ENERGY 2020 Documentation

Volume 2

Demand Sector Structure Overview

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INTRODUCTION

The demand overview lays out the basic structure of the ENERGY 2020 demand module and should provide both a broad overview as well as some specific (but non-mathematical) detail as to how these sectors simulate the demand structure. The key features of the demand sectors are listed in Table 0.1. The contrast with the classical econometric model is clear. The econometric model would have energy demands as a function of energy prices and GNP, usually with some elaboration. ENERGY 2020 demands are determined by calculations incorporating far more detail and structure.

Table 0.1: Demand Sector Features

- *Allows arbitrary number of end-uses.*
- *Allows arbitrary number of energy consuming sectors.*
- *Simulates energy demands for all fuels.*
- *Calibrates to unique service-area conditions and performs historical validation.*
- *Simulates marginal investments, fuel switching, fuel conversions, and retrofits.*
- *Simulates DSM penetration and take-back dynamics.*
- *Simulates market share, process-side, and device-side decisions.*
- *Trades off capital and efficiency with fuel prices dynamically.*
- *Simulates cogeneration investment, constrictions, and usage.*
- *Provides scenario database for user-specified definition and initiation of scenario packages. Large standardized set of pre-formatted reports.*
- *Simulates short-term effects such as budget constraints and temperature sensitive loads.*
- *Includes socioeconomic change (labor-participation, multifamily housing) and other non-energy price effects.*
- *Simulates fungible impacts.*

ENERGY 2020 allows an arbitrary number of end-uses to be specified by the user. Currently, most residential sectors use about eight - lighting, air conditioning, space heating, cooking, drying, refrigeration, and hot water are the major ones with a miscellaneous category picking up clothes washers, dish washers, microwaves, televisions, computers, etc. Along with an arbitrary number of end-uses, an arbitrary number of energy consuming sectors can be selected as well. Common configurations include single and multi-family residential, up to eleven commercial building types - office, retail, etc., - and industrial class by two-digit SIC codes. If the transportation sector is used, it too can incorporate any end-use the client desires and has data for.

ENERGY 2020 simulates demand for all fuels and can distinguish between changes in energy demand for a particular fuel that are attributable to a fuel switch from an overall energy usage decline. Demand effects considered by ENERGY 2020 include short-term effects such as budget constraints and fungible demand as well as the longer-term effects of fuel switching, improved efficiency and structural changes in the economy.

ENERGY 2020 models the complete demand structure by simulating all market share, process-side and device-side decisions through trade-off curves that relate improvements in energy efficiency to fuel costs and capital costs. Since cogeneration and DSM are also demand-side options, ENERGY 2020 incorporates structure to simulate these choices as well.

To understand how ENERGY 2020 simulates demand it is necessary to explain nine basic energy demand mechanisms. These mechanisms are listed in Figure 2.1 and form the basis for discussion in the remaining sections of this chapter.

In Figure 0.1, Demand Overview, the top left hand corner of the diagram contains Investments in Production Capacity - the economic component of the model. The changes in the economy come in terms of these investments. The bottom left hand corner has the fuel price term. From the arrows drawn it is clear that production capacity and prices together in some fashion determine energy demand. So this portion of the model looks at the relationship between the economy, energy prices and energy demand.

The way these relationships are represented is called causal modeling where the structure and relationships between prices, the economy and energy demand are defined. All of the structure of the demand model is represented in econometrics by income and price elasticities. ENERGY 2020 attempts to define what is creating these elasticities and to go beyond them. Static price elasticity alone cannot capture all the effects modeled in ENERGY 2020. The impact of price on demand (price elasticity) depends on efficiencies - both device and process - as well as fuel market share and the growth rate of the economy. If prices are high and the economy is growing, there will be a quick turnover of capital stock. Efficiency (assuming the efficiency of new stock is greater than the old) is going to increase more quickly as well. If the economic growth is low, there will be less investment and a smaller turnover in capital stock and fewer changes in energy efficiency and other variables. These dynamics cannot be completely captured in a single price elasticity term. ENERGY 2020 breaks simulates all these dynamics.

Elasticities are used at the “edges” of the model. The model incorporates all the structure and detail necessary to capture the interactions between the economy, energy prices and energy demand. Econometric equations are used to pick up the rest - the “outside the model” parameters that bound the structure. ENERGY 2020 combines both the dynamic structure of the energy demand market and the econometrically estimated parameters guiding this structure.

DEMAND OVERVIEW

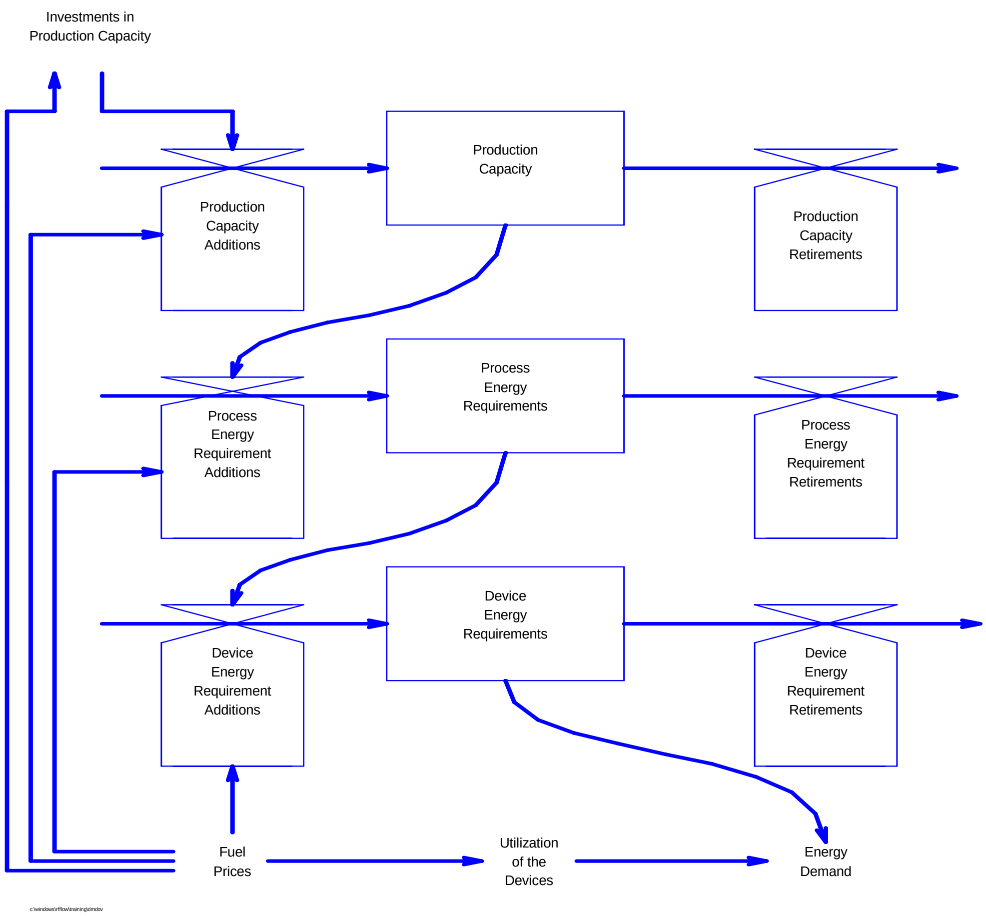

Figure 0.1

At the bottom of Figure 0.1, energy demand is represented as a function of Device Energy Requirements and the utilization of those devices. Device Energy Requirements simply consist of the energy required to run existing appliances - space heaters, air conditioning, hot water heaters, clothes dryers, refrigerators, etc.. Utilization of devices is related to behavior. For example, industrial customers may run their factories for one or several shifts. A plant using energy for process heat and lighting that is run for only one shift will have less energy demand than another plant with the same devices that is run for two shifts. Similarly, residential customers will scale back or increase their use of space heating or air conditioning based on temperature - a cold day will increase space heating demand and a hot one will increase air conditioning needs. For a given stock of devices, energy demand is fixed. What causes variations in demand for a fixed stock of devices are different utilization rates. Energy demand changes as utilization changes.

Distinguishing between levels and rates is important when trying to understand the dynamics in ENERGY 2020. The rectangles (boxes) in the Demand Overview represent levels or stocks. Levels exist even if time stands still. If we stop all the changes occurring in the energy demand market, we still have energy requirements for existing stock. Values which have a time component are rates - rates change levels over time. For example, there is an existing level of refrigerators at a given point in time. Adding to that stock are new refrigerators being purchased, and subtracting from that level are old refrigerators being retired. The number of new refrigerators being added and the number retired are referred to in terms of rates - the number in a given period of time. In ENERGY 2020 the time frame is usually one year. Therefore refrigerator additions would be stated in terms of the device requirement per year - such as 5 TBTU/year. Refrigerator retirements would be stated in exactly the same fashion. Note that it is the amount of energy consumed which is tracked, not the number of refrigerators. ENERGY 2020 integrates rates into levels - Device Energy Requirement additions each year (rate) go into Device Energy Requirements (level). Device Energy Requirement retirements behave in the same fashion. Devices are retired in the model usually when they exceed their normal lifetimes.

Device Energy Requirements and Device Energy Additions are a function of Process Energy Requirements as indicated by the arrows in the Demand Overview Figure. Process Energy Requirements are determined by the energy service that we need. For example, we need cool air inside a box to keep food fresh so we buy a refrigerator. Or we improve the thermal integrity of our home (by adding insulation or efficient windows) to keep warm air inside our home. For industrial applications, process efficiency would describe how much energy is needed to produce a certain level of output. Therefore the amount of energy service we need influences the choice of energy devices. The amount of refrigeration we need determines the number and size of the refrigerators we buy. An industrialist's determination of his energy needs determines the size of his factory.

The Process Energy Requirements are a function of production capacity (again refer to the arrows in the Demand Overview Diagram). Industrial process energy is energy required to produce a particular bundle of goods, measured in dollars of output, from existing production capacity. The industrialist needs a certain amount of mechanical energy to produce a product. his production quota for his product determines his Process Energy Requirements which in turn determine his Device Energy Requirements. The number of items produced represents production capacity which is measured in dollars of output ($ output). Each dollar of output has a process requirement which generates a Device Energy Requirement. Investment in production capacity is equal to a change in the level of output of goods and services in the economy. What is being measured is not the cost of factories, stores, or homes but the value of what this capital produces. When we talk about $100M capital increase we are talking about increasing the output from capital investment by $100 M, not the cost of the capital investment itself.

Commercial process energy is used to provide goods and services, measured in sales or, in certain categories such as hospitals or schools, expenses. Residential households are assumed to produce income; therefore, the measure of production capacity is personal income. All investments in Production Capacity come from economic models - in most cases for ENERGY 2020, the REMI model is used. It is the changes in this investment from year to year that drives the model.

Figure 0.2 and Figure 0.3 illustrate some examples.

Figure 0.2 illustrates the process for determining residential automobile energy demand. In the lower right hand corner is the energy demand, principally gasoline, attributed to residential autos. Automobile energy demand is a function of auto fuel requirements of the existing automobile stock under normal conditions. Automobile fuel requirements are a function of commuting requirements (related but not entirely determined by, the number of automobiles). These commuting requirements are described as a function of Personal Income . As personal income increases, workers drive to work more frequently and over longer distances. Therefore, as Personal Income increases, Commuting Requirements increase causing an increase in auto fuel requirements that in turn causes automobile energy demand to increase. This description is what is referred to as the income effect, where, as income rises, more goods and services are purchased. The assumption that ENERGY 2020 makes in regard to automobile energy demand is that more people drive more with increasing income. Other variables could be used as drivers such as population or number of households. However, an increase in Personal Income captures an increase in households as well as an increase in income per household making it a more comprehensive driver.

Figure 0.3 illustrates the process for determining commercial space heating energy demand. The energy requirement of furnaces changes with the net effect of additions of new furnace requirements less retirements of old furnaces and their requirements. New furnaces have to supply energy requirements that vary with economic output of the commercial sector (which can be measured by such things as sales or expenses). Retrofitting a building changes the process efficiency by the retirement of the “old shell” and the acquisition of a new shell efficiency even though the building itself remains. Therefore the same procedure that occurs in residential is occurring here: new capital investment (measured in sales or expenses or some similar manner) induces new heating requirements which in turn alters the energy requirement of furnaces. This becomes, modified by utilization factors, the commercial space heating energy demand.

Although ENERGY 2020 uses dollars of output as a commercial energy sector driver, other variables could be used as well. Square feet is often used but the problem with using square footage is the intensity can vary - not all the square footage is always used. This is a utilization problem that is over and above the utilization aspects picked up in the utilization variable at the bottom of the diagram which represents utilization of energy equipment, not utilization of existing floor space. Another problem with using square footage is that it is difficult to get a forecast for it. Economic forecasts are obtained from the many economic forecasting models in use.

Residential Automobiles

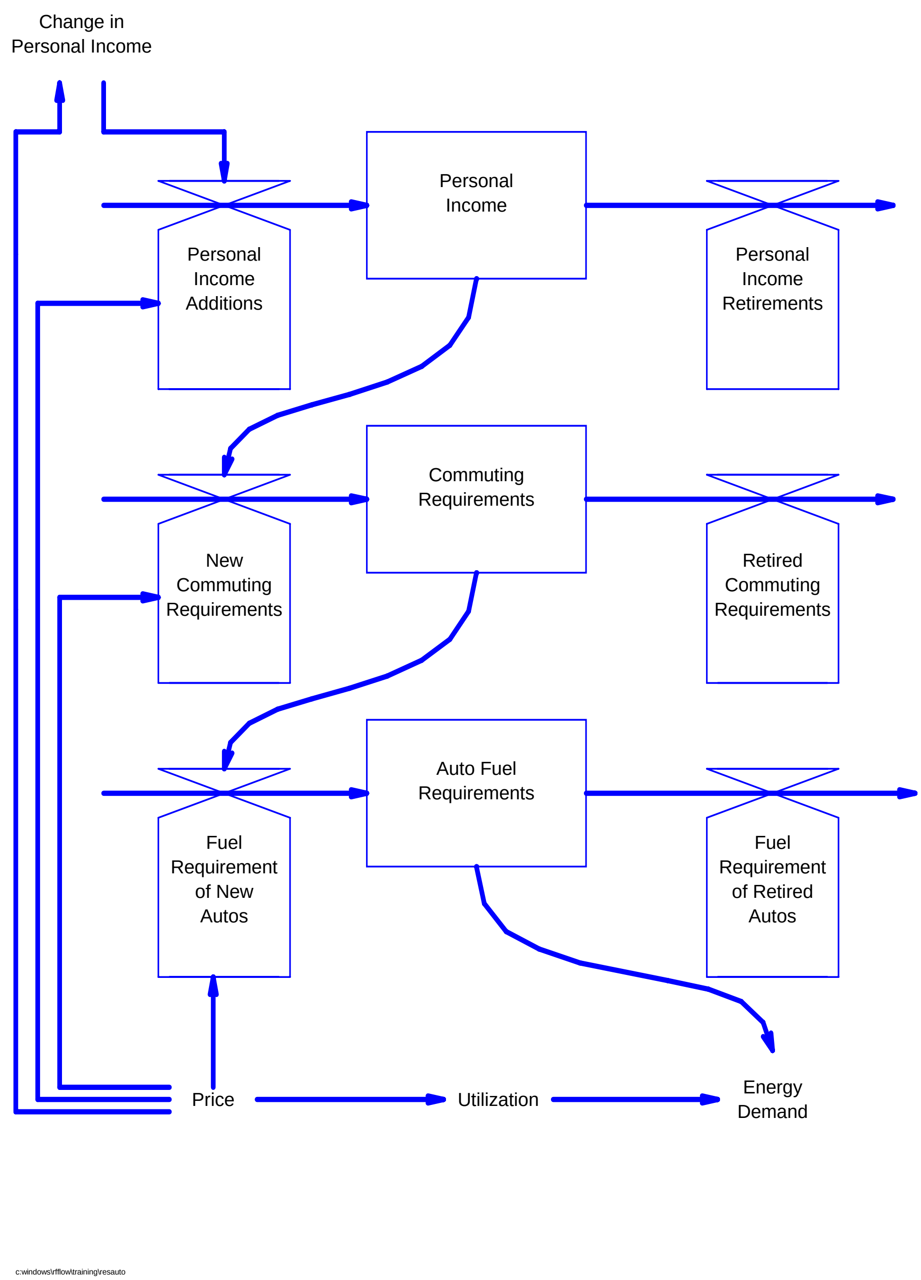

Figure 0.2

Commercial Furnaces

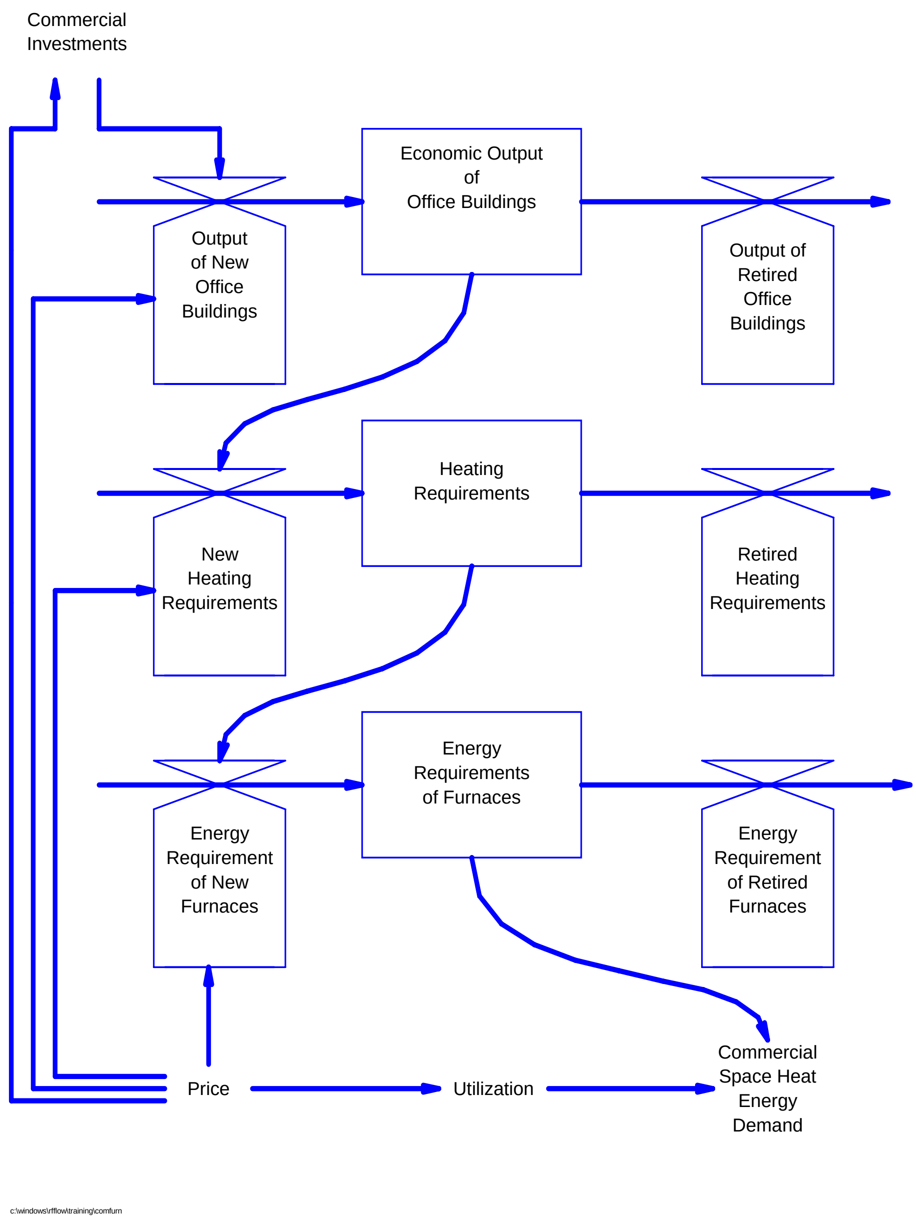

Figure 0.3

Figure 0.3 shows the demand for energy derived from industrial motor use. In this case, factory production generates mechanical energy requirements that are met with the appropriate number of motors. The energy requirement of these motors, modified by their utilization, forms the industrial motors energy demand. Industrial energy demand is driven in ENERGY 2020 by dollars of output. Other choices of drivers include employment. Dollars of output appears to be superior to employment because it can capture increases in productivity whereas employment does not. This is a serious omission given the sometimes spectacular increases in productivity seen in American industry over the past two decades.

In summary, personal income and dollars of output are used as drivers in ENERGY 2020 demand sectors substituting for the residential households, commercial square feet and industrial employment seen in other models. Our drivers forecast at least as well, and often better than the drivers they substitute for and have other advantages as well, such as consistency and availability of data.

The previous discussion concerned how the three levels contained in the demand sector - production capacity, Process Energy Requirements, and Device Energy Requirements - relate to one another and contribute to energy demand. Now the focus changes to the rates (the changes to these levels) and how they vary in the system. Because they affect each variable, fuel prices become important.

At the bottom of the Figure 0.1: Demand Overview, is a device utilization constraint. The utilization variable represents the effects of the consumers' budget constraint. It is a short-term response to increasing energy prices. As the price of energy rises, the consumer needs to maintain his budget. Since the budget is constant in the short run, and the proportions of the budget difficult to change, the initial response of a consumer is to reduce energy consumption to maintain the budget. This is usually a short-term behavioral response such as reducing fuel use by turning down the thermostats (or turning them up in the summer), turning off lights, and car pooling. Over the long term, the consumer can adjust the budget. As income rises, a disproportionate share can be allocated to energy use to bring the consumer back up the previous energy patterns. The effects of the budget constraint are temporary and occur when energy prices rise significantly in a short period of time.

Fuel prices also affect the Device Energy Requirement Additions . As fuel prices rise, higher efficiency devices will be purchased because it will become cost-effective to do so. This higher efficiency applies to marginal choices only; fuel prices do not directly affect the average efficiency. However, as marginal efficiency rises, average efficiency will rise as well.

In a similar manner, fuel prices affect the Process Energy Requirement Additions . As fuel prices rise, higher efficiency processes will be used. For example, residential homes will be better insulated, industrial production will become more efficient or substitute some other production factor for energy. An example of industrial production becoming more efficient can be found in the ice cream industry. Initially the entire factory was kept at 32 degrees to insure the ice cream produced stayed frozen. However, with rising fuel prices, only parts of these factories are now refrigerated - far more energy efficient.

Fuel prices also affect the fuel choice when production capacity is added. This is when the basic fuel choice is made. As one fuel becomes more expensive, other fuels are chosen more often and the fuel market shares are altered. For example, the choice between natural gas and electric heat is usually made at the time when construction occurs. High electric prices will increase the natural gas market share because at the margin, more new construction will be heated with the less expensive natural gas. The economy is also affected by fuel prices. As prices rise, the economy generally contracts (unless the economy in question contains the energy producing industries). The dampening effect of higher oil prices on the world economy has been clearly demonstrated by past experience.

It should be emphasized that these changes occur at the margin. It is Marginal Device Efficiency that changes as a result of price changes. Similarly it is the Marginal Process Efficiency that is altered as well. Fuel choices are made once and then usually not changed for the life of the capital stock. For example residential construction will choose a heating fuel, a level of insulation and a furnace efficiency at the time of construction. None of these decisions is easy to alter and most remain for the life of the appliance or the residence. These marginal decisions change the composition of the capital stock as their effects are incorporated into the existing capital stock and begin to work their way through the vintaging process.

In econometric models, all of these price effects are contained in the econometric price elasticity calculation. But instead of using fixed elasticities, ENERGY 2020 builds in structure to model each price change path in the economy. By modeling how energy prices change the demand for energy, specific policies that affect fuel market shares, process and device efficiencies, and utilization factors can be tested. In Summary, fuel prices in ENERGY 2020 affect energy demand in five ways:

1) Through the budget constraint. The budget constraint operates when energy prices rise rapidly. The consumer initially struggles to keep his spending in line with his budget. To do this he must cut back on his energy consumption. These cutbacks usually take the form of behavior changes such as setting back the thermostat, car pooling, shutting of lights, etc. and are short term behaviors. As income increases, the consumer will add back the energy he cut until his former energy consumption pattern resembles the original.

2) Through the Device Energy Requirements Additions . As fuel prices rise, consumers will purchase higher efficiency appliances (changing the Marginal Device Efficiency) because the increased capital cost for these appliances becomes more economic when fuel prices are climbing. Changing the efficiency of the appliance changes the total energy requirement from device additions. For example, the rising prices already mentioned will cause appliance efficiency to increase (and Device Capital Cost will also rise). If each appliance now has a higher efficiency, even if the same number of appliances are purchased as would have been before the price increase, the Device Energy Requirements Additions will fall.

3) Through the Process Energy Requirements Additions . In a similar manner the additions to Process Energy Requirements are affected by changing fuel prices. As the price of fuel rises, other, less energy intensive, methods of production are substituted for those that use more energy. There are many reasons why industrial processes change over time (technological breakthroughs, high labor costs, etc.) - ENERGY 2020 attempts to capture these changes in other parts of the model. Here only the energy price effects are being considered. If energy prices rise, industrial customers will be motivated to find more efficient processes (raising

Marginal Process Efficiency) which in turn will reduce the requirements additions even if the dollar value of the production output remains the same.

4) Through the Production Capacity Additions (EUPCA). When the decision is made to add new capacity - either residential housing, a commercial establishment or an industrial complex - the basic fuel choice is made at this time. Although some decisions can be modified at a later date, fuel decisions historically have a very small conversion rate and are costly. Most fuel choice decisions are made at the time of construction. The relative costs of using different energy sources are evaluated at this time and these costs, along with non-price factors determine fuel market shares of the EUPCA.

5) Through the Economy (PCA). The total change in investment in production capacity additions from year to year is affected in part by energy prices. In ENERGY 2020, this price feedback loop is endogenous by connecting the REMI model with ENERGY 2020 and letting the changing fuel prices in ENERGY 2020 flow back into REMI.

In summary, energy demand is modeled with three stocks: Production Capacity (EUPC), Process Energy Requirements (PER) and Device Energy Requirements (DER); the rates that add and subtract from these levels: retirements and additions (EUPCR, PERR, DERR for retirements and EUPCA, PERA, DERA for additions, respectively) as well as price effects, the investments in Production Capacity (PCA), and utilization effects on final Energy Demand (DMD).

PRODUCTION CAPACITY

Figure 0.4 Figure Production Capacity, illustrates the structure and variables which determine the additions to production capacity. Production Capacity Additions are a function of investments in Production Capacity and marginal fuel shares. The total additions to production capacity are split into fuel shares using the Marginal Fuel Share Fraction. For example, if twenty percent of the total Production Capacity will be generated with electricity then 20% times the total Production Capacity (in dollars of output) will be new electric demand.

The Marginal Fuel Share fraction is a function of both price and non-price factors. The price factors are the marginal cost of using fuel , the marginal process efficiency and the process capital cost . The marginal cost of using fuel implies getting a certain BTU level of process efficiency out of the device (for example, cubic feet of heated air). The Process Efficiency is concerned with how much hot air we need to achieve those cubic feet of heated air (could be improved with insulation, for example.) The Process Capital Cost would be the cost of the insulation. The total cost of selecting each fuel would be based on interaction of these three factors: marginal cost of fuel use, process efficiency and process capital cost. Non-price factors intervene as well, preventing the purely economic selection from always being made. Non-price factors include poor consumer information plus other non-price fuel attributes. For example, because of the ease of temperature regulation, some people prefer cooking with gas even if electric stoves are less expensive.

The three rectangles in the center of the diagram represent the aging of the capital stock. This aging process uses three “vintages”: new, medium and old, to describe the life cycle of capital stock. Production capacity retirements depend on Production Capacity Lifetime (PCPL) and are withdrawn from the third (old) capacity level. Production Capacity has the longest lifetime, logically outlasting both process and device lifetimes.

There are several types of delays that could be employed to represent the aging of capital stock. The first is called the pipeline delay - add something into the capital “pipeline” today and in 40 years (or however long the lifetime is), it is retired. This is a discrete type of delay and is used for debt retirement but does not describe the aging process of capital stock very well.

PRODUCTION CAPACITY

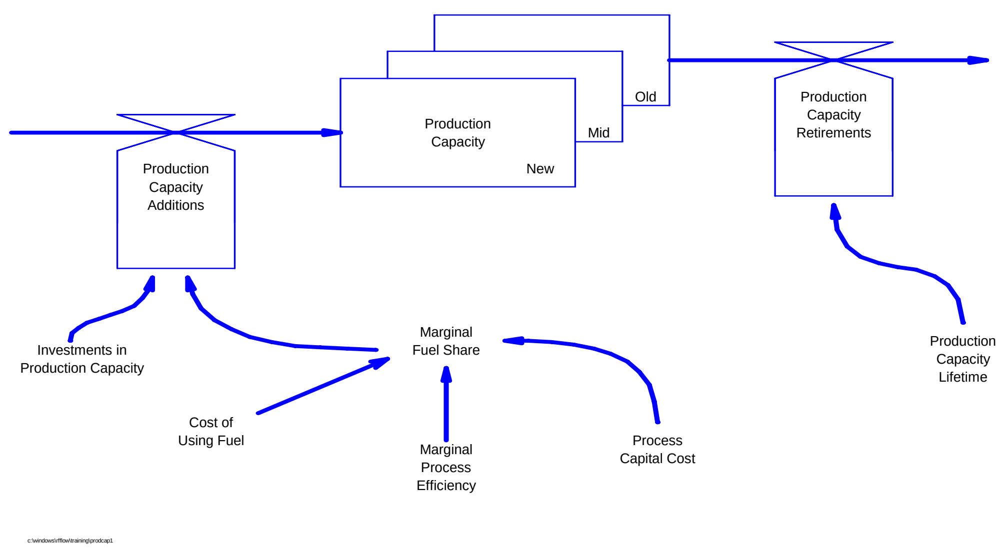

Figure 0.4

Another type of delay is the first order delay. With this type of delay, a certain percentage of the stock is retired each year - for 40 years, 2.5% would be retired each year. Since 2.5% of all the new stock is greater than 2.5% of say, half the stock, the biggest chunk of retirements happens the first year after the stock is added. Again, this does not seem to be a good description of the aging process for capital stock; however it does produce the desired pattern of retirements for devices. The most likely time for devices to fail is the first year of purchase, subsequent years have fewer retirements. Therefore the first order lag is used for devices but not capital stock.

A third type of delay, and the one selected to represent capital stock aging is the third order delay. Here new investment goes into the first phase (box) for thirteen years (assuming a forty year lifetime), moves to the next box for thirteen years and spends the remainder in the last box. This type of delay produces a shape that best mimics the flow of retirements - far more diffuse than the pipeline delay but without the inappropriate front loading of retirements found in a first order delay. The graphs below illustrate the shape of retirement functions from pipeline, first and third order delays resulting from an investment “spike” (if investment were constant every year, all delays would yield the same retirement patterns).

In summary, retirements are a function of total capital stock and its lifetime. Additions to capital stock are a function of investments in production capacity and fuel market share. Fuel market shares depends on the relative costs of fuels, marginal process efficiency, and process capital cost. Also considered are non-price factors including split incentives, ease of use, and personal taste. For example, selection of a gas furnace may be influenced positively by the perception that gas heat makes a warmer home or negatively by the perception that gas is a dangerous fuel. Coal may be inexpensive to use but is not easy to acquire or use at the residential level. Electricity may not be the least expensive fuel for residential space heat but may be selected for its inexpensive installation cost if the cost of operation is not going to be borne by the builder.

PROCESS ENERGY REQUIREMENTS

Figure 2.5 enables you to take a closer look at how Process Energy Requirements are determined. Starting on the left hand side of the diagram, Process Energy Requirement Additions is shown to be a function of Marginal Process Efficiency , Production Capacity, and saturation of devices. Production capacity is determined by the output targets of the industry - as in how much mechanical energy is required to make a certain number of widgets. Device saturation is important also - if there is a change in saturation levels of a particular device, process energy will change as well. Saturation refers to the percent of production capacity actually requiring a particular end-use, not the percentage of electric devices alone. For example, commercial air conditioning saturation refers to what percentage of commercial output uses air conditioning, not how much of the air conditioning uses electricity. As more commercial establishments acquire air conditioning (natural gas or electric), the saturation rises and the Process Energy Requirement rises as well.

The marginal process efficiency is also important. A building under construction has certain heating and cooling requirements that will become part of the stock with a certain Process Energy Requirement. Rising marginal process efficiencies will gradually increase the average process efficiency; falling marginal efficiencies produce the opposite result.

Marginal process efficiency refers to how much process energy is needed per unit of output. The level of process efficiency chosen depends on the cost of using fuel which in turn, depends on Fuel Prices, Device Efficiencies, and Device Capital Cost. Once a level of device efficiency is chosen, the capital cost is known from trade-off curves contained in the model. Alternatively, the capital cost can be chosen and the efficiency determined from those curves. A certain capital cost buys a certain level of efficiency. For example, when building a home, a decision must be made as to how much insulation to include. The insulation levels in new home construction will vary with, among other things, fuel costs. Each fuel has its own cost and will determine an economic level of insulation. The cost of using a particular fuel considers fuel costs, device efficiency and device capital cost simultaneously. There is an interaction with process efficiency as well. If a home is well insulated a smaller furnace may suffice, lowering not only the cost operation and reducing fuel costs but reducing device capital costs as well.

The Marginal Process Efficiency also alters the Average Process Efficiency. If the Marginal Process Efficiency is greater than the Average Process Efficiency, then the Average Process Efficiency should be increasing; the converse is also true. In addition to the Marginal Process Efficiency , the Average Process Efficiency is affected by the additions to production capacity. If the additions each year are large, then the marginal process efficiency will have a larger effect on the average. If the economy isn't growing very much, marginal changes will not have a large impact on the average efficiencies. If fuel prices are so high that they choke off investment, then the corresponding high efficiencies that would be selected in response to high fuel prices will not have a large effect on the average process efficiency because although the new process efficiency is higher, there are few new structures being added to the capital stock.

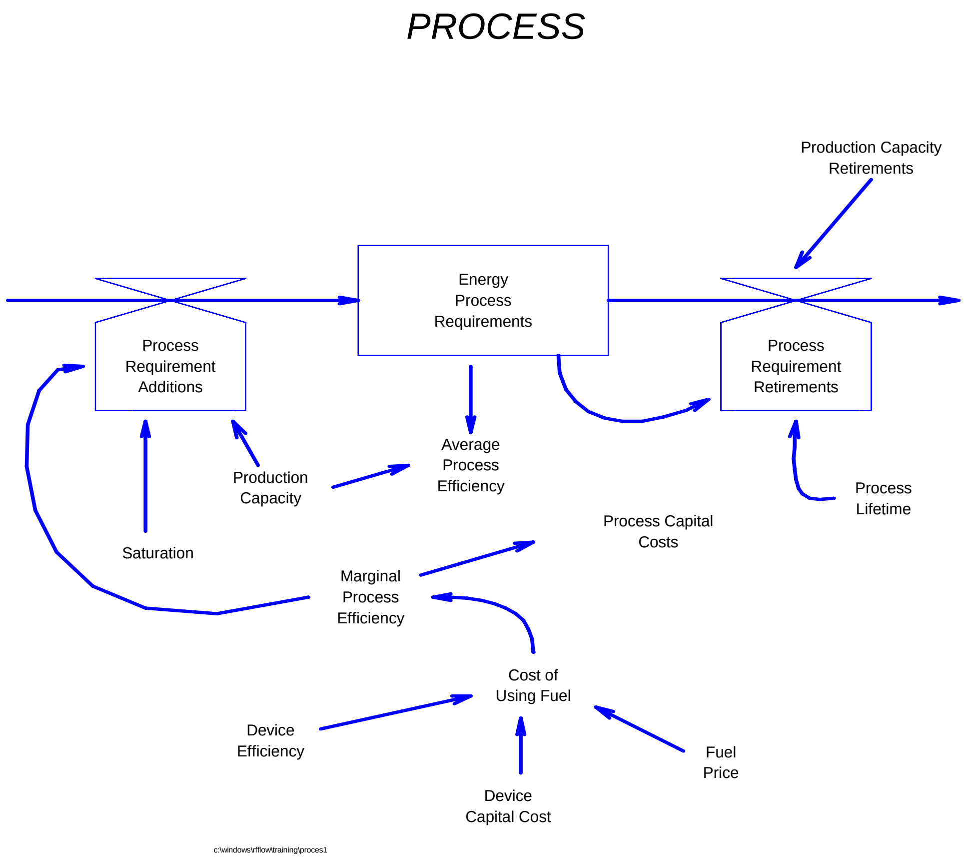

Figure 0.5

The Process Energy Requirement Retirements are a function not only of the Production Capacity Retirements but also a separate process lifetime. When production capacity retires, the Process Energy Requirement retires as well. Process lifetime is used primarily in determining industrial energy demand and captures the effects of process obsolescence. There are times when processes change before production capacity retires creating a shorter and different lifespan for Process Energy Requirements. For example, in the paper industry there has been a gradual change from mechanical to chemical pulping. Mechanical pulping equipment is becoming obsolete and is not replaced so that mechanical pulping becomes an increasingly smaller share of pulping energy requirements. The principal reason for this shift is economic - chemical pulping is cheaper. Although we focus on price-related reasons, other reasons may play a role in process obsolescence as well. The steel and auto industries have also changed their Process Energy Requirements in existing and still used structures. Process efficiency lifetimes are usually about the same as the lifetime of the production capacity but can be shorter.

The other component of Process Energy Requirement retirements is production capacity retirements. If a plant or building is closed or destroyed, the energy requirements obviously cease.

DEVICE ENERGY REQUIREMENTS

Figure 0.6 shows the calculation of Device Energy Requirements . Device Energy Requirements change in response to additions and retirements . Device Energy Requirement Additions are a function of Process Energy Requirements and Marginal Device Efficiency . The Process Energy Requirements determine the total energy needed, the marginal device efficiencies determine the number of devices added and are a function of fuel prices. As fuel prices rise, it becomes cost-effective to pay for greater device efficiency. To illustrate, the Device Energy Requirements of air conditioners measures how much cooling we can produce given a certain level of energy input (such as kWh). This depends in part on PER, which is how much cooling is required. The other component determining Device Energy Requirements is Marginal Device Efficiency (Marginal Device Efficiency), the ratio of energy into the device to the useable energy out of it. The Marginal Device Efficiency is determined by the fuel prices . As prices rise, marginal device efficiencies rise as well. As with marginal process efficiency, once Marginal Device Efficiency is known, Device Capital Costs are also known through the estimated trade-off curves. How much additional device efficiency will be selected as prices rise depends on consumer preferences for higher upfront capital costs over higher operating costs in the future.

DEVICES

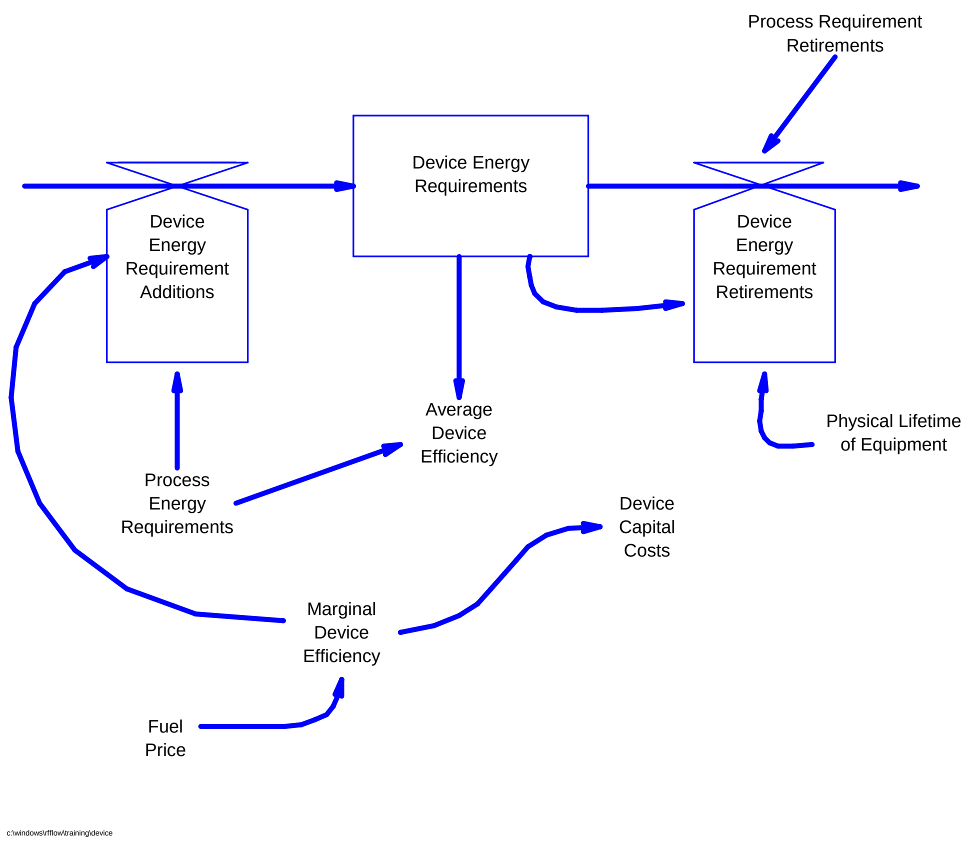

Figure 0.6

Device retirements depend on the physical life of the equipment as well as the life of the building in which it is contained. In a fashion similar to Process Energy Requirement retirements, Device Energy Requirement Retirements are calculated as a function of Physical Lifetime of Equipment and Process Energy Requirement Retirements . Device Energy Requirement Retirements occur when Process Energy Requirement Retirements occur. If a building is destroyed, the devices contained therein are also destroyed. But devices have a far shorter lifespan than buildings and can be replaced many times before the building is replaced. Each time the device is replaced, the entire efficiency cycle will be repeated. If fuel prices are rising, appliances with higher device energy efficiencies will be selected. Not that this structure allows replacement of devices for only two reasons - either the process or structure housing the process is retired or the device is exhausted. No retrofits (profit maximizing replacement of equipment not yet worn out) are included in this model routine. Retrofits are included elsewhere in the model.

As in the process efficiency calculations, an Average Device Efficiency is also calculated from the Marginal Device Efficiency and Process Energy Requirements . Again, if Process Energy Requirements are low due to the dampening effect on the economy of high fuel prices, although device efficiencies at the margin will rise, there will be little impact on average device efficiency.

UTILIZATION FACTORS

The utilization factors illustrated in Figure 0.7 modify the final Energy Demand . The calculation of Device Energy Requirements assumes the devices are run at a normal level. Often however, deviations from “normal” levels occur. The model isolates six utilization factors (eight variables) that can influence energy demand.

The first is the short term budget response that operates in response to higher fuel prices. As energy prices rise, consumers struggle to keep within their budgets. They do this by attempting to maintain the same dollar shares of the goods and services they desire. Therefore, they must cut back on their energy consumption - by turning off lights, using less hot water, turning back the thermostat, car pooling, and the like. Since their standard of living is affected by these behaviors, they will attempt to return to their previous standard as quickly as possible. The budget response, then, is a short-term response that gives way to long-term changes in behavior and is determined by fuel prices.

This response is modeled by creating two budgets: the average consumer budget and a new budget , influenced by changing fuel prices . As fuel prices change, the energy component of the budget changes as well. This new budget is compared to the average budget and an adjustment is made to the average budget. In time the new budget will equal the average budget . The length of time for this to occur is dictated by the Budget Adjustment Time . The Short-term Budget Response is a short-term effect, usually no longer than two years.

The next utilization adjustment identified is the Economic Capacity Utilization Factor . This factor measures the effects of the economy on the residential, commercial, and industrial sectors. For the residential sector, this adjustment picks up large changes in the employment rate; in the commercial sector, unusual changes in commercial output are the key and in the industrial sector, it is a measure of how hard factories are running. For example, during a recession, factories may run only one shift; during boom times factories may run twenty-four hours a day. The Economic Capacity Utilization Factor captures these dynamics. During recessionary periods, the value of Economic Capacity Utilization Factor is less than one; during very good times, greater than one.

The third factor (two variables) to be considered is weather. Two variables represent the effects of weather on energy demand - the Degree Day Multiplier and the fraction of Temperature Sensitive Load. Each end-use has a specified fraction of its load designated as temperature-sensitive. This fraction ranges from zero to one. This portion of the load is adjusted in response to a change in the degree day multiplier (usually set equal to one). If a period of time is expected to have warmer or cooler temperatures than normal, the Degree Day Multiplier is adjusted to reflect this expected temperature increase or decrease and the energy demand from temperature sensitive load is adjusted accordingly. What is considered temperature sensitive load in an end-use can vary by customer class. For example, residential air conditioning is usually entirely temperature sensitive; however some commercial air conditioning load is constant and does not vary with temperature. The fraction of temperature sensitive load for residential air conditioning would equal one; for commercial air conditioning, it would be something less than one.

The fourth utilization variable that affects energy demand is the Socio-Economic Factor. This is a calibrated variable that reflects behavioral and structural changes that cause a change in energy demand. For example, the changing labor force participation rate for women over the past twenty years has altered energy use levels and patterns. This variable can also pick up structural changes not otherwise accounted for in the model. Some versions of ENERGY 2020 do not distinguish between single and multi-family residential dwellings. If this distinction is not made and over the historical period there has been a shift from single family to multi-family dwellings or vise versa, CERSM will capture the changing energy use patterns.

The Socio-Economic Factor lies on the “edges” of the model, capturing the effects of structure not included in ENERGY 2020. It is modeled in an aggregate fashion, and as individual effects become of interest or internalized (such as the single and multi-family residential distinction), this variable becomes less important.

As you can see by the asterisk next to the variable, the model derives Socio-Economic Factor values through calibration. ENERGY 2020 begins in 1975 and from 1975 to the current year is referred to as its historical period. The calibration process attempts to see if the model can replicate history in all the important energy variables. We believe that this replication is a necessary (but not sufficient) condition for a successful forecasting model. While this calibration is being performed, certain parameters within the model are set at the same time. Socio-Economic Factor is one of these variables, and the values derived historically are used to forecast the relationship between changes in economic output and changes in energy demand, insofar as possible. If the value of Socio-Economic Factor is close or equal to one, then no significant changes have occurred that have not been captured by the model through the other adjustment factors. If the number is greater or less than one, then more or less energy is being used per dollar of output than before. If the Socio-Economic Factor is growing, the reason for this growth needs to be investigated or explained.

The fifth utilization factor is the Capacity Utilization Factor . This differs from the Economic Capacity Utilization Factor previously described. While Economic Capacity Utilization Factor picks up shifts in gross output, the Capacity Utilization Factor is a calibrated variable reflecting energy demand fluctuations not explained by the other utilization factors. Fluctuations in this variable should be random (no pattern of steady increase or decrease) when they occur and the variable’s usual value is one.

The final utilization variable is what we call “housekeeping DSM” . This variable captures the effects of certain policies or habits such as bicycling to work, turning down the thermostat, etc. It is considered a policy variable.

UTILIZATION FACTORS

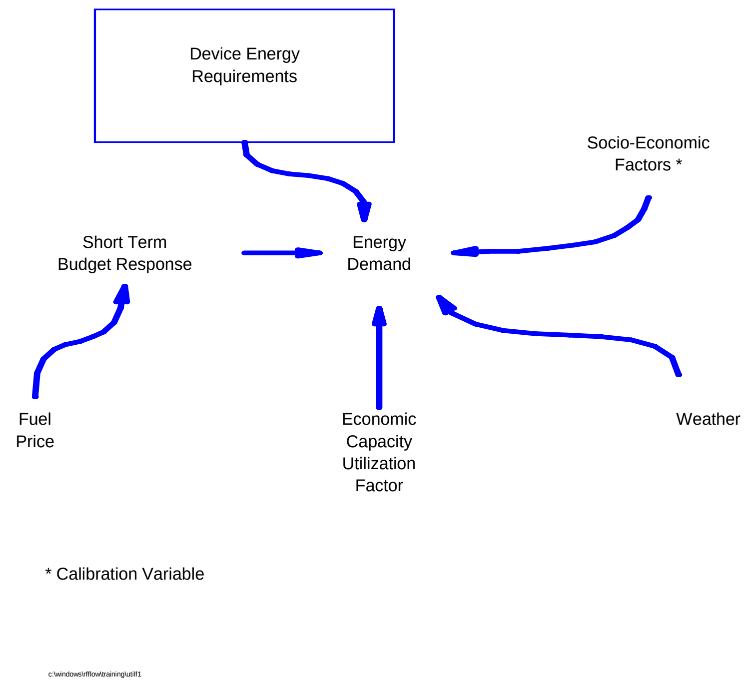

Figure 0.7

PRICE RESPONSE DYNAMICS

Figure 0.1 the Demand Overview, contains all the components that have been described in the preceding section. Notice that price responses are present at every level. These price responses are summarized and illustrated in Figure 0.8. Price Response Dynamics. This diagram traces the effects on a particular fuel's total energy demand from an increase in the price of that fuel.

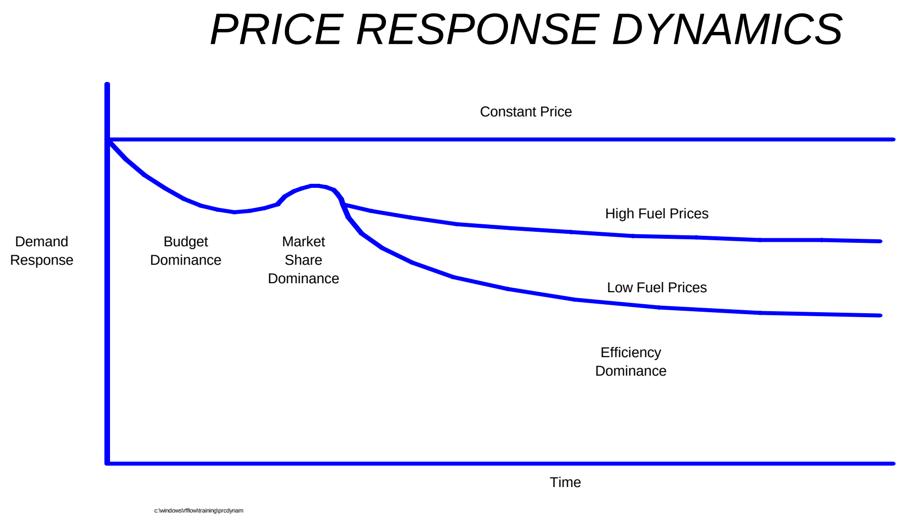

Figure 0.8

For example, consider residential automobiles as the demand component and gasoline as the fuel. If gasoline prices are constant, the demand price response remains constant as well, as illustrated by the straight line at the top of the picture. However, if gasoline prices increases, an overlapping three stage process begins to take effect. First, the short-term budget constraint begins to operate and consumers begin to reduce the amount of gasoline they require. They can car pool to work or school, eliminate unnecessary pleasure trips, walk instead of drive short distances, etc. As they are given more time to adjust, the decision to purchase a new car will incorporate the higher gasoline prices. It is possible to buy a car powered by something other than gasoline (diesel, electric, or a gasoline mix) but fuel market share changes probably will not be great. However, more fuel efficient cars will be selected. Therefore the path that the gasoline price demand response will follow would be the "High Fuel Prices" path, since the price of other fuels matters little to a basically non-substitutable end-use.

Consider another example - residential electric hot water heating. If the price of electricity rises, again the budget constraint begins to operate and less hot water (as well as other sources of electricity use) is used. As consumers have time to adjust, and replace appliances with substitutable energy requirements, a gas water heater may be purchased instead of an electric heater. At the very least, a more efficient electric water heater will be purchased. If all energy prices rose with electric prices, then less fuel switching would occur and the demand response would follow the "High Fuel Prices" path. If only electric prices rose, more fuel switching would occur and the demand response would follow the "Low Fuel Prices" path.

These price response dynamics include both process and device efficiencies. Devices generally have shorter lifetimes and therefore their fuel requirements and energy efficiencies are the first to show consumer response to higher prices.

CONSUMER CHOICE THEORY

The key theory that drives the demand sector is consumer choice theory - particularly two formulations described briefly below. Consumer choice theory itself is described in more detail in Chapter 4.

Efficiency Choice Curve

The first consumer choice formulation that is critical to the energy decision making process is the efficiency/capital cost trade-off. This is really a trade-off between high up-front costs and high future costs. If a very high efficiency furnace is purchased, the capital cost will be large, however, the operating costs in the future will be lower than with a lower efficiency furnace.

Figure 0.9 illustrates this principal. Either fuel price or capital cost can be used on the horizontal axis. Each price corresponds to two efficiency levels. The engineering curve selects the economically optimal level of efficiency for each capital cost or fuel price. The more useful and realistic curve is the consumer choice curve that shows a less than perfect relationship between efficiency and capital cost. The consumer choice curve reflects the fact that all additional capital cost dollars do not go into the purchase of higher efficiency. Top of the line appliances include many features (some energy using) that lower priced appliances do not. Self-defrosting freezers, ice makers, cold water spigots on the refrigerator door are all examples of the extra, energy using features, of high-end appliances.

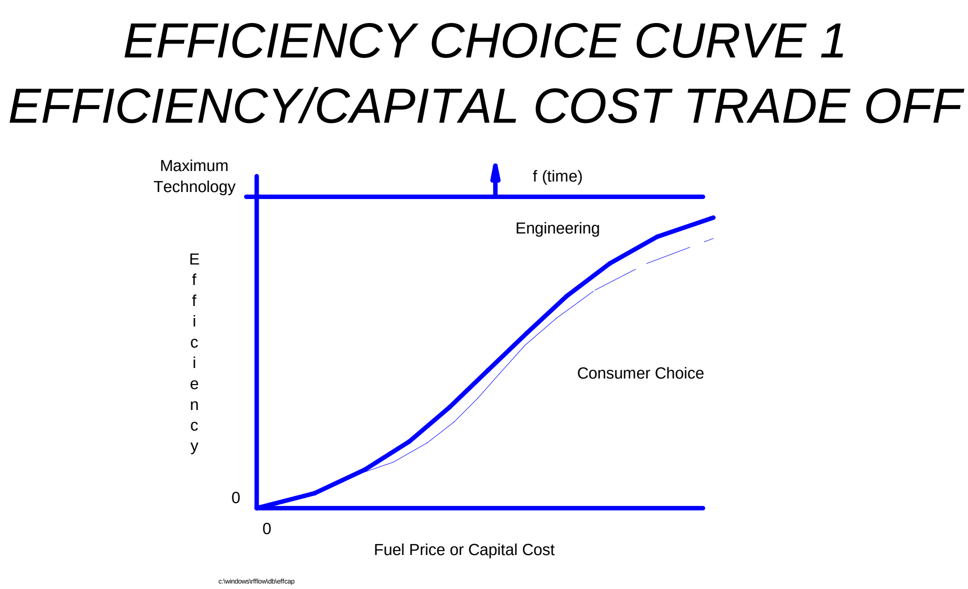

Figure 0.9

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

Market Share Mechanics

Figure 0.10 illustrates the process of fuel choice - trading off one fuel for another on the basis of relative prices. If consumers behaved with perfect economic rationality and had perfect information, the market share curve would look like the share with perfect knowledge illustrated in the diagram. On the horizontal axis is the ratio of the price of fuels. As long as the price of “1” is less than the price of “2”, the fraction will be less than one, and economically driven consumers will choose all fuel “1” making the market share of “2” equal to zero. However, as soon as the price of “1” exceeds the price of “2”, then the converse occurs - “2” grabs the entire market. In reality, fuel choice is a less clear cut process. As the price of one fuel rises relative to another, there will be a gradual shift to the cheaper fuel based on consumer perceptions of the relative prices (often made with imperfect information) as well as the influence of non-price factors. The curve formed by these decisions resembles the S-shaped curve in the diagram - even if price “1” is higher than price “2” some consumers will still choose the more expensive fuel. This can be the result of imperfect information or indifference (if fuel costs are a very small part of the budget) or because of a non-price related factor. For instance, some people choose gas stoves because they prefer to cook with them, not because of price differentials.

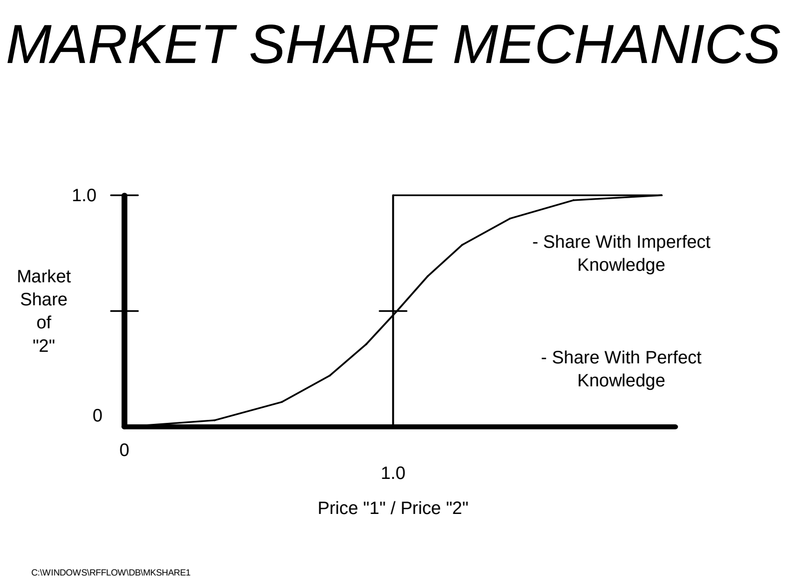

Figure 0.10

STRATEGIES AND DEMAND POLICY APPROACHES

Table 0.2 provides a list of the different types of policies that can be implemented in ENERGY 2020 given its causal demand structure. It is possible through policy choices to affect consumers’ decisions concerning fuel choice, device and process efficiencies, and energy use in general. Different financial treatments can be simulated such as shared savings, expensing vs. capitalizing conservation costs, rebates, loans, tax credits and such to estimate where the various costs and benefits of conservation and DSM programs will fall.

Table 0.2: DSM Strategies & Demand Policy Approaches

- *Trade-off Curve Choice*
- *Shared Savings*
- *Expense/Capitalize conservation*
- *Mandated Cut-Back*
- *Energy Taxes*
- *Device/Building Standards*
- *Appliance Rebate Programs*
- *Low-Interest Loans*
- *Capital cost Subsidies*
- *Technology Improvement (Research and Development)*
- *Device Saturation*
- *Tax Credits*
- *Environmental Controls*
- *Moratoriums*
- *Marketing/Information Programs*

Most DSM programs are easily simulated in ENERGY 2020. Mandated cutbacks and standards, taxes, rebates, loans, time-of-use rates and information programs are all modeled in ENERGY 2020. Given its unique model structure, these policies plug into the existing routines and their effects can been seen working their way throughout the entire energy system.

Device Technology Improvements And Efficiency Standards

2.11 is the same flow chart as Figure 0.6 with additional structure to represent technological improvements and efficiency standards. The new variables are Technological Improvements in Devices and Device Efficiency Standards.

DEVICES WITH TECHNOLOGICAL IMPROVEMENTS AND EFFICIENCY STANDARDS

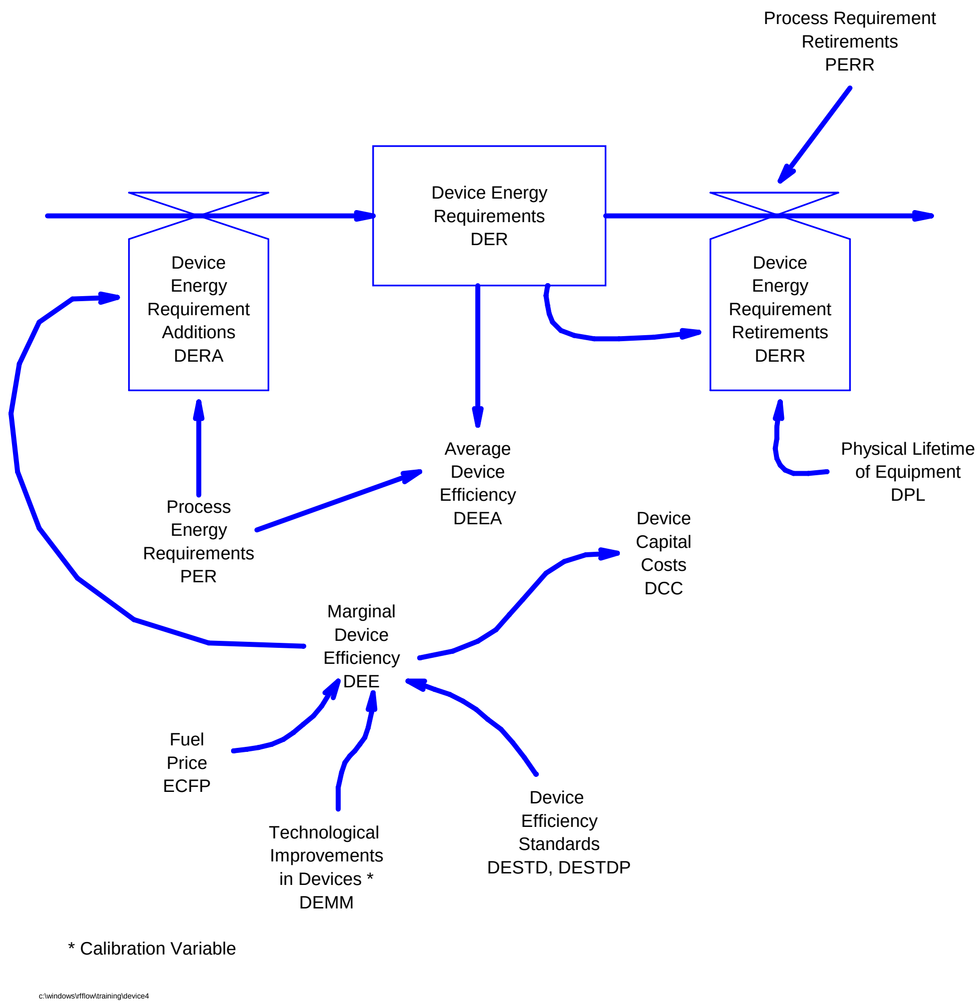

Figure 0.11

Technological Improvements in Devices is a non-price factor in the consideration of the level of device efficiency to be selected. It is a calibrated variable that can be altered in the future as a policy variable. During historical calibration, the model compares its estimated device efficiencies with the actual historical device efficiencies, to the extent that this information is available. If there is a difference between the two sets of values, improvements in technology are assumed.

The other non-price effect on Marginal Device Efficiency come from standards. Standards are assigned to one of two variables: one is for standards already in effect such as those included required from federal energy policy. The other is for policy development that allows the analyst to test out different standards as policies. The basecase version of the model includes the current standards for any end-use that has one.

Process Technology Improvements And Efficiency Standards

Figure 0.12 adds the same changes to Figure 0.8 as Figure 0.11 added to Figure 0.7- Technological Improvements and Efficiency Standards. Again, the new variables look very similar to those above: Technological Improvements in Processes and two Process Efficiency standards.

Technological Improvements in Processes is a calibrated variable reflecting non-price induced technological improvements which may reduce or improve process efficiency. Processes that become more energy intensive, often by substituting capital for labor, cause more energy to be used per dollar of output. For example, the use of robots instead of human labor means that more, and not less, electricity is used to produce a particular product. PEMM can change over time and these changes should be evaluated and connected to "real world" events. Structural changes can show up in this variable as well. In the commercial sector, movement from small, stand-alone stores to strip malls has created new energy requirements; Technological Improvements in Processes reflects these changes.

The two process standards behave in the same manner as the device standards. One reflects standards already in place and is included in the model's basecase data set. Standards on process are usually building shell efficiencies such as certain insulation requirements but theoretically there exists a process efficiency for each end-use which can be manipulated with a standard. The other is the policy variable used for testing different process efficiency standards in the future.

PROCESS WITH TECHNOLOGICAL IMPROVEMENTS AND EFFICIENCY STANDARDS

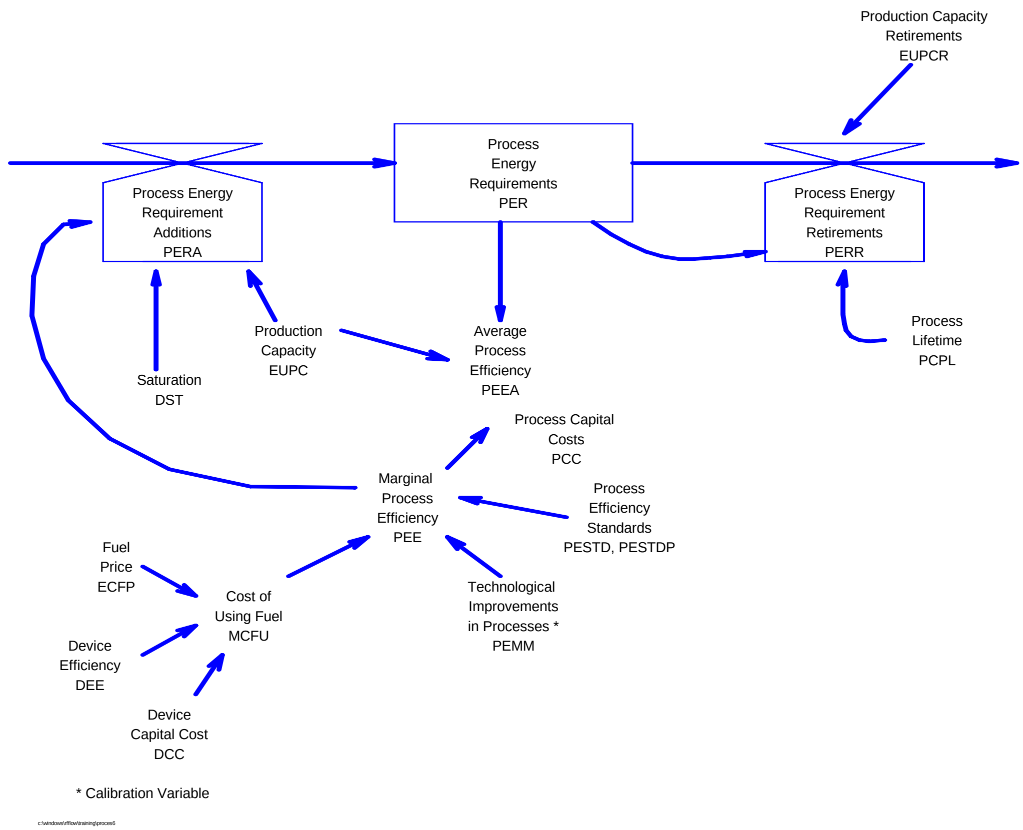

Figure 0.12

Production Capacity With Income Effects And Non-Price Factors

In Figure 0.13, the Production Capacity Diagram is shown before is augmented with Income Effects and Non-Price Factors. The calculation of the Marginal Fuel Share includes the price factors as discussed before - the cost of using fuel , the Marginal Process Efficiency and the Process Capital Cost . In addition now, the non-price factors are accounted for: income effects, a market potential multiplier and other non-price factors.

PRODUCTION CAPACITY WITH INCOME EFFECTS AND NON-PRICE FACTORS

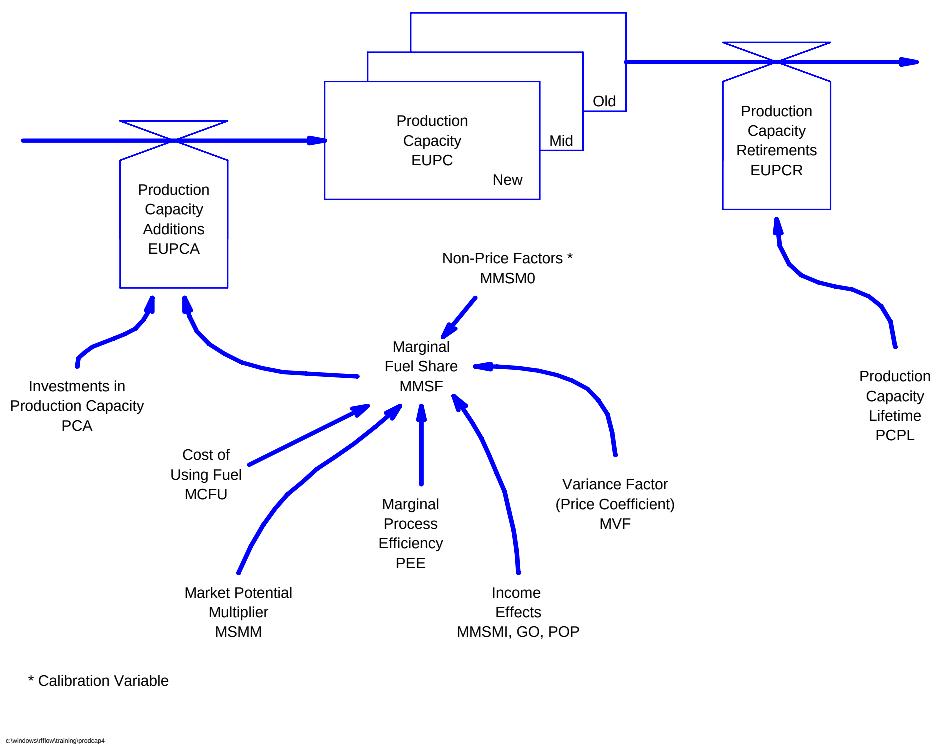

Figure 0.13

The other non-price factor is a calibrated variable derived from a comparison of the model-generated historical fuel splits with the actual splits. Using historical prices, we can estimate the non-price factors (the deviation from the economically optimal split based on historical prices). Many non-price factors are included in this variable, such as imperfect information, split incentives, or personal, non-price determined perceptions such as the perceived safety of a particular fuel.

The income effect factors are a new addition to the model and are not contained in the generic version. One is a measure of income elasticity, another represents gross annual output and the third is a population variable. Theory indicates that as income increases (gross output divided by population), fuel market shares change. In other words, as the income of residential customers begins to climb, they may show a different preference for fuel choices - a shift in the non-price factors. For example, an “all electric” house may be perceived as cleaner and a good worth purchasing as incomes rise, causing more residential customers to choose electricity over natural gas for space heating, water heating and drying needs.

The Market Potential Multiplier is a policy variable that modifies the non-price factors influencing the marginal fuel share. For example, an information program to promote heat pumps may change consumer attitudes about unreliability or unsuitability for their climates and enhance the non-price factors for electric technology. Similarly, an information program concerning the reliability, safety and availability of natural gas space cooling could enhance the natural gas market share for that end-use.

Device Rebates With Endogenous And Exogenous Participation Rates

Figure 0.14 is identical to Figure 2.15 except for the addition of the Device Rebate Price Multiplier . This variable represents the consumer’s response to a rebate and is based on three other variables: the Device Capital Cost that we are already familiar with; the Device Capital Charge Rate and the Device Capital Cost Rebate .

DEVICE REBATES WITH ENDOGENEOUS PARTICIPATION RATES

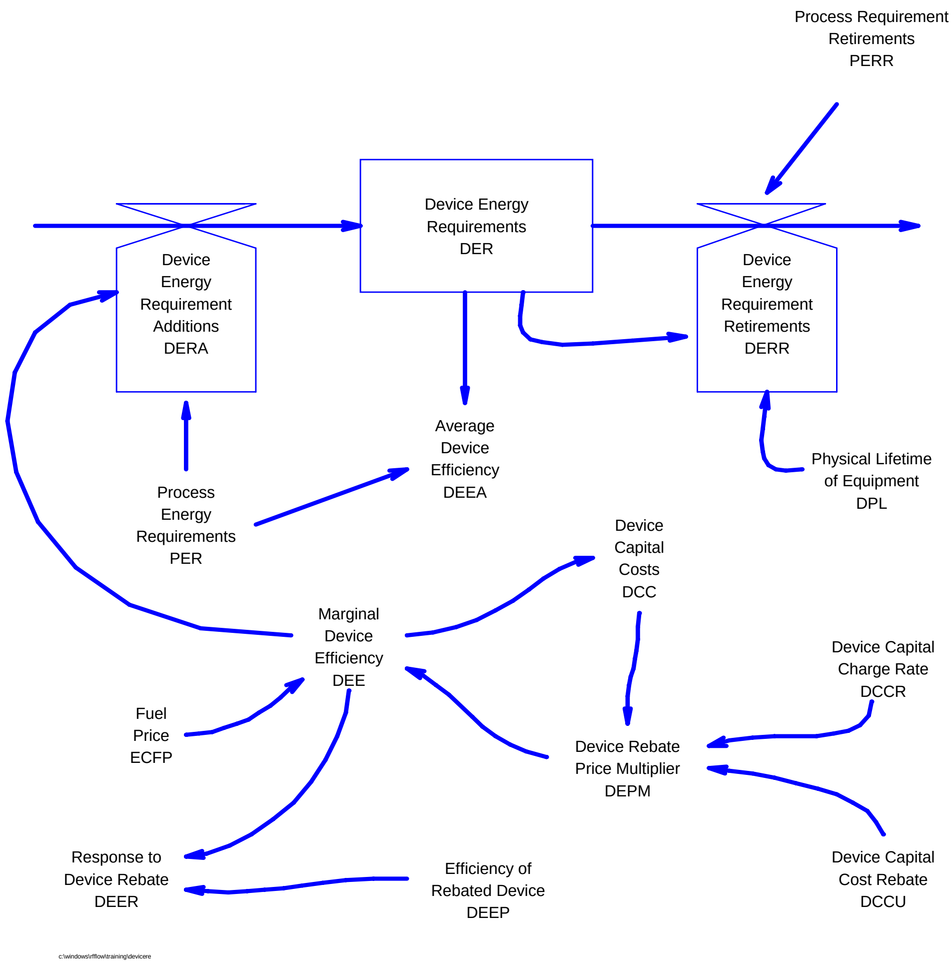

Figure 0.14

A rebate allows a consumer to pick a higher efficiency device for the same dollars. However, the actual capital cost of the device increases. Since we use efficiency curves that trade-off energy prices and efficiency levels, the model converts this higher capital cost to a higher energy price and selects the correct efficiency level. The Device Rebate Price Multiplier is the difference between the actual energy price and the "pseudo-energy" price determined by the rebate. It is calculated by deriving an annualized capital cost (Device Capital Cost times the Device Capital Charge Rate) and adding to it the value of the rebate.

As the Device Rebate Price Multiplier changes, the Marginal Device Efficiency changes as well - a higher price buys higher efficiency levels. The device efficiency of the rebated device as well as the new Marginal Device Efficiency determine the response to the Device Rebate, the participation rate in the program. As shown in Figure 0.15, the response to the Device Rebate can be entered into the model exogenously as well endogenously under the variable XDEER. The Device Rebate Price Multiplier is no longer calculated when an exogenous participation rate is assumed and the XDEER now directly influences the Marginal Device Efficiency. In the exogenous participation rate, consumer behavior is “known” and outside the model.

DEVICE REBATES WITH
EXOGENEOUS PARTICIPATION RATES

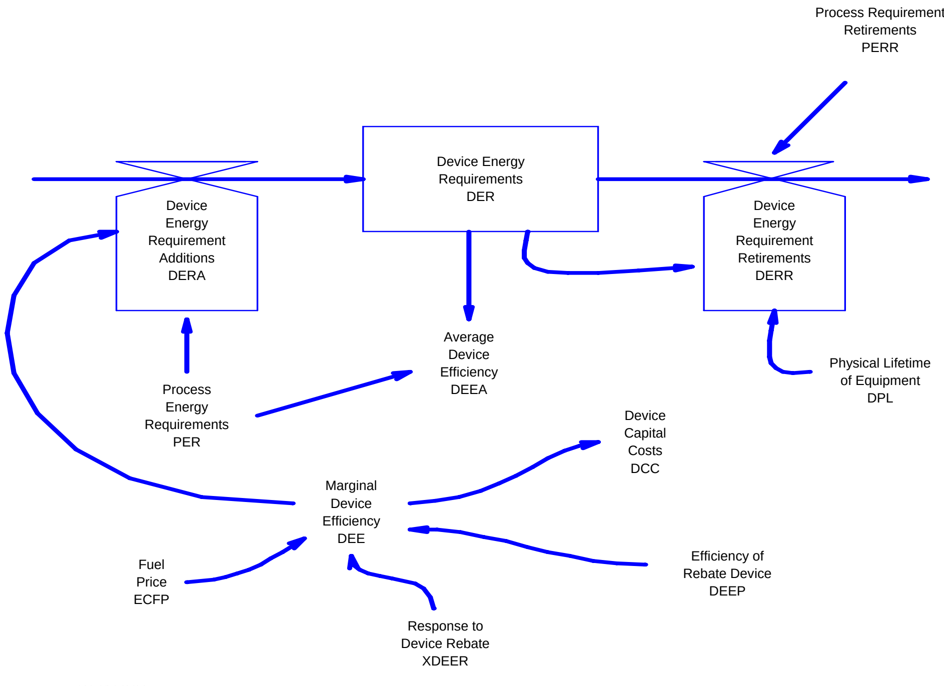

Figure 0.15

Process Rebates With Endogenous And Exogenous Participation Rates

A similar enhancement can be done to Process Efficiency Figure 0.5, creating 2.16. Here the new variables are the Process Rebate Price Multiplier , the efficiency of the Rebated Process and the Response to the Process Rebate . Again the multiplier is derived from the process capital costs, the process capital charge rate and process capital cost rebate. A higher level of price efficiency is selected through the creation of a “pseudo-energy price” that is higher than current energy prices. The marginal process efficiency selected is increased and, coupled with the efficiency of the rebated process, determines the participation rate in the program. Alternately, Marginal Process Efficiency Retirements can be entered exogenously and a new marginal process efficiency calculated (Figure 0.17). It can be instructive to run both scenarios and compare results.

PROCESS REBATES WITH ENDOGENEOUS PARTICIPATION RATES

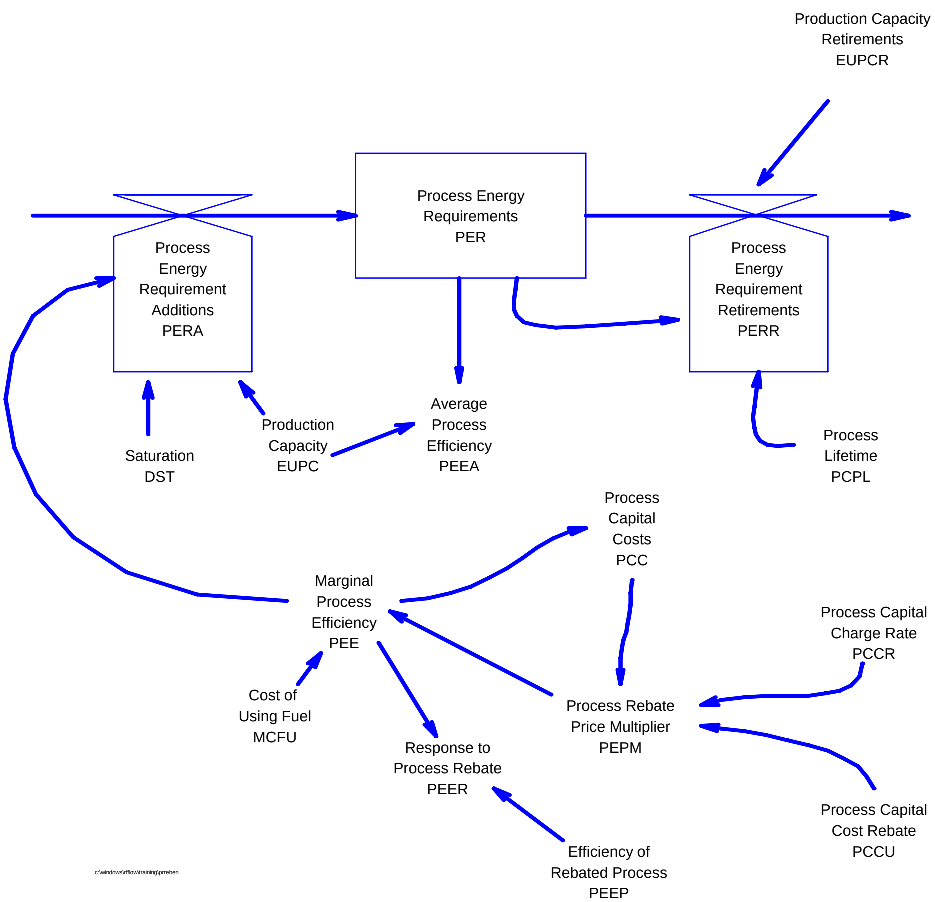

Figure 0.16

PROCESS REBATES WITH EXOGENOUS PARTICIPATION RATES

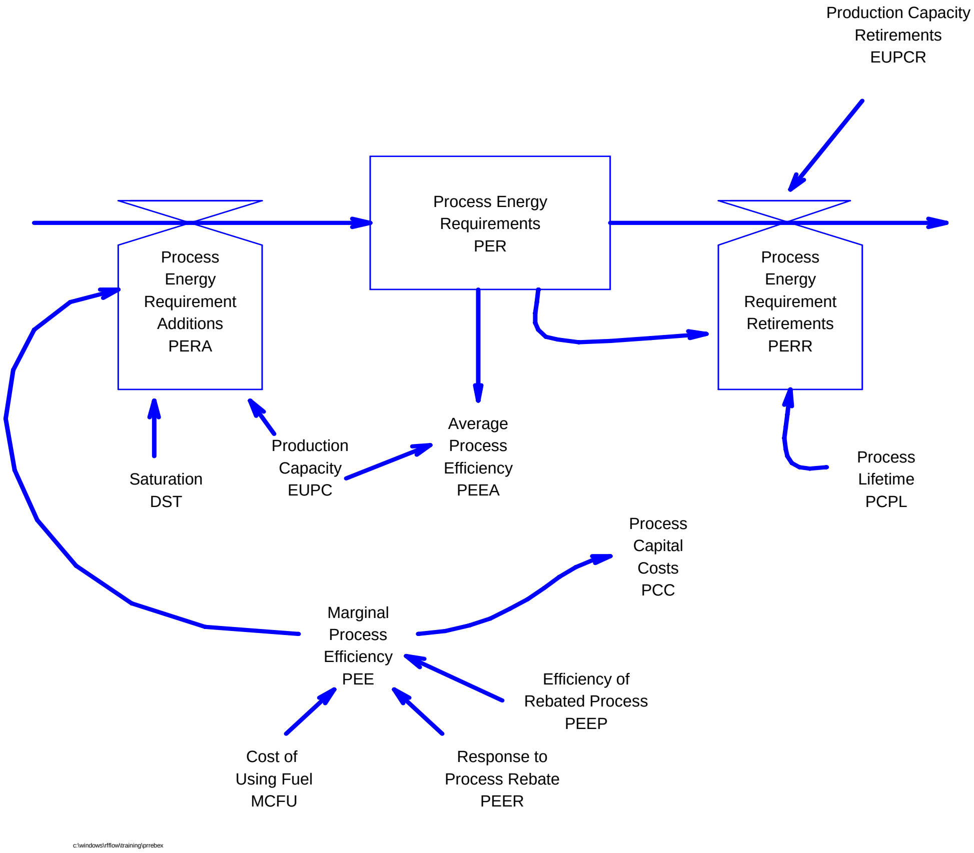

Figure 0.17

MODELING COGENERATION

Cogeneration Capacity

Figure 0.18 is the first of three diagrams illustrating the structure for modeling cogeneration capacity. In Figure 0.18, the key variable is MW of existing cogeneration capacity . Note that all cogeneration variables are prefaced with a CG. Modifying the stock of cogeneration capacity are cogeneration construction rate and retirements variables (additions to and subtractions from the stock of cogeneration on a yearly basis.) Cogeneration retirements are simply a function of the physical lifetime of cogeneration; however, cogeneration construction rates require a more complex calculation.

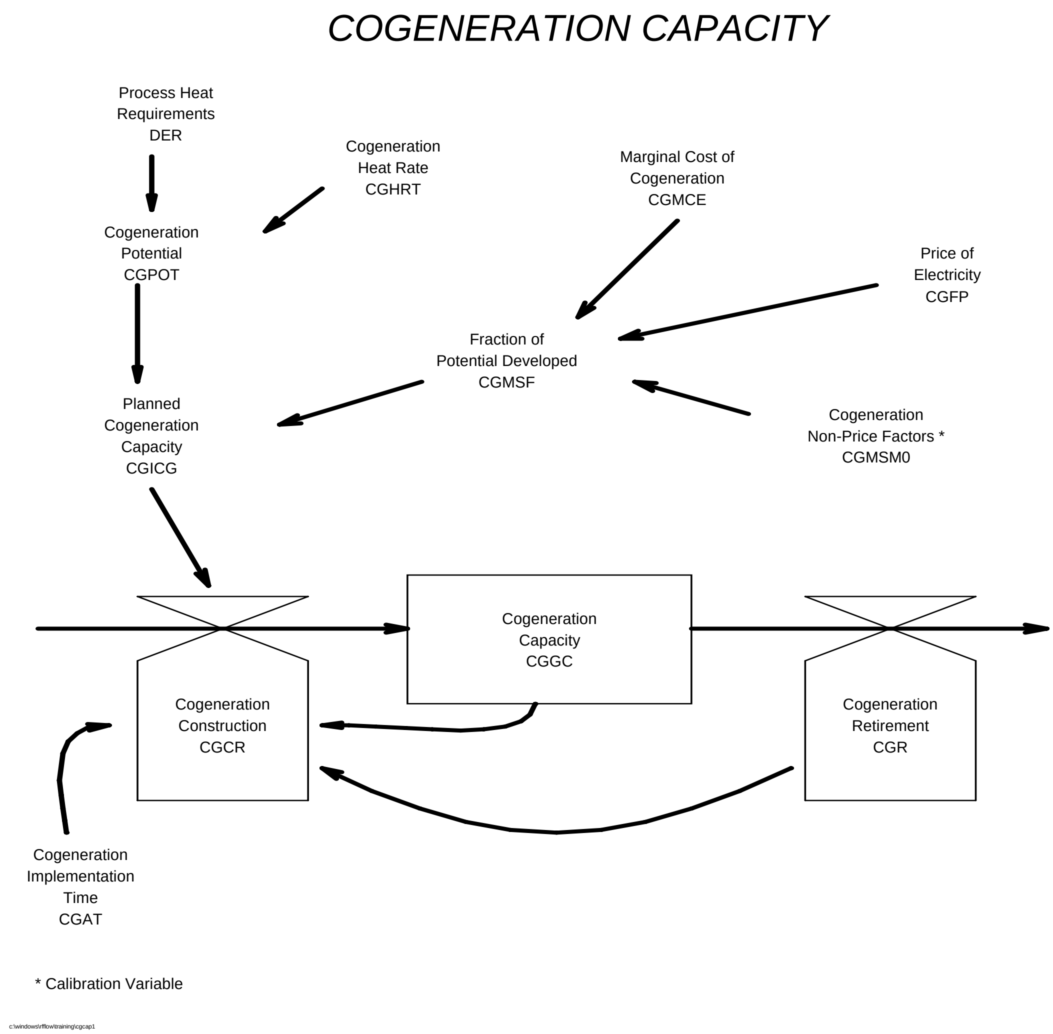

Figure 0.18

Actual cogeneration construction depends on planned cogeneration capacity which in turn is a function of cogeneration potential . The fraction of cogeneration potential that is actually developed is determined by the Fraction of Potential Development. This fraction depends on the marginal cost of cogeneration, the price of electricity to cogenerators, and cogeneration non-price factors. In a sense, this fraction is a market share choice between two options - self-generation and purchases from a utility. The choice is based on the relative prices of the two options plus non-price factors such as willingness to undertake such a project. The Cogeneration Non-Price Factors are calibrated in the same manner as other non-price factors - by looking at the historical market shares and prices and calculating the deviation from the economically optimal split.

The Planned Cogeneration Capacity is derived by applying the Fraction of Potential Development to the Cogeneration Potential. The Cogeneration Potential is determined by the process heat requirements and the cogeneration heat rate. Potentially all of these requirements could be met by cogeneration; however, through the Cogeneration Market Share Fraction, relative prices, and non-price factors reduce the potential to the more economically realistic planned cogeneration capacity .

The planned cogeneration capacity, additionally influenced by current cogeneration capacity (existing cogeneration would not be duplicated) as well as capacity retirements, is lagged by the Cogeneration Implementation Time to yield the amount of cogeneration construction that will be undertaken. The lag is important. Prices may dictate that cogeneration is the economically viable choice today but it may take a year or more for the cogenerator to get his system on line.

Cogeneration Marginal Cost

Figure 0.19 illustrates in full the calculation of the marginal cost of cogeneration used in Figure 0.18. In the lower left hand corner of the diagram you can see that the Cogeneration Marginal Cost is determined by the Cogeneration Capital Charge Rate, Cogeneration Capital Cost and Cogeneration Variable Cost. Cogeneration Capital Cost is multiplied by the Cogeneration Capital Charge Fate to get a levelized capital cost. The derivation of the capital charge rate is similar to the rate used in the utility sector of the model and will be discussed there. A cogeneration variable is calculated and added to the levelized fixed cost yielding the cost of cogeneration at the margin.

The cogeneration variable cost component of marginal cost is made up of four factors: fuel prices, heat rates, delivery charges, and operating costs. Fuel prices refer to the fuel used in the boilers, the heat rate is the efficiency of the boilers, the operating costs consider operating costs associated with the cogeneration alone, and the delivery prices include such miscellaneous costs as electric back service charges. There is also a cogeneration fuel cost switch which may be turned off if there is no fuel cost such as is the case with hydropower cogeneration.

COGENERATION MARGINAL COST

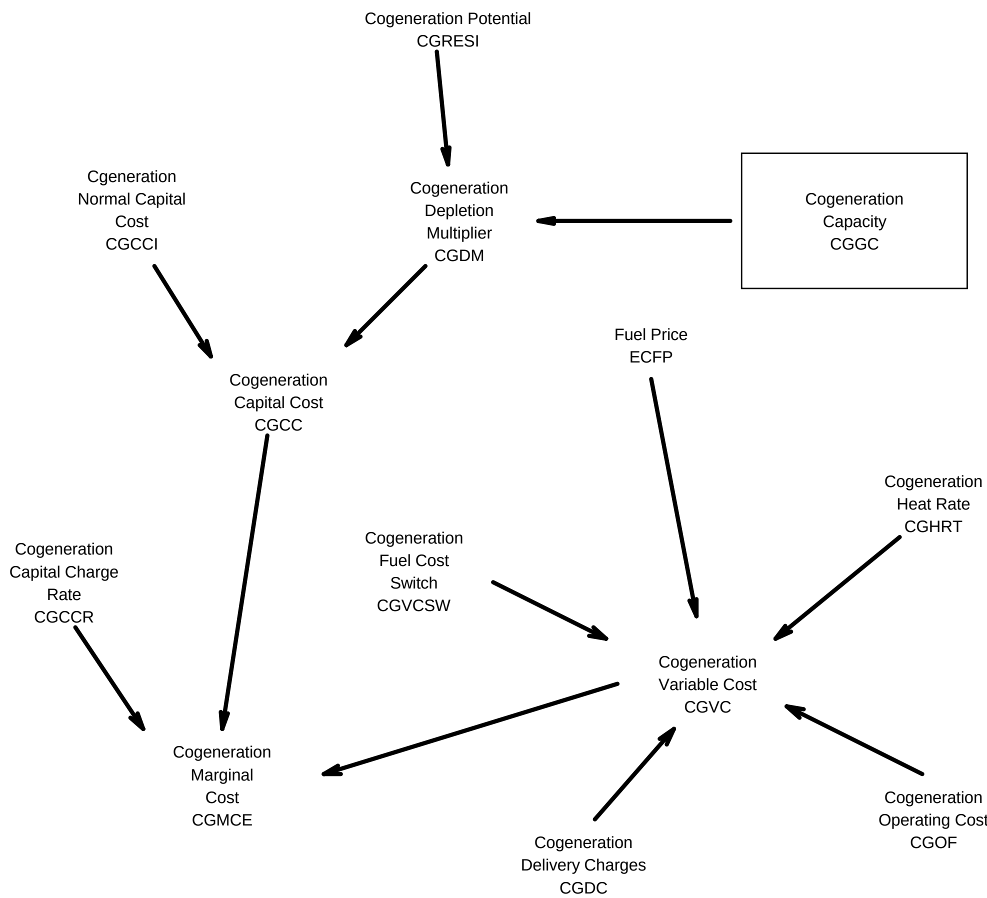

Figure 0.19

The cogeneration capital costs include the normal costs for cogeneration plus a factor to account for depletion of certain cogeneration resources. The Cogeneration Depletion Multiplier is calculated by assessing the Cogeneration Potential and subtracting from it the existing Cogeneration Capacity . For some technologies, costs increase as more cogeneration is developed. For example, hydropower cogeneration tends to be more expensive at later installations than the first because the cheapest (best flow, most accessible) sites are developed first. For technologies that experience this type of cost increase with subsequent installation, the Cogeneration Depletion Multiplier tracks these increasing costs.

Cogeneration Generation

Figure 0.20 illustrates the actual process of cogeneration. Cogeneration Generation is located in the center of the diagram and from the arrows you can tell that the amount of generation from cogenerating facilities depends on five factors: the Cogeneration Normal Capacity Utilization Factor, the Cogeneration Utilization Factor, Cogeneration Capacity, the Cogeneration Capacity Utilization Factor and the Economic Capacity Utilization Factor.

Some of these variables should look familiar. The cogeneration capacity obviously influences how much cogeneration will occur - its impossible to cogenerate if the facilities do not exist. The economic capacity utilization factor we have also seen before when describing factors influencing final demand. Here, it is mapped to another variable, and performs exactly the same function. If a plant is only running one shift, the cogeneration facility will be available only one third of the time; if three shifts are operating, cogeneration can occur around the clock.

The Cogeneration Normal Capacity Utilization Factor is fraction, less than one, that indicates normal usage of a cogeneration facility. Non-economy related changes (which would be picked up in WCUF) are reflected here. The calibrated variable - Cogeneration Capacity Utilization Factor - captures any other variations.

The final variable influencing Cogeneration Generation is the Cogeneration Utilization Factor which depends upon the Indicated Cogeneration Utilization Factor. This ratio is derived from a comparison between the current price of electricity to cogenerators and cogeneration variable costs modified by the cogeneration shared cost multiplier which reflects any other financial benefits to the industrial from cogenerating. It determines the desirability of cogenerating from existing facilities based on relative prices. For example, if the electric utility lowers its price to cogenerators then cogeneration becomes less attractive. The ratio becomes the utilization factor after a lag representing time to adjust to new circumstances (in this case, the growing attractiveness of utility-generated power) and implementation time called the Cogeneration Adjustment Time .

COGENERATION

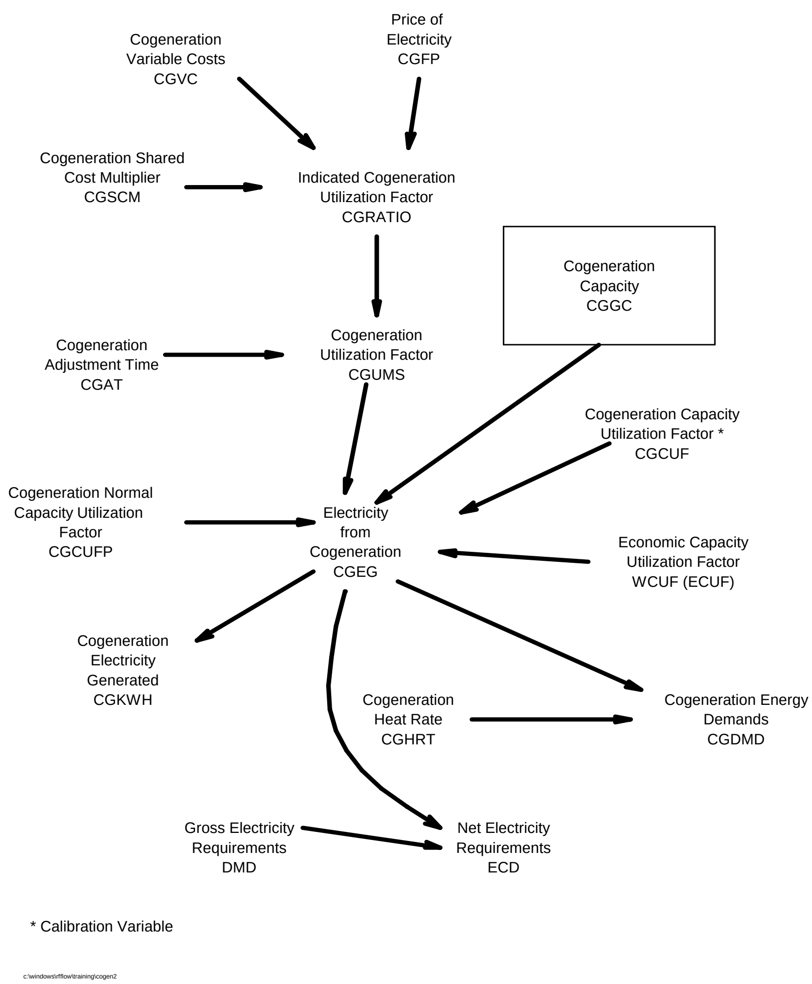

Figure 0.20

The Cogeneration Generation is accounted for in two ways. First the electricity generated is tracked in kWh by a variable called Cogeneration Electricity Generated. It is also, when multiplied by the Cogeneration Heat Rate, tracked by a variable called Cogeneration Energy Demands and is added to final net electric demand. ECD is electric DMD minus the energy needed to cogenerate. ECD is very close to electric sales.

CONCLUSION

What has been described in this demand overview is the basic structure of the ENERGY 2020 demand sectors (residential, commercial and industrial). These sectors simulate the energy consumer's decision making process. This simulation assumes that the decision making process in the future will be the same as it has been in the past; however, this does not necessarily result in consumers making the same decisions in the future that they made historically. For example, if energy consumers chose electric water heating twenty percent of the time in the past, that choice is not projected into the future but instead the decision making process that determined that fuel split is modeled. Since the factors that influenced the twenty percent split in the past may have changed, the twenty percent ratio may not remain constant in the future but the way the factors influenced the decisions that resulted in this split do hold through the forecast period. By simulating the decision making process, we incorporated the effects of changing factors such as changing relative fuel prices, capital costs and other non-price factors.

The individual model routines are described in more detail in Chapter 3. Chapter 4 contains a discussion of the theoretical underpinnings of the mechanisms (such as market share and trade-off curves) that make up the model. Individual variable descriptions are found in Chapter 7.