputs</p> | <ul style="list-style-type: none"> • Average pollution coefficients (POCA, CgPOCA, FsPOCA) • Pollution totals <ul style="list-style-type: none"> ○ Enduse (Polute, EnFPol) ○ Cogeneration (CgPolSector, CgFPol, CgPol) ○ Feedstocks/non-combustion (FSPol, NcFPol) ○ Total pollution (TotFPol) • Gross pollution before impact of pollution policies (GrossPol) |
| <p>Key Equations</p> | <ul style="list-style-type: none"> • Average coefficients (POCA, CgPOCA, FsPOCA) based on marginal coefficient (POCX) and energy additions (DERA) depending on model switches set • Calculate emissions inventories based on average coefficient (POCA) and total energy usage (Dmd) <ul style="list-style-type: none"> ○ $Polute = EuDem * POCA$; $EnFPol = \text{sum}(Enduse, EC)(Polute)$ ○ $FsPol = FsDem * FsPOCA$; $NcFPol = \text{sum}(EC, Fuel)(FsPol)$ ○ $CgPolSectorEC = CgDemSector * CgPOCA$ ○ $CgFPol = CgFPolSector + CgFPolUnit$; $CgPol = \text{sum}(FuelEP)(CgFPol)$ ○ $TotFPol = EnFPol + CgFPol + NcFPol$ • $GrossPol = Polute / RM * PCCov + FsPol * ECoverage(NonCombustion)$ |
| <p>11. INVESTMENTS</p> | |
| <p>Objective: Calculates device investments (equipment) and process (buildings) investments from annual additions to devices and production capacity made within the demand sector. These device and process investments are often sent as input to a macroeconomic model to determine the economic impacts of a particular policy.</p> <p>Related Model Code: <i>Procedure Investments</i></p> | |
| <p>Key Inputs</p> | <ul style="list-style-type: none"> • Device and process capital costs (DCC, PCC) • Device Capital Costs (DCCFC) • Device energy additions (DERA) • Retrofit device and process capital cost (RDCC, RPCC) • Retrofit device and process market share (RDMSF, RPMSF) • Production capacity additions (EUPCAPC) |

| Demand Module Code | Key Inputs, Outputs, and Equations |
|----------------------|---|
| Key Outputs | <ul style="list-style-type: none"> • Device investments (DInv, DeviceInvestments) • Process investments (PInv) |
| Key Equations | <ul style="list-style-type: none"> • Device investments are marginal costs multiplied by device energy additions, including any retrofiting. • Process investments are marginal costs multiplied by production capacity additions, including any retrofiting. |

5. Summary of Initialization and Calibration Procedures

Before forecast projections can be made, the variables are initialized for one historical starting year (typically 1985) and calibrated to the historical input data. During initialization and calibration, several supply sectors along with economic processing are initialized/calibrated before the demand sector is initialized/calibrated initialized and calibrated in order to obtain the energy prices and drivers (economic and production) that are required as input to the demand module.

In order to simulate the mechanisms that make up consumer energy demand (such as fuel shares, process and device energy efficiency, production capacity, process and device energy requirements), historical data are used to initialize model variables and to extract relationships that help to make projections into the future. These functions are performed during the initialization and calibration stage (before model execution of the forecast years).

The purpose of the demand sector initialization code is twofold: 1) to assign values to output variables in the model initialization year (typically 1985); and 2) to derive price response trade-off curves used in projecting future levels of efficiencies and capital costs.

The purpose of the demand sector calibration is to calculate values for “calibration” variables that are used in two key model equations: 1) the consumer choice calculation of fuel market shares (probability of choosing any particular type of fuel for a given end-use); and 2) the calculation of total end-use energy demand.

This section describes the key inputs and key outputs for the model initialization and calibration code as well as identifies the names and functions of the key procedures containing model code equations.

5.1. Demand Initialization Code

The two main objectives of the demand sector initialization code are: 1) to assign values to output variables in the model initialization year (typically 1985), and 2) to derive price response trade-off curves for projecting device and process efficiencies and capital costs.

Initialization Year: Whereas most variables are initialized in the year 1985 (which is the first historical year), there are some variables in which a more recent year is chosen as the model initialization year. One such example is with process and device efficiencies and capital costs in which residential and commercial efficiency and capital cost variables are initialized in the year 2000 and transportation in 2008. Alternative initialization years are selected when reliable historical data are not available back to 1985. In the case of the device and process efficiencies,

the year 2000 had the most internally consistent input data available; therefore, 2000 was set to be the initialization year for those variables. Because the efficiency and capital cost data are initialized in the year 2000, the price-response trade-off curves for efficiency and capital costs are also initialized in the year 2000. The curves initialized in the year 2000 are then assigned to all years and used to determine a calculated value for historical efficiency and capital costs based on the particular year’s fuel prices. With the exception of the efficiency and capital cost related variables, the initialization routines generally assign a value in a single initialization year for model calculated variables.

Initialization Procedures: Eight procedures perform the demand sector initialization. The names of these initialization procedures and a brief description of each of their objectives are listed in Table 6. For detailed descriptions of these procedures, see the *Appendix 3. Initialization Procedures and Equations* section at the end of this volume.

Table 6. Initialization Procedure Objectives

| Procedure Name | Procedure Objective |
|----------------|---|
| 1. Lifetimes | Initializes lifetimes and several other variables for use in the rest of the demand module. |
| 2. IPrice | Calculates the local fuel price by economic category and device capital charge rate. Local fuel prices by economic category are set by fuel prices except in the case of electric technologies, which instead use the electric price. Assigns fuel price for each economic category (ECFP). |
| 3. DEffCurve | Derives coefficients of trade-off curves for projecting device efficiency and capital costs based on input data provided for a single initialization year. |
| 4. Initial | Initializes variables required for developing process efficiency and cost curves. |
| 5. PEffCurve | Derives coefficients of trade-off curves for projecting process efficiency and process capital costs. |
| 6. PEffFuture | Assigns values for future years of process (and retrofit) capital cost and efficiency variables equal to the value in the initial year. |
| 7. PEffAdjust | Adjusts values for sectors or areas where driver is very small to allow for sectors that may not exist yet during initialization year. |
| 8. Pollution | Initializes the average pollution coefficients by setting equal to the marginal in the initial year. |

Key Inputs and Outputs: The key inputs to the demand sector initialization routines by type of input are shown in Figure 7. The supply sector initialization and calibration routines (to obtain a value for energy prices) and economic processing (to assign values to model drivers) occurs before the demand initialization and calibration. Energy prices and drivers are key inputs to the

demand sector initialization routines along with many exogenous input variables covering demand, emissions, and financial exogenous historical input data. Due to the lack of data availability related to marginal efficiencies and capital costs historically, exogenous historical inputs related to process and device technology characteristics are input for one initialization year. For efficiency data that is not available, estimates are determined based on the historical input data that are available. For example, note that exogenous historical device efficiency (XDEE) are inputs; however, historical process efficiency is calculated (PEE). By convention, variables that are assigned an “X” as a prefix, such as XDEE, represent exogenous input data.

The key outputs from the initialization routines are shown in Figure 10. Most outputs are simple assignments of exogenously input values to a model variable for the initialization year or simple transformations of input variables. For example, device energy efficiency (DEE) is an output and is simply an assignment of the value of the exogenous device energy efficiency, XDEE, to the model variable, DEE, in the initialization year. The exceptions are the coefficients of the device and process efficiency price-response trade-off curves. These coefficients are calculated in the initialization year then held constant across all other years.

Figure 6. Inputs to Demand Initialization

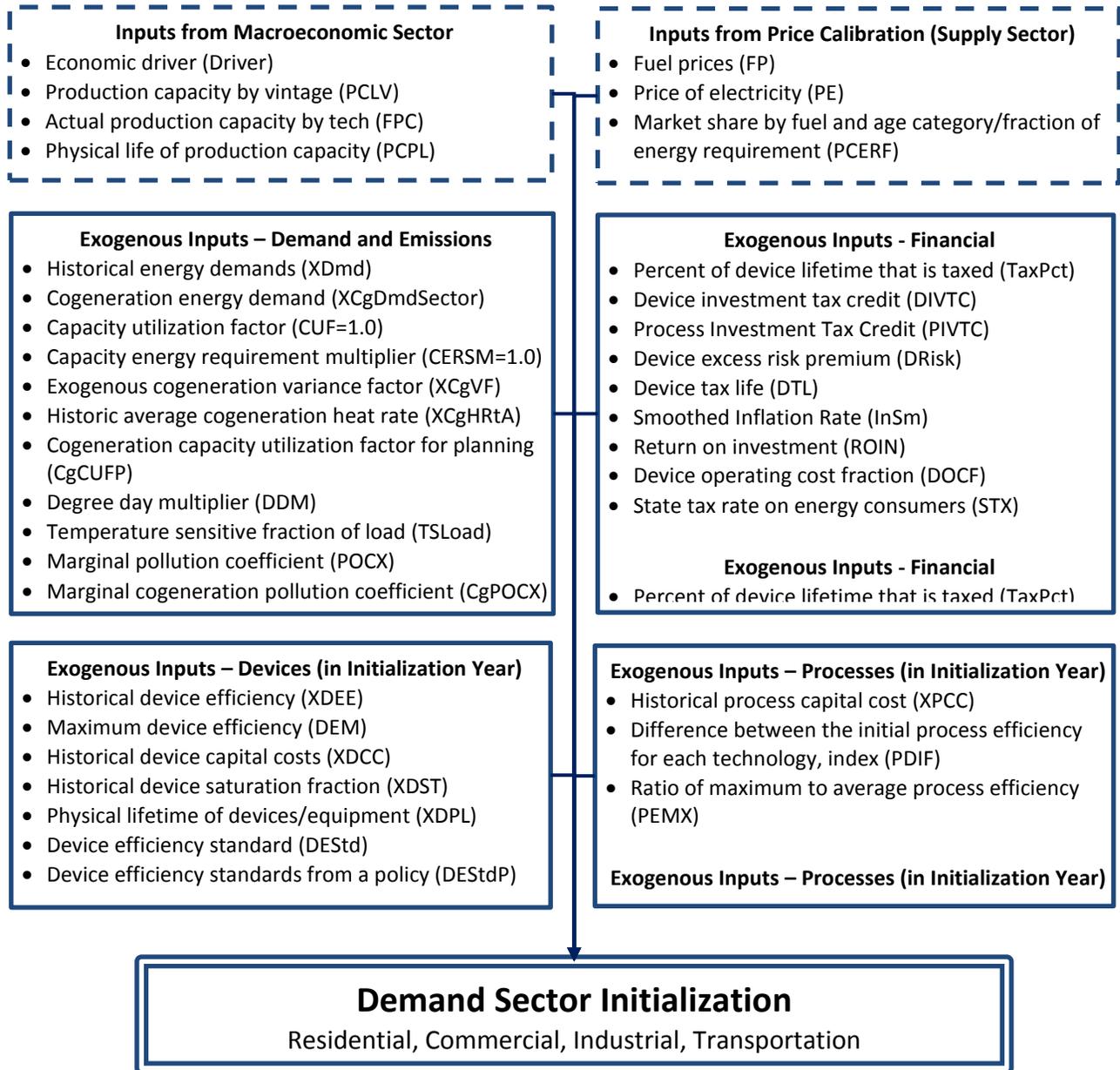
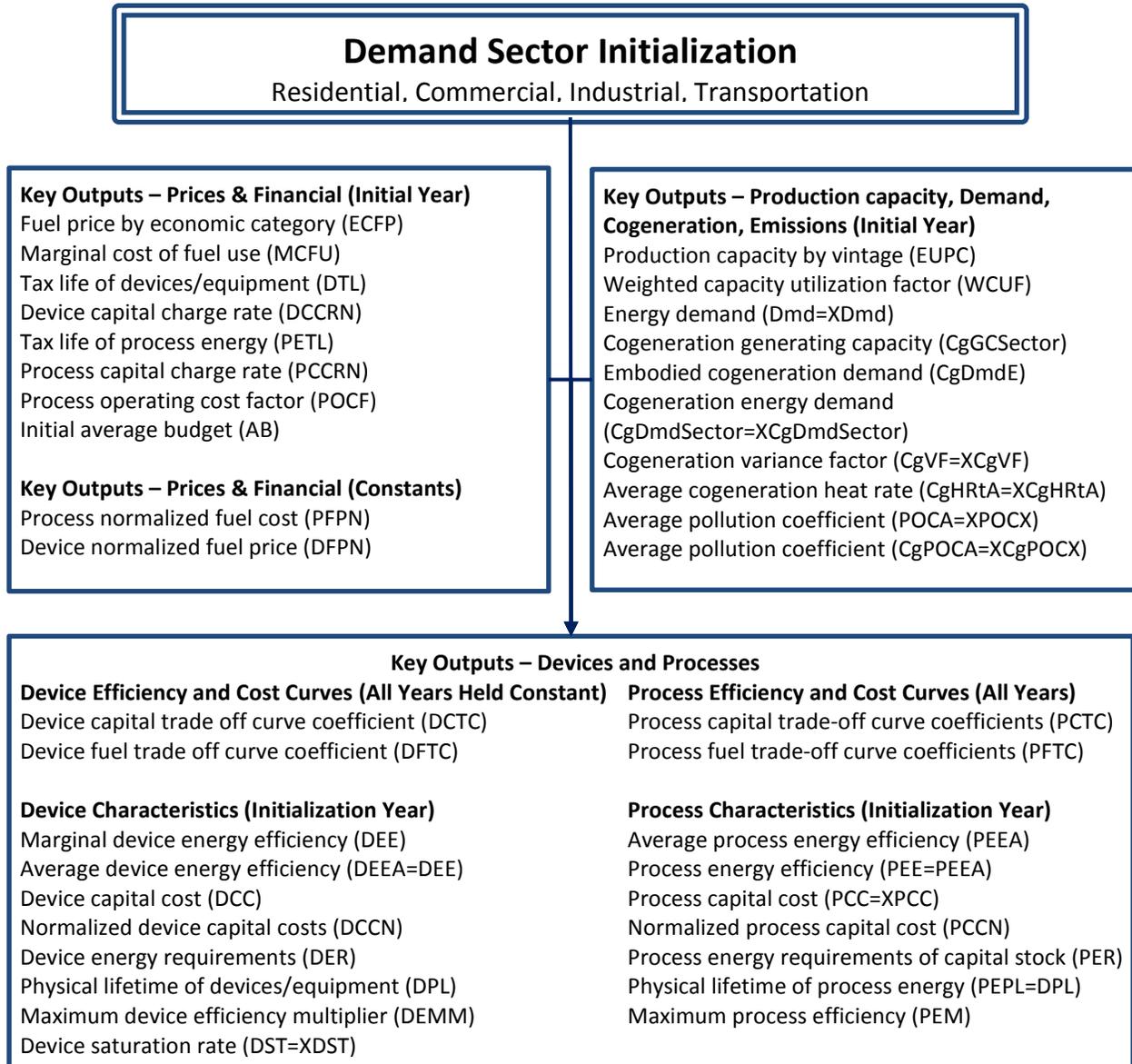


Figure 7. Outputs from Demand Initialization



5.2. Demand Calibration Code

The main objective of the demand calibration is to estimate calibration coefficients from the historical data. Although several methods are used, one method of calculating the coefficients is to apply model equations historically then back-calculating the unknown values given known historical values.

Procedurally, several calibration routines are executed more than once since the model has specified some historical policies which require a baseline (for example a 25% improvement in efficiency). In that case, the first calibration generates the baseline while the second calibration includes the policy as part of the calibration.

The main objective of the initialization and calibration routines is to extract relationships from the historical data for use making projections of: 1) energy efficiency choices (process and device); 2) fuel market share choices; and 3) energy demand utilization factors.

Outputs from the demand calibration include variables sent to the demand execution code to project marginal fuel market share (for end uses and cogeneration), energy demand (enduse, cogeneration, and feedstock), and energy efficiency (devices and processes).

Key outputs include:

Used to calculate fuel shares/marginal market shares

- Marginal market share multiplier/non-price factor (MMSM0)
- Cogeneration marginal market share multiplier (CgMSM0)

Used to calculate end use demand, cogeneration demand, and feedstock demand

- Capacity utilization factor (CUF)
- Capital energy requirement multiplier (CERSM)
- Cogeneration capacity utilization factor (CgCUF)
- Feedstock process efficiency (FsPEE)

Used to calculate device efficiency and process efficiency

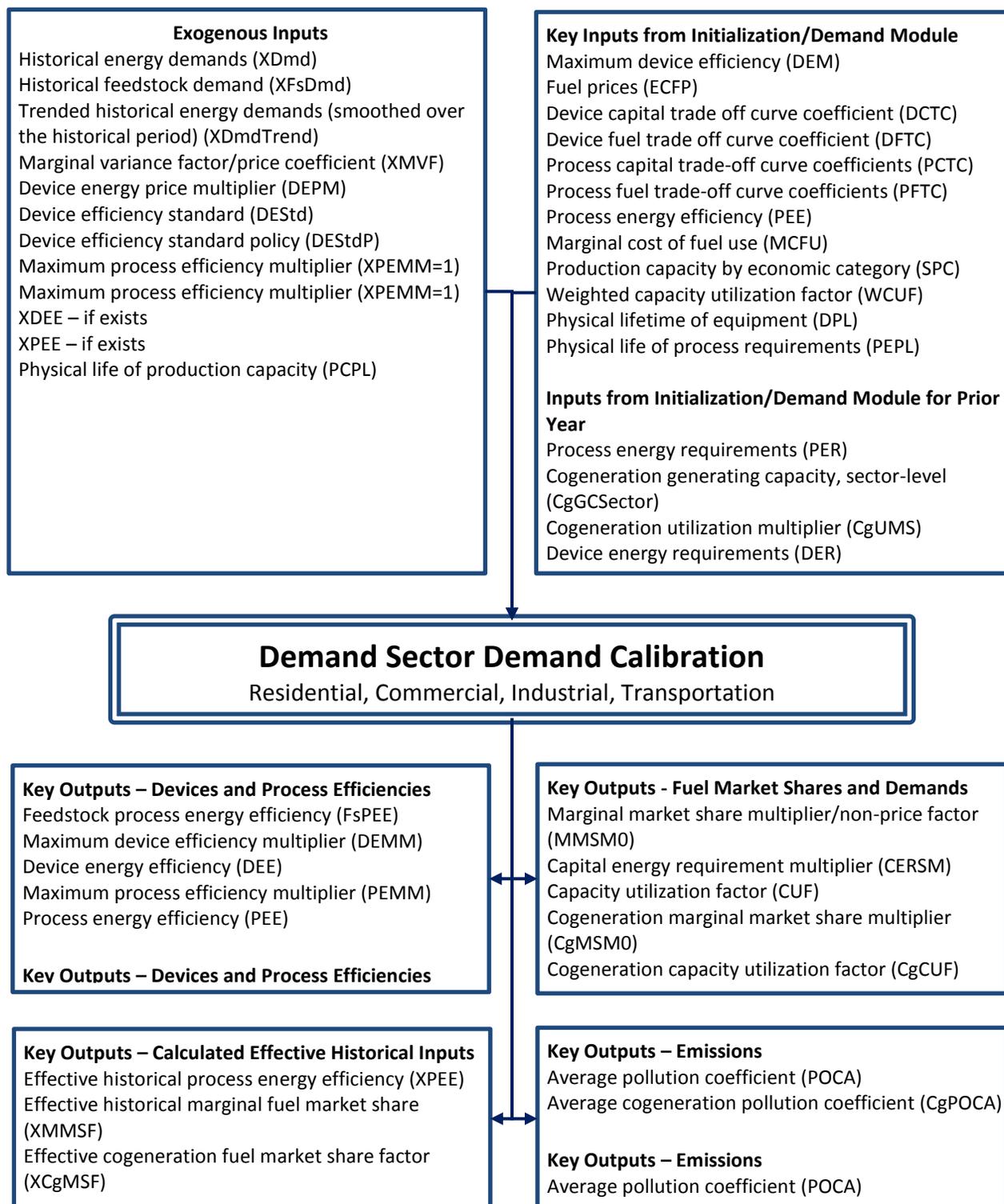
- Maximum device efficiency multiplier (DEMM)
- Maximum process efficiency multiplier (PEMM)

Other variables calculated during calibration:

- Effective historical process energy efficiency (XP EE)
- Effective historical marginal fuel market share (XMMSF)
- Effective cogeneration fuel market share factor (XCgMSF)
- Device energy efficiency (DEE)
- Process energy efficiency (PEE)
- Average pollution coefficient (POCA)
- Average cogeneration pollution coefficient (CgPOCA)

Figure 13 shows a diagram of key inputs to and outputs from the demand calibration routines.

Figure 8. Inputs and Outputs of Demand Calibration



The model code that calculates the calibration variables for each of residential, commercial, industrial, and transportation is contained in RCalib.src, CCalib.src, ICalib.src, and TCalib.src files. Table 7 lists the demand calibration procedures along with a summary description of each.

Table 7. Demand Calibration Procedure Descriptions

| Procedure Name | Procedure Description |
|-----------------------|---|
| 1. Initial | Assigns values to basic demand parameters – maximum process efficiency multiplier set equal to exogenous values (PEMM=XPEMM) and marginal variable factor (MVF) set equal to exogenous value (XMVF). Calculates a simple feedstock demand efficiency, FsPEE, as a ratio of historical production capacity to historical feedstock demand. |
| 2. CalDEMM | Calculates an implied historical device energy efficiency (DEE) before any standards were in place based on the device efficiency trade-off curve derived during initialization; 2. Calculates a calibrated variable, maximum device efficiency multiplier (DEMM), representing the difference between the calculated DEE, the historical efficiency (maximum of an exogenous device efficiency (XDEE) if it exists, a historical device efficiency standard (DEStd) or a device efficiency standard policy (DEStdP) if it exists). |
| 3. CalPEMM | Calculates a calibrated variable, maximum process efficiency multiplier (PEMM), representing the difference between PEE input in first year from initialization and XPEE which is equal to PEE if no exogenous values exist (XPEE). The process energy efficiency (PEE) is then adjusted by the multiplier: $PEE=PEE*PEMM$. Exception exists if residential/commercial heating and air conditioning both exist for a particular technology. In that case, computes a process efficiency multiplier for air conditioning that is based on the process efficiency and process energy requirements of heating. |
| 4. Coefficients | Calculates an implied historical marginal market share (XMMSF) based on calculated historical production capacity additions and retirements. Given values for historical marginal market share and calculated marginal cost of fuel use and an assumed price coefficient, back-calculates the non-price logit consumer choice parameter (MMSMO). Uses the demand equation, with a known historical trended energy demand (smoothed) and an assumed capacity utilization factor (CUF) equal to 1.0, back-calculates the capacity energy requirement multiplier (CERSM). Using the actual annual historical demand (XDmd), then applies the demand equation to back-calculate a value for the CUF which represents the historical annual fluctuations in energy demand. |

| Procedure Name | Procedure Description |
|-----------------------|---|
| 5. TPrice | Recalculates the effective price of energy (ECP) by combining the fuel price (FP, PE) with any emission charges (PCost). Recalculates changes in production capacity. |

After the calibrated variables have been calculated for the historical years, a method needs to be determined for projecting these values into the future. Following the calibration routines, a set of routines is called from the *.Future.src files to forecast the calibrated variables (Procedure FutCal). There are a multitude of potential projection methods, and ENERGY 2020 allows the user to select the specific methodology to be used. Different methods are able to be selected for different areas, economic sectors, technologies, or end uses. The default setting for most variables is to hold the value in the last historical year constant through the projection period.

The method of projecting the calibration variables is selected based on a set of exogenously-specified calibration control variables. These values of the calibration control variables are specified inside the *.Data.src files. Depending on type of calibration variable, each variable is assigned independent variables, weights, and a method based on the "Y" name of the variable.

The outputs from the Future routines consist of future values of the demand calibration variables. Inputs and outputs are listed in [Table 8](#), and options of projections methods built into the model are shown in [Table 9](#).

Table 8. Inputs to and Outputs from Procedure Future

| Exogenous Inputs (Calibration Control Variables) | Inputs (from Historical Calibration) | Outputs (from Future) |
|---|---|----------------------------------|
| YPEMM | DEMM | DEMM |
| YCERSM | PEMM | PEMM |
| YCUF | FsPEE | FsPEE |
| YDEMM | CERSM | CERSM |
| YFSPEE | CUF | CUF |
| YMMSM | MMSM0 | MMSM0 |
| YCgCUF | CgCUF | CgCUF |
| YCgMSM | CgMSM0 | CgMSM0 |

Table 9. Calibration Control Variable Assignments

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

Many of the calibration variables are held constant with the last historical years. Below are a few examples of exceptions:

| | |
|-------|--|
| MMSM0 | Calculate the MMSM0 so that the future MMSF equals average market share in last historical year (<i>AdjustMarketShare.txt</i>) basing the future values instead of the average market share in the last year (AMSF |
| CUF | Trended back to 1.0 in the forecast unless the CUF(Last) is outside the normal range. |

The following sections provide more detail on each of the procedures that make up the demand calibration.

Procedure Initial

Assigns exogenous values to key demand model variables and calculates a feedstock demand efficiency as a ratio of historical production capacity to historical feedstock demand.

| Procedure Initial: Estimate basic demand parameters. |
|--|
| Key Inputs |
| Exogenous inputs: <ul style="list-style-type: none">• XPEMM (Enduse,Tech,EC,Area,Year) 'Process Efficiency Maximum Multiplier ((\$/Btu)/(\$/Btu))'• XMVF (Enduse,Tech,EC,Area,Year) 'Market Share Variance Factor (\$/\$)'• XFsDmd (Tech,EC,Area,Year) 'Feedstock Energy (TBtu/Yr)' |
| Inputs from demand sector Initialization routines: <ul style="list-style-type: none">• WCUF (EC,Area) 'Capacity Utilization Factor Weighted by Output' |
| Inputs from Economic Processing module : <ul style="list-style-type: none">• PC (ECC,Area,Year) 'Production Capacity (M\$/Yr)' |
| Key Outputs |
| <ul style="list-style-type: none">• PEMM (Enduse,Tech,EC,Area,Year) 'Process Efficiency Maximum Multiplier ((\$/Btu)/(\$/Btu))'• MVF (Enduse,Tech,EC,Area,Year) 'Market Share Variance Factor (\$/\$)'• FsPEE (Tech,EC,Area,Year) 'Feedstock Process Efficiency (\$/mmBtu)'• SPC (EC,Area) 'Total Production Capacity (M\$/Yr)' |
| Key Equations |
| <ul style="list-style-type: none">• $PEMM = XPEMM$• $MVF = XMVF$• $SPC(EC,Area) = \text{sum}(ECC)(PC(ECC,Area) * ECCMap(EC,ECC))$• $FsPEE = SPC * WCUF / XFsDmd$ |

Procedure CalDEMM

This procedure calculates an implied historical device energy efficiency (DEE) before any standards were in place based on the device efficiency trade-off curve derived during initialization. It also calculates a calibration variable, the maximum device efficiency multiplier (DEMM), representing the ratio difference between the calculated DEE the effective historical efficiency (maximum of an exogenous device efficiency (XDEE) if it exists, a historical device efficiency standard (DEStd) or a device efficiency standard policy (DEStdP) if it exists).

| Procedure CalDEMM |
|--|
| Key Inputs |
| Exogenous inputs: <ul style="list-style-type: none">• XPEMM (Enduse,Tech,EC,Area,Year) 'Process Efficiency Maximum Multiplier ((\$/Btu)/(\$/Btu))'• XMVF (Enduse,Tech,EC,Area,Year) 'Market Share Variance Factor (\$/\$)'• XFsDmd (Tech,EC,Area,Year) 'Feedstock Energy (TBtu/Yr)' |
| Inputs from demand sector Initialization routines: |
| Key Outputs |
| <ul style="list-style-type: none">• |
| Key Equations |

The device efficiency maximum multiplier is set equal to the exogenously input value adjusted by the prior year's ratio of DEMM to the exogenous value (XDEMMPrior)

- $DEMM = XDEMMPrior * DEMMPrior / XDEMMPrior$
- $DEEBeforeStd = DEM * DEMM * (1 / (1 + (ECFP / Infla * DEPM / DFPN) ** DFTC))$

Device energy efficiency is the maximum of the efficiency before any standards and existing efficiency standards or policy efficiency standard.

- $DEE = \text{xmax}(DEEBeforeStd, DEStd, DEStdP)$
- $DEMM = \text{xmax}(DEMM, DEE / DEMM / (DEM * 0.98))$
- $DEMM = DEMM * \text{xmax}(XDEE, DESTD, DESTDP) / DEE$
- $DEE = \text{xmax}(XDEE, DESTD, DESTDP)$

Procedure CalPEMM: Calibrate Process Technology

$$XPPEE = \text{xmax}(XPPEE, PEE)$$

$$PEMM = PEMM * XPPEE / PEE$$

$$PEE = PEE * PEMM$$

- * If space heating (Heat) and air conditioning (AC) both exist, then
- * compute process efficiency multiplier (PEMM) for air conditioning.

$$PEE(AC, Tech, EC, Area) = \frac{\sum(TE)(PEE(Heat, TE, EC, Area) * PER(Heat, TE, EC, Area))}{\sum(TE)(PER(Heat, TE, EC, Area))} * (CHR(EC, Area) * CHR(M, EC, Area)) * PEMM(AC, Electric, EC, Area)$$

$$XPPEE = \text{xmax}(XPPEE, PEE)$$

$$PEMM = PEMM * XPPEE / PEE$$

- * If space heating (Heat) does not exist, but air conditioning (AC) does exist,
- * then compute process efficiency multiplier (PEMM) for air conditioning.

$$XPPEE = \text{xmax}(XPPEE, PEE)$$

$$PEMM = PEMM * XPPEE / PEE$$

$$PEE = PEE * PEMM$$

Procedure Coefficients

Calculate Calibration Parameters. Multinomial logit calculation of MMSF – based on back calculating MMSM0 given all other factors known historically and marginal variance fact an exogenous input.

Inputs

- Historical, exogenous energy demands (XDmd)
- Trended historical energy demands (smoothed over the historical period) (XDmdTrend)
- Marginal variable factor (MVF)
- Marginal cost of fuel use (MCFU)

Outputs

- Historical marginal market share factor (XMMSF)
- Marginal market share multiplier/non-price multinomial logit coefficient (MMSM0)
- Capital energy requirement multiplier (CERSM)
- Capacity utilization factor (CUF)

Equations

1. Estimate historical marginal market share (XMMSF) from other variables input (or calculated) for the historical period - calculate implied historical additions and retirements of device energy and process energy based on relationships between historical production capacity, device saturation levels, historical energy demand (trended), process efficiency, device efficiency, production capacity additions, process and device energy lifetimes.
2. Marginal fuel market share for each historical year: Back Solve for MMSM0 and normalize one fuel to Zero. Using multinomial logit function equation for probability of choosing a certain fuel from a set of fuels given MCFU.
3. Capacity energy requirement multiplier: Solve for CERSM using Dmd equation and using calculated value for MMSM0 and trended historical energy demands.
4. Solve for CUF by using actual annual values for historical energy demands rather than smoothed values.

Cogeneration Calibration

Inputs

- Electric price (ECFP)
- Prior year's
- Cogeneration generating capacity, sector-level (CgGCSector)
- Cogeneration utilization multiplier (CgUMS)
- Device energy requirements (DER)

Outputs: CgCUF, CgMMSM0, XCgMSF

Load Shape Calibration

The load shape calibration creates load shape factors from the historical data, adjusting for differences between calculated load shapes and exogenously input load shapes. These load shape factors will be sent as input to the model execution (Loads) routines that translate energy demands from the demand code into loads for input to the electric and natural gas supply sectors.

Two procedures calibrate the load shapes from the historical data: Procedure LoadShape and Procedure Normalize. Procedure LoadShape simply assigns exogenously specified load shape factors to model output variables, and Procedure Normalize modifies the output value of load shape factor by an adjustment factor (created to reconcile calculated loads with exogenously specified loads) obtained from the supply calibration then normalizes the resulting load shape factors. The key inputs and outputs are listed below.

Key Inputs (from Supply Calibration)

- Base adjustment to account for differences between calculated historical loads and exogenous loads (BaseAdj)
- Exogenous load shape factor by month for peak, average, minimum days (XLSF)
- Exogenous cogeneration load shape factor (XCgLSF)
- Exogenous cogeneration sold to the grid load shape factor (XCgLSFSold)

Key Outputs

- Electricity load shape factor by month for peak, average, minimum days (LSF)
- Cogeneration load shape factor (CgLSF)
- Cogeneration sold to the grid load shape factor CgLSFSold
- Natural gas daily use factor (DUF)

6. Summary of Load Curves Procedures

After the demand code has been executed electricity and natural gas demands are translated into load curves for input to the electricity and natural gas supply modules. The key inputs to these procedures are energy demands and load shape factors, and the key outputs are load curves. A summary of the procedures making up the load curve creation is listed below. See the *Appendix 2. Load Curve Procedures and Equations* section for a detailed look at each of the procedures.

1. **Procedure ETOU:** Electric Time-Of-Use Impacts. This procedure calculates the impacts of different time of use pricing on peak, average and minimum loads.
2. **Procedure LoadMgmt:** Impacts from Load Management Programs - calculates the effects on sales and peak demand from load management programs.
3. **Procedure LoadCurve:** Generating Electric Load Curve - derives economic class (ECLDC) and revenue class (CLDC) load shapes from demand (Dmd). Electric sales (ESales, ECSales, and Sales) are calculated from the load shapes. Cogeneration is accounted for and netted out of sales.
4. **Procedure NoLoadCurve:** Electric Sales when load shapes are not available Procedure derives electric sales (ESALES, ECSALES, and SALES) from demand (DMD). Accounts for cogeneration demand.
5. **Procedure DailyUse:** Gas Utility Daily Use Curve - calculates EUDUC, CDUC, (daily use curves by end-use and class, respectively), GSALES and SALES (sales by end-use and total sales) for the natural gas utility.
6. **Procedure NoDailyUse:** Gas Sales when load shapes are not available. Calculates GSales (gas sales by end-use and class) and Sales (total sales) when no load shapes are available and CCSales(transportation gas)

7. Summary of Economic Processing Module

The economic processing module assigns economic inputs to model variables and converts economic drivers into production capacity. Production capacity by vintage (old, middle, and new) is needed for input to the demand module. Production capacity drives the process energy requirements which, in turn, drive the device energy requirements. Tracking production capacity by vintage (old, middle, and new) allows the model to retire old capital stock at the end of its useful lifetime and replace it with new capital stock typically at higher efficiency levels.

The key inputs to the economic processing module consist of the economic driver (Driver) and other economic indicators obtained from an exogenous economic forecast.

The key outputs consist of production capacity (PC), production capacity by vintage - old, middle, and new – (PCLV), production capacity retirements (PCR), production capacity additions (PCA), and a capacity utilization factor (ECUF). The capacity utilization factor is based on the ration of the economic driver to production capacity ($ECUF = \text{Driver}/PC$).

Appendix 1. Demand Procedures and Equation Detail

7.1. Price and Pollution Policy Inputs Procedures

Two model code procedures are used to create the price and pollution policy inputs required for use in the demand module – *Procedure TPrice* and *Procedure PRReductions* – and are described in detail below.

Procedure TPrice: Pollution Costs, Fuel Prices and Technology Mapping

This procedure calculates the effective price of fuel by combining the by fuel prices with the emission fuel costs after calculating the emission fuel costs.

Calculate Pollution Costs by Technology

The cost of emissions for all pollution types is calculated for each technology as the sum of permit costs and the reduction multiplier weighted by the type of fuel consumed in the previous year as follows.

$$PCostTech(Tech,EC,A)=\sum(Poll)(\sum(F)((PCost(F,EC,Poll,A)*Infla+PCostExo(F,EC,Poll,A)*Infla)*\sum(EU)(POCX(EU,F,EC,Poll,A)*RM(F,EC,Poll,A)*xmax(EuDem(EU,F,EC,A),1e-12))*FETMap(F,Tech))/\sum(EU,F)(xmax(EuDem(EU,F,EC,A),1e-12)*FETMap(F,Tech)))/1E6$$

where:

PCostTech(Tech,EC,Area) 'Permit Cost (\$/mmBtu)'
PCostExo(FuelEP,EC,Poll,Area) 'Marginal Exogenous Permit Cost (Real \$/Tonnes)'
EuDem(Enduse,FuelEP,EC,Area) 'Enduse Demands (TBtu/Yr)'

A smoothed value for marginal emissions costs is calculated for energy efficiency investments based on pollution costs or carbon tax price depending on switches set by the model. A marginal cost is first set as follows

```
Do If PrPCostSw eq 1
  PrPCostMar=PCostTech
Else PrPCostSw eq 2
  PrPCostMar=eCO2Price+eCO2PriceExo*Infla
Else
  PrPCostMar=PrPCostPrior
End Do If
```

where:

PrPCostMar(Tech,EC,Area) 'Marginal Pollution Cost (\$/mmBtu)'
PrPCostPrior(Tech,EC,Area) 'Pollution Cost (\$/mmBtu)'
eCO2Price(Area) 'Carbon Tax plus Permit Cost (\$/eCO2 Tonnes)'
eCO2PriceExo(Area) 'Carbon Tax plus Permit Cost (\$/eCO2 Tonnes)'

The marginal cost is smoothed if previous values exist

```
Do If PrPCostMarPrior eq 0
  PrPCost=PrPCostMar
Else
```

PrPCost=PrPCostMar*(1/PrPCostAT)+PrPCostPrior*(1-1/PrPCostAT)
 End Do If

where:

PrPCost(Tech,EC,Area) 'Pollution Cost (\$/mmBtu)'
 PrPCostAT(EC,Area) 'Pollution Cost Adjustment Time (Years)'

Calculate End-Use Prices

The following equations map global fuel prices (FP) into local fuels prices (ECFP) and adds applicable emission costs for all non-electric fuels.

ECFP(T,EC,Area)=FP(FPMap(T,EC),Area)+PCostTech(T,EC,Area)

where:

ECFP(TECH,EC,YEAR): Fuel Price (\$/MBTU or \$/GJ)
 FP(Prices,Area) 'Fuel Prices (\$/mmBtu)'

Electric prices instead use the price of electricity as the input variable with a MWh to million Btu conversion using a map (ECCMap) from global to local electric prices.

ECFP(T,EC,Area)=sum(ECC)(PE(ECC,Area)*ECCMap(EC,ECC))/3412*1000+
 PCostTech(T,EC,Area)

where:

PE(ECC,Area) 'Price of Electricity (\$/mmBtu)'

In the following equations, production capacity, population, and a capacity utilization factor are mapped from ECC to EC. The capacity utilization factor (WCUF) is weighted by economic output (PC) to represent changes in economic conditions affecting capacity utilization in the determination of final demand (DMD).

SPC(EC,Area)=sum(ECC)(PC(ECC,Area)*ECCMap(EC,ECC))
 SPC0(EC,Area)=sum(ECC)(PC0(ECC,Area)*ECCMap(EC,ECC))
 SPOP(EC,Area)=sum(ECC)(POP(ECC,Area)*ECCMap(EC,ECC))
 SPOPO(EC,Area)=sum(ECC)(POPO(ECC,Area)*ECCMap(EC,ECC))
 WCUF(EC,Area)=sum(ECC)(PC(ECC,Area)*ECCMap(EC,ECC))/
 sum(ECC)(PC(ECC,Area)*ECCMap(EC,ECC))

where:

SPC(EC,Area) 'Total Production Capacity (M\$/Yr)
 SPC0(EC,Area) 'Total Production Capacity (M\$/Yr)
 SPOP(EC,Area) 'Population (Millions)
 SPOPO(EC,Area) 'Population (Millions)
 WCUF(EC,Area) 'Capacity Utilization Factor Weighted by Output'
 PC(ECC,Area) 'Production Capacity (M\$/Yr)
 ECUF(ECC,Area) 'Capital Utilization Fraction (Btu/Btu)'

Procedure PRReductions: Pollution Reduction Device Calculations

This procedure calculates cost of emission reduction devices and builds reductions in response to emission cap policies. Cost and stock of reduction devices is dependent on type of emissions cap and trading market.

Map Emissions Policy Variables

The following equations map global emissions policy coverage, cost, and targeted level of emissions reductions into local variables. This allows for the model to begin the process of estimating the impact of a program across possibly the entire economy for the sectors covered by the Demand file

$$\begin{aligned} ECoverage(EC,P,PCov,Area) &= ECovECC(ECC,P,PCov,Area) \\ PCCov(F,EC,P,Area) &= \max(PCov)(ECoverage(EC,P,PCov,Area)*PCovMap(F,ECC,PCov,Area)) \\ PCost(F,EC,P,Area) &= PCostECC(ECC,P,Area)*PCCov(F,EC,P,Area) \\ GPFFrac(EC,P,PCov,Area) &= GPFFracECC(ECC,P,PCov,Area) \\ RPolicy(EC,P,Area) &= RPolECC(ECC,P,Area) \\ ECMarket(EC,Market) &= ECCMarket(ECC,Market) \end{aligned}$$

where:

$$\begin{aligned} ECoverage(EC, Poll, PCov, Area) & \text{ 'Emissions Coverage (1=Covered)'} \\ ECovECC(ECC, Poll, PCov, Area) & \text{ 'Emissions Coverage (1=Covered)'} \\ PCCov(FuelEP, EC, Poll, Area) & \text{ 'Emissions Coverage by Tech or Fuel (Tonnes/Tonnes)'} \\ PCovMap(FuelEP, ECC, PCov, Area) & \text{ 'Pollution Coverage Map (1=Mapped)'} \\ PCost(FuelEP, EC, Poll, Area) & \text{ 'Permit Cost (\$/Tonne)'} \\ PCostECC(ECC, Poll, Area) & \text{ 'Permit Cost (\$/Tonne)'} \\ GPFFrac(EC, Poll, PCov, Area) & \text{ 'Emissions Gratis Permit Fraction (Tonnes/Tonnes)'} \\ GPFFracECC(ECC, Poll, PCov, Area) & \text{ 'Emissions Gratis Permit Fraction (Tonnes/Tonnes)'} \\ RPolicy(EC, Poll, Area) & \text{ 'Reduction Policy (Tonnes/Tonnes)'} \\ RPolECC(ECC, Poll, Area) & \text{ 'Reduction Policy (Tonnes/Tonnes)'} \\ ECCMarket(ECC, Market) & \text{ 'Economic Categories included in Market'} \\ ECMarket(EC, Market) & \text{ 'Economic Categories (ECs) in each Market'} \end{aligned}$$

The following equation maps the device capital charge rate (DCCRP) to the appropriate FuelEP type using the first enduse.

$$DCCRP(FuelEP, EC, Area) = \text{sum(Tech)}(DCCR(EU, Tech, EC, Area) * FETMap(FuelEP, Tech))$$

where:

$$\begin{aligned} DCCRP(FuelEP, EC, Area) & \text{ 'Device Capital Charge Rate for Policies (\$/Yr/\$)'} \\ DCCR(Enduse, Tech, EC, Area) & \text{ 'Device Capital Charge Rate (\$/Yr/\$)'} \\ FETMap(FuelEP, Tech) & \text{ 'FuelEP Tech Map'} \end{aligned}$$

Voluntary reductions are based on exogenous goal and time lag.

$$VR = VR + DT * (VRP - VR) / VRRT$$

where:

$$VR(FuelEP, EC, Poll, Area) \text{ 'Voluntary Reduction Policy (Tonnes/Tonnes)'}$$

VRP(FuelEP,EC,Poll,Area) 'Voluntary Reduction Policy (Tonnes/Tonnes)'
VRRT(EC) 'Voluntary Reduction response time (Years)'
DT 'Time Period'

Calculate Emission Reductions and Costs – Cap with Trading

The methodology for calculating the amount of reduction and reduction costs from an emissions policy is dependent on the specified type of cap and trade market. The capital cost for reduction technologies is based on reduction cost curve input data. Available input data currently contains different sources for some sectors with a corresponding difference in methodology needed to produce a dollar per tonne reduced result. These different inputs are referred to in the model code by the year of the source.

The following equation calculates the marginal reduction capital cost for markets specified as an emissions cap with emissions trading.

$$RCC=(PCost*PCCov*Infla+PCostExo*Infla)/(DCCRP+ROCF)$$

where:

RCC(FuelEP,EC,Poll,Area) 'Reduction Capital Cost (\$/Tonne)'
PCostExo(FuelEP,EC,Poll,Area) 'Marginal Exogenous Permit Cost (Real \$/Tonnes)'
Infla 'Inflation Index (\$/\$)'
ROCF(FuelEP,EC,Poll,Area) 'Pollution Reduction O&M (\$/Tonne)'

The indicated reductions are a function of the marginal reduction price and reduction curve parameters. The following equation calculates indicated reductions if the sector curve data is from 2009.

$$IRP=\ln(RCC/Infla/(PCostN/PCostM/RCostM))/PVF*PCCov$$

where:

IRP(FuelEP,EC,Poll,Area) 'Indicated Pollutant Reduction (Tonnes/Tonnes)'
PCostN(FuelEP,EC,Poll,Area) 'Pollution Reduction Cost Normal (\$/Tonne)'
PCostM(FuelEP,EC,Poll,Area) 'Permit Cost Multiplier (\$/Tonne/\$/Tonne)'
RCostM(FuelEP,Poll) 'Reduction Cost Technology Multiplier (\$/\$)'
PVF(FuelEP,EC,Poll,Area) 'Pollution Reduction Variance Factor ((\$/Tonne)/(\$/Tonne))'

The following equation calculates indicated reductions if the sector curve data is from 2004.

$$IRP=1/(1+((xmax((PCost+PCostExo)*PCostM,0.01)*RCostM)/PCostN)**PVF)*PCCov$$

Changes in actual reductions (RP) is produced from changes in indicated reductions, reduction construction time and physical lifespans

$$RP=RP+(xmax(RP,IRP)-RP)/RCD-RP/RCPL$$

where:

RP(FuelEP,EC,Poll,Area) 'Pollutant Reduction (Tonnes/Tonnes)'
RCD(EC,Poll) 'Reduction Capital Construction Delay (Years)'
RCPL(EC,Poll) 'Reduction Capital Physical Life (Years)'

Calculate Emission Reductions and Costs – Cap with No Trading

In markets with no trading, the reduction capital cost is based on the amount reduced instead of the permit price. Curve parameters develop the marginal capital costs as positively correlated with need for emissions reductions. Reductions are defined by the policy variable, by a marginal emissions coefficient standard, or can be exogenously specified as follows.

$$RP(F,EC,P,A)=x\max(RPolicy(EC,P,A),1-\min(EU)(POCS(EU,F,EC,P,A))/x\max(\max(EU)(POCX(EU,F,EC,P,A)),0.000001))*PCCov(F,EC,P,A)$$
$$RPF\text{Full}=1-(1-RP)*XRM$$

where:

$$POCS(Enduse,FuelEP,EC,Poll,Area) \text{ 'Pollution Standards (Tonnes/TBtu)'} \\ Infla \text{ 'Inflation Index (\$/\$)'} \\ POCX(Enduse,FuelEP,EC,Poll,Area) \text{ 'Marginal Pollution Coefficients (Tonnes/TBtu)'} \\ RPF\text{Full}(FuelEP,EC,Poll,Area) \text{ 'Full Pollutant Reduction (Tonnes/Tonnes)'} \\ XRM(FuelEP,EC,Poll,Area) \text{ 'Exogenous Average Pollution Coefficient Reduction Multiplier (Tonnes/Tonnes)'}'$$

The cost of emission reductions using 2009 input data is calculated as follows

$$RCC=(PCostN/RCostM)*Exp(PVF*RPF\text{Full})*Infla$$

The cost of emission reductions using 2004 input data is calculated as follows

$$RCC=(1/RPF\text{Full}-1)**(1/PVF)*PCostN/RCostM/(DCCRP+ROCF)*Infla$$

The cost of emission reductions using 2011 input data is calculated as follows

$$RCC=\exp((PCostN/RCostM)+(PVF*LN(RPF\text{Full}))*Infla$$

A smoothed permit cost is calculated using the marginal reduction cost, capital charge rate, and reduction operation and maintenance costs

$$IPCost=RCC*(DCCRP+ROCF)/Infla \\ PCost=PCostPrior+(IPCost-PCostPrior)/RCD$$

where:

$$IPCost(FuelEP,EC,Poll,Area) \text{ 'Indicated Permit Cost (\$/Tonne)'} \\ PCostPrior(FuelEP,EC,Poll,Area) \text{ 'Permit Cost in Prior Year (\$/Tonne)'}'$$

Calculate Reduction Cross-Impacts and Energy Impacts

With the amount of reductions specified, the impact on other non-covered pollutants can be applied using the cross-impact multiplier

$$RPXP(FuelEP,EC,Poll,PollX,Area)=CM(FuelEP,Poll,PollX)*RP(FuelEP,EC,Poll,Area)$$

where:

$$RPXP(FuelEP,EC,Poll,PollX,Area) \text{ 'Pollutant Reduction with Cross Impacts (Tonnes/Tonnes)'} \\ CM(FuelEP,Poll,PollX) \text{ 'Cross-over Reduction Multiplier (Tonnes/Tonnes)'}'$$

Impact of reduction devices on energy consumption is also accounted for similarly using an input energy multiplier

$$RPEI(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}) = \text{product}(\text{Poll}) (1 + \sum(\text{FuelEP}) (\text{RP}(\text{FuelEP}, \text{EC}, \text{Poll}, \text{Area}) * \text{FETMap}(\text{FuelEP}, \text{Tech})) * RPEIX(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}))$$

where:

RPEI(Enduse, Tech, EC, Area) 'Energy Impact of Pollution Reduction (Btu/Btu)'

RPEIX(Enduse, Tech, EC, Area) 'Energy Impact of Pollution Reduction Coefficient (Btu/Btu/Tonne/Tonne)'

FETMap(FuelEP, Tech) 'FuelEP Tech Map'

7.2. Device Efficiency and Device Capital Cost Procedures

Procedure DMarginal: Device Efficiency and Capital Costs

In this procedure, the device efficiencies (DEE), device capital costs (DCC), the marginal cost of fuel use (MCFU) and the device capital charge rate (DCCR) are computed.

Calculate Device Capital Charge Rate

The device capital charge rate is the annualization of device capital expenses (over the life of the device - DTL), accounting for taxes (TXRT), tax credits (DIVTC, DPIVTC), and return of principal and on investment (including risk premiums and inflation: 1+ROIN+CROIN+DRISK+INSM). $(1 - (1/(1+ROIN+CROIN+DRISK)))^{**}DPLN)/(1-TXRT)$ is the classical capital recovery term. The $(1-TXRT)$ term at the end converts the after tax calculation into before tax dollars. Investment tax credits reduce the cost of the facility by the tax credit after the first year of operation using nominal dollars. Therefore the value of the tax credit is $((DIVTC+DPIVTC)/(1+ROIN+CROIN+DRISK+INSM))$. Depreciation is modeled as a current dollar phenomenon which does not account for inflation. Therefore the net present value of the energy is calculated with the nominal rate of return: $(2/DTL)/(ROIN+CROIN+DRISK+INSM+2/DTL)$. It shows up as an additional negative term in the capital cost modifiers of DCCR because depreciation is a benefit (negative cost).

Device capital costs (DCC) are multiplied by the DCCR to get the annualized cost of the device used in computing market share calculations.

The formula for calculating the device capital charge rate:

$$DCCR = (1 - (DIVTC + DPIVTC) / (1 + ROIN - CROIN + DRISK + InSm) - TxRt * (2/DTL) / (ROIN - CROIN + DRISK + InSm + 2/DTL)) * (ROIN - CROIN + DRISK) / (1 - (1/(1 + ROIN - CROIN + DRISK)))^{**}DPLN / (1 - TxRt)$$

Where:

DIVTC(Tech, Area) 'Device Investment Tax Credit (\$/\$)'

DPIVTC(Tech, Area) 'Device Investment Tax Credit (\$/\$)'

DPLN(Enduse, Tech, EC, Area) 'Physical Life of Equipment (Years)'

DRISK(Enduse, Tech) 'Device Excess Risk (\$/\$)'

DTL(Enduse, Tech, EC, Area) 'Device Tax Life (Years)'

InSm 'Smoothed Inflation Rate (\$/Yr/\$)'

ROIN(EC, Area) 'Return on Investment (\$/Yr/\$)'

CROIN(Enduse,Tech,EC,Area) 'Conservation Return on Investment (\$/Yr/\$)'
TxRt(EC,Area) 'Tax Rate on Energy Consumer (\$/\$)'

Calculate Device Efficiencies & Capital Costs

The device efficiencies selected in the model are based on local fuel prices. As fuel prices rise, consumers will select higher efficiency devices, although not at the optimum level. The level of device efficiency selected, and other factors, has an associated capital cost that becomes the device capital cost.

ENERGY 2020 uses tables to determine device efficiencies selected at different price levels. Given fuel prices and emission costs, marginal energy efficiencies and capital costs for devices are determined using efficiency/cost trade-off curves based on consumer preferences. When energy prices increase, energy consumers could reduce their energy bills by purchasing more efficient devices or homes which use less energy (e.g. a more efficient furnace or more wall insulation). The increase in efficiency requires added equipment, design quality, or materials unless the response is to lose energy service (e.g. turn back the thermostat). DMARGINAL deals only with the increased efficiency of devices. CMARGINAL determines process efficiency in a similar manner. The consumer response of “cutting back” is addressed in UTILIZE.

Developing a trade-off curve between efficiency and capital costs begins with the identification of the upper bound on efficiency set by current technology. The technology upper bound can be raised through research and development until theoretical thermal efficiencies are reached. The rest of the curve represents the minimum cost of using energy for each efficiency level, done balancing the capital and operating costs of each device against its efficiency level and fuel costs. The values for the efficiency (DEE) and capital cost (DCC) curves are interpolated based on input values.

As fuel costs increase, total energy use costs can be minimized by increasing the energy efficiency even though higher efficiency requires equipment with a higher capital cost. The trade-off can be as a market share calculation where the “share” is the fraction of the maximum efficiency. The perceived costs of higher efficiency both by the manufacturer and the consumer determine the shape of the efficiency curve.

The marginal device efficiency (DEE) is determined by the relative energy price (ECFP,DFPN) and the device efficiency curve parameters (DEM,DFTC). Changes in the device capital charge rate (DCCRB, DCCR) use an assumed Cobb-Douglas substitution from Capital. The device efficiency multiplier (DEMM), the domestic grant fraction (DGF) and the device price multiplier (DEPM) are policy variables. The level of efficiency using only energy price is calculated below:

$$DEEPrice=DEM*DEMM*(1/(1+(ECFP/Infla*DEPM/DFPN)**DFTC*(1-DGF)*((1+STX)/(1+STXB))*(DCCR/DCCRB)))$$

where:

DEEPrice(Enduse,Tech,EC,Area) 'Device Efficiency from Energy Price (Btu/Btu)'
DEM(Enduse,Tech,EC,Area) 'Maximum Device Efficiency (Btu/Btu)'
DEMM(Enduse,Tech,EC,Area) 'Maximum Device Efficiency Multiplier (Btu/Btu)'
DEPM(Enduse,Tech,EC,Area) 'Device Energy Price Multiplier (\$/\$)'

DFPN(Enduse,Tech,EC,Area) 'Normalized Fuel Price (\$/mmBtu)'
DFTC(Enduse,Tech,EC,Area) 'Device Fuel Trade Off Coefficient (DLESS)'
DGF(Enduse,Tech,EC,Area) 'Domestic Grant Fraction (\$/\$)'
STX(Area) 'Sales Tax Rate on Energy Consumer (\$/\$)'
STXB(Area) 'Sales Tax Rate on Energy Consumer (\$/\$)'
DCCR(Enduse,Tech,EC,Area) 'Device Capital Charge Rate (\$/Yr/\$)'
DCCRB(Enduse,Tech,EC,Area) 'Base Case Device Capital Charge Rate (\$/Yr/\$)'

The level of efficiency can also be estimated by adding the cost of emissions as a modifier to energy prices depending on model parameters as follows

$$DEEPoll = DEM * DEMM * DEMMM * (1 / (1 + ((ECFP - PCostTech) / Infla * DEPM / DFPN) ** DFTC * (1 - DGF) * ((1 + STX) / (1 + STXB)) * (DCCR / DCCRB)))$$

where:

DEEPoll(Enduse,Tech,EC,Area) 'Device Efficiency from Pollution Price (Btu/Btu)'
DEMMM(Enduse,Tech,EC,Area) 'Device Efficiency Multiplier for Efficiency Program (Btu/Btu)',

Depending on model parameters, device efficiency (DEE) is set equal to DEEPrice, DEEPoll, or the higher of the two values. A further constraint on device efficiency (DEE) may be encountered. The equation below indicates that the final device efficiency (DEE) is the maximum (XMAX) of the computed efficiency and any the device efficiency standard (DESTD) in place. If the standard is effective, DEE will increase (i.e. the standard forces customers to choose higher levels of device efficiency than they would have given the current set of prices and capital costs.) DESTD is the variable the model uses to incorporate existing standards. DESTDP is for testing policies that include new standards.

$$DEEPrice = xmax(DEEPrice, DESTd, DESTdP, (DEEPrior * FZNDEE))$$

$$DEEPoll = xmax(DEEPoll, DESTd, DESTdP, (DEEPrior * FZNDEE))$$

where:

DESTd(Enduse,Tech,EC,Area) 'Device Efficiency Standards (Btu/Btu)'
DESTdP(Enduse,Tech,EC,Area) 'Device Efficiency Standards Policy (Btu/Btu)'
FZNDEE(Area) 'Frozen Device Efficiency'

The device capital cost (DCC) is computed based on the level of efficiency selected. The relationship between the normalized device capital cost (DCCN), the efficiency curve parameters, and device capital cost trade off coefficient (DCTC) is used to develop the capital cost. A multiplier on capital costs that calculates non-efficiency related price changes is included (such as ice makers in refrigerators -DCMM) and sales tax is also accounted for (1+STX).

$$DCCPrice = DCCN * DCMM * (DEM * DEMM / DEEPrice - 1) ** (1 / DCTC) * (1 + STX) * (1 - DGF) * Infla$$

where:

DCCPrice(Enduse,Tech,EC,Area) 'Device Capital Cost from Energy Price (\$/mmBtu/Yr)'
DCCN(Enduse,Tech,EC,Area) 'Normalized Device Capital Cost (\$/mmBtu)'
DCMM(Enduse,Tech,EC,Area) 'Capital Cost Maximum Multiplier (\$/\$)'
DCTC(Enduse,Tech,EC,Area) 'Device Cap. Trade Off Coefficient (DLESS)',
STX (YEAR): Sales Tax Rate on Energy Consumer (\$/\$)

Similar to device efficiency, the impact of pollution costs can be used as an input for developing the marginal capital cost.

$$DCCPoll = DCCN * DCMM * DCMMM * (DEM * DEMM * DEMMM / DEEPoll - 1) ** (1 / DCTC) * (1 + STX) * (1 - DGF) * Infla$$

where:

$DCCPoll(Enduse, Tech, EC, Area)$ 'Device Capital Cost from Pollution Price (\$/mmBtu/Yr)',
 $DCMMM(Enduse, Tech, EC, Area)$ 'Device Cost Efficiency Multiplier for Efficiency Program (\$/\$)'

Calculate Device Operation and Maintenance Costs

Each device has a cost to operate and maintain it over its lifetime. This is computed on an annual basis as some fraction (DOCF) of the total cost of the device (DCC). More expensive devices are assumed to have more expensive operation and maintenance costs associated with them.

The calculation for Device Operation and Maintenance Costs (DOMC) is:

$$DOMC = DOCF * DCC * ((1 + STXB) / (1 + STX)) / (1 - DGF)$$

where:

$DOMC(Enduse, Tech, EC, Area)$ 'Device Operating Cost (\$/mmBtu)'
 $DOCF(Enduse, Tech, EC, Area)$ 'Device Operating Cost Fraction (\$/Yr/\$)'

Calculate Marginal Fuel Cost

Each specific demand for energy is associated with a stock of capital. Investment in each type of capital stock by fuel type is allocated according to the cost of using each type of fuel. This cost is the perceived cost to the user and includes a risk factor (incorporated in the calculation of DCCR), annualized capital costs (DCCR*DCC), operating and maintenance costs (DOMC), any possible indirect costs (ldrtCost), and delivered marginal fuel costs (EFCP/DEE).

The marginal cost of using energy (MCFU) includes the cost of using energy for all end-uses. As such, a house that has a gas furnace but an electric water heater would be represented partially in the model's gas capital stock and partially in the electric capital stock. The investment includes capital using energy in addition to the energy source equipment.

MCFU is then used to determine process efficiencies (PEE) and the marginal market share (MMSF) of each fuel with regard to new capital additions.

$$MCFU = DCCR * DCC + DOMC + EFCP / DEE + ldrtCost * Infla$$

where:

$MCFU(Enduse, Tech, EC, Year)$: Marginal Cost of Fuel Use (\$/MBTU or \$/GJ)
 $ldrtCost(Enduse, Tech, EC, Area)$ 'Indirect Costs (\$/mmBtu)'

Procedure DDSM: Device Demand Side Management Programs

This procedure simulates the consumer response (DEER) to a demand side management program (rebate, standard or interest reduction) and its effects on device efficiency (DEE) and capital costs (DCC).

Calculate the Device Capital Charge Rate with an Incentive

The device efficiency, device capital cost and device capital charge rate before the incentive programs (DCC,DCCR) are saved (and renamed to DCCB and DCCBefore, respectively) to use for before and after comparisons.

$$\begin{aligned} \text{DCCB} &= \text{DCC} \\ \text{DCCBefore} &= \text{DCCR} \end{aligned}$$

The device capital charge rate with incentives (DCCRU) is very similar to the device capital charge rate without incentives (DCCR). It annualizes device capital expenses (over the life of the device - DTL), accounting for taxes (TXRT), investment tax credits plus any policy investment tax credits (DIVTC+DPIVTC), and return of principal and on investment (including interest on loans minus any subsidy (ROIN-CROIN), risk premiums and inflation: $1+(\text{ROIN-CROIN})+\text{DRISK}+\text{INSM}$). $(1-1/(1+(\text{ROIN-CROIN})+\text{DRISK}))^{**}\text{DPLN})/(1-\text{TXRT})$ is the classical capital recovery term, with the additional term (CROIN) accounting for any interest subsidy. The $(1-\text{TXRT})$ term at the end converts the after tax calculation into before tax dollars. Investment tax credits (including policy tax credits -DIVTC+DPIVTC) reduce the cost of the facility by the tax credit after the first year of operation using nominal dollars. Therefore the value of the tax credit is $((\text{DIVTC}+\text{DPIVTC})/(1+(\text{ROIN-CROIN})+\text{DRISK}+\text{INSM}))$. Depreciation is modeled as a current dollar phenomena which does not account for inflation. Therefore the net present value of the energy is calculated with the nominal rate of return: $(2/\text{DTL})/((\text{ROIN-CROIN})+\text{DRISK}+\text{INSM}+2/\text{DTL})$. It shows up as an additional negative term in the capital cost modifiers of DCCR because depreciation is a benefit (negative cost).

Device capital costs (DCC) are multiplied by the DCCRU to get the annualized cost of the device when incentives are present used in computing market share calculations.

The formula for calculating the device capital charge rate when subsidies are present is:

$$\text{DCCRU} = \frac{(1 - (\text{DIVTC} + \text{DPIVTC}) / (1 + \text{ROIN} - \text{CROIN} + \text{DRISK} + \text{INSM}) - \text{TXRT} * (2 / \text{DTL}) / (\text{ROIN} - \text{CROIN} + \text{DRISK} + \text{INSM} + 2 / \text{DTL})) * (\text{ROIN} - \text{CROIN} + \text{DRISK}) / (1 - (1 / (1 + \text{ROIN} - \text{CROIN} + \text{DRISK}))^{**}\text{DPLN}) / (1 - \text{TXRT})$$

Calculate Device Efficiencies and Capital Costs with Incentives

The device capital cost (DCC) must be increased because the consumer is paying less interest so he can purchase a more expensive device for the same money. The Device Capital Cost multiplier (DCCM) captures the income effect of the difference between the capital charge rate before (DCCBefore) and after (DCCRU) the incentive programs.

$$\text{DCCM} = \text{DCCRU} / \text{DCCBefore}$$

where:

$$\text{DCCM}(\text{TECH}): \text{ Device Capital Charge Rate Multiplier } ((\$/\text{YR})/\$)$$

The device efficiency (DEE) is determined by the efficiency curves and the capital cost (DCC) including rebate (DCCU). A capital cost incentive increase the actual capital related expenses in that the utility picks up the ADDED cost while the customer spends the same amount of money to get a better device. For each dollar level, more efficiency can be purchased.

Calculate Consumer Response to Incentive Programs

An exogenous consumer response fraction (XDEER) to incentive programs can be specified and used to recalculate device efficiency and capital costs as follows.

$$\begin{aligned} \text{DEER} &= \text{XDEER} \\ \text{DEE} &= \text{DEE} * (1 - \text{XDEER}) + \text{DEEP} * \text{XDEER} \\ \text{DOMC} &= \text{DOCF} * \text{DCC} \\ \text{MCFU} &= \text{DCCR} * (\text{DCC} - \text{DCCU} * \text{DEER}) + \text{DOMC} + \text{ECFP} / \text{DEE} + \text{IdrtCost} * \text{Infla} \end{aligned}$$

where:

$$\text{XDEER}(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}) \text{ 'Exogenous Policy Participation Response (Btu/Btu)'}$$

The device capital cost (DCC) is computed to include the impact of the device efficiency. The technology multiplier effect is removed from DEE (DEE/DEMM) before the table is used. A multiplier on capital costs that captures non-efficiency related price changes is included (such as ice makers in refrigerators -DCMM) and sales tax is also accounted for (1+STX).

$$\begin{aligned} \text{DCC} &= \text{DCC} * (1 - \text{XDEER}) + (\text{DCCP} * \text{Infla}) * \text{XDEER} \\ \text{DCCR} &= (\text{DCCBefore} * (1 - \text{DEER})) + (\text{DCCRU} * \text{DEER}) \end{aligned}$$

where:

$$\text{DEER}(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}) \text{ 'Policy Participation Response (Btu/Btu)'}$$

Calculate Device Operation and Maintenance Costs

Each device has a cost to operate and maintain it over its lifetime. This is computed on an annual basis as some fraction (DOCF) of the total cost of the device (DCC). More expensive devices are assumed to have more expensive operation and maintenance costs associated with them.

The calculation for Device Operation and Maintenance Costs (DOMC) is:

$$\text{DOMC} = \text{DOCF} * \text{DCC}$$

Calculate Marginal Fuel Cost

Each specific demand for energy is associated with a stock of capital. Investment in each type of capital stock by fuel type is allocated according to the cost of using each type of fuel. This cost is the perceived cost to the user and includes a risk factor (incorporated in the calculation of DCCR), annualized capital costs (DCCR*DCC), operating and maintenance costs (DOMC), and delivered marginal fuel costs (ECFP/DEE).

With the addition of an incentive, two other terms are needed. DCCU is the amount of rebate being offered. It is subtracted from the capital cost (DCC) after it is modified by the DEER - the policy participation response rate that indicates what fraction of those purchasing a device will select the rebated device and participate in the rebate program.

For example, a 100% participation rate (DEER=1) would reduce the term in the brackets to (DCC-DCCU).

The marginal cost of using energy (MCFU) includes the cost of using energy for all end-uses. As such, a house that has a gas furnace but an electric water heater would be represented partially

in the model's gas capital stock and partially in the electric capital stock. The investment includes capital using energy in addition to the energy source equipment.

MCFU is then used to determine process efficiencies (PEE) and the marginal market share (MMSF) of each fuel with regard to new capital additions.

$$MCFU = DCCR * (DCC - DCCU * DEER) + DOMC + ECFP / DEE + IdrtCost * Infla$$

7.3. Process Efficiency and Capital Costs Procedures

Procedure CMarginal: Process Efficiency and Capital Costs

In this procedure, the marginal process efficiencies (PEE) and capital costs (PCC), cost of fuel use (MCFU) and the process capital charge rate (PCCR) are computed.

Calculate Process Capital Charge Rate

The process capital charge rate is the annualization of process capital expenses (over the life of the process capital - PETL), accounting for taxes (TXRT), tax credits (PIVTC), and return of principal and on investment (including and inflation: $1 + ROIN - CROIN + INSM$). $(1 - (1 / (1 + ROIN - CROIN)))^{**} PEPLN / (1 - TXRT)$ is the classical capital recovery term. The $(1 - TXRT)$ term at the end converts the after tax calculation into before tax dollars. Investment tax credits reduce the cost of the facility by the tax credit after the first year of operation using nominal dollars. Therefore the value of the tax credit is $(PIVTC / (1 + ROIN - CROIN + INSM))$. Depreciation is modeled as a current dollar phenomena which does not account for inflation. Therefore the net present value of the energy is calculated with the nominal rate of return: $(2 / PETL) / (ROIN - CROIN + INSM + 2 / PETL)$. It shows up as an additional negative term in the capital cost modifiers of PCCR because depreciation is a benefit (negative cost).

Process capital costs (PCC) are multiplied by the PCCR to get the annualized cost of the process capital used in computing market share calculations.

$$PCCR = (1 - PIVTC / (1 + ROIN - CROIN + INSM) - TXRT * (2 / PETL) / (ROIN - CROIN + INSM + 2 / PETL)) * (ROIN - CROIN) / (1 - (1 / (1 + ROIN - CROIN)))^{**} PEPLN / (1 - TXRT)$$

Where:

$$PCCR(Enduse, Tech, EC, Area) \quad 'Process \text{ Capital Charge Rate } (\$/Yr/\$)'$$

$$PEPL(Enduse, Tech, EC, Area) \quad 'Physical \text{ Life of Process Requirements (Years)'$$

$$PETL(Enduse, Tech, EC, Area) \quad 'Tax \text{ Life of Process Requirements (Years)'$$

Calculate Process Efficiency & Capital Cost

The marginal process efficiency (PEE) is determined by the marginal fuel cost price (MCFU, PFPN) and the process efficiency curve parameters (PEM, PFTC). Changes in the process capital charge rate (PCCRB, PCCR) use an assumed Cobb-Douglas substitution from Capital. The process

efficiency multiplier (PEMM) and the process price multiplier (PEPM) are policy variables. The level of efficiency using only marginal fuel cost is calculated below.

$$PEEPrice = PEM * PEMM * (1 / (1 + (MCFU / Infla * PEPM / PFPN) ** PFTC * (PCCR / PCCRB)))$$

where:

PEEPrice(Enduse, Tech, EC, Area) 'Process Efficiency (\$/Btu)'
PEM(Enduse, EC, Area) 'Maximum Process Efficiency (\$/mmBtu)'
PEMM(Enduse, Tech, EC, Area) 'Process Efficiency Max. Mult. (\$/Btu/(\$/Btu))'
PEPM(Enduse, Tech, EC, Area) 'Process Energy Price Mult. (\$/\$)'
PFPN(Enduse, Tech, EC, Area) 'Process Normalized Fuel Price (\$/mmBtu)'
PFTC(Enduse, Tech, EC, Area) 'Process Fuel Trade Off Coefficient',

The level of efficiency can also be estimated by adding the cost of emissions as a modifier to energy prices depending on model parameters as follows

$$PEEPoll = PEM * PEMM * PEMMM * (1 / (1 + ((MCFU - PCostTech / DEE) / Infla * PEPM / PFPN) ** PFTC * (PCCR / PCCRB)))$$

where:

PEEPoll(Enduse, Tech, EC, Area) 'Process Efficiency from Pollution Price (\$/Btu)',
PEMMM(Enduse, Tech, EC, Area) 'Process Efficiency Multiplier for Efficiency Program (\$/Btu/(\$/Btu))',

Process efficiency can also be calculated as a function of the change in marginal fuel cost and a pre-defined price elasticity.

$$PEEElas = PEM * PEMM * (1 / (1 + (MCFU / Infla / MCFU0) ** PEElas))$$

where:

PEEElas(Enduse, Tech, EC, Area) 'Process Efficiency from Long Term Price Elasticity (\$/Btu)'
PEElas(Enduse, Tech, EC, Area) 'Long Term Price Elasticity for Process Efficiency (\$/Btu)'

Depending on model parameters, process efficiency (PEE) is set equal to PEEPrice, PEEPoll, the higher of the two values, or the elasticity efficiency. A further constraint on process efficiency (PEE) may be encountered. The equation below indicates that the final process efficiency (PEE) is the maximum (XMAX) of the computed efficiency and any the process efficiency standard (PESTD) in place. If the standard is effective, PEE will increase (i.e. the standard forces customers to choose higher levels of process efficiency than they would have given the current set of prices and capital costs.) PESTD is the variable the model uses to incorporate existing standards. PESTDP is for testing policies that include new standards.

$$PEEPrice = xmax(PEEPrice, PESTd, PESTdP)$$

$$PEEPoll = xmax(PEEPoll, PESTd, PESTdP)$$

$$PEEElas = xmax(PEEElas, PESTd, PESTdP)$$

where:

PEStd(Enduse, Tech, EC, Area) 'Process Efficiency Standards (Btu/Btu)'
PEStdP(Enduse, Tech, EC, Area) 'Process Efficiency Standards Policy (Btu/Btu)'

The process capital cost (PCC) is computed based on the level of efficiency selected. The relationship between the normalized process capital cost (PCCN), the process efficiency curve parameters, and process capital cost trade off coefficient (PCTC) is used to develop the capital cost.

$$PCCPrice = PCCN * PCCMM * Infla * (1 + STX) * (PEM * PEMM / PEEPrice - 1) ** (1 / PCTC)$$

where:

$PCCPrice(Enduse, Tech, EC, Area)$ 'Process Capital Cost from Energy Price (\$/(\$/yr))'

$PCCN(Enduse, Tech, EC, Area)$ 'Normalized Process Capital Cost (\$/mmBtu)'

$PCTC(Enduse, Tech, EC, Area)$ 'Process Capital Trade Off Coefficient (DLESS)'

Similar to process efficiency, the impact of pollution costs can be used as an input for developing the marginal capital cost.

$PCCPoll = PCCN * PCCMM * PCMMM * Infla * (1 + STX) * (PEM * PEMM * PEMMM / PEEPoll - 1) * (1 / PCTC)$

where:

$PCCPoll(Enduse, Tech, EC, Area)$ 'Process Capital Cost from Pollution Price (\$/(\$/yr))'

$PCMMM(Enduse, Tech, EC, Area)$ 'Process Cost Efficiency Multiplier for Efficiency Program (\$/\$)'

The air conditioning process efficiency (PEE(AC)) is based on the space heating process efficiency (PEE(HEAT)), the heating-to-cooling ratio (CHR), the heating-to-cooling ratio multiplier (CHRM), and the process efficiency multipliers (PEMM, PEMMM) weighted by the process energy requirement (PEM).

For residential and commercial air conditioning:

$PEE(AC, Tech, EC, Area) = \frac{\sum(TE)(PEE(Heat, TE, EC, Area) * PER(Heat, TE, EC, Area))}{\sum(TE)(PER(Heat, TE, EC, Area)) / (CHR(EC, Area) * CHRM(EC, Area)) * PEMM(AC, Tech, EC, Area) * PEMMM(AC, Tech, EC, Area)}$

where:

$PER(Enduse, Tech, EC, Area)$ 'Process Energy Requirement (mmBtu/YR)'

$CHR(EC, Area)$ 'Cooling to Heating Ratio (Btu/Btu)'

$CHRM(EC, Area)$ 'Cooling to Heating Ratio Multiplier'

7.4. Energy Stock Changes Procedures

Procedure MStock: Marginal Stock Changes

This procedure calculates end-use saturations (using electricity or weighted-average as the reference fuel), and process and device energy additions.

End-Use Saturations

This formula captures the non-price induced asymptotic saturation of devices. The Device Saturation (DST) is some fraction of the maximum device saturation (DSTM). This fraction is determined by the existing level of device saturation modified by changes in the marginal costs of using each fuel ((MCFU/INFLA/PEE)/(MCFU0/INFLA/PEE0) - both changes in device efficiency and fuel price changes are captured here) and income effects (DSTI*(STCO/SPOP)/(STCO0/SPOPO)) The income effects on the device saturation depend on the ratio of current and last period total output capacity per person.

$DST = DSTM / (1 + \exp(DST0 + DSTP * \ln((MCFU/INFLA/PEE)/(MCFU0/INFLA/PEE0)) + DSTI * (SPC/SPOP)/(SPC0/SPOPO)))$

where:

DST(ENDUSE,EC,YEAR): Device Saturation (BTU/BTU or J/J)
DSTO(ENDUSE,EC,YEAR): Device Saturation (BTU/BTU or J/J)
DSTI(ENDUSE,EC): Device Saturation Income Utility (\$/\$)
DSTM(ENDUSE,EC): Maximum Device Saturation (BTU/BTU or J/J)
DSTP(ENDUSE,EC): Device Saturation Price Utility (\$/\$)
INFLA(YEAR): Inflation Index (\$/\$)
MCFU(ENDUSE,TECH,EC,YEAR): Marginal Cost of Fuel Use (\$/MBTU or \$/GJ)
MCFUO(ENDUSE,TECH,EC,FIRST): Marginal Cost of Fuel Use (\$/MBTU or \$/GJ)
PEE(ENDUSE,TECH,EC,YEAR): Marginal Process Efficiency (\$/BTU or \$/J)
PEEO(ENDUSE,TECH,EC,FIRST): Marginal Process Efficiency (\$/BTU or \$/J)
SPOP(EC,YEAR): Population (MILLIONS)
SPOPO(EC,FIRST): Population (MILLIONS)
SPC(EC): Total Production Capacity (M\$/YR)
SPCO(EC): Total Production Capacity (M\$/YR)

Production capacity is associated with a service or process energy requirement. The process energy requirement (PER) is the delivered process energy needed to produce the output implied by the capital output. The device energy requirement (DER) represents the energy needed by furnaces, for example to provide a process energy requirement. The production capacity (PC) last from 45 to 60 years. The devices which serve those stocks only last 15 to 20 years. Therefore the model separates the capital stock and their process requirements (EUPC, PER) into three age classes or vintages: new, middle, and old. As the stock passes from one age class to another, the devices which serve it are replaced. Therefore the device efficiency can change more often than the process efficiency.

Stock Life-Cycle Dynamics - Capital Stock Failure/Wear-out

Capital stock is retired (EUPCRPC) depending on the lifetime (PCPL) specified. If the lifetime is 30 years, then 1/30 of the capital stock (EUPC) is retired each year.

$$EUPCRPC(EU,TE,A,EC,Area)=EUPC(EU,TE,A,EC,Area)/((\text{sum}(ECC)(PCPL(ECC,Area))*ECCMap(EC,ECC))/\text{sum}(ECC)(ECCMap(EC,ECC)))/3$$

where:

EUPCRPC(Enduse,Tech,Age,EC,Area) 'Production Capacity Retirements from Capacity Retirements (M\$/Yr/Yr)'

EUPC(Enduse,Tech,Age,EC,Area) 'Production Capacity by Enduse (M\$/Yr)'

PCPL(ECC,Area) 'Physical Life of Production Capacity (Years)'

Stock Life-Cycle Dynamics - Changes in Stock Due to New Stock Growth

Capital Additions (EUPCAPC) by technology and economic class are calculated by dividing the production capacity additions (PCA) by the market share fractions for each economic class and fuel.

$$EUPCAPC(EU,TE,New,EC,Area)=\text{sum}(ECC)(PCA(New,ECC,Area)*ECCMap(EC,ECC))*MMSF(EU,TE,EC,Area)$$

Capital is “aged” by moving it into different vintages. The “retired” capital from one age category becomes the “new” capital in the next vintage:

Select Age(Mid,Old)

$$EUPCAPC(EU,TE,A,EC,Area)=EUPCRPC(EU,TE,A-1,EC,Area)$$

where:

$EUPCAPC(Enduse, Tech, Age, EC, Area)$ 'Production Capacity Additions from New Production Capacity (M\$/Yr/Yr)'

$MMSF(Enduse, Tech, EC, Area)$ 'Market Share Fraction by Device (\$/\$)'

$PCA(AGE, ECC, YEAR)$: Production Capacity Additions ((M\$/YR)/YR)

New Process Additions from Changes in Device Saturation

Every increase in device saturations will result in process additions equal to total production capacity (EUPC) less production capacity retirements (EUPCRPC). For example, an increase in the saturation of air conditioners will produce an increase in energy requirements for AC cooling without any increase in housing. The additional process requirements are calculated as the difference between saturation in current period (DST) and the device saturation in the previous period (DSTL) over the average process efficiency average (PEEA)

$$PERADST(EU, TE, EC, Area) = (\text{sum}(Age)(EUPC(EU, TE, Age, EC, Area)) - EUPCRPC(EU, TE, Old, EC, Area)) * \text{xmax}(0, (DST(EU, EC, Area) - DSTL(EU, EC, Area))) / PEEA(EU, TE, EC, Area)$$

where:

$PERADST(Enduse, Tech, EC, Area)$ 'Process Additions from Increases in Saturation (mmBtu/Yr/Yr)'

$PEEA(Enduse, Tech, EC, Area)$ 'Average Process Efficiency (\$/Btu)'

$DST(Enduse, EC, Area)$ 'Device Saturation (Btu/Btu)'

Process Retirements from Changes in Device Saturation

Similar to the above equation, a decrease in device saturation compared to the previous period will retire process requirements.

$$PERRDST(EU, TE, EC, Area) = (\text{sum}(Age)(EUPC(EU, TE, Age, EC, Area)) - EUPCRPC(EU, TE, Old, EC, Area)) * \text{xmax}(0, (DSTL(EU, EC, Area) - DST(EU, EC, Area))) / PEEA(EU, TE, EC, Area)$$

where:

$PERRDST(Enduse, Tech, EC, Area)$ 'Process Retire. from Reductions in Saturation (mmBtu/Yr/Yr)',

New Process Additions from Capital Additions

Every new capital addition (EUPCAPC) causes a fuel-specific service energy requirement (PERAPC). This requirement is modified by the device saturation and divided by the marginal process energy efficiency (dollars of output per service energy input).

$$PERAPC(EU, TE, EC, Area) = EUPCAPC(EU, TE, New, EC, Area) * DST(EU, EC, Area) / PEE(EU, TE, EC, Area)$$

where:

$PERAPC(Enduse, Tech, EC, Area)$ 'Process Additions from Production Capacity Additions (mmBtu/Yr/Yr)'

Process Energy Retirements Due to Capital Retirements

Process retirements due to capital retirements are accounted the process energy removed due to the retired capital (EUPCRPC/PEEA - note the use of average efficiency and not marginal) modified by the device saturation as of the last period (DSTL).

$$PERRPC(EU, TE, EC, Area) = EUPCRPC(EU, TE, Old, EC, Area) * DSTL(EU, EC, Area) /$$

PEEA(EU,TE,EC,Area)

where:

$PERRPC(Enduse,Tech,EC,Area)$ 'Process Retire. from Production Capacity Retire. (mmBtu/Yr/Yr)'

Device Retirements Due to Process Retirements and Changes in Device Saturation

When capital stock is retired, the devices are retired as well. The process energy requirements (PERRPC) eliminated due to capital stock retirements and process energy retirements from change in device saturation are divided by the average device efficiency (DEEA) to produce the device energy requirement (DERRPC) than is eliminated as well.

$DERRPC=(PERRPC+PERRDST)/DEEA$

where:

$DERRPC(Enduse,Tech,EC,Area)$ 'Device Retire. from Production Capacity Retirements and Reductions in Device Saturation (mmBtu/Yr/Yr)'

$DEEA(Enduse,Tech,EC,Area)$ 'Average Device Efficiency (Btu/Btu)'

Device Replacements Due to Process Additions and Changes in Device Saturation

New devices are added to meet the needs of additions to process and increases in device saturations. Note that equation below uses marginal device efficiency (DEE) since the requirements are being met by new devices

$DERAPC=(PERAPC+PERADST)/DEE$

where:

$DERAPC(Enduse,Tech,EC,Area)$ 'Device Additions from PCap Additions & Increases in Device Saturation (mmBtu/Yr/Yr)',

Changes in Process Stock Due to Normal Failures and Replacement

In addition to process retirements, some stock is replaced due to process failure. Process failure or wear-out (PERRP) is calculated as the process energy requirement (PER) less capital and saturation retirements (PERRPC,PERRDST) divided by the process capital lifetime (PEPL).

$PERRP=(PER-PERRPC-PERRDST)/PEPL$

where:

$PERRP(Enduse,Tech,EC,Area)$ 'Process Retire. from Process Retire. (mmBtu/Yr/Yr)'

Process Replacement with New Efficiency

Retired process requirements from aging are replaced by new stock using the marginal process efficiency (PEE). If the marginal efficiency is greater than the average (PEEA) then process requirements will fall (the replacement stock will be more efficient than the existing stock).

$PERAP=PERRP*PEEA/PEE$

where:

$PERAP(Enduse,Tech,EC,Area)$ 'Process Additions from Process Retire. (mmBtu/Yr/Yr)'

Device Retirements Due to Changes in Process Stock Aging

Devices are retired if the process retirements (PERRP) from aging are greater than the process additions (PERAPC) at the level of existing stock efficiency (DEEA). If additions are greater than retirements then no devices are replaced due to process aging.

$$DERRP = \text{xmax}(0, (PERRP - PERAP)) / DEEA$$

where:

$$DERRP(\text{Enduse, Tech, EC, Area}) \quad \text{'Device Retire. from Process Retire. (mmBtu/Yr/Yr)'}'$$

Device Additions Due to Changes in Process Stock Aging

Similar to above, devices are added from process aging if the additions (PERAPC) are greater than the retirements (PERRP) at the level of new marginal efficiency (DEE)

$$DERAP = \text{xmax}(0, (PERAP - PERRP)) / DEE$$

where:

$$DERAP(\text{Enduse, Tech, EC, Area}) \quad \text{'Device Additions from Process Retire. (mmBtu/Yr/Yr)'}'$$

Procedure TStock: Total Stock Update

The procedure updates the total productive capacity (EUPC), the process energy requirements (PER) and the device energy requirements (DER) with additions and retirements. All three variables are calculated in the same general fashion - the difference between additions to and subtractions from existing capacity and energy requirements are added to the current respective levels.

Productive capacity is updated by summing the calculated additions and retirements and using the summed values to update the total stock

$$\begin{aligned} EUPCA &= EUPCAPC + EUPCAC \\ EUPCR &= EUPCRPC + EUPCRC \\ EUPC &= EUPC + DT * (EUPCA - EUPCR) \end{aligned}$$

where:

$$\begin{aligned} EUPC(\text{Enduse, Tech, Age, EC, Area}) & \quad \text{'Production Capacity by Enduse (M\$/Yr)'} \\ EUPCA(\text{Enduse, Tech, Age, EC, Area}) & \quad \text{'Production Capacity Additions ((M\$/YR)/YR)'} \\ EUPCR(\text{Enduse, Tech, Age, EC, Area}) & \quad \text{'Production Capacity Retirement ((M\$/YR)/YR)'} \end{aligned}$$

Process energy requirements are updated by summing the calculated additions and retirements and using the summed values to update the total stock. Note the process requirements additionally includes changes from retrofits and saturations.

$$\begin{aligned} PERA &= PERAPC + PERADST + PERAP + PERARC \\ PERR &= PERRPC + PERRDST + PERRP + PERRR + PERRRC \\ PER &= PER + DT * (PERA - PERR) \end{aligned}$$

where:

$$PERA(\text{Enduse, Tech, EC, Area}) \quad \text{'Process Energy Requirement Additions (mmBtu/Yr/Yr)'}'$$

$PERR(Enduse, Tech, EC, Area)$ 'Process Energy Requirement Retirements (mmBtu/Yr/Yr)'

Device energy requirements are updated in a similar manner as above. In this equation, process retirements from retrofits are applied directly ($PERRR/DEEA$) rather than through an intermediary variable.

$DERA = DERAPC + DERAP + DERAD$
 $DERR = DERRPC + DERRP + DERRD + DERRR + PERRR/DEEA$
 $DER = DER + DT * (DERA - DERR)$

where:

$DERA(Enduse, Tech, EC, Area)$ 'Energy Requirement Addition (mmBtu/YR)'
 $DERR(Enduse, Tech, EC, Area)$ 'Device Energy Rqmt. Retire. (mmBtu/Yr/Yr)'

Once calculated, an equation allows for the adjustment of the updated stocks with an exogenously specified policy variable ($STKADJ$). This variable can be utilized by the user to adjust stock levels for events not covered by changes in economy activity, aging, retrofitting, or conversions. As an example, the stock can be exogenously adjusted to simulate the impacts of a natural disaster.

$DERADJ(EU, TE, EC, Area) = DER(EU, TE, EC, Area) * \sum(ECC)(STKADJ(ECC, Area) * ECCMap(EC, ECC))$
 $DER = DER + DERADJ$

 $PERADJ(EU, TE, EC, Area) = PER(EU, TE, EC, Area) * \sum(ECC)(STKADJ(ECC, Area) * ECCMap(EC, ECC))$
 $PER = PER + PERADJ$

 $EUPCADJ(EU, TE, A, EC, Area) = EUPC(EU, TE, A, EC, Area) * \sum(ECC)(STKADJ(ECC, Area) * ECCMap(EC, ECC))$
 $EUPC = EUPC + EUPCADJ$

where:

$STKADJ(ECC, Area)$ 'Exogenous Capital Stock Adjustment (\$/\$)'
 $DERADJ(Enduse, Tech, EC, Area)$ 'Device Energy Rqmt. Adjustment (mmBtu/Yr/Yr)'
 $PERADJ(Enduse, Tech, EC, Area)$ 'Process Energy Rqmt. Adjustment (mmBtu/Yr/Yr)'
 $EUPCADJ(Enduse, Tech, Age, EC, Area)$ 'Production Capacity Adjustment (M\$/Yr/Yr)'

Once stocks are finalized, the average stock market share ($AMSF$) for each technology in a given sector, area, and enduse is calculated as a function of the productive capacity stock ($EUPC$).

$AMSF(EU, TE, EC, Area) = \sum(A)(EUPC(EU, TE, A, EC, Area)) / \sum(A, Tech)(EUPC(EU, Tech, A, EC, Area))$

where:

$AMSF(Enduse, Tech, EC, Area)$ 'Average Market Share (\$/\$)'

7.5. Fuel Market Shares Procedures

Procedure MShare: Marginal Fuel Market Shares

A market allocation weight (MAW) is computed for each fuel (TE) in each end-use (EU) in each economic class (EC). Summing over the fuels, a total allocation weight by (EC) and (EU) is calculated. The ratio of the MAW/TAW yields the fuel market share fraction by device for each economic class (MMSF).

Market Share Determination

ENERGY 2020 uses standard market share concepts to allocate fuels to specific end uses. Not all investment funds are allocated to the least expensive energy form. Uncertainty, regional variations and limited knowledge make the perceived price on which choices are based, a distribution. The investments allocated to any fuel type are then proportional to the fraction of times one fuel is perceived as less expensive than all others.

A market allocation weight (MAW) is computed for each fuel (TE) in each end-use (EU) in each economic class (EC). Summing over the fuels, a total allocation weight by (EC) and (EU) is calculated. The ratio of the MAW/TAW yields the market share fraction by device for each economic class (MMSF).

In the most basic terms, market share (MMSF) is determined by price [more specifically, the increase in the efficiency-adjusted real prices: $(MCFU/INFLA/PEE)/(MCFU0/INFLA0/PEE0)$] and a variance factor on perceived prices (MVF). Other adjustments to market share come from non-price factors (MMSM0), income induced buying pattern changes (MMSM1, modified by population and capital output variables), and a market potential multiplier (MSMM) that captures non-price determinants such as color or style. The natural log form of MSMM implies that it is a direct multiplier on MAW (for example, if $MSMM=0.5$, then the value of MAW is $MAW*0.5$). A final variable, the energy supply constraint multiplier, (TENMSM), can be used to represent any existing or predicted fuel supply constraints that would prevent all demand for a particular fuel from being met.

First determine each fuel market allocation weight (MAW) for each EC:

$$MAW=EXP(MMSM0+LN(MSMM)+MMSM1*(SPC/SPOP)/(SPC0/SPOP0)+MVF*LN((MCFU/INFLA/PEE)/(MCFU0/INFLA0/PEE0)))*TENMSM$$

The total market allocation weight for each EC is the individual MAWs summed over fuel:

$$TMAW(EC)=SUM(TE)(MAW(TE,EC))$$

The marginal market share fraction for each fuel for each EC is the ratio of the MAW of the particular fuel to the total (TMAW):

$$MMSF=MAW/TMAW$$

where:

MAW(TECH,EC,YEAR): Marginal Allocation Weight (\$/\$)

TMAW(EC,YEAR): Total Allocation. Weight (\$/\$)

MMSF(ENDUSE,TECH,EC,YEAR): Market Share Fraction by Device (\$/\$)

MMSM0(ENDUSE,TECH,EC,YEAR): Non-price Factors (\$/\$)
MMSMI(ENDUSE,TECH,EC): Market Share Multiplier from Income (\$/\$)
MSMM(ENDUSE,TECH,YEAR): Market Potential Multiplier
MCFU(ENDUSE,TECH,EC,YEAR): Marginal Cost of Fuel Use (\$/MBTU or \$/GJ)
MCFU0(ENDUSE,TECH,EC,FIRST): Marginal Cost of Fuel Use (\$/MBTU or \$/GJ)
MVF(ENDUSE,TECH,EC): Market Share Variance Factor (\$/\$)
INFLA(YEAR): Inflation Index (\$/\$)
INFLA0(FIRST): Inflation Index (\$/\$)
PEE(ENDUSE,TECH,EC,YEAR): Marginal Process Efficiency (\$/BTU or \$/J)
PEE0(ENDUSE,TECH,EC,FIRST): Marginal Process Efficiency (\$/BTU or \$/J)
TENMSM(TECH): Energy Supply Constraint Multiplier (BTU/BTU or J/J)
SPOP(EC,YEAR): Population (Millions)
SPOPO(EC,FIRST): Population (Millions)
SPC(EC,YEAR): Total Production Capacity (M\$/YR)
SPCO(EC,FIRST): Total Production Capacity (M\$/YR)

7.6. Retrofits and Conversions Procedures

Procedure InitRetrofits: Initialize Retrofit Variables

ENERGY 2020 allows users the option to implement retrofitting policies, where existing energy requirements operating at the stock level of energy efficiency and cost can be replaced by new requirements at a higher level of efficiency. Retrofitting can be used to improve efficiency for existing stocks during the middle of their lifespan instead of waiting for stocks to retire and be replaced by higher efficiency devices.

This procedure calculates the retrofit device and capital charge rates for use in the main RETROFIT procedure. These equations are similar to the device and process capital charge rate methodology. The equation below is used for the retrofit device capital charge rate.

$$RDCCR = \frac{(1 - (DIVTC + DRIVTC)) / (1 + ROIN - RCROIN + RRISK + \ln Sm) - TxRt * (2 / DTL) / (ROIN - RCROIN + RRISK + \ln Sm + 2 / DTL) * (ROIN - RCROIN + RRISK) / (1 - (1 / (1 + ROIN - RCROIN + RRISK)) * DPL) / (1 - TxRt)}$$

where:

RDCCR(Enduse,Tech,EC,Area) 'Device Retrofit Capital Charge Rate (\$/Yr/\$)'
DIVTC(Tech,Area) 'Device Investment Tax Credit (\$/\$)'
DRIVTC(Tech,Area) 'Device Retrofit Investment Tax Credit (\$/\$)'
lnSm 'Smoothed Inflation Rate (\$/Yr/\$)'
TxRt(EC,Area) 'Tax Rate on Energy Consumer (\$/\$)'
DTL(Enduse,Tech,EC,Area) 'Device Tax Life (Years)'
ROIN(EC,Area) 'Return on Investment (\$/Yr/\$)'
RCROIN(Enduse,Tech,EC,Area) 'Retrofit Conservation Subsidy on Return on Investment (\$/Yr/\$)'
RRISK(Enduse,Tech,Area) 'Retrofit Excess Risk (\$/\$)'
DPL(Enduse,Tech,EC,Area) 'Physical Life of Equipment (Years)'

The retrofit process capital charge rate is calculated in a similar manner as the process capital charge rate. Note that value is calculated using 50% of the lifespan value (PEPL/2).

$$RPCCR = \frac{(1 - (PIVTC + RPIVTC)) / (1 + ROIN - RCROIN + InSm) - TxRt * (4 / PETL) / (ROIN + 0 + InSm + 4 / PETL) * (ROIN - RCROIN)}{(1 - (1 / (1 + ROIN + 0))) ** (PEPL / 2)) / (1 - TxRt)}$$

where:

RPCCR(Enduse, Tech, EC, Area) 'Process Retrofit Capital Charge Rate (\$/Yr/\$)
PIVTC 'Process Policy Investment Tax Credit (\$/\$)
RPIVTC(Area) 'Process Retrofit Policy Investment Tax Credit (\$/\$),
PETL(Enduse, Tech, EC, Area) 'Tax Life of Process Requirements (Years)
PEPL(Enduse, Tech, EC, Area) 'Physical Life of Process Requirements (Years)'

The model code allows for setting the retrofit capital charge rate equations equal to a base case value if requested by the user.

Procedure Retrofit: Retrofit Efficiency and Capital Costs

Retrofits are applied to device and process efficiencies dependent on policy input variables and an execution switch (RetroSw) specified by the user. Retrofits can be applied to devices (RetroSw = 1), process (RetroSw = 2), both (RetroSw = 3), or be exogenously specified (RetroSw = 0). The default switch value in the current model is -99, which instructs the model to bypass the code in this procedure.

Device Retrofits

The following code is executed if RetroSw is equal to 1 or 3 for any given enduse, sector, or area. Marginal efficiency for retrofit devices (RDEE) is set equal to the input retrofit device efficiency standard (RDEStd)

$$RDEE = RDEStd$$

where:

RDEE(Enduse, Tech, EC, Area) 'Retrofit Device Efficiency (Btu/Btu)'
RDEStd(Enduse, Tech, EC, Area) 'Retrofit Device Efficiency Standards (Btu/Btu)'

Retrofit device capital costs (RDCC) are a function of device capital costs and the user specified retrofit device capital cost multiplier

$$RDCC = DCC * RDCCM$$

where:

RDCC(Enduse, Tech, EC, Area) 'Retrofit Device Capital Cost (\$/(\$/yr))'
DCC(Enduse, Tech, EC, Area) 'Device Capital Cost (\$/mmBtu/yr)'
RDCCM(Enduse, Tech, EC, Area) 'Retrofit Device Capital Cost Multiplier (\$/\$)'

A marginal value of device retrofits (MVDR) is calculated based on the relationship between stock device efficiency (DEEA) and the retrofit efficiency (RDEE) when including the retrofitting cost factors.

$$MVDR = (ECFP * (1 / DEEA - 1 / RDEE) - (RDCCR + DOCF + RHCM) * RDCC) / RDCC - RRISK$$

where:

$MVDR(Enduse, Tech, EC, Area)$ 'Marginal Value of Device Retrofits (\$/\$)'
 $ECFP(Tech, EC, Area)$ 'Fuel Price (\$/mmBtu)'
 $DEEA(Enduse, Tech, EC, Area)$ 'Average Device Efficiency (Btu/Btu)'
 $DOCF(Enduse, Tech, EC, Area)$ 'Device Operating Cost Fraction (\$/Yr/\$)'
 $RHCM(EC, Area)$ 'Retrofit Hassle-Cost Multiplier (\$/\$)'
 $RDCC(Enduse, Tech, EC, Area)$ 'Retrofit Device Capital Cost (\$/(\$/yr))'
 $DCC(Enduse, Tech, EC, Area)$ 'Device Capital Cost (\$/mmBtu/Yr)'

The retrofit market share fraction per device (RDMSF) is based on the relationship between stock and retrofit efficiency adjusted by the user specified device retrofit market share multiplier (RDMSM).

$$RDMSF = \text{xmax}(0, (1 / (1 + (DEEA / RDEE)) - 0.5)) / 2 * RDMSM$$

where:

$RDMSF(Enduse, Tech, EC, Area)$ 'Device Retrofit Market Share Fraction by Device (1/Yr)'
 $RDMSM(Enduse, Tech, EC, Area)$ 'Device Retrofit Market Share Multiplier (1/Yr)'

Process Retrofits

The following code is executed if RetroSw is equal to 2 or 3 for any given enduse, sector, or area. Marginal efficiency for retrofitted processes (RPEE) are set equal to the input retrofit process efficiency standard (RPEStd)

$$RPEE = RPEStd$$

where:

$RPEE(Enduse, Tech, EC, Area)$ 'Retrofit Process Efficiency (\$/BTU)'
 $RPEStd(Enduse, Tech, EC, Area)$ 'Retrofit Process Efficiency Standard (\$/Btu)'

Capital costs for retrofitted processes (RPCC) are a function of process capital costs and the user specified retrofit process capital cost multiplier

$$RPCC = PCC * RPCCM$$

where:

$RPCC(Enduse, Tech, EC, Area)$ 'Process Retrofit Capital Cost (\$/(\$/yr))'
 $PCC(Enduse, Tech, EC, Area)$ 'Process Capital Cost (\$/(\$/yr))'
 $RPCCM(Enduse, Tech, EC, Area)$ 'Retrofit Process Capital Cost Multiplier (\$/\$)'

A marginal value of process retrofitting (MVPR) is calculated based on the relationship between stock process efficiency (PEEA) and the retrofit efficiency (RPEE) when including the retrofitting cost factors.

$$MVPR = (ECFP / DEEA * (1 / PEEA - 1 / RPEE) - (RPCCR + POCF + RHCM) * RPCC) / RPCC - RRISK$$
$$RPMSF = \text{xmin}(\text{xmax}(0, (1 / (1 + (PEEA / RPEE)) - 0.5)) / 2 * RPMSM, RPMSLimit)$$

where:

$MVPR(Enduse, Tech, EC, Area)$ 'Marginal Value of Process Retrofits (\$/\$)'
 $PEEA(Enduse, Tech, EC, Area)$ 'Average Process Efficiency (\$/Btu)'
 $POCF(Enduse, Tech, EC, Area)$ 'Process Operating Cost Fraction (\$/Yr/\$)'

The retrofit market share fraction per process (RPMSF) is based on the relationship between stock and retrofit efficiency adjusted by the user specified device retrofit market share multiplier (RDMSM) and a maximum bound (RPMSLimit).

$$RPMSF = \text{xmin}(\text{xmax}(0, (1/(1+(PEEA/RPEE)) - 0.5)) / 2 * RPMSM, RPMSLimit)$$

where:

RPMSF(Enduse, Tech, EC, Area) 'Process Retrofit Market Share Fraction by Device (1/Yr)'

RPMSM(Enduse, Tech, EC, Area) 'Process Retrofit Market Share Multiplier (1/Yr)'

RPMSLimit(EC, Area) 'Process Retrofit Market Share Limit (1/Yr)'

Similar to the process efficiency calculation code, due to their linked nature an exception is made for air conditioning retrofitting efficiency to be set based on the retrofitting efficiencies for space heat.

$$RPEE(AC, Tech, EC, Area) = \text{sum}(TE)(RPEE(Heat, TE, EC, Area) * PER(Heat, TE, EC, Area)) / \text{sum}(TE)(PER(Heat, TE, EC, Area)) / (\text{CHR}(EC, Area) * \text{CHRM}(EC, Area) * RPEMM(AC, Tech, EC, Area))$$

$$RPCC(AC, Tech, EC, Area) = RPCC(Heat, Tech, EC, Area)$$

$$PFS = \text{ECFP} / \text{DEEA} * (1 / \text{PEEA} - 1 / \text{RPEE})$$

where:

PER(Enduse, Tech, EC, Area) 'Process Energy Requirement (mmBtu/YR)'

RPEMM(Enduse, Tech, EC, Area) 'Process Efficiency Max. Mult. (\$/Btu/(\$/Btu))'

CHR(EC, Area) 'Cooling to Heating Ratio (Btu/Btu)'

CHRM(EC, Area) 'Cooling to Heating Ratio Multiplier'

PFS(Enduse, Tech, EC, Area) 'Process Fuel Savings (\$/Yr)'

Exogenous Retrofits

The following code is executed if RetroSw is equal to 0 for any given enduse, sector, or area. Retrofitting parameters are directly set equal to input values specified by the user as follows:

$$RPEE = RPESd$$

$$RPEE = XRPEE$$

$$RPCC = XRPCC$$

$$RPMSF = XRPMSF$$

$$RDEE = RDEStd$$

$$RDCC = DCC$$

$$RDMSF = XRDMSF$$

where:

XRPEE(Enduse, Tech, EC, Area) 'Exogenous Retrofit Process Efficiency (\$/BTU)'

XRPCC(Enduse, Tech, EC, Area) 'Exogenous Process Retrofit Capital Cost (\$/(\$/Yr))'

XRPMSF(Enduse, Tech, EC, Area) 'Exogenous Process Retrofit Market Share Fraction by Device (1/Yr)'

XRDMSF(Enduse, Tech, EC, Area) 'Exogenous Device Retrofit Market Share Fraction by Device (1/Yr)'

Retrofitting Stock Adjustments

Any enduses that contain retrofitting use the parameters set above to adjust energy requirement stocks and costs where relevant. Process requirements are reduced based on the retrofit process market share and level of efficiency based on the current capital stock level

$$FXCO(EU,TE,EC,Area)=\text{sum}(Age)(EUPC(EU,TE,Age,EC,Area))-EUPCRPC(EU,TE,Old,EC,Area)$$

$$PERRR=RPMSF*FXCO*(1/PEEA-1/RPEE)$$

where:

XRPEE(Enduse,Tech,EC,Area) 'Exogenous Retrofit Process Efficiency (\$/BTU)'

FXCO(Enduse,Tech,EC,Area) 'Fixed Capital Output Capacity by Enduse (M\$/Yr)'

EUPC(Enduse,Tech,Age,EC,Area) 'Production Capacity by Enduse (M\$/Yr)'

EUPCRPC(Enduse,Tech,Age,EC,Area) 'Production Capacity Retirements from Capacity Retirements (M\$/Yr/Yr)'

PERRR(Enduse,Tech,EC,Area) 'Process Energy Retire. Process Retrofit ((mmBtu/Yr)/Yr)'

Device retrofitting retirements are based on the retrofit device market share and level of efficiency based on the current process requirements level.

$$DERRR=RDMSF*(PER-PERRPC)*(1/DEEA-1/RDEE)$$

where:

DERRR(Enduse,Tech,EC,Area) 'Device Energy Retire. Retrofit ((mmBtu/Yr)/Yr)'

PERRPC(Enduse,Tech,EC,Area) 'Process Retire. from Production Capacity Retire. (mmBtu/Yr/Yr)'

Conservation costs are adjusted given the costs and market share of the retrofits when accounting for rebates (RGF).

$$CONEXP=RDMSF*(PER-PERRPC)*RDCC/1E6+RPMSF*FXCO*RPCC$$

$$CONCAP=CONCAP+RDMSF*(PER-PERRPC)*(DCC-RDCC)*(1-RGF)/1E6+RPMSF*FXCO*(RPCC-RPCC)$$

$$CONADM=CONADM+ADDCST*RDMSF*(PER-PERRPC)/1E6+ADCCST*RPMSF*FXCO$$

where:

CONEXP(Fuel,Area) 'Conservation Expense (M\$/Yr)'

CONCAP(Fuel,Area) 'Capitalized Conservation Expenses (M\$/Yr)'

RGF(Enduse,Tech,EC,Area) 'Retrofit Rebate Fraction (\$/\$)'

CONADM(Fuel,Area) 'Conservation Administration Costs (M\$/Yr)'

Procedure Conversion: Device Retirements and Fuel Conversions

A device conversion (for example changing from an electric to a natural gas water heater) is a fuel choice decision. The decision to replace with a device using a different fuel is based on the relative total cost of energy service (MCFU). Policies used in this routine represent rebates. Low interest loans would require additional calculations (a CMCFU based a FDCCRU).

Market Share

If the choice is made endogenously, then it is a function of the cost of the new technology (MCFU) less the "hurdle" cost (FDCC). The hurdle cost for space heating represents the cost of ducts. These costs are "hurdle" costs in the sense that if change from electric baseboard heat to a gas furnace you must add duct work to the house.

In the most basic terms, conversion market share (CMSF) is determined by price [more specifically, the increase in the efficiency-adjusted real prices: (MCFU/INFLA/ (MCFU0/INFLA0) and a variance factor on perceived prices (CVF). Other adjustments to market share come from non-price factors (CMSM0) and income induced buying pattern changes (CMSM1, modified by population and capital output variables).

First determine each fuel market allocation weight (CMAW) for each EC:

$$CMAW = \frac{\text{EXP}(CMSM0 + CVF * \text{LN}(((MCFU - DCCR * (FDCC + FDCCU)) / INFLA) / (MCFU0 / INFLA0)) + CMSMI * (SPC / SPOP) / (SPC0 / SPOP0))}{\text{SUM}(\text{Tech})(CMAW(\text{Tech}, \text{CTech}, \text{EC}, \text{Area}))}$$

The total market allocation weight for each EC is the individual CTMAWs summed over fuel:

$$CTMAW(\text{CTech}, \text{EC}, \text{Area}) = \text{SUM}(\text{Tech})(CMAW(\text{Tech}, \text{CTech}, \text{EC}, \text{Area}))$$

The marginal market share fraction for each fuel for each EC is the ratio of the CMAW of the particular fuel to the total (CTMAW):

$$CMSF = CMAW / CTMAW$$

where:

CMAW(Tech,CTech,EC,Area) 'Conversion Alloc. Weight (\$/\$)
CTMAW(CTech,EC,Area) 'Conversion Alloc. Weight (\$/\$)
CMSF(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share Fraction by Device (\$/\$)
CMSM0(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share Multiplier (\$/\$)
CMSMI(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share Multiplier (\$/\$)
MCFU(Enduse,Tech,EC,Area) 'Marginal Cost of Fuel Use (\$/mmBtu)
MCFU0(Enduse,Tech,EC,Area) 'Marginal Cost of Fuel Use (\$/mmBtu) in First Year
CVF(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share Variance Factor (DLESS)
Infla 'Inflation Index (\$/\$)
Infla0 Inflation Index in First Year (\$/\$)
SPOP(EC,Area) 'Population (Millions)
SPOPO(EC,Area) 'Population in First Year (Millions)
SPC(EC,Area) 'Total Production Capacity (M\$/Yr)
SPCO(EC,Area) 'Total Production Capacity in First Year (M\$/Yr)
FDCC(Enduse,Tech,CTech,Area) 'Fixed Device Capital Cost (\$/(MBTU/YR))
FDCCU(Enduse,Tech,CTech,Area) 'Conversion Rebate
DCCR(Enduse,Tech,EC,Area) 'Device Capital Charge Rate (\$/Yr/\$)

The marginal market share fraction can also be specified exogenously as follows

$$CMSF = XCMSF$$

where:

XCMSF(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share by Device (\$/\$)

Procedure DeviceDynamics: Device Dynamics with Conversions

This procedure simulates the dynamics of device wear-out (DERRD) and device replacements (DERAD). When a device wears out, the device is replaced since the process energy requirements still exist. The new device has the current marginal device efficiency (DEE), while the old device is assumed to have a device efficiency equal to the average device efficiency (DEEA). The new device is normally the same technology or fuel type as the old device; however, if the "conversion" switch has been turned on, then the new device may select a different technology.

The device retirements or failures (DERRD) are equal to the device energy requirements (DER) less production capacity retirements (DERRPC) and process retirements (DERRP) divided by the average lifetime of the devices (DPL).

$$DERRD=(DER-DERRPC-DERRP)/DPL$$

where:

DERRD(Enduse,Tech,EC,Area) 'Device Retire. from Device Retire. (mmBtu/Yr/Yr)'

DER(Enduse,Tech,EC,Area) 'Energy Requirement (mmBtu/YR)'

DERRPC(Enduse,Tech,EC,Area) 'Device Retire. from Production Capacity Retirements and Reductions in Device Saturation (mmBtu/Yr/Yr)'

DERRP(Enduse,Tech,EC,Area) 'Device Retire. from Process Retire. (mmBtu/Yr/Yr)'

DPL(Enduse,Tech,EC,Area) 'Physical Life of Equipment (Years)'

If there are no conversions, then the device additions from device wear-outs (DERAD) are equal to the device retirements (DERRD) times the old (average) device efficiency (DEEA) divided by the new (marginal) device efficiency (DEE).

$$DERAD=DERRD*DEEA/DEE$$

where:

DERAD(Enduse,Tech,EC,Area) 'Device Additions from Device Retirements (mmBtu/yr)'

DEE(Enduse,Tech,EC,Area) 'Device Efficiency (Btu/Btu)'

DEEA(Enduse,Tech,EC,Area) 'Average Device Efficiency (Btu/Btu)'

If there are conversions, then the device additions from device wear-out and conversions (DERAD) are equal to the device retirements (DERRD) times the old (average) device efficiency (DEEA) times the fraction of the devices converted (CMSF) from one Technology (CTech) to another Technology (Tech) divided by the new (marginal) device efficiency (DEE).

$$DERAD(EU,Tech,EC,Area)=\sum(CTech)(DERRD(EU,CTech,EC,Area)*DEEA(EU,CTech,EC,Area)*CMSF(EU,Tech,CTech,EC,Area))/DEE(EU,Tech,EC,Area)$$

Procedure RCPCDynamics: Secondary Retrofit and Conversion Dynamics

This procedure calculates the impact on process energy requirements and production capacity from device conversions.

The process removals from conversions (PERRRC) are equal to the device replacements (DERRD) times the conversion market share (CMSF). The terms are multiplied times the average device efficiency (DEEA) to convert from device to process energy requirements.

$$PERRRC(EU,FromTech,EC,Area)=PERRRC(EU,FromTech,EC,Area)+DERRD(EU,FromTech,EC,Area)*DEEA(EU,FromTech,EC,Area)*CMSF(EU,ToTech,FromTech,EC,Area)$$

where:

PERRRC(Enduse,Tech,EC,Area) 'Process Retire. from Device Conversions ((MBTU/YR)/YR)'

DERRD(Enduse,Tech,EC,Area) 'Device Retire. from Device Retire. (mmBtu/Yr/Yr)'

DEEA(Enduse,Tech,EC,Area) 'Average Device Efficiency (Btu/Btu)'

CMSF(Enduse,Tech,CTech,EC,Area) 'Conversion Market Share Fraction by Device (\$/\$)'

The process additions from conversions (PERARC) are calculated the same as the process removals except for the index in the conversion market share variable (CMSF). The process energy requirements are simply being moved from one technology (CTech) to another (Tech)

$$\text{PERARC}(\text{EU}, \text{ToTech}, \text{EC}, \text{Area}) = \text{PERARC}(\text{EU}, \text{ToTech}, \text{EC}, \text{Area}) + \text{DERRD}(\text{EU}, \text{FromTech}, \text{EC}, \text{Area}) * \text{DEEA}(\text{EU}, \text{ToTech}, \text{EC}, \text{Area}) * \text{CMSF}(\text{EU}, \text{ToTech}, \text{FromTech}, \text{EC}, \text{Area})$$

where:

$$\text{PERARC}(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}) \text{ 'Process Additions from Device Conversions ((MBTU/YR)/YR)'$$

The production capacity "retirements" due to conversions (EUPCRC) are the process energy "retirements" due to conversions (PERRRC) times the average process efficiency (PEEA). These "retirements" are split between the vintages based on the age distribution of the production capacity (EUPC).

$$\text{EUPCRC}(\text{EU}, \text{TE}, \text{Age}, \text{EC}, \text{Area}) = \text{PERRRC}(\text{EU}, \text{TE}, \text{EC}, \text{Area}) * \text{PEEA}(\text{EU}, \text{TE}, \text{EC}, \text{Area}) * \text{EUPC}(\text{EU}, \text{TE}, \text{Age}, \text{EC}, \text{Area}) / \text{sum}(\text{V})(\text{EUPC}(\text{EU}, \text{TE}, \text{V}, \text{EC}, \text{Area}))$$

where:

$$\text{EUPCRC}(\text{Enduse}, \text{Tech}, \text{Age}, \text{EC}, \text{Area}) \text{ 'Production Capacity Retirements from Device Conversions ((M\$/YR)/YR)'$$

$$\text{PEEA}(\text{Enduse}, \text{Tech}, \text{EC}, \text{Area}) \text{ 'Average Process Efficiency (\$/Btu)'$$

$$\text{EUPC}(\text{Enduse}, \text{Tech}, \text{Age}, \text{EC}, \text{Area}) \text{ 'Production Capacity by Enduse (M\$/Yr)'$$

The production capacity "additions" due to conversions (EUPCAC) are the process energy "additions" due to conversions (PERARC) times the average process efficiency (PEEA). These "retirements" are split between the vintages based on the age distribution of the production capacity (EUPC).

$$\text{EUPCAC}(\text{EU}, \text{TE}, \text{Age}, \text{EC}, \text{Area}) = \text{PERARC}(\text{EU}, \text{TE}, \text{EC}, \text{Area}) * \text{PEEA}(\text{EU}, \text{TE}, \text{EC}, \text{Area}) * \text{EUPC}(\text{EU}, \text{TE}, \text{Age}, \text{EC}, \text{Area}) / \text{sum}(\text{V})(\text{EUPC}(\text{EU}, \text{TE}, \text{V}, \text{EC}, \text{Area}))$$

where:

$$\text{EUPCAC}(\text{Enduse}, \text{Tech}, \text{Age}, \text{EC}, \text{Area}) \text{ 'Production Capacity Additions from Device Conversions ((M\$/YR)/YR)'$$

7.7. End Use and Feedstock Demand Procedures

Procedure DmdEnduse: End-Use Demand Dynamics

This procedure calculates the new and average consumer energy budgets, average and marginal process efficiencies and end use demand. The new and average consumer budgets are used to formulate a budget induced usage multiplier for the end-use demand equation. The average and marginal process efficiencies are calculated for use in the new budget equation as well as for many other equations in the model. End use demand is used in the total demand procedure.

Budget Response

The budget constraint or response is the fuel-specific capacity utilization representing the short-term response of an energy user to rising energy prices. This response takes the form of a budget

constraint which limits how much a user can afford to pay for energy in the short-term and what temporary energy saving actions the user can take (for example, turning down the thermostat, closing off rooms, biking to work).

At any point in time a change in the cost of using energy must at first be kept within the budget. Thus, if energy costs rise 10%, the first consumer response is to cut back 10%. Efficiency changes, however, alter the amount of energy required and thus reduce the energy bill. Therefore the budget response is always less than the indicated response. After the economy and the household adjusts to the new prices, or at least the perception of them, energy use increases until the current budget matches the remembered history of the budget (called the average budget (AB)).

The current energy bill (NB - new budget) is a function of energy prices and average efficiencies. In the short run, efficiencies are constant, so a rise in energy prices causes an increase in the current energy bill, given no behavioral or capital changes.

$$NB = ECFP / INFLA * DST / (PEEA * DEEA)$$

The “average budget” is the remembered energy bill, or in system dynamics terms, the “smoothed” energy bill. It changes from year by an increment determined by the difference between the new budget, the old average budget divided by the budget averaging time, that incrementally moves the average budget toward the new budget. For example, if the new budget is \$100 more than the average budget, and the budget averaging time is equal to five years, then the average budget will increase by twenty dollars.

$$AB = AB + DT * (NB - AB) / BAT$$

where:

AB(Enduse, Tech, EC, Area) 'Average Budget (\$/\$)',
BAT: Short Term Utilization Adjustment Time (YR)
NB(Enduse, Tech, EC, Area) 'New Budget (\$/\$)'

The ratio of the current budget to the average budget, modified by a budget elasticity term (BE) creates a usage multiplier (UMS) which represents the budget response on normal demand. It also is modified by the budget multiplier derived in Procedure 14. UMS appears in the demand equation (DMD), below, representing a short term response to conservation of changing prices which exaggerates the long term response. It also causes a later recovery to “normal” conditions - the “take-back” effect where the customer returns to a more energy intensive operating style. . An example of this would be an air conditioning retrofit that does not provide the amount of expected energy savings because the consumer has turned down the thermostat to enjoy cooler rooms. ENERGY 2020 formulation captures both the up and downside dynamics.

$$UMS = (NB / AB) ** BE * BM$$

where:

UMS(Enduse, Tech, EC, Area) 'Short Term Price Response (Btu/Btu)'
BE: Budget Elasticity Factor (\$/\$)
BM(Enduse, Tech, EC, Area) 'Budget Multiplier (\$/\$)'

Average Process and Device Efficiency

Average process efficiency is calculated by multiplying the end-use production capacity for each economic class by the class device saturation divided by the process energy requirement.

$$PEEA(TE,EC)=SUM(A)(EUPC(TE,A,EC))*DST(EC)/PER(TE,EC)$$

The average device efficiency (DEEA) is simply the process energy requirements (PER) divided by the device energy requirements (DER):

$$DEEA=PER/DER$$

Endogenous End-use Demand

The final demand for energy can now be calculated. The device energy requirements (DER) are first multiplied by a short term budget constraint and by the utilization of capital stock (UMS and CUF). The budget constraint reflects the assumption that the short-term response to price fluctuations is primarily a cutback on consumption. The capital utilization considers that a factory may be equipped and ready but unless there is a demand for the product made in that factory, no energy will be needed. Another utilization factor (WCUF) represents utilization changes resulting from general economic disturbances.

Non-price impacts (CERSM) are included and capture such socioeconomic effects as reduced housing sizes, an increase in multifamily dwellings, and all-parent labor participation (leaving an empty house during the day).

Temperature sensitive load considerations are also included (DDM*TSLOAD) along with any changes in energy demand due to emissions reductions (RPEI).

$$DMD=DER*UMS*CERSM*CUF*WCUF*(DDM*TSLOAD+(1-TSLOAD))*RPEI/1E6$$

where:

$$\begin{aligned} Dmd(Enduse,Tech,EC,Area) & \text{ 'Total Energy Demand (TBtu/Yr)'} \\ CERSM(Enduse,EC,Area) & \text{ 'Capital Energy Requirement (Btu/Btu)',} \\ CUF(Enduse,Tech,EC,Area) & \text{ 'Capacity Utilization Factor (\$/Yr/\$/Yr)'} \\ WCUF(EC,Area) & \text{ 'Capacity Utilization Factor Weighted by Output'} \\ TSLoad(Enduse,EC,Area) & \text{ 'Temperature Sensitive Fraction of Load (Btu/Btu)'} \\ DDM(Enduse,Area) & \text{ 'Degree Day Multiplier (DD/DD Normal)'} \\ RPEI(Enduse,Tech,EC,Area) & \text{ 'Energy Impact of Pollution Reduction (Btu/Btu)'} \end{aligned}$$

Electric demand is further modified by in impact of demand side management programs

$$Dmd(EU,T,EC,Area)=Dmd(EU,T,EC,Area)-DSMEU(EU,EC,Area)$$

where:

$$DSMEU(Enduse,EC,Area) \text{ 'Exogenous Enduse DSM Adjustment (GWh/Yr)'}$$

Feedstock Demands

Feedstock demands are calculated as a function of total capacity output, divided by the feedstock process efficiency (FSPEE) and modified by a utilization factor.

$$FSDMD=SPC/FSPEE*WCUF$$

where:

$$\begin{aligned} FsDmd(Tech,EC,Area) & \text{ 'Feedstock Energy Demand (TBtu/Yr)'} \\ FsPEE(Tech,EC,Area) & \text{ 'Feedstock Process Efficiency (\$/mmBtu)'} \\ SPC(EC,Area) & \text{ 'Total Production Capacity (M\$/Yr)'} \end{aligned}$$

Exogenous Demands

Some demand for certain technologies or economic categories may be exogenously determined in a primarily endogenous routine. For selected technologies and/or EC's:

$$\begin{aligned} Dmd &= XDmd \\ FsDmd &= XFsDmd \end{aligned}$$

Procedure EECalculation: Impact of Energy Efficiency Programs on Demand

This procedure applies energy savings from energy efficiency programs to the model demand output and accumulates program costs

Endogenous Energy Efficiency (EE) is enduse demand (Dmd) times reduction from EE (EEImpact) times the fraction of load with EE (EESat).

$$EE=Dmd*EEImpact*EESat$$

where:

$$\begin{aligned} Dmd(Enduse,Tech,EC,Area) & \text{ 'Total Energy Demand (TBtu/Yr)'} \\ EE(Enduse,Tech,EC,Area) & \text{ 'Energy Efficiency (TBtu/Yr)'} \\ EEImpact(Enduse,Tech,EC,Area) & \text{ 'Energy Efficiency Impact (Btu/Btu)'} \\ EESat(Enduse,Tech,EC,Area) & \text{ 'Energy Efficiency Saturation (Btu/Btu)'} \end{aligned}$$

Exogenous Energy Efficiency (EE) is set equal to the exogenous input variable

$$EE=XEE$$

where:

$$XEE(Enduse,Tech,EC,Area) \text{ 'Exogenous Energy Efficiency (TBtu)'}'$$

Total Energy Efficiency costs (EECosts) are calculated using the input cost per unit (EEUCosts)

$$EECosts=EE*EEUCosts$$

where:

$$\begin{aligned} EECosts(Enduse,Tech,EC,Area) & \text{ 'Energy Efficiency Costs (\$M)'} \\ EEUCosts(Enduse,Tech,EC,Area) & \text{ 'Energy Efficiency Unit Costs (\$/mmBtu)'} \end{aligned}$$

Demand is adjusted downwards with Energy Efficiency savings

$$Dmd=Dmd-EE$$

Energy Efficiency savings and costs by global sector is accumulated

$$\begin{aligned} EEECC(F,ECC,A) &= \text{sum}(EU,T,EC)(EE(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*ECCMap(EC,ECC)) \\ EECoECC(F,ECC,A) &= \text{sum}(EU,T,EC)(EECosts(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*ECCMap(EC,ECC)) \end{aligned}$$

where:

EECC(Fuel,ECC,Area) 'Energy Efficiency (TBtu/Yr)'
DmFrac(Enduse,Fuel,Tech,EC,Area) 'Energy Demands Fuel/Tech Split (Btu/Btu)'
ECCoECC(Fuel,ECC,Area) 'Energy Efficiency Costs (\$M)'

7.8. Cogeneration Demand Procedures

Procedure CogenerationSector: Cogeneration Potential and Demand by Sector

Traditionally, the industrial sector met its electricity requirements entirely with purchases from a utility. Now the industrial sector, as well as other sectors, can meet some or all of their electricity needs by converting some of its waste heat into usable electric energy when economics warrant such an action. ENERGY 2020 considers cogeneration to be self-generation - generation for own use only. Customers who sell power are considered small power producers and are simulated in the supply sector.

This procedure simulates cogeneration at the 'sector' level of the model, where cogeneration is aggregated by economic category. Cogeneration can also be simulated at the unit level, where cogeneration is disaggregated to the 'unit' level. Unit cogeneration code is contained in the electric generation portion of the model.

Cogeneration Emission Charges

Previous year permit costs for cogeneration at the global level are inflated and mapped to the appropriate technology.

$CgPCost1 = CgPCost + CgPCostExo * Infla$
 $CgPCost2(Fuel,ECC,Area) = \text{sum}(FuelEP)(CgPCost1(FuelEP,ECC,Area) * FFPMap(FuelEP,Fuel))$
 $CgPCost3(Fuel,EC,Area) = \text{sum}(ECC)(CgPCost2(Fuel,ECC,Area) * ECCMap(EC,ECC))$
 $CgPCostTech(Tech,EC,Area) = \text{sum}(Fuel)(CgPCost3(Fuel,EC,Area) * FTMap(Fuel,Tech))$

where:

CgPCost(FuelEP,ECC,Area) 'Cogen Permit Cost in Previous Year (\$/mmBtu)'
CgPCost1(FuelEP,ECC,Area) 'Cogen Permit Cost (\$/mmBtu)'
CgPCost2(Fuel,ECC,Area) 'Cogen Permit Cost (\$/mmBtu)'
CgPCost3(Fuel,EC,Area) 'Cogen Permit Cost (\$/mmBtu)'
CgPCostExo(FuelEP,ECC,Area) 'Exogenous Cogen Permit Cost (Real \$/mmBtu)'
CgPCostTech(Tech,EC,Area) 'Cogeneration Permit Cost (\$/mmBtu)'

Apply emissions charges to cogeneration fuel price

$CgEFCP(T,EC,Area) = FP(FPMap(T,EC),Area) + CgPCostTech(T,EC,Area)$

where:

CgEFCP(Tech,EC,Area) 'Cogeneration Fuel Price (\$/mmBtu)'
FP(Prices,Area) 'Fuel Prices (\$/mmBtu)'

Renewable Resources and Cost Curves

$$\begin{aligned} CgDM &= 1 + CgDmSw * ((CgResl - CgGC) / CgResl) \\ CgDM &= \text{xmax}(CgDM, \text{Epsilon}) \\ CgCC &= CgCC * CgDM \end{aligned}$$

where:

$$\begin{aligned} CgDM(\text{Tech}, \text{Area}) & \text{ 'Depletion Multiplier (\$/\$)'} \\ CgDmSw(\text{Tech}) & \text{ 'Depletion Multiplier Switch for Selecting Technology',} \\ CgCC(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Capital Cost (\$/mmBtu/Yr)'} \\ CgResl(\text{Tech}, \text{Area}) & \text{ 'Resource Base (mmBtu)'} \end{aligned}$$

Cogeneration Capital Charge Rate

The cogeneration capital charge rate is the annualization of cogeneration capital expenses (over the life of the cogeneration facility - CGTL), accounting for taxes (TXRT), tax credits (CGIVTC), and return of principal and on investment (including a cogeneration risk premium and inflation: $1 + ROIN + CGRISK + INSM$). $(1 - (1 / (1 + ROIN + CGRISK)))^{**} CGBL / (1 - TXRT)$ is the classical capital recovery term. The $(1 - TXRT)$ term at the end converts the after tax calculation into before tax dollars. Investment tax credits reduce the cost of the facility by the tax credit after the first year of operation using nominal dollars. Therefore the value of the tax credit is $(CGIVTC / (1 + ROIN + CGRISK + INSM))$. Depreciation is modeled as a current dollar phenomena which does not account for inflation. Therefore the net present value of the energy is calculated with the nominal rate of return: $(2 / CGTL) / (ROIN + CGRISK + INSM + 2 / CGTL)$. It shows up as an additional negative term in the capital cost modifiers of CGCCR because depreciation is a benefit (negative cost).

Cogeneration capital costs (CGCC) are multiplied by the CGCCR to get the annualized cost of the cogeneration used in computing market share calculations.

The formula for calculating the cogeneration capital charge rate:

$$\begin{aligned} CgCCR &= (1 - CgIVTC / (1 + ROIN + CgRisk + InSm) - TxRt * (2 / CgTL) / \\ & (ROIN + CgRisk + InSm + 2 / CgTL)) * (ROIN + CgRisk) / (1 - (1 / (1 + ROIN + CgRisk)))^{**} CgBL / (1 - TxRt) \end{aligned}$$

where:

$$\begin{aligned} CgCCR(\text{EC}, \text{Area}) & \text{ 'Cogeneration Capital Charge Rate (\$/Yr/\$)'} \\ CgIVTC & \text{ 'Cogeneration Inv. Tax Credit (\$/\$)'} \\ ROIN(\text{EC}, \text{Area}) & \text{ 'Return on Investment (\$/Yr/\$)'} \\ CgRisk(\text{Tech}) & \text{ 'Cogeneration Excess Risk (DLESS)'} \\ InSm & \text{ 'Smoothed Inflation Rate (\$/Yr/\$)'} \\ TxRt(\text{EC}, \text{Area}) & \text{ 'Tax Rate on Energy Consumer (\$/\$)'} \\ CgTL(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Tax Life (YR)'} \\ CgBL(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Equipment Book Value Lifetime (Years)',} \end{aligned}$$

Marginal Cost of Cogeneration

The amount of investment in cogeneration and the amount of cogeneration produced depend on the competitiveness of cogenerated electricity with utility supplied electricity. Questions of competitiveness are resolved by the calculation of market shares.

The marginal cost of cogeneration is the fixed cost (CGCCR*CGCC/CGCUFP) plus the variable costs (CGVC). The fixed cost is the capital cost of cogeneration equipment (CGCC), multiplied by the cogeneration capital charge rate (CGCCR) to get the annualized capital cost. Variable costs (CGVC) are composed of cogeneration operating costs (CGOMC - calculated as a fraction (CGOCF) of capital costs (CGCC)) plus the cost of additional fuel, if any (CGVCSW - if this switch is on then an additional fuel cost is calculated), for the cogeneration equipment (fuel cost (EFCF) multiplied by the cogeneration heat rate (CGHRT)) and a delivery charge (CGDC) which electric utilities may still require because they must have the capacity to supply all industrial electricity needs even when no cogeneration occurs. A normal capacity utilization term (CGCUFP) is incorporated to reflect the wide variety in cogeneration capacity utilization across economic sectors.

$$\begin{aligned} \text{CgVC} &= (\text{CgCC} * \text{CgOF} + \text{CgDC}) * \text{Infla} + \text{CgVCSW} * (\text{CgEFCF} * \text{CgHrtM} / \text{EECONV}) \\ \text{CgMCE} &= \text{CgCCR} * \text{CgCC} / \text{CgCUFP} * \text{Infla} + \text{CgVC} \end{aligned}$$

where:

$$\begin{aligned} \text{CgVC}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Variable Costs (\$/mmBtu)'} \\ \text{CgCC}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Capital Cost (\$/mmBtu/Yr)'} \\ \text{CgOF}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Operation Cost Fraction (\$/Yr/\$)'} \\ \text{CgDC}(\text{Tech}, \text{Area}) & \text{ 'Cogeneration Delivery Charge (\$/mmBtu)'} \\ \text{CgVCSW}(\text{Tech}) & \text{ 'Cogeneration Variable Costs Switch for Selecting Tech'} \\ \text{CgHrtM}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Marginal Cogeneration Heat Rate (Btu/KWh)'} \\ \text{EEConv} & \text{ 'Electric Energy Conversion (Btu/KWh)'} \\ \text{CgMCE}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogen. Marginal Cost of Energy (\$/mmBtu)'} \\ \text{CgCUFP}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Normal Cogen. Cap. Utilization Factor (Btu/Btu)'} \end{aligned}$$

Allocation Weight and Market Share

The marginal cost of cogeneration is then compared with the cost of purchased electricity (EFCF-electric) to produce the cogeneration market share. A marginal allocation weight (CGMAW) is calculated for all the cogeneration fuel possibilities. Non-price influences (CGMSM0) such as the additional work involved by the cogenerator, and an economic factor (CGMSMI). The CGMAW is compared to the allocation weight associated with purchased electricity (CGEAW - CGVF is the variance factor for energy decisions) to obtain the market share (CGMSF).

$$\begin{aligned} \text{CgMAW} &= \exp(\text{CgMSM0} + \text{LN}(\text{CgMSMM}) + \text{CgMSMI} * (\text{SPC} / \text{SPC0}) + \text{CgVF} * \text{LN}(\text{CgMCE} / \text{CgMCE0})) \\ \text{CgEAW} &= \exp(\text{CgVF} * \text{LN}(\text{CgFP} / \text{CgFP0})) \\ \text{CgMSF} &= \text{CgMAW} / (\text{CgMAW} + \text{CgEAW}) \end{aligned}$$

where:

$$\begin{aligned} \text{CgMAW}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Market Allocation Weight (\$/\$)'} \\ \text{CgMSM0}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Market Share Non-Price Factor (Btu/Btu)'} \\ \text{CgMSMM}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Market Share Non-Price Factor Multiplier (Btu/Btu)'} \\ \text{CgMSMI}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Market Share Income Factor (Btu/\$)'} \\ \text{SPC}(\text{EC}, \text{Area}) & \text{ 'Total Production Capacity (M\$/Yr)'} \\ \text{SPC0}(\text{EC}, \text{Area}) & \text{ 'Total Production Capacity in First Year (M\$/Yr)'} \\ \text{CgVF}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Variance Factor (\$/\$)'} \\ \text{CgEAW}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Electricity Allocation Weight (\$/mmBtu)'} \\ \text{CgFP}(\text{EC}, \text{Area}) & \text{ 'Electric Price (\$/mmBtu)'} \\ \text{CgFP0}(\text{EC}, \text{Area}) & \text{ 'Electric Price in First Year (\$/mmBtu)'} \\ \text{CgMSF}(\text{Tech}, \text{EC}, \text{Area}) & \text{ 'Cogeneration Market Share (Btu/Btu)'} \end{aligned}$$

Cogeneration Capacity Retirements

The cogeneration retiring each year is determined by the total cogeneration capacity (CgGCSector) divided by the lifetime of a cogeneration plant (CgPL)

$$CgR = CgGCSector / CgPL$$

where:

$$\begin{aligned} CgR(Tech, EC, Area) & \text{ 'Cogeneration Cap. Retirements (MW/Yr)'} \\ CgGCSector(Tech, EC, Area) & \text{ 'Generating Capacity in Sector Cogeneration (MW)'} \\ CgPL(Tech, EC, Area) & \text{ 'Cogeneration Equipment Lifetime (Years)'} \end{aligned}$$

Cogeneration Capacity Additions

All energy used for heating is a candidate for cogeneration. This Cogeneration Potential (CGPOT) is the maximum cogeneration power that could be used given maximum market share conditions. The basis for the potential can either be process heat demand (CgPot0) or electricity demand (CgPot1) depending on the switch (CgPotSw) set by the model user.

$$\begin{aligned} CgPot0(Tech, EC, Area) &= \text{sum}(EU)(DER(EU, Tech, EC, Area)) / \\ & \quad CgHRtM(Tech, EC, Area) / 8760 * 1000 \\ CgPotElec(EC, Area) &= \text{sum}(EU, Tech)(DER(EU, Tech, EC, Area) / WCUF(EC, Area)) / \\ & \quad EEConv / 8760 * 1000 \\ CgPot1(Tech, EC, Area) &= CgPotElec(EC, Area) / CgCUFP(Tech, EC, Area) \\ CgPot &= (CgPot0 * (1 - CgPotSw) + CgPot1 * CgPotSw) * CgPotMult \end{aligned}$$

where:

$$\begin{aligned} CgPot0(Tech, EC, Area) & \text{ 'Cogeneration Potential (MW)'} \\ DER(Enduse, Tech, EC, Area) & \text{ 'Energy Requirement (mmBtu/YR)'} \\ CgPotElec(EC, Area) & \text{ 'Cogeneration Potential Electricity Demands (MW)'} \\ WCUF(EC, Area) & \text{ 'Capacity Utilization Factor Weighted by Output'} \\ CgPot1(Tech, EC, Area) & \text{ 'Cogeneration Potential (MW)'} \\ CgCUFP(Tech, EC, Area) & \text{ 'Normal Cogen. Cap. Utilization Factor (Btu/Btu)'} \\ CgPot(Tech, EC, Area) & \text{ 'Cogeneration Potential (MW)'} \\ CgPotSw(Tech, EC, Area) & \text{ 'Cogeneration Potential Switch (0=Steam, 1=Electric)'} \\ CgPotMult(Tech, EC, Area) & \text{ 'Cogeneration Potential Multiplier (Btu/Btu)'} \end{aligned}$$

Cogeneration Capacity Additions

For simplicity, cogeneration additions (CgCR) are captured as a delayed response of consumers' perceptions of cogeneration's competitive advantages; actual investments are not calculated. The delay (CgAT) represents the time to approve and build a cogeneration facility. The market share declines with retirements (CgR) of cogeneration facilities (using a 20 year lifetime - CgPL) if the indicated market share is less than the actual share. Since it is not possible to have a negative construction rate, a XMAX function is added to keep CgCR zero or positive. The equations for cogeneration capacity construction (CgCR) are:

$$\begin{aligned} CgIGC &= \text{xmax}(CgPot * CgMSF, XCgIGC) \\ CgCR &= (CgIGC - CgGC) / CgAT + CgR \end{aligned}$$

$$CgCR = \text{xmax}(CgCR, 0)$$

where:

$CgIGC(Tech, EC, Area)$ 'Indicated Cogeneration Capacity (MW)'
 $XCgIGC(Tech, EC, Area)$ 'Exogenous Indicated Cogeneration Capacity (MW)'
 $CgCR(Tech, EC, Area)$ 'Cogeneration Capacity Construction Rate (MW/Yr)'
 $CgAT(tv)$ 'Cogeneration Implementation Time (Years)'

Cogeneration Capacity

Cogeneration Capacity each year is simply the current level of cogeneration capacity (CgGC) plus any additions (CgCR) and less any retirements (CgR).

$$CgGC_{Sector} = CgGC_{Sector} + DT * (CgCR - CgR)$$

where:

$CgGC_{Sector}(Tech, EC, Area)$ 'Generating Capacity in Sector Cogeneration (MW)'

Cogeneration Embodied Energy Demands

Cogeneration embodied energy demands are each year are calculated as a function of capacity additions and retirements by the respective heat rates

$$CgDmdE = CgDmdE + DT * (CgCR * CgHRtM - CgR * CgHRtA) * CgCUFP * 8760 / 1e3 / 1e6$$

where:

$CgDmdE(Tech, EC, Area)$ 'Cogeneration Embodied Energy Demand (TBtu/Yr)'
 $CgCUFP(Tech, EC, Area)$ 'Normal Cogen. Cap. Utilization Factor (Btu/Btu)'

Average Heat Rate

Heat rates in the forecast are updated following the cogeneration capacity additions and retirements

$$CgHRtA = CgDmdE / (CgGC_{Sector} * CgCUFP * 8760 / 1e3 / 1e6)$$

Cogeneration Load and Energy

The utilization of cogeneration depends on the variable cost (CgVC) of operating the cogenerator versus the cost of electricity. Only the decision to build includes all the costs of cogeneration; once these costs are incurred they are “sunk” and do not figure in the decision to run the cogeneration unit. The variable cost of cogeneration can be considered to be less than the fuel costs because the cogeneration is integrally tied to the primary heat process. Shutting down the cogenerator may increase costs for the rest of the processes. Therefore, only a portion (CgSCM) of the variable cost (CgVC) is used for the shutdown decision. That portion of the cogeneration variable cost must be less than electric price or the cogeneration facility will shut down.

$$CgRatio = CgFP / (\text{xmax}(CgVC, 0.000001) * CgSCM)$$

$$CgRatio = \text{xmin}(1.0, CgRatio)$$

where:

$CgRatio(Tech,EC,Area)$ 'Cogeneration Cost Ratio \$/\$'
 $CgSCM(Tech)$ 'Cogeneration Shared Cost Multiplier (\$/\$)'

The utilization multiplier also includes a delay (CgAT) reflecting the time an owner waits to determine whether a change in economic conditions is temporary or semi-permanent. The delay also captures the distribution of many cogenerators whose costs vary from the mean. Therefore, if the current utilization factor is 60% but the ratio of electric to cogenerator energy prices (CgRatio) indicates the price differential makes it economic to cogenerate (e.g. equals 1.0), the utilization multiplier will increase not by 40% but by some fraction of that determined by the CGAT.

$$CgUMS = CgUMS + DT * (CgRatio - CgUMS) / CgAT$$

where:

$CgUMS(Tech,EC,Area)$ 'Cogeneration Utilization Multiplier (Btu/Btu)'

Electric Generation from Cogeneration

The actual cogeneration demand for energy (CgEGSector) is determined by the cogeneration capacity (CgGCSector) multiplied by the cogeneration utilization factor (CgUMS) and further weighted by three other utilization multipliers - CgCUFP, a normal capacity utilization term reflecting the wide variety in cogeneration capacity utilization across economic sectors; WCUF, a utilization factor reflecting the variability in cogeneration caused by changes in economic output; and CgCUF, representing other customer-specific economic variables that weigh in the decision making process.

$$CgEGSector = CgGCSector * CgUMS * CgCUFP * WCUF * 8760 / 1E3$$

where:

$CgEGSector(Tech,EC,Area)$ 'Generation from Sector Cogeneration (GWh/YR)'

Fuel Demands from Cogeneration

Fuel demands are converted from cogeneration electricity generated (CgEGSector) by multiplying by the average heat rate (CgHrtA):

$$CgDmdSector = CgEGSector * CgHrtA / 1E6$$

where:

$CgDmdSector(Tech,EC,Area)$ 'Energy Demand from Sector Cogeneration (TBtu/Yr)'

Procedure CogenerationTotals: Cogeneration Mapping and Summation

This procedure maps and sums cogeneration demands, generation, and capacities to combine the outputs from the sector and unit level calculations

Sector cogeneration mapped to Fuel

$CgDemandSector(Fuel,ECC,A)=\sum(Tech)(CgDmdSector(Tech,EC,A)*CgFrac(Fuel,Tech,EC,A))$
 $CgGenSector(Fuel,ECC,A) =\sum(Tech)(CgEGSector(Tech,EC,A) *CgFrac(Fuel,Tech,EC,A))$
 $CgCapSector(Fuel,ECC,A) =\sum(Tech)(CgGCSector(Tech,EC,A) *CgFrac(Fuel,Tech,EC,A))$

where:

CgDmdSector(Tech,EC,Area) 'Energy Demand from Sector Cogeneration (TBtu/Yr)'
CgFrac(Fuel,Tech,EC,Area) 'Cogeneration Demands Fuel/Tech Split (Fraction)'
CgGenSector(Fuel,ECC,Area) 'Cogeneration Generation (TBtu/Yr)'
CgCapSector(Fuel,ECC,Area) 'Cogeneration Capacity (TBtu/Yr)'

Unit cogeneration mapped to Tech

$CgDmdUnit(Tech,EC,A)=\sum(Fuel)(CgDemandUnit(Fuel,ECC,A)*FTMap(Fuel,Tech))$
 $CgEGUnit(Tech,EC,A) =\sum(Fuel)(CgGenUnit(Fuel,ECC,A)*FTMap(Fuel,Tech))$
 $CgGCUnit(Tech,EC,A) =\sum(Fuel)(CgCapUnit(Fuel,ECC,A)*FTMap(Fuel,Tech))$

where:

CgDmdUnit(Tech,EC,Area) 'Energy Demand from Industrial Units (TBtu/Yr)'
CgEGUnit(Tech,EC,Area) 'Generation from Industrial Units (GWh/Yr)'
CgGCUnit(Tech,EC,Area) 'Generating Capacity from Industrial Units (MW)'

Sum both variable types to produce totals

$CgDemand=CgDemandSector+CgDemandUnit$
 $CgGen =CgGenSector +CgGenUnit$
 $CgCap =CgCapSector +CgCapUnit$
 $CgDmd =CgDmdSector +CgDmdUnit$
 $CgEG =CgEGSector +CgEGUnit$
 $CgGC =CgGCSector +CgGCUnit$
 $CgDem(FuelEP,EC,A)=\sum(ECC,F)(CgDemand(F,ECC,A)*FFPMap(FuelEP,F)*ECCMap(EC,ECC))$
 $CgDemSector(FuelEP,EC,A)=\sum(ECC,F)(CgDemandSector(F,ECC,A)*FFPMap(FuelEP,F)*ECCMap(EC,ECC))$
 $CgEC(ECC,A)=\sum(F)(CgGen(F,ECC,A))$

where:

CgDemand(Fuel,ECC,Area) 'Cogeneration Demands (TBtu/Yr)'
CgGen(Fuel,ECC,Area) 'Cogeneration Generation (GWh/Yr)'
CgCap(Fuel,ECC,Area) 'Cogeneration Capacity (MW)'
CgDmd(Tech,EC,Area) 'Cogeneration Energy Demand (TBtu/Yr)'
CgEG(Tech,EC,Area) 'Cogeneration Generation (GWh/YR)'
CgGC(Tech,EC,Area) 'Cogeneration Generating Capacity (MW)'
CgDem(FuelEP,EC,Area) 'Cogeneration Demands (TBtu/Yr)'
CgDemSector(FuelEP,EC,Area) 'Cogeneration Demands (TBtu/Yr)'
CgEC(ECC,Area) 'Cogeneration by Economic Category (GWh/YR)'

7.9. Accumulate Total Energy Demand Procedures

Procedure TotDemand: Total Demands and Prices

This procedure develops summary level outputs from the demand and price results from earlier calculations. In this procedure total demand by class (ECD) and sector (DMDDES) are calculated as well as total energy costs (ECosts) and energy costs per dollar of output (ECost).

Demand across Enduse

Total demand by tech and economic sector is the sum over end-uses of all demand - including cogeneration and feedstock. An adjustment is made to cogeneration demand to avoid double counting.

$$ECD(TE,EC,Area)=\sum(EU)(Dmd(EU,TE,EC,Area))+(CgDmd(TE,EC,Area)*CgLoad(TE)+(1-CgLoad(TE))*(-\sum(Tech)(CgDmd(Tech,EC,Area)/CgHRtA(Tech,EC,Area))*EECONV))+FSDmd(TE,EC,Area)$$

where:

$$ECD(Tech,EC,Area) \text{ 'Fuel Demand (TBtu/Yr)'} \\ CgLoad(Tech) \text{ 'Flag to Exclude "Electric" Cogeneration (Hydro) from Electric Demands (0=no, 1=yes)'}'$$

Demand Totals by Type

The equations below sum energy and feedstock demands.

$$EuDemF(EU,F,ECC,A)=\sum(T,EC)(Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*ECCMap(EC,ECC)) \\ EuDem(EU,FuelEP,EC,A)=\sum(F,T)(Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*FFPMap(FuelEP,F)) \\ EuDemand(F,ECC,A)=\sum(EU)(EuDemF(EU,F,ECC,A)) \\ FsDem(F,EC,A)=\sum(T)(FsDmd(T,EC,A)*FsFrac(F,T,EC,A)) \\ FsDemand(F,ECC,A)=\sum(T,EC)(FsDmd(T,EC,A)*FsFrac(F,T,EC,A)*ECCMap(EC,ECC))$$

where:

$$EuDemF(Enduse,Fuel,ECC,Area) \text{ 'Energy Demands (tBtu/Yr)'} \\ DmFrac(Enduse,Fuel,Tech,EC,Area) \text{ 'Energy Demands Fuel/Tech Split (Btu/Btu)'} \\ EuDem(Enduse,FuelEP,EC,Area) \text{ 'Enduse Demands (TBtu/Yr)'} \\ EuDemand(Fuel,ECC,Area) \text{ 'Enduse Energy Demands (TBtu/Yr)'} \\ FsDem(Fuel,EC,Area) \text{ 'Feedstock Demands (TBtu/Yr)'} \\ FsFrac(Fuel,Tech,EC,Area) \text{ 'Feedstock Demands Fuel/Tech Split (Fraction)'} \\ FsDemand(Fuel,ECC,Area) \text{ 'Feedstock Demands (tBtu)'}'$$

Solar and Geothermal technology use a slightly difference calculation based on device efficiency:

$$EuDemF(EU,F,ECC,A)=\sum(EC)(Dmd(EU,T,EC,A)*DEEA(EU,T,EC,Area)*ECCMap(EC,ECC))$$

Electricity Usage

Gross electric usage is based on demand for the Electric and Solar fuel types

$$\text{Select Fuel(Electric,Solar)} \\ GrElec(ECC,A)=\sum(F)(EuDemand(F,ECC,A))/3412*1e6$$

where:

GrElec(ECC,Area) 'Gross Electric Usage (GWh)'

Total purchases from electric grid accounts for cogeneration (CgEC) and a minimum purchase fraction (MinPurF)

$$\text{PurECC} = \text{xmax}(\text{GrElec} - \text{CgEC}, \text{GrElec} * \text{MinPurF})$$

where:

MinPurF(ECC,Area) 'Minimum Fraction of Electricity which is Purchased (GWh/GWh)'

Total power sold back to grid (PSoECC)

$$\text{PSoECC} = \text{xmax}(\text{CgEC} + \text{PurECC} - \text{GrElec}, 0)$$

where:

PSoECC(ECC,Area) 'Power Sold to Grid (GWh)'

Total Fuel Demands

The sum of all demand types (TotDemand) is calculated with an adjustment to remove cogeneration from Electric

$$\begin{aligned} \text{TotDemand} &= \text{EuDemand} + \text{CgDemand} + \text{FSDemand} \\ \text{TotDemand}(\text{Electric}, \text{ECC}, \text{A}) &= \text{TotDemand}(\text{Electric}, \text{ECC}, \text{A}) - \text{CgEC}(\text{ECC}, \text{A}) * \text{EEConv} / 1\text{E}6 \end{aligned}$$

where:

TotDemand(Fuel,ECC,Area) 'Energy Demands (TBtu/Yr)'

The sum of all demand types across all sectors (DmdES) is the sum of total demand (TotDemand)

$$\text{DmdES}(\text{F}, \text{A}) = \text{sum}(\text{ECC})(\text{TotDemand}(\text{F}, \text{ECC}, \text{A}))$$

where:

DmdES(Fuel,Area) 'Energy Demand (TBtu/Yr)'

Average Fuel Prices

Weight an average fuel price per global sector (FPPCost) including emissions costs. Temporarily mandate that energy demands (Dmd) have at least a small value so that average prices are not zero.

$$\begin{aligned} \text{Dmd} &= \text{xmax}(\text{Dmd}, 0.0000001) \\ \text{FPPCost}(\text{F}, \text{ECC}, \text{A}) &= \text{sum}(\text{EU}, \text{T}, \text{EC})(\text{ECFP}(\text{T}, \text{EC}, \text{A}) * \text{Dmd}(\text{EU}, \text{T}, \text{EC}, \text{A}) * \text{DmFrac}(\text{EU}, \text{F}, \text{T}, \text{EC}, \text{A}) * \text{ECCMap}(\text{EC}, \text{ECC})) / \text{sum}(\text{EU}, \text{T}, \text{EC})(\text{Dmd}(\text{EU}, \text{T}, \text{EC}, \text{A}) * \text{DmFrac}(\text{EU}, \text{F}, \text{T}, \text{EC}, \text{A}) * \text{ECCMap}(\text{EC}, \text{ECC})) \end{aligned}$$

where:

FPPCost(Fuel,ECC,Area) 'Fuel Prices including Emission Costs (\$/mmBtu)'
ECFP(Tech,EC,Area) 'Fuel Price (\$/mmBtu)'

Calculate prices without emissions costs (based on FP) in order to calculate prices excluding emissions costs (FPFuel). Prices for Electric are based on the electricity price (PE)

$$\begin{aligned} \text{FPTech}(\text{T}, \text{EC}, \text{Area}) &= \text{FP}(\text{FPM}(\text{T}, \text{EC}), \text{Area}) \\ \text{Select Tech If ElecMap}(\text{Tech}) & \text{ eq } 1 \\ \text{FPTech}(\text{T}, \text{EC}, \text{Area}) &= \text{sum}(\text{ECC})(\text{PE}(\text{ECC}, \text{Area}) * \text{ECCMap}(\text{EC}, \text{ECC})) / 3412 * 1000 \end{aligned}$$

where:

FPTech(Tech,EC,Area) 'Fuel Price by Technology (\$/mmBtu)'
FP(Prices,Area) 'Fuel Prices (\$/mmBtu)'
PE(ECC,Area) 'Price of Electricity (\$/mmBtu)'

Average delivered price by sector and fuel type excluding emission costs:

$$FPECC(F,ECC,A)=\frac{\sum(EU,T,EC)(FPTech(T,EC,A)*Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*ECCMap(EC,ECC))}{\sum(EU,T,EC)(Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A)*ECCMap(EC,ECC))}$$
$$FPFuel(F,A)=\frac{\sum(EU,T,EC)(FPTech(T,EC,A)*Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A))}{\sum(EU,T,EC)(Dmd(EU,T,EC,A)*DmFrac(EU,F,T,EC,A))}$$

where:

FPECC(Fuel,ECC,Area) 'Fuel Prices excluding Emission Costs (\$/mmBtu)'
FPFuel(Fuel,Area) 'Fuel Prices (\$/mmBtu)'

Revenue and Tax

Total revenue is simply total demand by fuel multiplied by the average fuel price

$$RVV=DmdES*FPFuel$$

where:

RVV(Fuel,Area) 'Revenues (M\$/Yr)'

Total energy tax income (TaxEnergy) is calculated by the total amount of tax per unit of energy (UTax) applied to total demand by fuel (DmdES)

$$UTax=FP/(1+FPSM)*FPSM+FPTax*Infla$$
$$TaxEnergy=DmdES*UTax$$

where:

UTax(Fuel,Area) 'Unit Energy Tax (\$/mmBtu)'
FPSM(Prices,Area) 'Energy Sales Tax (\$/\$)'
FPTax(Prices,Area) 'Fuel Tax (\$/mmBtu)'
TaxEnergy(Fuel,Area) 'Energy Taxes (M\$/Yr)'

Steam Sales and Purchases

Steam sales (StSold) are a function of demand (Dmd) in the Excess Steam enduse and the steam heat rate (ESHrt)

$$StSold(ECC,Area)=\frac{\sum(Tech,EC)(Dmd(Enduse,Tech,EC,Area)/ESHrt(Tech,EC,Area)*ECCMap(EC,ECC))}{ECCMap(EC,ECC)}$$

where:

StSold(ECC,Area) 'Excess Steam Generated (tBtu/Yr)'
ESHrt(Tech,EC,Area) 'Excess Steam Heat Rate (Btu/KWh)'

Steam purchases (StPur) are a function of demand (Dmd) in the Steam technology for all enduses

$$StPur(ECC,Area)=\sum(Enduse,EC)(Dmd(Enduse,Tech,EC,Area)*ECCMap(EC,ECC))$$

where:

$StPur(ECC,Area)$ 'Net Steam Purchases (tBtu/Yr)',

7.10. Emissions Procedures

Procedure PollCoefficients: Pollution Coefficient Calculations

In this accounting procedure, the emissions coefficients of CO₂, CO, volatile organics, NO_X, SO_X, and particulates from the burning of fuels at the consumer end-use and energy-supply technology level are calculated. The methodology for calculating coefficients varies depending on the switch (PolSw) set by the user.

Calculation using embedded values

The equations below are used when the pollution switch (PolSw) is set to 1

Pollution from New Devices

Pollution from new devices (POEMA) is the sum across end-uses of the product of the device energy requirement additions (DERA) and the marginal pollution coefficient associated with operating each device (POCX).

$$POEMA=DERA*POCX/1e6$$

where:

$POEMA(Enduse,FuelEP,EC,Poll,Area)$ 'Pollution Additions (Tonnes/Yr)'

$DERA(Enduse,Tech,EC,Area)$ 'Energy Requirement Addition (mmBtu/YR)'

$POCX(Enduse,FuelEP,EC,Poll,Area)$ 'Marginal Pollution Coefficients (Tonnes/TBtu)'

Pollution from Retired Devices

Pollution from retired devices (POEMR) is calculated in a similar fashion - as the sum across end-uses of the product of the energy associated with retired devices (DERR) and the average pollution level (POCA) when accounting for policy emission reductions (RMPrior).

$$POEMR=DERR*POCA/RMPrior/1e6$$

where:

$POEMR(Enduse,FuelEP,EC,Poll,Area)$ 'Pollution Retirements (Tonnes/Yr)'

$DERR(Enduse,Tech,EC,Area)$ 'Device Energy Rqmt. Retire. (mmBtu/Yr/Yr)'

$POCA(Enduse,FuelEP,EC,Poll,Area)$ 'Average Pollution Coefficients (Tonnes/TBtu)'

$RMPrior(FuelEP,EC,Poll,Area)$ 'Reduction Multiplier in Prior Year (Tonnes/Tonnes)'

Embedded Pollution

Embedded pollution is calculated as the existing pollution level plus any addition from new devices and reduced by pollution eliminated by retired devices.

$$POEM=POEM+DT*(POEMA-POEMR)$$

where:

$$POEM(\text{Enduse, FuelEP, EC, Poll, Area}) \text{ 'Embodied Pollution (Tonnes/Yr)'}'$$

Average Pollution

Average pollution (POCA) is calculated as the embodied pollution divided by the device energy requirement (DER) accounting for reductions (RM).

$$POCA=POEM/DER*1E6*RM$$

where:

$$RM(\text{FuelEP, EC, Poll, Area}) \text{ 'Reduction Multiplier(Tonnes/Tonnes)'}'$$

Pollution from New Cogeneration

Pollution from new cogeneration (CgPOEA) is the product of new cogeneration capacity (in MW, multiplied by the heat rate and modified by a utilization factor) and the pollution coefficient associated with operating each device (CgPOCX).

$$CgPOEA=CgCR*CgHRtA*CgCUFP*8760/1E9*CgPOCX$$

where:

$$\begin{aligned} CgPoEA(\text{FuelEP, EC, Poll, Area}) & \text{ 'Pollution Additions (Tonnes/Yr)'} \\ CgCR(\text{Tech, EC, Area}) & \text{ 'Cogeneration Capacity Construction Rate (MW/Yr)'} \\ CgHRtA(\text{Tech, EC, Area}) & \text{ 'Average Cogeneration Heat Rate (Btu/KWh)'} \\ CgCUFP(\text{Tech, EC, Area}) & \text{ 'Normal Cogen. Cap. Utilization Factor (Btu/Btu)'} \\ CgPOCX(\text{FuelEP, EC, Poll, Area}) & \text{ 'Cogeneration Pollution Coefficient (Tonnes/TBtu)'} \end{aligned}$$

Pollution from Retired Cogeneration

Pollution from retired cogeneration (CgPOEA) is the product of the amount of retired cogeneration capacity (in MW, multiplied by the heat rate and modified by a utilization factor) and the average cogeneration pollution rate (CgPOCA).

$$CgPOER=CgR*CgHRtM*CgCUFP*8760/1E9*CgPOCA/RMPrior$$

where:

$$\begin{aligned} CgPoER(\text{FuelEP, EC, Poll, Area}) & \text{ 'Pollution Retirements (Tonnes/Yr)'} \\ CgR(\text{Tech, EC, Area}) & \text{ 'Cogeneration Cap. Retirements (MW/Yr)'} \\ CgHRtM(\text{Tech, EC, Area}) & \text{ 'Marginal Cogeneration Heat Rate (Btu/KWh)'} \\ CgPOCA(\text{FuelEP, EC, Poll, Area}) & \text{ 'Cogeneration Average Pollution Coefficient (Tonnes/TBtu)'} \end{aligned}$$

Embodied Cogeneration Pollution

Embodied cogeneration pollution is calculated as the existing cogeneration pollution plus any additions from new cogeneration and minus any reductions by pollution eliminated by retired cogeneration.

$$CgPOE=CgPOE+DT*(CgPOEA-CgPOER)$$

where:

$$CgPoE(FuelEP,EC,Pol,Area) \text{ 'Cogeneration Embodied Pollution (Tonnes/Yr)'}'$$

Average Cogeneration Pollution

Average cogeneration pollution is calculated as the embodied pollution divided by the cogeneration capacity (modified by the heat rate to convert to BTUs and a utilization factor).

$$CgPOCA=CgPOE/(CgGCSector*CgHRtA*CgCUFP*8760/1E9)*RM$$

where:

$$CgGCSector(Tech,EC,Area) \text{ 'Generating Capacity in Sector Cogeneration (MW)'}'$$

Calculation assuming Average equals Marginal

The equations below are used when the pollution switch (PolSw) is set to 2. This instructs the model to set average coefficients equal to the marginal without accounting for additions and retirements.

Average Pollution

Average pollution (POCA) is set equal to the marginal after accounting for reductions (RM).

$$POCA=POEM/DER*1E6*RM$$

Embedded Pollution

Embedded pollution is produced using the average coefficient (POCA) calculated above combined with the device energy requirements (DER).

$$POEM=POCA*DER/1e6/RM$$

Average Cogeneration Pollution

Similar to above, the average cogeneration coefficient is calculated using the marginal.

$$CgPOCA=CgPOCX*RM$$

where:

$$CgGCSector(Tech,EC,Area) \text{ 'Generating Capacity in Sector Cogeneration (MW)'}'$$

Embedded Cogeneration Pollution

Embedded pollution is produced using the average coefficient (CgPOCA) calculated above.

$$CgPOE=CgPOCA*(CgGCSector*CgHRtA*CgCUFP*8760/1e9)/RM$$

Calculation using embedded values for Enduse and Marginal for Cogeneration

When the pollution switch (PolSw) is set to 3 the enduse emissions coefficients are calculated using the embedded method (PolSw = 1) while the cogeneration coefficients are set using the marginal values (PolSw = 2).

Non-Energy Pollution

The feedstock average emission coefficient (FsPOCA) is set equal to the marginal value (FsPOCX) or an emissions standard (FsPOCS), whichever is higher.

$$FsPOCA = \text{xmin}(FsPOCX, FsPOCS)$$

where:

FsPOCA(Fuel, EC, Poll, Area) 'Feedstock Pollution Coefficients (Tonnes/TBtu)'
FsPOCX(Fuel, EC, Poll, Area) 'Feedstock Marginal Pollution Coefficients (Tonnes/TBtu)'
FsPOCS(Fuel, EC, Poll, Area) 'Feedstock Pollution Standards (Tonnes/TBtu)'

Black Carbon

An exception for Black Carbon emissions is available to instead calculate its coefficients based on a ratio of the coefficient of Particulate Matter if a model switch (BCarbonSw) is set.

$POCX(EU, FuelEP, EC, BC, A) = POCX(EU, FuelEP, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $POCA(EU, FuelEP, EC, BC, A) = POCA(EU, FuelEP, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $CgPOCX(FuelEP, EC, BC, A) = CgPOCX(FuelEP, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $CgPOCA(FuelEP, EC, BC, A) = CgPOCA(FuelEP, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $FsPOCX(Fuel, EC, BC, A) = FsPOCX(Fuel, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $FsPOCA(Fuel, EC, BC, A) = FsPOCA(Fuel, EC, PM25, A) * BCMult(Fuel, ECC, A)$
 $RM(FuelEP, EC, BC, A) = RM(FuelEP, EC, PM25, A)$

where:

BCarbonSw 'Black Carbon coefficient switch (1=POCX set relative to PM25)'
BCMult(Fuel, ECC, Area) 'Fuel Emission Multiplier between Black Carbon and PM 2.5 (Tonnes/Tonnes)'

Procedure PollutionGenerated: Emission Inventories

The following procedure produces emissions inventories from emissions coefficients and energy consumption by type

Pollution by Enduse and Technology

$Polute = EuDem * POCA$
 $EnFPol(FuelEP, ECC, P, A) = \text{sum}(EU, EC)(Polute(EU, FuelEP, EC, P, A) * ECCMap(EC, ECC))$
 $EnPol(ECC, Poll, Area) = \text{sum}(FuelEP)(EnFPol(FuelEP, ECC, Poll, Area))$

where:

Polute(Enduse, FuelEP, EC, Poll, Area) 'Pollution (Tonnes/Yr)'
EnFPol(FuelEP, ECC, Poll, Area) 'Energy Related Pollution (Tonnes/Yr)'
EnPol(ECC, Poll, Area) 'Energy Related Pollution (Tonnes/Yr)'

Non-Combustion Pollution

$FsPol = FsDem * FsPOCA$
 $NcFPol(Fuel, ECC, Poll, Area) = \text{sum}(EC)(FsPol(Fuel, EC, Poll, Area) * ECCMap(EC, ECC))$
 $NcPol(ECC, Poll, Area) = \text{sum}(Fuel)(NcFPol(Fuel, ECC, Poll, Area))$

where:

$FsPol(Fuel, EC, Poll, Area)$ 'Feedstock Pollution (Tonnes/Yr)'
 $NcFPol(Fuel, ECC, Poll, Area)$ 'Non Combustion Related Pollution (Tonnes/Yr)'
 $NcPol(ECC, Poll, Area)$ 'Non Combustion Related Pollution (Tonnes/Yr)'

Cogeneration Pollution By EC

$CgPolSectorEC = CgDemSector * CgPOCA$
 $CgPolUnitEC(FuelEP, EC, Poll, Area) = \sum(ECC)(CgFPolUnit(FuelEP, ECC, Poll, Area) * ECCMap(EC, ECC))$
 $CgPolEC = CgPolSectorEC + CgPolUnitEC$

where:

$CgPolSectorEC(FuelEP, EC, Poll, Area)$ 'Cogeneration Pollution (Tonnes/Yr)'
 $CgPolUnitEC(FuelEP, EC, Poll, Area)$ 'Cogeneration Pollution (Tonnes/Yr)'
 $CgPolEC(FuelEP, EC, Poll, Area)$ 'Cogeneration Pollution (Tonnes/Yr)'

Cogeneration Pollution By ECC

$CgFPolSector(FuelEP, ECC, Poll, Area) = \sum(EC)(CgPolSectorEC(FuelEP, EC, Poll, Area) * ECCMap(EC, ECC))$
 $CgFPol = CgFPolSector + CgFPolUnit$
 $CgPol(ECC, Poll, Area) = \sum(FuelEP)(CgFPol(FuelEP, ECC, Poll, Area))$

where:

$CgFPolSector(FuelEP, ECC, Poll, Area)$ 'Pollution in Sector Cogeneration (Tonnes/Yr)'
 $CgFPol(FuelEP, ECC, Poll, Area)$ 'Cogeneration Pollution (Tonnes/Yr)'
 $CgPol(ECC, Poll, Area)$ 'Cogeneration Related Pollution (Tonnes/Yr)'

Pollution Totals

$TotFPol(FuelEP, ECC, P, A) = EnFPol(FuelEP, ECC, P, A) + CgFPol(FuelEP, ECC, P, A) + \sum(Fuel)(NcFPol(Fuel, ECC, P, A) * FFPMap(FuelEP, Fuel))$
 $TFPol(FuelEP, P, A) = \sum(ECC)(TotFPol(FuelEP, ECC, P, A))$
 $TSPol(P, A) = \sum(FuelEP)(TFPol(FuelEP, P, A))$

where:

$TotFPol(FuelEP, ECC, Poll, Area)$ 'Pollution (Tonnes/Yr)'
 $TFPOL(FuelEP, Poll, Area)$ 'Energy Sector Pollution (Tonnes/Yr)'
 $TSPOL(Poll, Area)$ 'Energy Sector Pollution (Tonnes/Yr)'

Gross Pollution Total

Gross Pollution (GrossPol) is the covered pollution before the impact of a pollution policy.

$GrossPol(ECC, Poll, A) = \sum(FuelEP)((\sum(EU)(Polute(EU, FuelEP, EC, Poll, A)) + CgFPol(FuelEP, ECC, Poll, A)) / RM(FuelEP, EC, Poll, A) * PCCov(FuelEP, EC, Poll, A)) + \sum(Fuel)(FsPol(Fuel, EC, Poll, A) * ECoverage(EC, Poll, NonCombustion, A))$

Procedure PRAccounting: Pollution Reduction Accounting

The following procedure simulates the construction, stock, and retirement of emission reduction devices to meet reduction goals from an emissions reductions program. Reduction devices, such as smokestack scrubbers, have an associated cost, construction time, and useful lifespan in the model. Retired reductions need to be replaced with new purchases in order for the emission reduction to stay at a constant level. A gradually harsher emissions cap will require more reductions constructed annually to continue to meet the target.

Reduction Accounting

Indicated Reduction Capacity (RICap) is emissions divided by the reduction multiplier (to give back total embodied emissions) times the pollution reduction (RP) which tells how many tonnes of pollution can be reduced.

$$\text{RICap}(F,EC,P,Area) = \frac{\text{sum}(EU)(\text{Polute}(EU,F,EC,P,Area) + \text{CgPoIEC}(F,EC,P,Area))}{\text{RM}(F,EC,P,Area)} * \text{RP}(F,EC,P,Area)$$

where:

RICap(FuelEP,EC,Poll,Area) 'Indicated Reduction Capital (Tonnes/Yr)'
Polute(Enduse,FuelEP,EC,Poll,Area) 'Pollution (Tonnes/Yr)'
CgPoIEC(FuelEP,EC,Poll,Area) 'Cogeneration Pollution (Tonnes/Yr)'
RM(FuelEP,EC,Poll,Area) 'Reduction Multiplier (Tonnes/Tonnes)'
RP(FuelEP,EC,Poll,Area) 'Pollutant Reduction (Tonnes/Tonnes)'

The rate of reduction capacity initiation is based previous year's values for existing capacity (RCap) and completion rate (RCR) coupled with the current indicated reduction capacity (RICap) and the construction delay (RCD)

$$\text{RCI} = \text{xmax}(0, \text{RICap} - \text{RCap} - \text{RCR} * \text{RCD} + \text{RCap} / \text{RCPL}) / \text{RCD}$$

where:

RCI(FuelEP,EC,Poll,Area) 'Reduction Capital Initiation (Tonnes/Yr/Yr)'
RCap(FuelEP,EC,Poll,Area) 'Reduction Capital (Tonnes/Yr)'
RCR(FuelEP,EC,Poll,Area) 'Reduction Capital Completion Rate (Tonnes/Yr/Yr)'
RCD(EC,Poll) 'Reduction Capital Construction Delay (Years)'
RCPL(EC,Poll) 'Reduction Capital Physical Life (Years)'

Embedded reduction capital costs are a function of the completion rate (RCR) and marginal reduction capital cost (RCC). Costs are accumulated from the previous year's value.

$$\text{RCCEm} = \text{RCCEm} + \text{DT} * \text{RCC} * \text{RCR}$$

where:

RCCEm(FuelEP,EC,Poll,Area) 'Embedied Reduction Capital Cost (\$)'
RCC(FuelEP,EC,Poll,Area) 'Reduction Capital Cost (\$/Tonne)'

Reduction capacity for the current year is calculated based on the previous year's value, the previous amount of capacity completed (RCR) and existing capacity retirements.

$$\text{RCap} = \text{RCap} + \text{DT} * (\text{RCR} - \text{RCap} / \text{RCPL})$$

Finally, the reduction completion rate for the current year is calculated based on the amount initiated (RCI) and the amount of construction delay (RCD)

$$RCR = RCR + DT * (RCI - RCR) / RCD$$

Cost Accounting

The total amount spent on reductions is calculated as a model output. Expenses are generated using the capital cost (RCC) of completed devices (RCR) and the operation costs (ROCF) of existing devices (RCCEm). A ratio variable (AGFr) is used to allow for splitting of costs into the private or government sectors as specified by the user.

$$PRExp(ECC, Poll, Area) = \text{sum}(F) \{ (RCR(F, EC, Poll, Area) * RCC(F, EC, Poll, Area) * (1 - AGFr(ECC, Poll, Area)) + RCCEm(F, EC, Poll, Area) * ROCF(F, EC, Poll, Area)) / 1e6$$

$$GRExp(ECC, Poll, Area) = \text{sum}(F) \{ (RCR(F, EC, Poll, Area) * RCC(F, EC, Poll, Area) * AGFr(ECC, Poll, Area)) / 1e6 + PAdCost(ECC, Poll, Area)$$

where:

$$PRExp(ECC, Poll, Area) \quad \text{'Reduction Private Expenses (M\$/Yr)'} \\ AGFr(ECC, Poll, Area) \quad \text{'Government Subsidy (\$/\$)'} \\ GRExp(ECC, Poll, Area) \quad \text{'Reduction Government Expenses (M\$/Yr)'}$$

7.11. Investments Procedures

Procedure Investments: Total Cost Accounting

The following procedure calculates total investments and operation and maintenance costs for devices, process, and cogeneration. Total fuel expenditures are also generated as a function of demand and fuel price.

Investments

Spending on new devices (DInv) is calculated based on the marginal device capital cost (DCC), additions to the process energy requirements (PERA), and the cost and amount of retrofit devices.

$$DInv(EU, T, EC, Area) = (DCCFC(EU, T, EC, Area) * PERA(EU, T, EC, Area) + RDCC(EU, T, EC, Area) * PER(EU, T, EC, Area) * RDMSF(EU, T, EC, Area)) / 1e6 \\ DeviceInvestments(ECC, Area) = \text{sum}(EU, T) (DInv(EU, T, EC, Area))$$

where:

$$DInv(Enduse, Tech, EC, Area) \quad \text{'Device Investments (M\$/Yr)'} \\ DCCFC(Enduse, Tech, EC, Area) \quad \text{'Device Capital Cost Full Cost (\$/mmBtu/Yr)'} \\ PERA(Enduse, Tech, EC, Area) \quad \text{'Process Energy Rqmt. Addition (mmBtu/Yr/Yr)'} \\ RDCC(Enduse, Tech, EC, Area) \quad \text{'Retrofit Device Capital Cost (\$/(\$/Yr))'} \\ PER(Enduse, Tech, EC, Area) \quad \text{'Process Energy Requirement (mmBtu/YR)'} \\ RDMSF(Enduse, Tech, EC, Area) \quad \text{'Device Retrofit Market Share Fraction by Device (1/Yr)'} \\ DeviceInvestments(ECC, Area) \quad \text{'Device Investments (M\$/Yr)'}$$

Process investments (PInv) are a function of the process capital cost (PCC), capacity additions (EUPCAPC), and any process retrofits. Note that the model selects the values from the first enduse (Heat) to avoid any issues with double counting spending.

$$PInv(ECC,Area)=\sum(T)(PCC(Heat,T,EC,Area)*EUPCAPC(Heat,T,New,EC,Area)+RPCC(Heat,T,EC,Area)*\sum(Age)(EUPC(Heat,T,Age,EC,Area))*RPMSF(Heat,T,EC,Area))$$

where:

$$\begin{aligned} PInv(ECC,Area) & \text{ 'Process Investments (M\$/Yr)'} \\ PCC(Enduse,Tech,EC,Area) & \text{ 'Process Capital Cost (\$/(\$/Yr))'} \\ EUPCAPC(Enduse,Tech,Age,EC,Area) & \text{ 'Production Capacity Additions from New Production Capacity (M\$)'} \\ RPCC(Enduse,Tech,EC,Area) & \text{ 'Process Retrofit Capital Cost (\$/(\$/Yr))'} \\ EUPC(Enduse,Tech,Age,EC,Area) & \text{ 'Production Capacity by Enduse (M\$/Yr)'} \\ RPMSF(Enduse,Tech,EC,Area) & \text{ 'Process Retrofit Market Share Fraction by Device (1/Yr)'} \end{aligned}$$

Cogeneration investments are accumulated for each enduse and technology and vary depending on if the cogeneration demands are simulated at the unit level or the sector level. In the case of the former (CgSwUnit = 1), cogeneration investments (CgInv) are summed from the individual units.

$$CgInv=CgInvUnit$$

where:

$$\begin{aligned} CgInv(ECC,Area) & \text{ 'Cogeneration Investments (M\$/Yr)'} \\ CgInvUnit(ECC,Area) & \text{ 'Cogeneration Investments (M\$/Yr)'} \end{aligned}$$

When simulated at the sector level (CgSwUnit != 1), cogeneration investments (CgInv) are calculated based on marginal capital cost (CgCC) and the cogen construction rate (CgCR)

$$CgInv=CgInv+CgCC*CgCR*CgHRtM*8760*Infla/1e9$$

where:

$$\begin{aligned} CgCC(Tech,EC,Area) & \text{ 'Cogeneration Capital Cost (\$/mmBtu/Yr)'} \\ CgCR(Tech,EC,Area) & \text{ 'Cogeneration Capacity Construction Rate (MW/Yr)'} \\ CgHRtM(Tech,EC,Area) & \text{ 'Marginal Cogeneration Heat Rate (Btu/KWh)'} \end{aligned}$$

Operation and Maintenance Costs

The equation for calculating O&M costs are similar across each cost category, where O&M spending is based on an input ratio of capital cost of the total stock for the year. Two versions of device O&M costs are estimated, one with cogeneration (OMExp) and one without (DOMExp).

$$OMExp(ECC,Area)=\sum(EU,T)(DCCFC(EU,T,EC,Area)*DOCF(EU,T,EC,Area)*PER(EU,T,EC,Area))/1e6+\sum(T)((CgCC(T,EC,Area)*CgOF(T,EC,Area)+CgDC(T,Area))*CgDmd(T,EC,Area))*Infla$$

$$DOMExp(ECC,Area)=\sum(EU,T)(DCCFC(EU,T,EC,Area)*DOCF(EU,T,EC,Area)*PER(EU,T,EC,Area))/1e6*Infla$$

$$POMExp(ECC,Area)=\sum(EU,T)(PCCFC(EU,T,EC,Area)*POCF(EU,T,EC,Area)*\sum(Age)(EUPC(EU,T,Age,EC,Area)))*Infla$$

$$CGOMExp(ECC,Area)=\sum(T)((CgCC(T,EC,Area)*CgOF(T,EC,Area)+CgDC(T,Area))*CgDmd(T,EC,Area))*Infla$$

where:

OMExp(ECC,Area) 'O&M Expenditures (M\$)
DInv(Enduse,Tech,EC,Area) 'Device Investments (M\$/Yr)
DOCF(Enduse,Tech,EC,Area) 'Device Operating Cost Fraction (\$/Yr/\$)
CgOF(Tech,EC,Area) 'Cogeneration Operation Cost Fraction (\$/Yr/\$)
CgDC(Tech,Area) 'Cogeneration Delivery Charge (\$/mmBtu)
CgDmd(Tech,EC,Area) 'Cogeneration Energy Demand (TBtu/Yr)
DOMExp(ECC,Area) 'Device O&M Expenditures (M\$)
POMExp(ECC,Area) 'Process O&M Expenditures (M\$)
POCF(Enduse,Tech,EC,Area) 'Process Operating Cost Fraction (\$/Yr/\$)

Fuel Expenditures

Total fuel expenditures (FuelExp) is a function of energy consumption (Dmd, CgDmd) and the fuel price (FPTech).

$$\text{FuelExp}(EU,T,EC,Area) = (\text{Dmd}(EU,T,EC,Area) * \text{FPTech}(T,EC,Area)) + (\text{CgDmd}(T,EC,Area) * \text{FPTech}(T,EC,Area))$$

where:

FuelExp(Enduse,Tech,EC,Area) 'Fuel Expenditures (M\$)
Dmd(Enduse,Tech,EC,Area) 'Total Energy Demand (TBtu/Yr)
FPTech(Tech,EC,Area) 'Fuel Price by Technology (\$/mmBtu)

Appendix 2. Load Curve Procedures and Equations Detail

1. **Procedure ETOU:** Electric Time-Of-Use Impacts. This procedure calculates the impacts of different time of use pricing on peak, average and minimum loads.
2. **Procedure LoadMgmt:** Impacts from Load Management Programs - calculates the effects on sales and peak demand from load management programs.
3. **Procedure LoadCurve:** Generating Electric Load Curve - derives economic class (ECLDC) and revenue class (CLDC) load shapes from demand (Dmd). Electric sales (ESales, ECSales, and Sales) are calculated from the load shapes. Cogeneration is accounted for and netted out of sales.
4. **Procedure NoLoadCurve:** Electric Sales when load shapes are not available Procedure derives electric sales (ESALES, ECSALES, and SALES) from demand (DMD). Accounts for cogeneration demand.
5. **Procedure DailyUse:** Gas Utility Daily Use Curve - calculates EUDUC, CDUC, (daily use curves by end-use and class, respectively), GSALES and SALES (sales by end-use and total sales) for the natural gas utility.
6. **Procedure NoDailyUse:** Gas Sales when load shapes are not available. Calculates GSales (gas sales by end-use and class) and Sales (total sales) when no load shapes are available and CCSales(transportation gas)

Procedure LoadMgmt: Load Management

This procedure calculates endogenous Load Management.

Load Management Device Capital Charge Rate:

$$\text{LMDCCR} = \frac{(1 - \text{LMDIVTC}) / (1 + \text{ROIN} + \text{LMDRISK} + \text{INSM}) - \text{TXRT} * (2 / \text{DTL}) / (\text{ROIN} + \text{LMDRISK} + \text{INSM} + 2 / \text{DTL})}{(\text{ROIN} + \text{LMDRISK}) / (1 - (1 / (1 + \text{ROIN} + \text{LMDRISK}))^{**} \text{DPLN}) / (1 - \text{TXRT})} *$$

where:

LMDCCR: LMDCCR Load Management Capital Charge Rate

LMDIVTC: Device Investment Tax Credit (DLESS)

LMDRISK: Device Excess Risk (DLESS):

Load Management Fuel Price

The load management “fuel price” contains both a fuel and a capital cost component. The load management capital charge rate is used to annualize the capital cost of the load management project. This cost is added to the cogeneration fuel price to arrive at the load management fuel price.

$$\text{LMFP}(U) = ((\text{LMDCC}(U) - \text{LMDCCP}(U)) * \text{LMDCCR} / (8760 * 1000) + \text{LMIC}(U)) * \text{INFLA} - \text{LMEVF}(U) * \text{CGFP}(EC) / 3.412$$

where:

LMFP(ENDUSE): Load Management Fuel Price
INFLA(YEAR): Inflation Index (\$/\$)
LMDCCR: LMDCCR Load Management Capital Charge Rate
LMDCC(ENDUSE): LMDCC Load Management Capital Cost
LMDCCP(ENDUSE): LMDCCP Load Management Policy Capital Cost
LMIC(ENDUSE): Load Management Indirect Cost (DLESS):
LMEVF(ENDUSE): Load Management Energy Value Fraction
CGFP(TECH,EC,YEAR): Electric Price (\$/MBTU OR \$/GJ)

Load Management Indicated Market Share

The load management indicated market share is function of the load management fuel price (relative to the cogeneration fuel price) modified by the load management multiplier and variance factor.

$$LMIMS(U) = LMMSM(U) / (LMMSM(U) + (CGFP(EC) / 3.412 / LMFP(U)) ** LMVF)$$

where:

LMFP(ENDUSE): Load Management Fuel Price
CGFP(TECH,EC,YEAR): Electric Price (\$/MBTU OR \$/GJ)
LMVF: Load Management Market Share Variance Factor (DLESS)
LMMSM(ENDUSE, YEAR): Load Management Market Share Multiplier
LMIMS(ENDUSE): Load Management Indicated Market Share

Train Transportation Only:

$$LMMS(U) = LMMS(U) + DT * ((XMAX(LMMS(U), LMIMS(U)) - LMMS(U)) / LMRT - LMMS(U) / DPLN(TE, EC))$$

where:

LMMS(ENDUSE, YEAR): Load Management Market Share
LMIMS(ENDUSE): Load Management Indicated Market Share
LMRT: Load Management Response Time

Load Management Capitalized

$$LMCAP = SUM(U, EC) ((XMAX(LMMS(U), LMIMS(U, EC)) - LMMS(U)) / LMRT(TE, EC) * LMDCCP(TE, EC) * LMLSFR(U, PEAK) * DMD(U, TE, EC) * MAX(SS)(LSF(U, EC, PEAK, SS))) / (8760 * MJKWH) * 1000 + XLMCAP$$

where:

LMMS(ENDUSE, YEAR): Load Management Market Share
LMDCCP(ENDUSE): LMDCCP Load Management Policy Capital Cost
LMIMS(ENDUSE): Load Management Indicated Market Share

Load Management Expended:

$$LMEXP = LMCAP * LMOCF + XLMCAP$$

where:

LMEXP(ENDUSE, YEAR): Load Management Expended (M\$)
LMCAP(ENDUSE, YEAR): Load Management Capitalized (M\$)
XLMCAP(ENDUSE, YEAR): Load Management Capitalized (M\$)
LMOCF: LMOCF Load Management Operating Cost Factor

Load Management can also be specified exogenously:

LMMS=XLMMMS
LMCAP=XLMCAP
LMEXP=XLMEXP

Procedure LoadCurve

Each electric end-use has a set of load shape factors (LSF) attributed to it. The LSF are estimated, end-use specific ratios that compare the kW contribution to the system seasonal peak and minimum load to the average load. (The load shape classifications are Peak, Average, Minimum load for each season - Winter, Spring, Summer, Fall, Late Fall). For example, the LSF (Winter Peak) for residential air conditioning is 0.0 while the LSF (Summer Peak) may be 6.0. The LSF (Average) over the year is always 1.0 unless a load management policy is specified. The seasonal LSF (Average) may, however, be much different than one.

Device Load Curves

The economic category and end-use load duration curve (ECLDC) by class, season, and loadshape classification is demand (DMD) multiplied by the respective LSF (DMD*LSF).

If time of use rates are being simulated, the time of use fraction (TOU) will further modify the ECLDC. Similarly, load management policies will activate LMMS (share of demand) and LMLSFR (load shape reduction fraction) and further modify the economic category load shapes

$$ECLDC = ECLDC + DMD * LSF * TOU * (1 - LMMS * LMLSFR) / (8760 * EECONV) * 1E9$$

where:

ECLDC(ENDUSE, EC, LOAD, SEASON): Load Curve by Economic Category (MW)

EECONV: Electric Energy Conversion (BTU/KWH OR GJ/KWH)

CLDC(CLASS, LOAD, SEASON, YEAR): Load Curve by Revenue Class (MW)

LMLSFR(ENDUSE, LOAD): Load Management Load Shape Reduction

LMMS(ENDUSE, YEAR): Load Management Market Share

The ECLDC (Peak) is corrected by an exogenous hourly multiplier (HPKM) to account for weather effects on temperature sensitive loads (such as air conditioning (TSLOAD)).

$$ECLDC = ECLDC * (HPKM * TSLOAD + (1 - TSLOAD))$$

where:

ECLDC(ENDUSE, EC, LOAD, SEASON): Load Curve by Economic Category (MW)

HPKM(SEASON, YEAR): Hourly Peak Day Multiplier

TSLOAD(ENDUSE, EC): Temperature Sensitive Fraction of Load (BTU/BTU or J/J)

Netting Out Cogeneration

Cogeneration can be thought of as a negative demand (DMD) converted from input BTUs to output kWh. DMD is the customer's need for electricity while CLDC is the demand the utility experiences. Therefore cogeneration demand must be subtracted from the electric loadcurves.

To begin, a cogeneration fraction (CGFR) is developed to isolate the contribution to load made by cogeneration. This fraction is determined by multiplying the cogeneration demand (CGDMD) times its load shape factor (by economic category) in a manner analogous to the calculation of ECLDC above. This load shape is then divided by the appropriate class ECLDC to derive the fraction of each ECLDC that is served by cogeneration.

$$CGFR(EC,L,SS) = \frac{SUM(T)(CGDMD(T,EC)/CGHRT(T)) * LSF(CGMAP(EC),L,SS)/8760 * 1E9}{SUM(EU)(ECLDC(EU,EC,L,SS))}$$

If cogeneration present (if CGFR is not zero), The amount of cogeneration's contribution to the class load curve (ECLDC*CGFR) is then subtracted from the appropriate class load duration curve (ECLDC) under the assumption that all end-uses are reduced by the same amount of cogeneration.

$$ECLDC = ECLDC - (ECLDC * CGFR)$$

where:

ECLDC(ENDUSE,EC,LOAD,SEASON): Load Curve by Economic Category (MW)

CGFR(EC,LOAD,SEASON): Cogeneration Fraction (Dless)

Deriving the Temperature Sensitive Portion of Load

The temperature sensitive portion of electric load is also calculated by multiplying the economic category load duration curve (ECLDC) by the fraction of temperature sensitive load in each end use for each economic class (TSLOAD)

$$TSLDC(L,SS) = SUM(EU,EC)(ECLDC(EU,EC,L,SS) * TSLOAD(EU,EC))$$

where:

TSLDC(CLASS,LOAD,SEASON,YEAR): Temperature Sensitive Load Curve

ECLDC(ENDUSE,EC,LOAD,SEASON): Load Curve by Economic Category (MW)

TSLOAD(ENDUSE,EC): Temperature Sensitive Fraction of Load (BTU/BTU or J/J)

Computing the Class Load Curve

The revenue class load duration curve (CLDC) is the ECLDCs summed over end-uses and economic categories.

$$CLDC(L,S) = SUM(EU,EC)(ECLDC(EU,EC,L,S))$$

End-use sales

Sales by end-use and class (ESALES) are the average ECLDCs summed over hours (hours per season summed over all seasons). Sales by class ECSALES are ESALES summed over end-uses. Total sales (SALES) are sales by class (ECSALES) summed over class.

$$ESALES(EU,EC) = SUM(SS)(ECLDC(EU,EC,AVERAGE,SS) * HOURS(SS)) / 1000$$

$$ECSALES(EC) = SUM(EU)(ESALES(EU,EC))$$

$$SALES(ELECTRIC) = SUM(EC)(ECSALES(EC))$$

where:

SALES(CLASS,FUEL,YEAR): Sales (Natural Units/YR)

ECSALES(EC, YEAR): Electricity Sales by Economic Category (GWH/YR)
ESALES(ENDUSE, EC, YEAR): Electricity Sales (GWH/YR)
ECLDC(ENDUSE, EC, LOAD, SEASON): Load Curve by Economic Category (MW)

Procedure NoLoadCurve: Electric Sales when load shapes are not available

If no load shapes are available, then electric demand is converted by TBTU to KWH ESALES by end-use and economic category. In the same fashion as above, ESALES is summed over all end-uses to arrive at sales by economic class (ECSALES)

$$\begin{aligned} \text{ESALES}(\text{EU}, \text{EC}) &= \text{SUM}(\text{TE}) (\text{DMD}(\text{EU}, \text{TE}, \text{EC}) * \text{FTMAP}(\text{F}, \text{TE})) / \text{EECONV} * 1\text{E}6 \\ \text{ECSALES}(\text{EC}) &= \text{SUM}(\text{EU}) (\text{ESALES}(\text{EU}, \text{EC})) \end{aligned}$$

where:

ECSALES(EC, YEAR): Electricity Sales by Economic Category (GWH/YR)
ESALES(ENDUSE, EC, YEAR): Electricity Sales (GWH/YR)
DMD(ENDUSE, TECH, EC, YEAR): Total Energy Demand (TBTU/YR OR PJ/YEAR)
EECONV: Electric Energy Conversion (BTU/KWH OR GJ/KWH)

Netting Out Cogeneration

The cogeneration fraction is determined by cogeneration sales divided by the total sales in each economic category.

$$\text{CGFR} = \text{CGEC} / \text{ECSALES}$$

where:

CGFR(EC, LOAD, SEASON): Cogeneration Fraction (Dless)
CGEC(EC, YEAR): Cogeneration by Economic Category (GWH/YR)
ECSALES(EC)=SUM(EU)(ESALES(EU,EC))

The cogeneration fraction for each economic category is used to reduce end-use sales in that economic category. All end-uses within the economic category are reduced by the same amount. Then ESALES is summed across end-uses to derive ECSALES which is then summed across economic category to arrive at total sales (SALES).

$$\begin{aligned} \text{ESALES} &= \text{ESALES} - (\text{ESALES} * \text{CGFR}) \\ \text{ECSALES}(\text{EC}) &= \text{SUM}(\text{EU}) (\text{ESALES}(\text{EU}, \text{EC})) \\ \text{SALES}(\text{ELECTRIC}) &= \text{SUM}(\text{EC}) (\text{ECSALES}(\text{EC})) \end{aligned}$$

where:

SALES(CLASS, FUEL, YEAR): Sales (Natural Units/YR)
ECSALES(EC, YEAR): Electricity Sales by Economic Category (GWH/YR)
ESALES(ENDUSE, EC, YEAR): Electricity Sales (GWH/YR)
CGFR(EC, LOAD, SEASON): Cogeneration Fraction (Dless)

Procedure DailyUse: Gas utility Daily use curve

Each end-use has a set of load shape factors (DUF) associated with it. The DUFs are estimated end-use specific ratios that compare the MTherm/Day contribution to the system seasonal peak and minimum load to the average load. (The load shape classifications are Peak, Average, and Minimum Load for each season). As an example, the DUF(winter peak) for residential space heat may be 3.0 whereas the DUF(summer peak) is 0.0. The DUF(average) over the year is always 1.0 unless a load management policy is specified. The seasonal DUF average may, however, be much different than 1.0.

The end-use daily use curve (EUDUC) by class, season, and loadshape classification is the demand (DMD with or without (DUCFSW) cogeneration and feedstock demands (CGDMD+FSDMD)) multiplied by the respective DUF (DMD*DUF)..

$$ECDUC = ECDUC + (DMD + (CGDMD + FSDMD) * DUCFSW) * DUF / 365 * GECONV$$

where:

ECDUC(ENDUSE,EC,LOAD,SEASON): Gas End-use Load Curve (M THERM/DAY)
DMD(ENDUSE,TECH,EC,YEAR): Total Energy Demand (TBTU/YR OR PJ/YEAR)
CGDMD(TECH,EC,YEAR): Cogeneration Energy Demand (TBTU/YR OR GJ/YR)
GECONV: Gas Energy Conversion (THERM/MBTU or THERM/GJ)
FSDMD(TECH,EC,YEAR): Feedstock Energy Demand (TBTU/YR OR GJ/YR)
DUF(SHAPE,LOAD,SEASON) 'Daily Use Factor (THERM/THERM)

The winter daily use curves (EUDUC for PEAK) are comprised largely of temperature sensitive primary heating load (TSLOAD). This load is corrected for daily peak weather effects (DPKM).

$$ECDUC = ECDUC * (DPKM * TSLOAD + (1 - TSLOAD))$$

where:

ECDUC(ENDUSE,EC,LOAD,SEASON): Gas End-use Load Curve (M THERM/DAY)
DPKM(SEASON) 'DAILY Peak Day Multiplier', TYPE=REAL(8,3)
TSLOAD(ENDUSE,EC): Temperature Sensitive Fraction of Load (BTU/BTU or J/J)

Gross Class Load Curve

The class load duration curve (CDUC) is the EUDUCs summed over end-uses:

$$CDUC(L,SS) = \text{SUM}(EU,EC)(ECDUC(EU,EC,L,SS))$$

where:

ECDUC(ENDUSE,EC,LOAD,SEASON): Gas End-use Load Curve (M THERM/DAY)
CDUC(LOAD,SEASON): Gas Gross Load Curve (M THERM/DAY)

Temperature Sensitive Portion of Load

The temperature sensitive portion of load (TSDUC) is the daily use curve multiplied by the fraction of load that is temperature sensitive (TSLOAD)

$$TSDUC(L,SS) = \text{SUM}(EU,EC)(ECDUC(EU,EC,L,SS) * TSLOAD(EU,EC))$$

where:

ECDUC(ENDUSE,EC,LOAD,SEASON): Gas End-use Load Curve (M THERM/DAY)
TSLOAD(ENDUSE,EC): Temperature Sensitive Fraction of Load (BTU/BTU or J/J)
TSDUC(LOAD,SEASON): Temperature Sensitive Load Curve

End-use sales

Sales by class are the average daily load curves (ECDUC) summed over days. Total sales are the sales summed over all classes.

$GSALES(EU,EC)=SUM(SS)(ECDUC(EU,EC,AVERAGE,SS)*DAYS(SS))$
 $SALES(GAS)=SUM(EU,EC)(GSALES(EU,EC))$

where:

SALES(CLASS,FUEL,YEAR): Sales (Natural Units/YR)
GSALES(ENDUSE,EC,YEAR): Gas Sales (M THERM/YR)
ECDUC(ENDUSE,EC,LOAD,SEASON): Gas End-use Load Curve (M THERM/DAY)

Procedure NoDailyUse: Gas Sales when load shapes are not available

Gas Sales by end-use and Economic Category.

Gas sales are the calculated as the share of demand, including cogeneration and feedstock, that is belongs to natural gas, converted from TBTUs to M THERMS.

$GSALES(EU,EC)=SUM(TE)((DMD(EU,TE,EC)+CGDMD(TE,EC)+FSDMD(TE,EC))*FTMAP(GAS,TE))*GECONV$

where:

GSALES(ENDUSE,EC,YEAR): Gas Sales (M THERM/YR)
FSDMD(TECH,EC,YEAR): Feedstock Energy Demand (TBTU/YR OR GJ/YR)
CGDMD(TECH,EC,YEAR): Cogeneration Energy Demand (TBTU/YR OR GJ/YR)
DMD(ENDUSE,TECH,EC,YEAR): Total Energy Demand (TBTU/YR OR PJ/YEAR)
GECONV: Gas Energy Conversion (THERM/MBTU or THERM/GJ)

Total sales are the sales summed over all classes.

$SALES(GAS)=SUM(EU,EC)(GSALES(EU,EC))$

where:

SALES(CLASS,FUEL,YEAR): Sales (Natural Units/YR)
GSALES(ENDUSE,EC,YEAR): Gas Sales (M THERM/YR)

Exogenous Transportation Sales

Transportation sales are calculated as a proportion (XCCMS) of natural gas sales. This proportion is exogenously specified by year and can change over time.

$CCSALES=SALES(GAS)*XCCMS$

where:

CCSALES (CLASS,YEAR): Transportation Sales of Gas (M THERM/YR)
SALES(CLASS,FUEL,YEAR): Sales (Natural Units/YR)
XCCMS(YEAR): Transportation Market Share (Frac)

Appendix 3. Initialization Procedures and Equations Detail

A summary of the procedures that make up the demand initialization code is listed below. Details on the key inputs, outputs, and equations of each of these procedures follows.

Table 10. Initialization Procedure Objectives

| Procedure Name | Procedure Objective |
|----------------|--|
| 1. Lifetimes | Initializes lifetimes and several other variables for use in the rest of the demand module. |
| 2. IPrice | Calculates the local fuel price by economic category and device capital charge rate. Local fuel prices by economic category are set by fuel prices except in the case of electric technologies, which instead use the electric price. Assigns fuel price for each economic category (ECP). |
| 3. DEffCurve | Derives coefficients of trade-off curves for projecting device efficiency and capital costs based on input data provided for a single initialization year. |
| 4. Initial | Initializes variables required for developing process efficiency and cost curves. |
| 5. PEffCurve | Derives coefficients of trade-off curves for projecting process efficiency and process capital costs based on input data provided for a single initialization year. |
| 6. PEffFuture | Assigns values for future years of process (and retrofit) capital cost and efficiency variables equal to the value in the initial year. |
| 7. PEffAdjust | Adjusts values for sectors or areas where driver is very small to allow for sectors that may not exist yet during initialization year. |
| 8. Pollution | Initializes the average pollution coefficients by setting equal to the marginal in the initial year. |

7.12. Procedure Lifetimes

This procedure initializes device and process lifetimes and several other variables for use in the rest of the demand module.

| Procedure Lifetimes | |
|----------------------------------|--|
| Key Inputs | |
| • XDPL(Enduse,Tech,EC,Area,Year) | 'Exogenous Physical Life of Equipment (Years)' |
| • PCPL(ECC,Area,Year) | 'Physical Life of Production Capacity (Years)' |
| • TaxPct(Area) | 'Standard accounting percent of device life that is taxed' |
| • PEPL(Enduse,Tech,EC,Area,Year) | 'Physical Life of Process Energy Requirements (Years)' |
| Key Outputs | |
| • DPL(Enduse,Tech,EC,Area,Year) | 'Physical Life of Equipment (Years)' |

| |
|--|
| <ul style="list-style-type: none"> • DTL(Enduse,Tech,EC,Area,Year) 'Device Tax Life (Years)' • PETL(Enduse,Tech,EC,Area,Year) 'Tax Life of Process Energy Requirements (Years)' |
| <p>Key Equations</p> <p>Device lifespans (DPL) are assumed to be equal to the input value (XDPL) or the productive capacity lifespan (PCPL), whichever is shorter</p> $DPL(EU,TE,EC,Area,Y)=x\min(XDPL(EU,TE,EC,Area,Y),\text{sum}(ECC)(PCPL(ECC,Area,Y)*ECCMap(EC,ECC)))$ <p>where:</p> <p>The device tax lifetime is based on the device lifespan (DPL) and the percentage of taxable lifespan variable (TAXPCT)</p> $DTL(EU,TE,EC,Area,Y)=DPL(EU,TE,EC,Area,Zero)*TAXPCT(Area)$ <p>where:</p> <p>Process requirement lifespans (PEPL) are equal to device lifespans (DPL), except in the case of the Heat and AC enduses which instead use the productivity capacity lifespan (PCPL). The tax life is set similarly as devices.</p> <pre> PEPL=DPL Do If (EUKey eq "Heat") OR (EUKey eq "AC") PEPL(EU,TE,EC,Area,Y)=sum(ECC)(PCPL(ECC,Area,Y)*ECCMap(EC,ECC)) End Do If </pre> $PETL(EU,TE,EC,Area,Y)=PEPL(EU,TE,EC,Area,Zero)*TAXPCT(Area)$ |

7.13. Procedure IPrice

This procedure calculates the local fuel price by economic category and device capital charge rate. Local fuel prices by economic category are set by fuel prices except in the case of electric technologies, which instead use the electric price. Assigns fuel price for each economic category (ECFP).

| Procedure IPrice |
|---|
| <p>Key Inputs</p> <p><i>Inputs from Price Calibration</i></p> <ul style="list-style-type: none"> • FP(Prices,Area,Year) 'Fuel Prices (\$/mmBtu)' • PE(ECC,Area,Year) 'Price of Electricity (Mills per kWh)' <p><i>Inputs from Procedure Lifetimes</i></p> <ul style="list-style-type: none"> • DPL(Enduse,Tech,EC,Area,Year) 'Physical Life of Equipment (Years)' • DTL(Enduse,Tech,EC,Area,Year) 'Device Tax Life (Years)' <p><i>Exogenous Inputs</i></p> <ul style="list-style-type: none"> • DIVTC(Tech,Area,Year) 'Device Investment Tax Credit (\$/\$)' • DRISK(Enduse,Tech) 'Device Excess Risk (DLESS)' • InSm 'Smoothed Inflation Rate (1/Yr)' • ROIN(EC,Area) 'Return on Investment (\$/Yr/\$)' • XDCC(Enduse,Tech,EC,Area,Year) 'Device Capital Cost (\$/mmBtu/Yr)' • XDEE(Enduse,Tech,EC,Area,Year) 'Historical Device Efficiency (Btu/Btu)' • DOCF(Enduse,Tech,EC,Area,Year) 'Device Operating Cost Fraction' |

Key Outputs

Calculated Outputs (For Initialization Year)

- ECFP(Tech,EC,Area,Year) 'Fuel Price (\$/mmBtu)'
- DCCRN(Enduse,Tech,EC,Area,Year) 'Device Capital Charge Rate (\$/Yr/\$)'
- MCFU(Enduse,Tech,EC,Area,Year) 'Marginal Cost of Fuel Use (\$/mmBtu)'

Key Equations

Local fuel prices by economic category are set by fuel prices except in the case of electric technologies, which instead use the electric price:

$$\begin{aligned} \text{ECFP}(\text{TE}, \text{EC}, \text{Area}) &= \text{FP}(\text{FPMap}(\text{TE}, \text{EC}), \text{Area}) \\ &\text{Select Tech if ElecMap eq 1} \\ \text{ECFP}(\text{TE}, \text{EC}, \text{Area}) &= \text{sum}(\text{ECC})(\text{PE}(\text{ECC}, \text{Area}) * \text{ECCMap}(\text{EC}, \text{ECC})) / 3412 * 1000 \end{aligned}$$

Investment Levelization Rate - the Capital Charge Rate

The device capital charge rate is the annualization of device capital expenses (over the life of the device - DTL), accounting for taxes (TXRT), tax credits (DIVTC), and return of principal and on investment (including risk premiums and inflation: $1 + \text{ROIN} + \text{DRISK} + \text{INSM}$). $(1 - (1 / (1 + \text{ROIN} + \text{DRISK}))^{**} \text{DPL}) / (1 - \text{TXRT})$ is the classical capital recovery term. The $(1 - \text{TXRT})$ term at the end converts the after tax calculation into before tax dollars. Investment tax credits reduce the cost of the facility by the tax credit after the first year of operation using nominal dollars. Therefore the value of the tax credit is $(\text{DIVTC} / (1 + \text{ROIN} + \text{DRISK} + \text{INSM}))$. Depreciation is modeled as a current dollar phenomena which does not account for inflation. Therefore the net present value of the energy is calculated with the nominal rate of return: $(2 / \text{DTL}) / (\text{ROIN} + \text{DRISK} + \text{INSM} + 2 / \text{DTL})$. It shows up as an additional negative term in the capital cost modifiers of DCCR because depreciation is a benefit (negative cost).

Device capital costs (DCC) are multiplied by the DCCRN to get the annualized cost of the device used in computing market share calculations.

The formula for calculating the device capital charge rate:

$$\text{DCCRN} = (1 - \text{DIVTC} / (1 + \text{ROIN} + \text{DRISK} + \text{INSM}) - \text{TXRT} * (2 / \text{DTL}) / (\text{ROIN} + \text{DRISK} + \text{INSM} + 2 / \text{DTL})) * (\text{ROIN} + \text{DRISK}) / (1 - (1 / (1 + \text{ROIN} + \text{DRISK}))^{**} \text{DPL}) / (1 - \text{TXRT})$$

Cost of Using a Device

Each specific demand for energy is associated with a stock of capital. Investment in each type of capital stock by fuel type is allocated according to the cost of using each type of fuel. This cost is the perceived cost to the user and includes a risk factor (incorporated in the calculation of DCCRN), annualized capital costs ($\text{DCCRN} * \text{XDCC}$), and delivered marginal fuel costs ($\text{ECFP} / \text{XDEE}$).

The marginal cost of using energy (MCFU) includes the cost of using energy for all end-uses. As such, a house that has a gas furnace but an electric water heater would be represented partially in the model's gas capital stock and partially in the electric capital stock. The investment includes capital using energy in addition to the energy source equipment.

$$\text{MCFU} = (\text{DCCRN} + \text{DOCF}) * \text{XDCC} + \text{ECFP} / \text{XDEE}$$

7.14. Procedure DEffCurve

This procedure derives the device Consumer Preference Efficiency and Capital Cost Curves based on the input data provided for the single initialization year (CurTime). Once calculated, the capital cost and fuel cost coefficients (DCTC, DFTC) are held constant for all years in the model.

| Procedure DEffCurve |
|---|
| Key Inputs |
| <p>Inputs from Procedure IPrice</p> <ul style="list-style-type: none"> • ECFP(Tech,EC,Area,Year) 'Fuel Price (\$/mmBtu)' • DCCRN(Enduse,Tech,EC,Area,Year) 'Device Capital Charge Rate (\$/Yr/\$)' <p>Exogenous Inputs</p> <ul style="list-style-type: none"> • XDEE(Enduse,Tech,EC,Area,Year) 'Historical Device Efficiency (Btu/Btu)' • DESTD(Enduse,Tech,EC,Area,Year) 'Device Efficiency Standards (Btu/Btu)' • DESTDP(Enduse,Tech,EC,Area,Year) 'Device Efficiency Standards Policy (Btu/Btu)' • DOCF(Enduse,Tech,EC,Area,Year) 'Device Operating Cost Fraction' • DEM(Enduse,Tech,EC,Area) 'Maximum Device Efficiency (Btu/Btu)' • XDCC(Enduse,Tech,EC,Area,Year) 'Device Capital Cost (\$/mmBtu/Yr)' |
| Key Outputs |
| <p>Calculated Outputs (for Initialization Year)</p> <ul style="list-style-type: none"> • DEEStd(Enduse,Tech,EC,Area) 'Device Efficiency with Standard (Btu/Btu)' • DCCN(Enduse,Tech,EC,Area) 'Normalized Device Capital Cost (\$/mmBtu)' • DFPN(Enduse,Tech,EC,Area) 'Normalized Fuel Price (\$/mmBtu)' <p>Outputs (for All Years)</p> <ul style="list-style-type: none"> • DCTC(Enduse,Tech,EC,Area,Year) 'Device Cap. Trade Off Coefficient (DLESS)' • DFTC(Enduse,Tech,EC,Area,Year) 'Device Fuel Trade Off Coefficient (DLESS)' • RDCTC(Enduse,Tech,EC,Area,Year) 'Retrofit Device Cap. Trade Off Coefficient (DLESS)' • RDFTC(Enduse,Tech,EC,Area,Year) 'Retrofit Device Fuel Trade Off Coefficient (DLESS)' |
| Key Equations |
| <p>Apply Device Efficiency Standard</p> <p>Assume that the input capital cost data (XDCC) is based on the level of efficiency of a historical standard for the initialization year if one exists.</p> $DEEStd = \text{xmax}(XDEE, DESTD, DESTDP)$ <p>Capital Cost Coefficient</p> $DCTC = -1 / ((ECFP / \text{Infla} / XDEE) / ((DCCRN + DOCF) * XDCC) * (1 - XDEE / DEM))$ <p>Fuel Cost Coefficient</p> $DCCN = XDCC / (DEM / DEEStd - 1) ** (1 / DCTC)$ <p>Normal Capital Cost</p> $DCCN = XDCC / (DEM / DEEStd - 1) ** (1 / DCTC)$ <p>Normal Fuel Cost</p> $DFPN = -(DOCF + DCCRN) * DCCN * DEM / DCTC$ |

7.15. Procedure Initial

This procedure performs variable initializations for various device, process, and budget parameters. This section is used as an input for developing the process efficiency curves.

The calibrated capacity utilization factor (by ECC) is weighted by its share of economic driver and summed over ECC to yield a weighted capacity utilization factor by EC. The ECCMap maps the ECCs (subclasses such as offices or food processing) into the correct EC (economic class such as commercial or industrial).

| Procedure Initial |
|--|
| <p>Key Inputs</p> <p>Exogenous Inputs</p> <ul style="list-style-type: none"> • XDmd(Enduse,Tech,EC,Area,Year) 'Energy Demand (TBtu/Yr)' • XCgDmdSector(Tech,EC,Area,Year) 'Cogeneration Energy (TBtu/Yr)' • XCgVF(Tech,EC) 'Cogen. Variance Factor (\$/\$)' • XCgHRtA(Tech,EC,Area) 'Historic Average Cogeneration Heat Rate (Btu/KWh)' • XDST(Enduse,EC,Area) 'Device Saturation (Btu/Btu)' • DEM(Enduse,Tech,EC,Area) 'Maximum Device Efficiency (Btu/Btu)' • DESTD(Enduse,Tech,EC,Area,Year) 'Device Efficiency Standards (Btu/Btu)' • DESTDP(Enduse,Tech,EC,Area,Year) 'Device Efficiency Standards Policy (Btu/Btu)' • STX(Area,Year) 'Sales Tax Rate on Energy Consumer (\$/\$)' • DDAnnual(Enduse,Area,Year) 'Annual Degree Days (Degree Days)' • DDAnnualNorm(Enduse,Area) 'Normal Annual Degree Days (Degree Days)' • DDCoefficient(Enduse,EC,Area,Year) 'Annual Energy Degree Day Coefficient (DD/DD)' • TSLoad(Enduse,EC,Area) 'Temp. Sensitive Fraction of Load' • <i>Capacity utilization factor (CUF=1.0)</i> • <i>Capacity Energy Requirement multiplier (CERSM=1.0)</i> • PDIF(Enduse,Tech,EC,Area) 'Difference between the Initial Process Efficiency for each Fuel' • DCCRN(Enduse,Tech,EC,Area) 'Device Capital Charge Rate (\$/Yr/\$)' <p>Inputs from Economic Sector</p> <ul style="list-style-type: none"> • Driver(ECC,Area) 'Economic Driver (Various Millions/Yr)' • FPC(Enduse,Tech,EC,Area) 'Actual Production Capacity by Tech (\$/YR)' • PCLV(Age,ECC,Area,Year) 'Production Capacity (M\$/Yr)' <p>Inputs from Supply Sector</p> <ul style="list-style-type: none"> • PCERFF(Fuel,Age,ECC,Area) 'Fraction of Energy Requirement by Age and Fuel' • PCgRFF(Age,ECC,Area) 'Fraction of Energy Requirement by Age' <p>Inputs from DEffCurve Procedure</p> <ul style="list-style-type: none"> • DCCN(Enduse,Tech,EC,Area) 'Normalized Device Capital Cost (\$/mmBtu)' • DCTC(Enduse,Tech,EC,Area,Year) 'Device Cap. Trade Off Coefficient (DLESS)' • DFTC(Enduse,Tech,EC,Area,Year) 'Device Fuel Trade Off Coefficient (DLESS)' |
| <p>Key Outputs</p> <p>Output for Initialization Year Only (Assignments to Exogenous Inputs)</p> <ul style="list-style-type: none"> • Energy demand (Dmd=XDmd) • Device saturation rate (DST=XDST) • Cogeneration energy demand (CgDmdSector=XCgDmdSector) |

- Cogeneration variance factory (CgVF=XCgVF)
 - Average cogeneration heat rate (CgHRtA=XCgHRtA)
- Output from Procedure Initial – Calculated Values**
- DCC(Enduse,Tech,EC,Area,Year) 'Device Capital Cost (\$/mmBtu/Yr)'
 - DEE(Enduse,Tech,EC,Area) 'Device Efficiency (Btu/Btu)'
 - DEMM(Enduse,Tech,EC,Area) 'Maximum Device Efficiency Multiplier (Btu/Btu)' - is used as an adjustment if the efficiency calculation above differs (DEE) from historical inputs (XDEE).
 - DEEA(Enduse,Tech,EC,Area,Year) 'Average Device Efficiency (Btu/Btu)' - DEEA=DEE
 - DER(Enduse,Tech,EC,Area,Year) 'Energy Requirement (mmBtu/YR)'
 - PEE(Enduse,Tech,EC,Area) 'Process Efficiency (\$/Btu)'
 - PER(Enduse,Tech,EC,Area) 'Process Energy Requirement (mmBtu/YR)'
 - CgGCSector(Tech,EC,Area,Year) 'Cogeneration Gen. Capacity (MW)'
 - CgCUFP(Tech,EC,Area) 'Cogeneration CUF for Planning (Btu/Btu)'
 - CgDmdE(Tech,EC,Area) 'Cogeneration Embodied Energy Demand (TBtu/Yr)'
 - DEMM(Enduse,Tech,EC,Area,Year) 'Maximum Device Efficiency Multiplier (Btu/Btu)'
 - WCUF(EC,Area) 'Capacity Utilization Factor Weighted by Output'
 - PEEA(Enduse,Tech,EC,Area,Year) 'Average Process Efficiency (\$/Btu)'
 - AB(Enduse,Tech,EC,Area,Year) 'Initial Average Budget (\$/\$)'
 - EUPC(Enduse,Tech,Age,EC,Area,Year) 'Production Capacity by Vintage (M\$/Yr)'

Key Equations

Device Efficiency

Device marginal efficiency (DEE) is a function of maximum efficiency, fuel price (ECFP), and the capital and fuel cost coefficients (DCTC, DFTC).

$$DEE = DEM / (1 + ((ECFP / Infla) / DFPN) ** DFTC)$$

$$DEE = x_{max}(DEE, DESTD, DESTDP)$$

The device efficiency multiplier (DEMM) is used as an adjustment if the efficiency calculation above differs (DEE) from historical inputs (XDEE).

$$DEMM = x_{max}(DEMM, DEE / DEMM / (DEM * 0.98))$$

$$DEMM = DEMM * x_{max}(XDEE, DESTD, DESTDP) / DEE$$

$$DEE = x_{max}(XDEE, DESTD, DESTDP)$$

Device Capital Cost

Device marginal capital cost (DCC) is a function of the normal capital cost (DCCN), the level of efficiency (DEE), and the capital cost coefficient (DCTC)

$$DCC = DCCN * Infla * (1 + STX) * (DEM / DEE - 1) ** (1 / DCTC)$$

Weighting the Capacity Utilization Factor by Output

The calibrated capacity utilization factor (by ECC) is weighted by its share of economic driver and summed over ECC to yield a weighted capacity utilization factor by EC. The ECCMAP maps the ECCs (subclasses such as offices or food processing) into the correct EC (economic class such as commercial or industrial)

$$WCUF(EC, Area) = \frac{\sum(ECC)(Driver(ECC, Area) * ECUF(ECC, Area) * ECCMap(EC, ECC))}{\sum(ECC)(Driver(ECC, Area) * ECCMap(EC, ECC))}$$

Energy Requirements by End-use

Demand is set equal to exogenous historical demands:

$$DMD=XDMD$$

Device Energy Requirements by End-use are calculated as from the exogenous demands by dividing by the weighted capacity utilization factor and normalizing for weather effects:

$$DER(EU,TE,EC,Area)=Dmd(EU,TE,EC,Area)/WCUF(EC,Area)/(DDM(EU)*TSLoad(EU,EC,Area)+(1-TSLoad(EU,EC,Area)))*1E6$$

If there is no initial demand, then set the initial demand to 1/1e12 times the maximum demand (XDmdYr).

$$DER(EU,TE,EC,Area)=xmax(DER(EU,TE,EC,Area),max(Year)(XDmdYr(EU,TE,EC,Area,Year))/1E12)$$

where:

$$XDmdYr(Enduse,Tech,EC,Area,Year) \text{ 'Energy Demand (TBtu/Yr)'}'$$

Set the initial average efficiency (DEEA) equal to the initial marginal efficiency (DEE):

$$DEEA=DEE$$

Process Energy Requirements of Capital Stock

The process energy requirements of capital stock are equal to the device requirements times the average device efficiency:

$$PER=DER*DEEA$$

Saturation

The initial device saturation is set equal to its exogenous value:

$$DST=XDST$$

Calculate indicated EUPC as FPC

Actual Production Capacity by Technology (\$) is equal to the process energy requirements by technology (MBTU) divided by the device saturation (BTU/BTU) times the difference in process efficiency between technologies (PDIF).

$$FPC=PER/DST*PDIF$$

FPC is allocated fractionally to sum to the initial production capacity (PCLVI (EUPC)):

First total actual production capacity is calculated by summing the actual production capacity across technologies:

$$TFPC(EU,EC,Area)=sum(TE)(FPC(EU,TE,EC,Area))$$

The desired production capacity (FPCI) is derived from the initial production capacity (PCLV) by splitting PCLV by the ratio of a given technology's production capacity to the total capacity (FPC/TFPC).

$$FPCI(EU,TE,EC,Area)=sum(A,ECC)(PCLV(A,ECC,Area)*ECCMap(EC,ECC))*FPC(EU,TE,EC,Area)/TFPC(EU,EC,Area)$$

where:

TFPC(Enduse,EC,Area) 'Total Production Capacity by Tech (\$/YR)
 FPCI(Enduse,Tech,EC,Area)'Desired Production Capacity by Tech (M\$/Yr)

Calculate Process Efficiency

Average process efficiency is calculated by multiplying the production capacity by the device saturation and dividing by the energy requirements:

$$PEEA=FPCI*DST/PER$$

For the initial year the average efficiency is also the marginal efficiency:

$$PEE=PEEA$$

Split Capital Stock by Age

This routine uses the market share for each age category (PCERF) to split the capital stock (FPCI) into capital stock by age and fuel (EUPCI) for each end-use

The first step is to renormalize PCERF to be consistent with PCGRF.

Rename the fraction of energy requirement by fuel to be before modification:

$$PCERFI=PCERF$$

Develop a weighted sum of PCERF (LOC3):

$$LOC3(A,EC,Area)=\frac{\sum(TE)(PCERF(TE,A,EC,Area)*FPCI(EU,TE,EC,Area))}{\sum(Tech)(FPCI(EU,Tech,EC,Area))}$$

Scale to match PCERG (growth rate):

$$PCERF=PCERF*PCgRF/LOC3$$

Move residual to next AGE group (AGENEXT). Since AGENEXT is defined as AGE:S-1, this moves the residual into the MID category from the OLD category so that it works with large negative growth:

$$PCERF(TE,AGENEXT,EC,Area)=PCERF(TE,AGENEXT,EC,Area)+PCERFI(TE,A,EC,Area)-PCERF(TE,A,EC,Area)$$

$$PCERF(TE,AGENEXT,EC,Area)=x\max(PCERF(TE,AGENEXT,EC,Area),0.001)$$

Normalize PCERF to sum to 1.0:

$$LOC4(TE,EC,Area)=\sum(A)(PCERF(TE,A,EC,Area))$$

$$PCERF=PCERF/LOC4$$

Production capacity by end-use (EUPC) is then the sum over fuel and economic subclass of the product of the fraction of energy requirement by AGE and FUEL and the desired production capacity. The desired production capacity is allocated by technology, age and economic class in EUPC.

$$EUPC=PCERF*FPCI$$

Cooling to Heating Efficiency Ratio

If there is no HEAT, skip the following equation for CHR. The cooling to heating efficiency ratio is the ratio of the heating

$$CHR(EC,Area)=\frac{\sum(TE)(PEE(Heat,TE,EC,Area)*PER(Heat,TE,EC,Area))}{\sum(TE)(PER(Heat,TE,EC,Area))} / \frac{\sum(TE)(PEE(AC,TE,EC,Area)*PER(AC,TE,EC,Area))}{\sum(TE)(PER(AC,TE,EC,Area))}$$

Initialize Average Budget

AB=ECFP/INFLA*DST/(PEEA*DEEA)

Initialize Cogeneration

CgDmdSector=XCgDmdSector

CgVF=XCgVF

CgHRtA=XCgHRtA

CgUMS=1.0

CgGCSector(TE,EC,Area)=CgDmdSector(TE,EC,Area)/sum(ECC)(ECUF(ECC,Area)*

ECCMap(EC,ECC))/CgCUFP(TE,EC,Area)/CgHRtA(TE,EC,Area)/8760*1E9

CgDmdE=CgGCSector*CgHRtA*CgCUFP*8760/1e3/1e6

7.16. Procedure PEffCurve

This procedure derives the process Consumer Preference Efficiency and Capital Cost Curves based on the input data provided for the single initialization year.

| Procedure PEffCurve |
|--|
| Key Inputs |
| Exogenous Inputs <ul style="list-style-type: none">• XPCC(Enduse,Tech,EC,Area,Year) 'Process Capital Cost (\$/(\$/yr))'• PEMX(Enduse,Tech,EC,Area) 'Ratio of Maximum to Average Process Efficiency (\$/Btu/(\$/Btu))'• PIVTC(Year) 'Process Investment Tax Credit (DLESS)' |
| Inputs from Procedure Lifetimes <ul style="list-style-type: none">• PEPL(Enduse,Tech,EC,Area,Year) 'Physical Life of Process Energy Requirements (Years)'• PETL(Enduse,Tech,EC,Area,Year) 'Tax Life of Process Energy Requirements (Years)' |
| Inputs from Procedure IPrice <ul style="list-style-type: none">• MCFU(Enduse,Tech,EC,Area,Year) 'Marginal Cost of Fuel Use (\$/mmBtu)' |
| Inputs from Procedure Initial <ul style="list-style-type: none">• PEE(Enduse,Tech,EC,Area) 'Process Efficiency (\$/Btu)'• PEEA(Enduse,Tech,EC,Area,Year) 'Average Process Efficiency (\$/Btu)' |
| Key Outputs |
| Assigned Value Outputs (for Initial Year) <ul style="list-style-type: none">• Process capital cost (PCC=XPCC) |
| Output from Procedure Initial – Calculated Values <ul style="list-style-type: none">• PCCRN(Enduse,Tech,EC,Area,{Year=Zero}) 'Process Capital Charge Rate'• POCF(Enduse,Tech,EC,Area) 'Process Operating Cost Fraction'• PEM(Enduse,EC,Area) 'Maximum Process Efficiency (\$/mmBtu)'• PFPN(Enduse,Tech,EC,Area) 'Process Normalized Fuel Price (\$/mmBtu)'• PCCN(Enduse,Tech,EC,Area) 'Normalized Process Capital Cost (\$/mmBtu)'• PCTC(Enduse,Tech,EC,Area,Year) 'Process Capital Cap. Trade Off Coef. (DLESS)'• PFTC(Enduse,Tech,EC,Area,Year) 'Process Fuel Trade Off Coefficient'• RPCTC(Enduse,Tech,EC,Area,Year) 'Retrofit Process Capital Trade Off Coefficient (DLESS)' |

- RPFTC(Enduse,Tech,EC,Area,Year) 'Retrofit Process Fuel Trade Off Coefficient'

Key Equations

Cost of Using a Device

$$MCFU=(DCCRN+DOCF)*DCC+ECFP/DEE$$

Capital Charge Rate

$$PCCRN = (1-PIVTC/(1+ROIN+0+INSM)-TXRT * (2/PETL)/(ROIN+0+INSM+2/PETL)) * (ROIN+0)/(1-(1/(1+ROIN+0))**PEPL)/(1-TXRT)$$

Operating Cost Factor

$$POCF=(Infla-MCFU/1000000/PEEA)/XPCC-PCCRN$$

$$POCF=xmax(POCF,0)$$

Maximum Process Efficiency

Maximum Process Efficiency is based on the highest fuel.

$$PEM(EU,EC,Area)=max(Tech)(PEEA(EU,Tech,EC,Area)*PEMX(EU,Tech,EC,Area))$$

Process Fuel and Capital Cost Coefficients

$$PCTC = -1/((MCFU/1000000/PEEA)/((PCCRN+POCF)*XPCC) * (1-PEEA/PEM))$$

$$PFTC = PCTC/(1-PCTC)$$

Process Normal Fuel Cost

$$PFPN=-((PCCRN+POCF)*XPCC*PEM*1000000)/(PCTC*(PEM/PEE-1)**(1/PCTC))$$

Normal Process Capital Cost

For the first enduse only:

$$PCCN=XPCC/(PEM/PEE-1)**(1/PCTC)$$

otherwise:

$$PCCN=0$$

Initialize Process Capital Cost

$$PCC(EU,T,EC,Area)=XPCC(EU,T,EC,Area)$$

Procedure PEffAdjust

This procedure was developed to adjust the process initialization variables after calculation if the value for Driver in a given sector or area is very small or zero. This allows for the process cost and efficiency curves to operate normally for sectors that might not exist until after the initial year. The average coefficients area applied in the event that the driver is very small or zero.

Procedure PEffAdjust

Key Inputs

Inputs from Macroeconomic Sector

- Driver(ECC,Area) 'Economic Driver (Various Millions/Yr)'

Inputs from Procedure PEffCurve

- PCCN(Enduse,Tech,EC,Area) 'Normalized Process Capital Cost (\$/mmBtu)'
- PCTC(Enduse,Tech,EC,Area,Year) 'Process Capital Cap. Trade Off Coef. (DLESS)'
- PCCRN(Enduse,Tech,EC,Area,{Year=Zero}) 'Process Capital Charge Rate'
- POCF(Enduse,Tech,EC,Area) 'Process Operating Cost Fraction'
- PEM(Enduse,EC,Area) 'Maximum Process Efficiency (\$/mmBtu)'
- PFPN(Enduse,Tech,EC,Area) 'Process Normalized Fuel Price (\$/mmBtu)'

Key Outputs

Calculated Outputs

- PCCN(Enduse,Tech,EC,Area) 'Normalized Process Capital Cost (\$/mmBtu)'
- PCTC(Enduse,Tech,EC,Area,Year) 'Process Capital Cap. Trade Off Coef. (DLESS)'
- PCCRN(Enduse,Tech,EC,Area,{Year=Zero}) 'Process Capital Charge Rate'
- POCF(Enduse,Tech,EC,Area) 'Process Operating Cost Fraction'
- PEM(Enduse,EC,Area) 'Maximum Process Efficiency (\$/mmBtu)'
- PFPN(Enduse,Tech,EC,Area) 'Process Normalized Fuel Price (\$/mmBtu)'

Key Equations

The average coefficient of all areas is weighted based on the driver for each area over the driver of all areas.

$$\begin{aligned} AvPEM(EU,EC) &= \text{sum}(Ar)(PEM(EU,EC,Ar) * Driver(ECC,Ar)) / \text{sum}(Area)(Driver(ECC,Area)) \\ AvPOCF(EU,T,EC) &= \text{sum}(Ar)(POCF(EU,T,EC,Ar) * Driver(ECC,Ar)) / \text{sum}(Area)(Driver(ECC,Area)) \\ AvPCTC(EU,T,EC) &= \text{sum}(Ar)(PCTC(EU,T,EC,Ar) * Driver(ECC,Ar)) / \text{sum}(Area)(Driver(ECC,Area)) \\ AvPFPN(EU,T,EC) &= \text{sum}(Ar)(PFPN(EU,T,EC,Ar) * Driver(ECC,Ar)) / \text{sum}(Area)(Driver(ECC,Area)) \\ AvPCCN(EU,T,EC) &= \text{sum}(Ar)(PCCN(EU,T,EC,Ar) * Driver(ECC,Ar)) / \text{sum}(Area)(Driver(ECC,Area)) \end{aligned}$$

where:

$$\begin{aligned} AvPEM(Enduse,EC) & \text{ 'Average Value of PEM'} \\ AvPOCF(Enduse,Tech,EC) & \text{ 'Average Value of POCF'} \\ AvPCTC(Enduse,Tech,EC) & \text{ 'Average Value of PCTC'} \\ AvPFPN(Enduse,Tech,EC) & \text{ 'Average Value of PFPN'} \\ AvPCCN(Enduse,Tech,EC) & \text{ 'Average Value of PCCN'} \end{aligned}$$

The average coefficients area applied in the event that the driver is very small or zero.

$$\begin{aligned} & \text{Select Area if Driver It } 0.0001 \\ & \text{Do If Driver It } 0.0001 \\ & PEM = AvPEM \\ & POCF = AvPOCF \\ & PCTC = AvPCTC \\ & PFTC = PCTC / (1 - PCTC) \\ & PFPN = AvPFPN \\ & PCCN = AvPCCN \end{aligned}$$

7.17. Procedure PEffFuture

This procedure simply sets the process and retrofit fuel and capital cost variables for all years equal to the value in the initial year.

| Procedure P _{EffFuture} |
|--|
| Key Outputs |
| <p>Calculated Outputs</p> <ul style="list-style-type: none"> • PCTC(Enduse,Tech,EC,Area,Year) 'Process Capital Cap. Trade Off Coef. (DLESS)' • PFTC(Enduse,Tech,EC,Area,Year) 'Process Fuel Trade Off Coefficient' • RPCTC(Enduse,Tech,EC,Area,Year) 'Retrofit Process Capital Trade Off Coefficient (DLESS)' • RPFTC(Enduse,Tech,EC,Area,Year) 'Retrofit Process Fuel Trade Off Coefficient' |
| Key Equations |
| <p>This procedure simply sets the process and retrofit fuel and capital cost variables for all years equal to the value in the initial year.</p> <p style="padding-left: 40px;">PCTC=PCTC0 PFTC=PFTC0 RPCTC=PCTC0 RPFTC=PFTC0</p> |

7.18. Procedure Pollution

This procedure initializes the pollution variables by setting average coefficients equal to the marginal exogenous pollution coefficients.

| Procedure D _{EffCurve} |
|--|
| Key Inputs |
| <p>Exogenous Inputs</p> <ul style="list-style-type: none"> • POCX (Enduse,FuelEP,EC,Poll,Area,Year) 'Marginal Pollution Coefficients (Tonnes/TBtu)' • CgPOCX (FuelEP,EC,Poll,Area,Year) 'Cogeneration Pollution Coefficient (Tonnes/TBtu)' |
| Key Outputs |
| <p>Assigned Outputs (for initial year)</p> <ul style="list-style-type: none"> • POCA (Enduse,FuelEP,EC,Poll,Area,Year) 'Average Pollution Coefficients (Tonnes/TBtu)' • CgPOCA (FuelEP,EC,Poll,Area,Year) 'Cogeneration Avg. Pollution Coefficient (Tonnes/TBtu)' |
| Key Equations |
| <p>Embodied Pollution from Cogeneration</p> <p>The average pollution coefficient is set equal to the exogenous value:</p> <p style="padding-left: 40px;">$CgPOCA = CgPOCX$</p> |
| <p>Embodied Pollution</p> <p>The average pollution coefficient is set equal to the exogenous marginal value:</p> <p style="padding-left: 40px;">$POCA = POCX$</p> |