



**Long-range Energy Alternatives Planning System**

## **TRAINING EXERCISES**

**February 2016  
Updated for LEAP 2015**



These exercises are for use with LEAP2015 for Windows.  
Download the latest version of LEAP from [www.energycommunity.org](http://www.energycommunity.org) before using these exercises.



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# TRAINING EXERCISES FOR LEAP

## Introduction

These training exercises will introduce you to LEAP, the Long-range Energy Alternatives Planning system, and how it can be applied to energy and environmental analysis. The exercises are normally used as part of LEAP training courses. They assume that you have some background in energy issues and familiarity with Windows-based software, including spreadsheets (such as Microsoft Excel).

The training exercises are designed in a modular fashion. If you only have a few hours and want to get a general impression of how LEAP works, then complete Exercise 1. Further exercises are intended to give you a deeper understanding of additional LEAP capabilities.

- **Exercise 1** will introduce you to the basic elements of energy demand and supply analysis, of projecting energy requirements and calculating environmental loadings. You must complete Exercise 1 before beginning Exercise 2.
- **Exercises 2 and 3** allow you to develop a basic energy analysis, to create scenarios, and to evaluate a handful of individual policy and technical options, such as energy efficiency standards and switching power plants from coal to natural gas. The exercises cover demand, supply, and scenario analysis, and can be done individually or together. Altogether they will take about 2 to 4 days to complete fully.
- **Exercise 4** lets you explore the costs and benefits of several alternative scenarios. Scenarios are implemented on both the demand and supply side, and you will explore the use of LEAP as a cost-benefit calculator to find the costs of reducing emissions under each scenario. Exercise 4 requires that you begin with a completed version of Exercise 3.

Each of these four exercises use the backdrop of a fictional country called “Freedonia”, which is based on data that are similar to information you may encounter in the real world. As in the real world, in some cases you will need to convert data into a format suitable for entry into LEAP. We provide you with hints to assist you and to help ensure that your approaches are consistent. Most of the exercises come with answer keys, provided in this document that you can use to check your work.

Within LEAP, you can use the Area: Revert to Version menu option to see the results of individual exercises. For instance, users interested only in Exercise 3 can revert to the version of the Freedonia area corresponding to a completed Exercise 3.

- **Exercise 5** lets you use LEAP’s transportation analysis features to construct a range of scenarios that examine different policies for reducing fuel use and pollution emissions from cars and sport utility vehicles (SUVs). You can begin Exercise 5 without having completed any of the previous exercises.
- **Exercise 6** lets you use LEAP’s optimization features to explore least-cost optimization of energy systems. You also explore how to model a cap on CO<sub>2</sub> emissions – including how a cap might alter the set of technologies chosen and the overall costs of a scenario.

**Hardware Requirements:** In order to complete these exercises, you will need a standard Windows-based computer with at least 1 GB of RAM and with Microsoft Windows 7 or higher running LEAP. You will also need a pen, paper and a calculator, such as the one built-in to Windows. Some exercises also require that you have access to Microsoft Excel.

## Getting Started in LEAP

If LEAP is installed, start LEAP from the **Start/Programs/LEAP** menu. If not, run the installation program directly from the setup.exe file or download and run LEAP from [www.energycommunity.org/download](http://www.energycommunity.org/download), following the on-screen instructions. Once started, LEAP will display a title screen, and then the main screen will be shown.

NB: To complete these exercises you **must be using a registered version** of LEAP. The evaluation version of LEAP does not allow you to save data and so cannot be used for these exercises. To learn more about licensing, please go to [www.energycommunity.org/licensing](http://www.energycommunity.org/licensing).

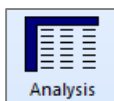
The main screen of LEAP consists of eight major “views”, each of which lets you examine different aspects of the software. The View Bar located on the left of the screen, displays an icon for each view. Click on one of the View Bar icons or use the View Menu to change views,

***Hint:** If you are working on a lower resolution screen, you may want to hide the View Bar to make more space on the screen. Use the menu option View: View Bar to do this. When the View Bar is hidden, use the View menu below the tree to switch views.*

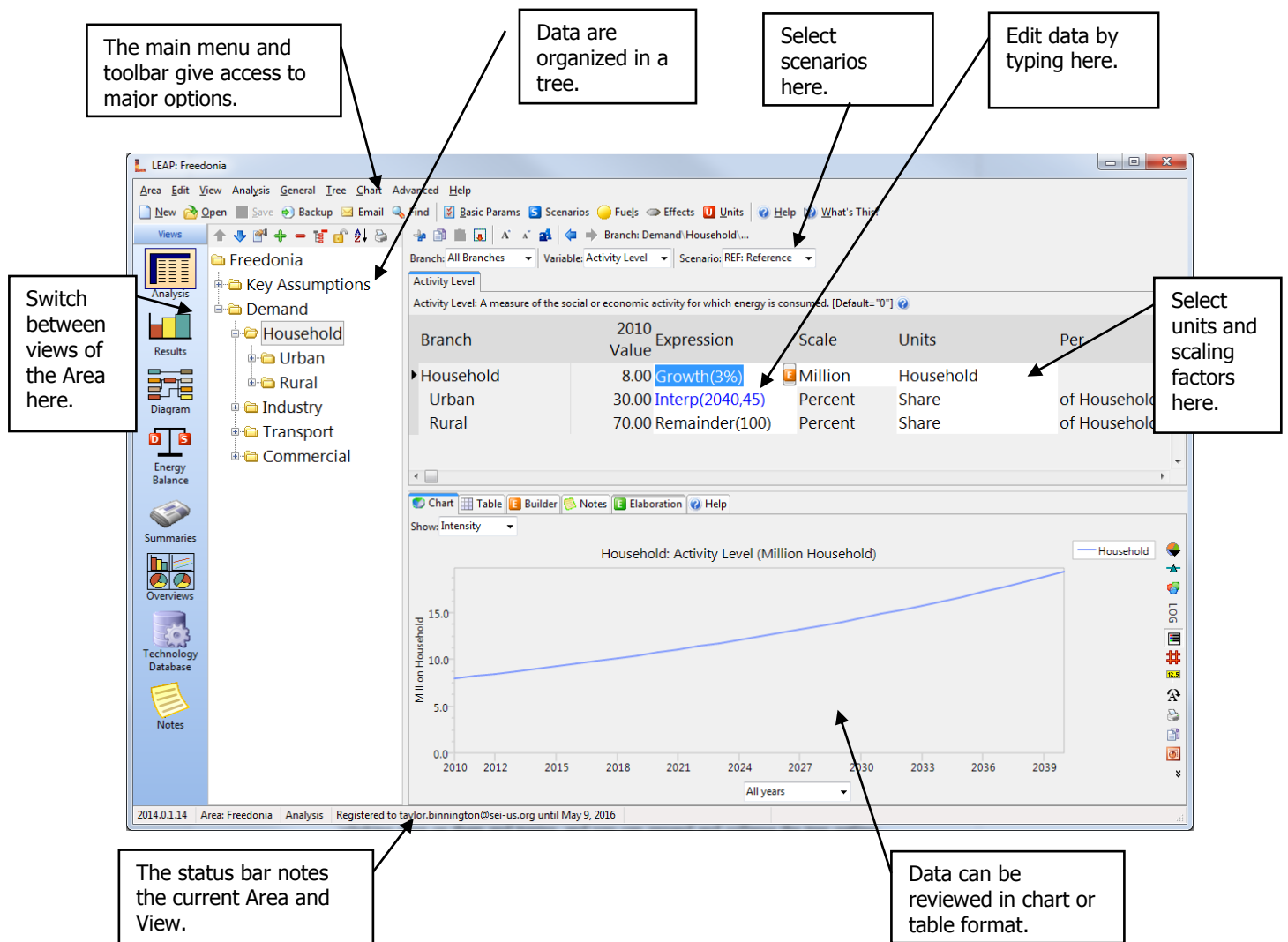
- The **Analysis View** is where you enter or view data and construct your models and scenarios.
- The **Diagram View** shows you your energy system depicted as a Reference Energy System Diagram.
- The **Results View** is where you examine the outcomes of the various scenarios as graphs and tables.

For information on the other views, click on Help.

## The Analysis View




The **Analysis View** (shown below) contains a number of controls apart from the view bar mentioned above. On the left is a tree in which you view or edit your data structures. On the right are two linked panes. At the top is a table in which you edit or view data and create the modeling relationships. Below it is an area containing charts and tables that summarize the data you entered above. Above the data table is a toolbar that lets you select the data you want to edit. The topmost toolbar gives access to standard commands such as saving data, creating new areas, and accessing the supporting fuels, effects and references databases.












The main parts of the **Analysis View** are described in more detail below:

- Tree:** The tree is the place where you organize your data for both the demand and supply (also called transformation) analyses. In most respects the tree works just like the ones in standard Windows tools such as the Windows Explorer. You can rename branches by clicking once on them and typing, and you can expand and collapse the tree outline by clicking on the **+** and **-** symbols. Use the right-click menu to expand or collapse all branches or to set the outline level.

To edit the tree, right-click on it and use the *Add* (**+**), *Delete* (**-**) and *Properties* () buttons. All of these options are also available from the Tree menu option. You can move selected tree branches by clicking and dragging them, or you can copy parts of the tree by holding down the **Ctrl** key and then clicking and dragging branches.

The tree contains different types of branches. The type of a branch depends on its context (for example whether it is part of your demand or transformation data structure, or whether it is one of your own independent variables added under the “Key

Assumptions” branch. Different branch icons indicate different types of branches. The main types of branches are listed below:


-  **Category branches** are used mainly for the hierarchical organization of data in the tree. In a demand analysis, these branches only contain data on activity levels and costs. In a supply analysis, category branches are used to indicate the main energy conversion “modules” such as electric generation, oil refining and resource extraction, as well as groups of processes and output fuels.
  -  **Technology branches** contain data on the actual technologies that consume, produce and convert energy. In a supply analysis, technology branches are shown with the  icon. They are used to indicate the particular processes within each module that convert energy (for example a particular power plant in an electric generation module). In a demand analysis, technology branches are associated with particular fuels and also normally have an energy intensity associated with them. Demand technology branches can appear in three different forms depending on the type of demand analysis methodology chosen. These methodologies are activity analysis () , stock analysis () and transport analysis () . This latter methodology is described in more detail in Exercise 5.
  -  **Key Assumption branches** are where you create your own independent variables such as macroeconomic or demographic indicators. These variables can then be referred to in expressions under other branches.
  -  **Fuel branches** are found under the Resources tree branch. They also appear under each Transformation module, representing the **Output Fuels** produced by the module and the **Auxiliary** and **Feedstock Fuels** consumed by the module.
  -  **Environmental Loading branches** represent the various pollutants which are emitted by energy demand and transformation technologies or which are tracked in LEAP’s “Non Energy” emissions branches. Effect branches are always the lowest level branches.
- **Data Table:** The **Analysis View** contains two panes to the right of the tree. The top pane is a table in which you can view and edit the data associated with the variables at each branch in the tree. As you click on different branches in the tree, the data screen shows the data associated with branches at and immediately below the branch in the tree. Each row in the table represents data for a branch in the tree. For example, in the sample data set click on the “Demand” branch in the tree, and the data screen lists the sectors of your demand analysis, then click on “Households” in the tree and the data screen summarizes the household subsectors (in this case urban and rural).

At the top of the table is a set of tabs giving access to the different variables associated with each branch. The tabs you see depend on how you specified your data structures, and on what part of the tree you are working on. For example, when editing demand sectors you will normally see tabs giving access to the **Activity Level** and **Demand**



**Cost** variables, while at the lowest levels of the tree you will also see tabs for **Final Energy Intensity** and **Environmental Loading** data.

- **Chart/Table/Notes:** The lower pane summarizes the data entered above as a chart or a table. When viewing charts, use the toolbar on the right to customize the chart. Graphs can be displayed in various formats (bar, pie, etc.), printed, or copied to the clipboard for insertion into a report. The toolbar also allows you to export the data to Microsoft Excel or PowerPoint.
- **Scenario Selection Box:** Above the data table is a selection box, which you can use to select between Current Accounts and any of the scenarios in an area. Current Accounts data is the data for the base year of your study. Different scenarios in LEAP all begin from the base year. This box also shows you the basic *inheritance* of each scenario. In LEAP, scenarios can *inherit* modeling expressions from other scenarios. All scenarios ultimately inherit expressions from the Current Accounts data set. In other words, unless you specifically enter scenario data for a variable, its value will be constant in the future.

To create a new scenario, click on **Scenarios** (  ). When you create a new scenario, you can specify that it be based on (i.e. inherits from) another scenario. Until you change some expressions in the new scenario, it will give exactly the same results as its parent scenario. Expressions displayed in the data table are color-coded so you can tell if they were explicitly entered in the scenario (colored blue) or if they are inherited from the parent scenario (colored black).

## Exercise 1: Introduction to LEAP


### 1.1 Overview of Freedonia

In order to illustrate how LEAP can be used in a variety of contexts, we have structured the data in Freedonia to reflect the characteristics of both an industrialized, and developing country. For instance, Freedonia's urban population is fully electrified and living at OECD standards, while its poorer rural population has limited access to modern energy services, and is heavily reliant on biomass fuels to meet basic needs. To simplify the exercises and reduce repetitive data entry, we have deliberately left out a number of common sectors and end uses. For example, Exercise 1 considers only a partial residential sector: appliance energy use in Freedonia's urban households, and cooking and electricity use for Freedonia's rural residents. Similarly, in Exercise 2, there is no agriculture sector, and the only energy used by commercial buildings is for space heating.

### 1.2 Basic Parameters

Before beginning the exercises, set the basic parameters of your study. These include the standard energy unit for your study, the standard currency unit (including its base year), and basic monetary parameters.

LEAP comes supplied with a completed Freedonia data set, so for the purpose of these exercises, you will make a new blank data set called "New Freedonia". Start by creating a new area in LEAP called "New Freedonia" that is based only on default data (click on the menu option Area: New).

Review the **Basic Params** screen () and in the Years tab set the base year and end year for the analysis. Choose 2010 as the *Base Year*, 2011 as your *First Scenario Year* and 2040 for the *End Year*. For exercises you will do later on, set the *Monetary Year* to 2010 and the *First Depletion Year* to 2011. On the Scope & Scale tab, you can initially leave all of the options unchecked since you will start by only conducting a demand analysis. All other options can be left at their default values. Note: in this exercise you will be using only one year of historical data (2010).

## 1.3 Demand

This preliminary demand analysis exercise considers only the energy used in Freedonia households. You will start by developing a set of Current Accounts that depict household energy uses in the most recent year for which data are available (2010). You will then construct a reference scenario that examines how energy consumption patterns are likely to change in the coming years in the absence of any new policy measures. Finally, you will develop a policy scenario that examines how energy consumption growth can be reduced by the introduction of energy efficiency measures.

### 1.3.1 Data Structures

The first step in an energy analysis is to design your data structure. The structure will determine what kinds of technologies, policies, and alternative development paths you can analyze. It will be guided by the information you collect (data and assumptions) and by the relationships you assume. For instance, you might consider whether you want to include branches for all possible end-uses or only for major categories of residential energy consumption, you might consider whether residential energy intensities should be developed on a per capita (i.e. per person) or per household basis, or you might consider whether energy demand be a direct function of income or prices. In this simple exercise you don't need to include these factors.

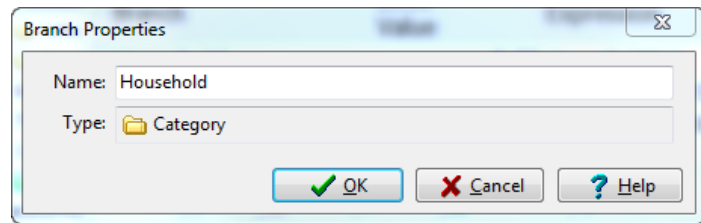
Before using the software, it is therefore important to plan the way you will enter data into the program. Read the following description of the relevant data (in sections 1.3.2 to 1.3.4) to get an idea of the types of data structures that are possible. *Note that there is more than one branch structure that can be created with the data provided.*

It is a good idea to sketch the structure before entering it into LEAP. Use the blank spaces below for your sketch. If you are working as part of a training course, discuss your first sketch with your instructor and revise your drawing if needed.

First Sketch of Demand Tree	Second Sketch of Demand Tree

After reading through the following sections and finalizing a sketch of a demand tree, you should now be ready to create a demand tree structure in LEAP that reflects the organization of household demand data in Freedonia.

Create the tree structure using the *Add* (+), *Delete* (-) and *Properties* (🔧) commands available either by right clicking on the Tree, or on the Tree menu. In this exercise, you will create various sub-sectors, end-uses, and devices beneath the “Households” branch. Upper level branches will be created as *Category* branches (📁), while the lower level branches at which you select a fuel and enter an energy intensity will be of the type *Technology with Energy Intensity* (⚙️).



### 1.3.2 Current Accounts

In the year 2010, Freedonia’s 40 million people are living in about 8 million households. 30% of these are in urban areas. The key data are given below. Note that unless otherwise specified, expressions entered into LEAP’s variables are interpreted as annual values in each year.

#### Urban Households

- All of Freedonia’s urban residents are connected to the electric grid, and use electricity for lighting and other devices.
- 95% have refrigerators, which consume 500 KWh per year on average.
- The average urban household annually consumes 400 KWh for lighting.
- Other devices such as computers, televisions, and fans annually consume 800 KWh per urban household.
- 30% of Freedonia’s urban dwellers use electric stoves for cooking: the remainder use natural gas stoves. All households have only one type of cooking device.
- The annual energy intensity of electric stoves is 400 KWh per household, for natural gas stoves it is 60 cubic meters per household.

**Hint 1:** In general, you can enter the above data as simple numeric values in the *Current Accounts* Expression field. In the *Scale and Units* columns, select appropriate units for the **Activity Level** and **Energy Intensity** for each branch (scaling factors can be left blank). If you specify “Share” as the unit of activity for each cooking stove (natural gas or electric), then you need only type the percentage value for electric stoves. For gas stoves, enter the expression `Remainder(100)` into the **Activity Level** variable, and LEAP will use this expression to calculate the share of households using gas stoves.

**Hint 2:** When selecting units for **Activity Level**, it is important to select carefully between “Saturation” and “Share”. Shares should be used only where activity levels for adjacent branches need to sum to 100%, as in the case above of stove fuel shares above. LEAP calculations require that shares always sum to 100% across immediately neighboring branches. Therefore, be sure to use

*“Saturation” for items such as refrigerator ownership that need not sum to 100% to avoid later error messages.*

## Rural Households


- A recent survey of all rural households (both electrified and non-electrified) indicates the following types of cooking devices are used:

Cooking Technology	Fuel Consumed	Share of Rural Households	Annual Energy Intensity per Household
Charcoal Stove	Charcoal	30 %	166 kg
LPG Stove	LPG	15 %	59 kg
Wood Stove	Wood	55 %	525 kg

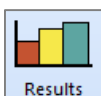
- Only 25% of rural households have access to grid-connected electricity.
- 20% of the electrified rural households own a refrigerator, which consumes 500 KWh per year on average.
- All electrified rural households use electricity for lighting, which consumes 335 KWh per household. 20% of these households also use kerosene lamps for additional lighting, using about 10 liters per year.

**Hint:** Use “Saturation” for your activity units here since some households own more than one lighting device. These units are often appropriate when technologies may be used non-exclusively, such as electric lights AND kerosene lamps.

- Other electric devices (TV, radio, fans, etc.), account for 111 KWh per household per year.
- Non-electrified households rely exclusively on kerosene lamps for lighting, averaging 69 liters consumption per household per year.

**Hint:** This is a good place to save your data before going on. Do this by clicking the  icon or by selecting Area: Save. It is always a good idea to save your data often.

### 1.3.3 Viewing Results



Click on the **Results View** to check your results for Current Accounts. Notice that at this stage we will only be viewing result for a single base year: 2010. Results can be viewed in either chart or table format. For this exercise, click on the Table tab at the top of the display window. On the toolbar above the table select **Demand: Energy Demand Final Units**, then, using the Tree, select the demand branches you want to chart. Click on the “Household” branch to display the household energy demands for Freedonia. Configure the content of your table by displaying *All Branches* for the table's rows and *All Fuels* for the table's columns. Use the decimal place buttons in the toolbar on the right of the table to show data with one decimal place accuracy.

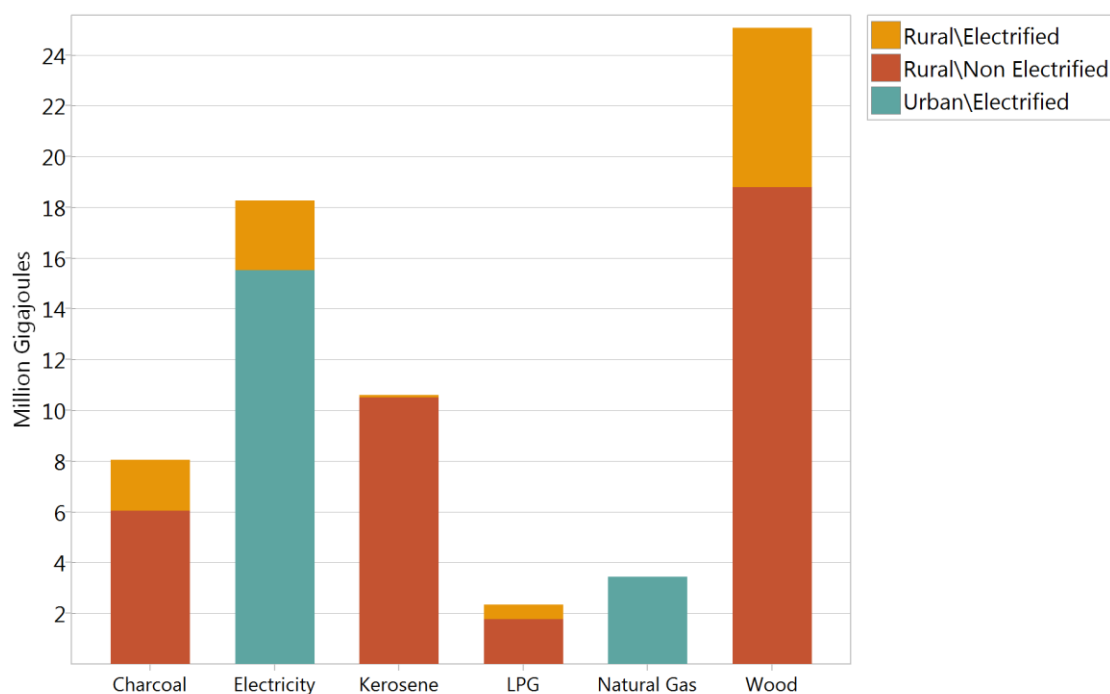
Adjusting the number of levels in the table will help you calculate category subtotals. Choose an appropriate number by increasing the *Levels*: to display the total fuel requirements for each end use for “Rural” and “Urban”, “Electrified” and “Non Electrified” categories. You can save this configuration for future reference creating a favorite chart under the Favorites: Save Chart as Favorite menu. This feature works much like the favorite/bookmark options in Internet browsers. Compare your results to the table below.

#### Current Accounts Energy Demand in 2010 (Million GJ)

Branches	Charcoal	Wood	LPG	Kerosene	Natural Gas	Electricity	Total
Urban	-	-	-	-	3.4	15.5	19.0
Electrified	-	-	-	-	3.4	15.5	19.0
Refrigeration	-	-	-	-	-	4.1	4.1
Lighting	-	-	-	-	-	3.5	3.5
Other Uses	-	-	-	-	-	6.9	6.9
Cooking	-	-	-	-	3.4	1.0	4.5
Rural	8.1	25.1	2.3	10.6	-	2.8	48.8
Electrified	2.0	6.3	0.6	0.1	-	2.8	11.7
Lighting	-	-	-	0.1	-	1.7	1.8
Other Uses	-	-	-	-	-	0.6	0.6
Cooking	2.0	6.3	0.6	-	-	-	8.9
Refrigeration	-	-	-	-	-	0.5	0.5
Non Electrified	6.0	18.8	1.8	10.5	-	-	37.1
Lighting	-	-	-	10.5	-	-	10.5
Cooking	6.0	18.8	1.8	-	-	-	26.6
Total	8.1	25.1	2.3	10.6	3.4	18.3	67.8

**Hint:** To display subcategories, you will need to ensure that the Subtotals button has been checked, and increase the number of levels to three (both of these options are in the toolbar at the top of **Results View**).

### Current Accounts Energy Demand in 2010 (Million GJ)



**Hint:** to get this chart in **Results View**, select All Fuels on the X-axis and All Branches on the legend. Show 2 levels of detail for branches.

#### 1.3.4 Reference Scenario

You are now ready to create your first forward-looking scenario for the period 2011 to 2040. This will analyze how household energy demands are likely to evolve over time under current policy conditions. Click the **Scenarios** button (S) and use the Manage Scenarios screen to add a first scenario. Give it the name “Reference” and the abbreviation “REF”. Add an explanatory note to describe the scenario, e.g., “business-as-usual development; official GDP and population projections; no new policy measures.”

Exit the Scenario Manager and, if necessary, select the Reference scenario from the selection box at the top of the screen. Now enter the assumptions and predictions of the future data in Freedonia as described below.

**Hint:** If you wish to edit the base year data, you need to first return to Current Accounts. Always check that you are entering data into the correct scenario.

First enter the basic demographic changes that are expected to take place in Freedonia. The number of households is expected to grow from 8 million in the year 2010 at 3% per year.

**Hint:** To enter a growth rate, press **Ctrl-G** or click on the E button attached to the expression field and select Growth Rate (you must be in a non-Current Accounts scenario to see this option). You can also type Growth(3%) directly into the Expression field.



## Urban Households

- By 2040, 45% of Freedonia's households will be in urban areas.

**Hint:** This is an example of a common situation in LEAP, one in which you wish to specify just a few data values (2010, implicitly, and 2040) and then have LEAP linearly interpolate to calculate the values of all the years between. You can enter interpolated data in a number of different ways. The simplest way is to click on the button attached to the expression field and select End Year Value. Then simply type in the value 45. When you click OK, LEAP will enter an Interp function into your expression. You can also type the function directly into the Expression field as `Interp(2040, 45.0)`.


**Important:** You may need to adapt the expressions you enter into LEAP to reflect local number formatting conditions. For example, in many Spanish and French speaking countries the above expression would be entered as `Interp(2040; 45,0)`. In these exercises all the expressions are written assuming English (US) number formatting.

- Increased preference for electric stoves results in a 55% market share by 2040.
- The energy intensity of electric and gas stoves is expected to decrease by half a percent every year due to the penetration of more energy-efficient technologies.
- As incomes rise and people purchase larger appliances, annual refrigeration intensity increases to 600 kWh per household by 2040.
- Similarly, annual lighting intensity increases to 500 kWh per household by 2040.
- The use of other electricity-using equipment grows rapidly, at a rate of 2.5% per year.

**Hint:** To specify a decrease, simply enter a negative growth rate.

## Rural Households

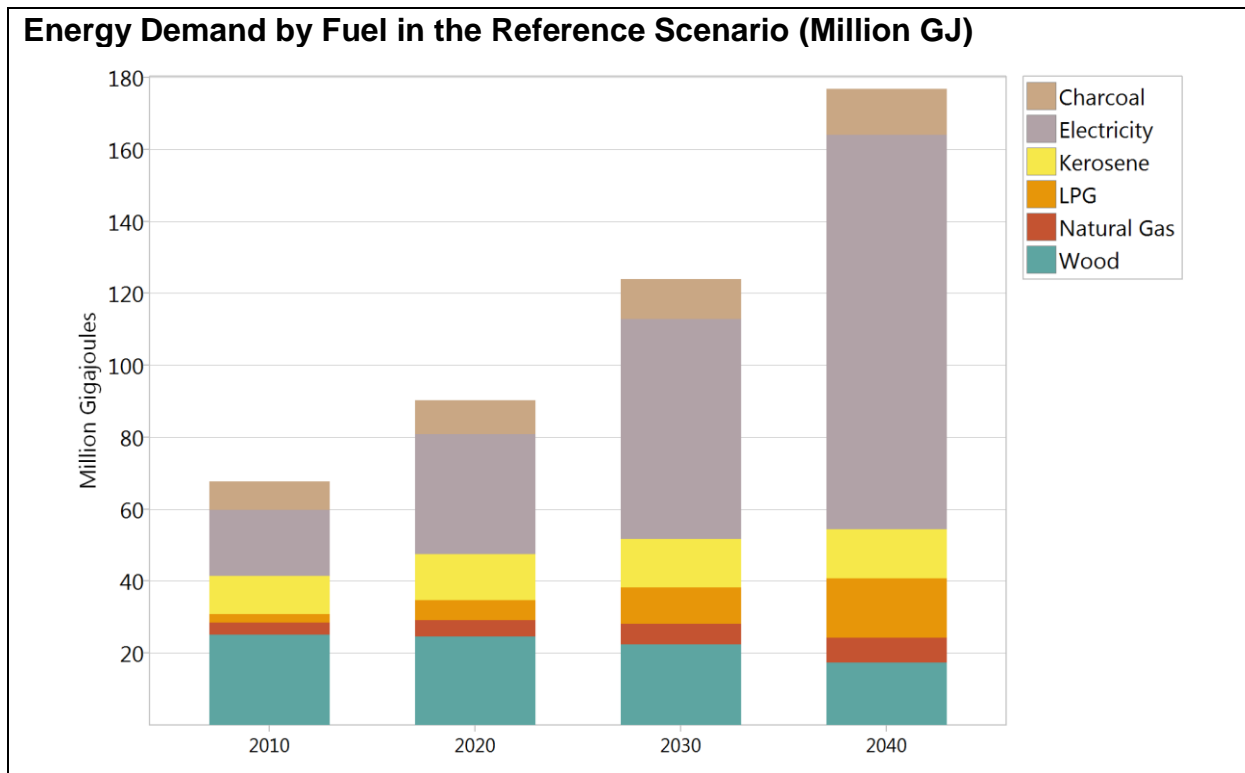
- An ongoing rural electrification program is expected to increase the percentage of rural households with electricity service to 28% in 2020 and 50% in 2040.
- As incomes increase, the energy intensity of electric lighting is expected to increase by 1% per year.
- The number of grid-connected rural homes using a refrigerator is expected to increase to 40% in 2020, and 66% in 2040.
- Due to rural development activities the share of various cooking devices in all households (both electrified and non-electrified) changes so that by 2040, LPG stoves are used by 55% of households, and charcoal stoves by 25%. The remaining rural households use wood stoves.

**Hint:** Save your data before going on by pressing the Save button () or keyboard shortcut **Ctrl-S**.

Click on the **Results View** again. This time, select the Chart tab at the top of the display window to display your results graphically.

To configure your results:

- On the Chart, use the selection boxes to select which types of data you want to see on the legend and X-axis of the chart. Typically, you will select years as the X-axis for many charts and fuels or branches as the legend.
- Choose **Demand: Energy Demand Final Units**, as you did for the table in the Current Accounts exercise. Then, using the Tree, select the demand branch you want to chart. Click on the “Demand” branch to display the total energy demands for Freedonia.
- Double-click on the chart's Y-axis units to change the units of the report. You can further customize chart options using the toolbar on the right of the chart. Use the toolbar to select options such as the chart type (area, bar, line, pie, etc.) or whether the bar chart is stacked or not.



Compare your projections in detail with the tables shown below (note that tables in LEAP are formatted slightly differently than those shown here, but you should be able to find all of the relevant information by adjusting the number of branch levels). Start by checking results at the highest levels (i.e. start by clicking on “Demand” and then work your way down to more detailed levels to investigate where any problems may lie. Adjust your data before proceeding. For this exercise, you may ignore differences of less than 1%.

### Energy Demand by Fuel in the Reference Scenario (Million GJ)

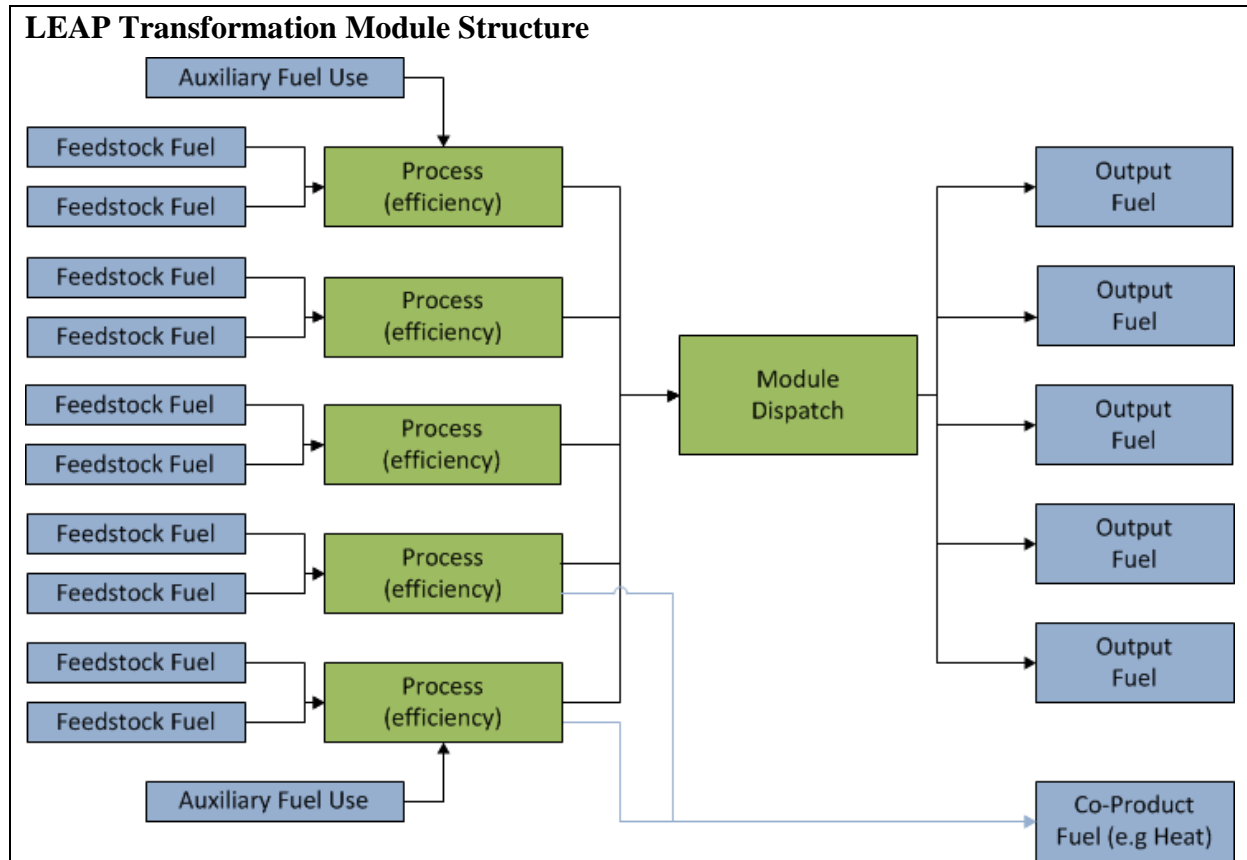
<b>Fuel</b>	<b>2010</b>	<b>2020</b>	<b>2030</b>	<b>2040</b>
Charcoal	8.1	9.5	11.1	12.8
Electricity	18.3	33.4	61.3	109.6
Kerosene	10.6	12.7	13.5	13.7
LPG	2.3	5.5	10.1	16.4
Natural Gas	3.4	4.5	5.7	6.9
Wood	25.1	24.6	22.3	17.4
<b>Total</b>	<b>67.8</b>	<b>90.3</b>	<b>123.9</b>	<b>176.8</b>

### Energy Demand by Branch in the Reference Scenario (Million GJ)


<b>Branch</b>	<b>2010</b>	<b>2020</b>	<b>2030</b>	<b>2040</b>
<b>Rural</b>	<b>48.8</b>	<b>57.2</b>	<b>66.5</b>	<b>77.5</b>
<b>Electrified</b>	<b>11.7</b>	<b>16.0</b>	<b>26.8</b>	<b>40.8</b>
Cooking	8.9	11.1	17.0	23.3
Charcoal	2.0	2.7	4.3	6.4
LPG	0.6	1.5	3.9	8.2
Wood	6.3	6.9	8.7	8.7
Lighting	1.8	2.7	5.2	9.1
Electric	1.7	2.6	5.0	8.7
Kerosene	0.1	0.1	0.2	0.4
Other uses	0.6	0.8	1.4	2.1
Refrigeration	0.5	1.4	3.2	6.3
<b>Non Electrified</b>	<b>37.1</b>	<b>41.1</b>	<b>39.8</b>	<b>36.6</b>
Cooking	26.6	28.6	26.5	23.3
Charcoal	6.0	6.8	6.8	6.4
LPG	1.8	4.0	6.2	8.2
Wood	18.8	17.7	13.6	8.7
Lighting	10.5	12.6	13.2	13.4
<b>Urban</b>	<b>19.0</b>	<b>33.1</b>	<b>57.4</b>	<b>99.3</b>
Cooking	4.5	6.5	9.2	12.9
Electric	1.0	2.0	3.5	6.0
Gas	3.4	4.5	5.7	6.9
Lighting	3.5	5.9	9.7	15.7
Other uses	6.9	13.9	27.3	52.8
Refrigeration	4.1	6.9	11.2	17.9
<b>Total</b>	<b>67.8</b>	<b>90.3</b>	<b>123.9</b>	<b>176.8</b>

## 1.4 Transformation

The Transformation sector uses special branches called “Modules” to model energy supply and conversion sectors such as electricity generation, refining, or charcoal production. Each module contains one or more “Processes”, which represent an individual technology such as a particular type of electric plant or oil refinery, and produces one or more “Output Fuels”. These represent the energy products produced by the module. The basic structure of a module is shown below:

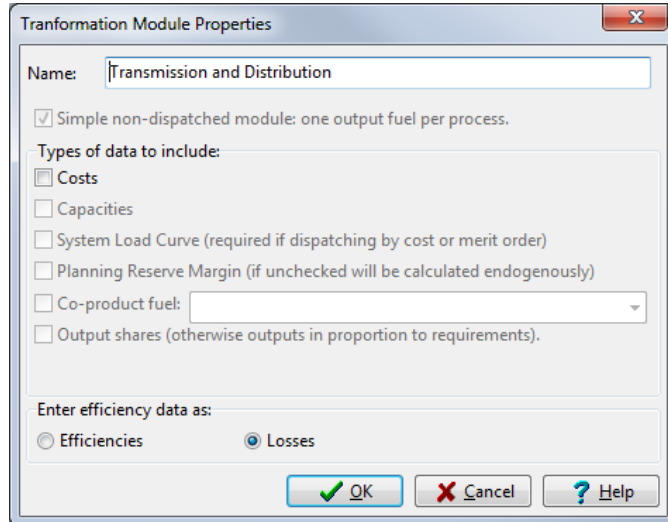


In this exercise you will develop a simplified model of the electricity transmission and generation sectors in Freedonia. This model will be the basis for the more detailed and realistic model you will create in Exercise 3.

Return to the **Basic Params** screen (  ) and check the box marked Transformation & Resources, since you are now going to enter data for various Transformation modules.

### 1.4.1 Transmission and Distribution

You will start by adding a simple, non-dispatched module to represent electricity and transmission and distribution (T&D) losses and natural gas pipeline losses. In the base year, electricity T&D losses amount to 15% of the electricity generated in 2010. In the Reference scenario these are expected to decrease to 12% by 2040. Natural gas pipeline losses amount to 2% in 2010, and are expected to decrease to 1.5% by 2040 in the Reference scenario.



To create a simple module, right-click on the Transformation branch on the Tree and select the *Add* command (+). On the resulting Module properties screen (shown above), enter the name “Transmission and Distribution”, and use the checkboxes to indicate the types of data you will be entering.

**Important:** check the box marked “Simple non-dispatched module: one output fuel per process”, and then mark that you want to enter efficiency data as Losses.

When you click OK the module is added. Expand the branches beneath the newly created module and you will see a new branch marked “Processes”. Click on this and add a new process called “Electricity”. Select the **Feedstock Fuel** (electricity), and then enter percentage share of electricity losses on the **Energy Losses** tab. Repeat this process to add a process for natural gas then enter the data on natural gas pipeline losses.

***Hint:** Use the same features as in demand to enter time-varying data: switch to the Reference scenario and use the Interp function to specify how electric losses change over time.*

## 1.4.2 Electricity Generation

Next you will simulate how electricity is generated in Freedonia. Add a second Transformation module called “Electricity Generation”.

Make sure that the Electricity Generation module appears below the Transmission and Distribution module in the list of modules. You may need to use the up (↑) and down (↓) buttons to reorder modules. The sequencing of modules reflects the flow of energy resources from primary/extraction (bottom of the list) to final use (top of the list). Electricity must be generated before it is transmitted and distributed. Similarly, a module for mining of coal that feeds electricity generation would need to be added lower down on the list.

The screenshot shows the 'Transformation Module Properties' dialog box with the title 'Electricity Generation'. It contains several options and input fields:


- Name:** Electricity Generation
- ☐ Simple non-dispatched module: one output fuel per process.
- Types of data to include:**
  - ☒ Costs
  - ☒ Capacities
  - ☒ System Load Curve (required if dispatching by cost or merit order)
  - ☒ Planning Reserve Margin (if unchecked will be calculated endogenously)
  - ☐ Co-product fuel: [dropdown menu]
  - ☐ Output shares (otherwise outputs in proportion to requirements).
- Enter efficiency data as:**
  - ☒ Efficiencies
  - ☐ Losses
  - ☐ Heat rates
- Buttons: OK (green checkmark), Cancel (red X), Help (blue question mark).

Make sure that you set correct *Properties* (🔧) for Electricity Generation module (see above). Since you will be specifying data on plant Capacities, Costs (although we will not be entering cost data until a later time), Efficiencies, and a System Load Curve, be sure that these items are checked. Also check the Planning Reserve Margin option.

Next you will add three processes to represent the various power plants available in the region. Information on some of the basic characteristics of these plants is given in the following table:

Plant Type	Feedstock	Exogenous Capacity (MW)	Efficiency (%)	Merit Order	Maximum Availability (%)	Historical Production (GWh)
Existing Coal Steam	Coal Bituminous	1000	30	1 (base)	70	3343.2
Existing Hydro	Hydro	500	100	1 (base)	70	1731.3
Existing Oil Combustion Turbine	Residual Fuel Oil	800	25	2 (peak)	80	895.5

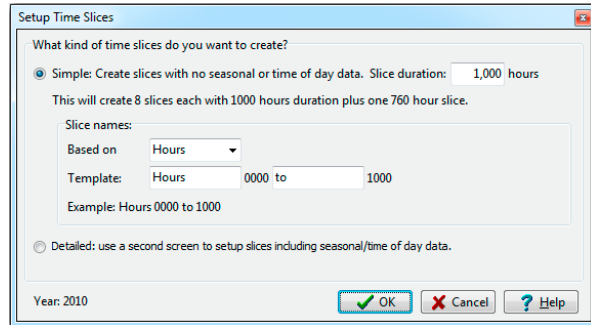
In this exercise you are going to simulate base year operations in a special way, since for that year you have data describing known (historical) operation of power plants. In later years, for which there are no operational data, you will simulate the dispatch of different power plants by specifying a dispatch rule and various parameters that will allow LEAP to simulate the dispatch of power plants by merit order.

To enable this type of simulation first make sure that the **First Simulation Year** variable is set to its default expression of *FirstScenarioYear* in Current Accounts. If not, just delete any existing expression to reset to this default. Next, set the **Process Dispatch Rule** to *MeritOrder* for all processes. These rules will be obeyed from 2011 onwards. You can select the dispatch rule from the list of available options from the  button at the end of the expression box.

The electricity system operates with a minimum **Planning Reserve Margin** of 35%. Enter this at the Electricity Generation branch.

You also need to specify a system load shape that describes how the electric load varies from hour to hour within each year. Follow this three-step process for entering a system load shape:

1. First create the set of time slices into which the year will be divided. These are entered on the General: Time Slices screen. Use the setup button to create nine slices as in the screen shown right.



Setup Time Slices

What kind of time slices do you want to create?

☒ Simple: Create slices with no seasonal or time of day data. Slice duration: 1,000 hours

This will create 8 slices each with 1000 hours duration plus one 760 hour slice.

Slice names:

Based on: Hours

Template: Hours 0000 to 1000

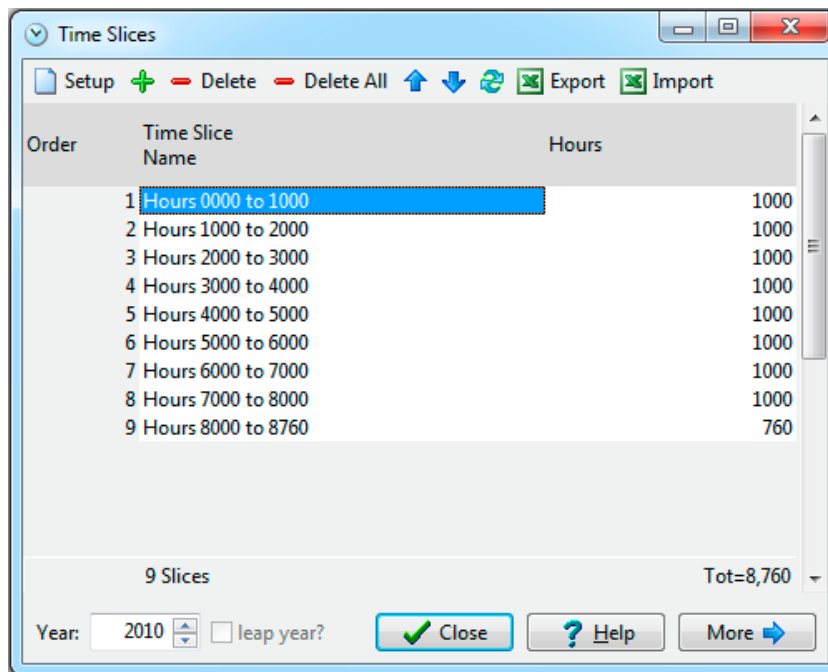
Example: Hours 0000 to 1000

☐ Detailed: use a second screen to setup slices including seasonal/time of day data.

Year: 2010

OK Cancel Help

The time slices created should then look like this:



Time Slices

Setup + Delete - Delete All ↑ ↓ ↺ Export Import

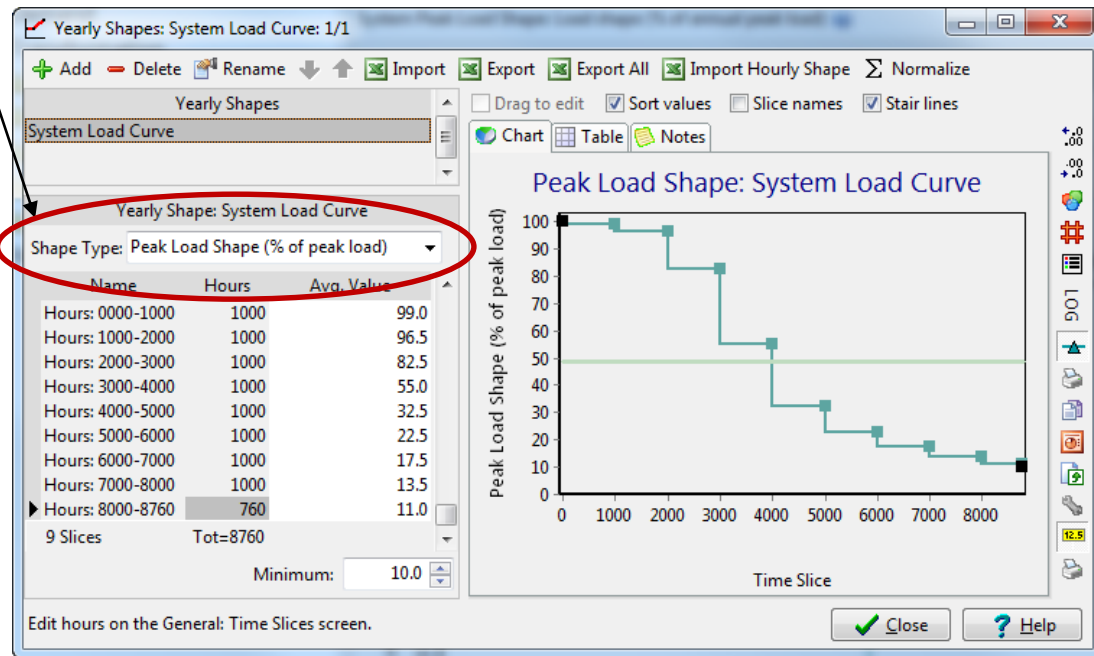
Order	Time Slice Name	Hours
1	Hours 0000 to 1000	1000
2	Hours 1000 to 2000	1000
3	Hours 2000 to 3000	1000
4	Hours 3000 to 4000	1000
5	Hours 4000 to 5000	1000
6	Hours 5000 to 6000	1000
7	Hours 6000 to 7000	1000
8	Hours 7000 to 8000	1000
9	Hours 8000 to 8760	760

9 Slices Tot=8,760

Year: 2010 ☐ leap year? Close Help More

2. Next, you need to create a yearly load shape with values for each of the hourly slices you just specified. To do this, go to the General: Yearly Shapes screen (shown below) and enter a “Peak Load Shape” for the entire system. Enter the values as shown in the screen below.

Important:  
Select **Peak**  
Load Shape!



***Hint:** The value in hour 0 implicitly is always 100%. This does need to be entered explicitly. Make sure you enter the minimum value of 10% in the Minimum: box at the bottom of the screen, which corresponds to the hour 8760.*

- Finally, return back to the Analysis View screen and select Current Accounts. Now create a link to this new load shape in the **System Peak Load Shape** variable at the Electricity Generation branch.

The easiest way to do this is click on the  button attached to the expression field and select *YearlyShape: System Load Curve* option.

***Hint:** If you don't see a variable named **System Peak Load Shape**, you may need to go to the Loads tab in Basic Params and make sure that you choose the option Load Shape for Entire System (Entered as % of Peak Generation).*

#### 1.4.2.1 The Reference Scenario

You can now specify how the electric generation system is likely to change in the future in the Reference scenario.

- In the Reference scenario, existing coal power plants are expected to be retired. Five hundred megawatts of existing coal-fired steam plants will be retired in 2020 and the remaining five hundred megawatts are retired in 2030.

***Hint:** The resulting expression for coal capacity should appear as:*




**Step(2020, 500, 2030, 0)**



When entering explicit capacity values to reflect existing capacity and/or planned capacity and retirements, use the **Exogenous Capacity** tab.

- In the future, to meet growing demands and replace retired plants, new power plants are expected to consist of base load coal-fired steam plants (built in units of 500 MW, with a thermal efficiency of 35%) and new peak load fuel oil-fired combustion turbines (built in units of 300 MW with a thermal efficiency of 30%). Both types of plants have a life expectancy of 30 years and a maximum availability of 80%.

Enter this data in LEAP by adding two new processes “New Coal Steam” and “New Oil Combustion Turbine”, under Current Accounts. Use the above data to specify the **Efficiency**, **Maximum Availability** and **Lifetime** of the plants. Note however that these two plants don’t actually exist in the base year (they are candidates for addition in the future). Therefore, leave **Exogenous Capacity** and **Historical Production** for these two plants set to zero in Current Accounts. Before leaving Current Accounts, you should also set the **Dispatch Rule** for these two processes to *MeritOrder* (the same rule used for all processes) and set the **Merit Order** variable for these processes to “1” for New Coal Steam and “2” for New Oil Combustion Turbine.

Next, return to the Reference scenario. Here you are going to use the **Endogenous Capacity** variable to specify the new capacity for these two plants will be added automatically by LEAP in order to prevent the reserve margin falling below the planning reserve. In the **Endogenous Capacity** screen, Use the  button on the right to add each of these two new processes into the screen. Next, enter the *Addition Size Expression* for each of the two new processes (500 MW and 300 MW). It is important to ensure that New Coal Steam appears first in the list. If necessary, you can adjust its position using the  and  arrows. Your screen should then look like the following:

Addition Order	Build Order	Process	Addition Size Expression
▶	1	0 New Coal Steam	500
	2	0 New Oil Combustion Turbine	300

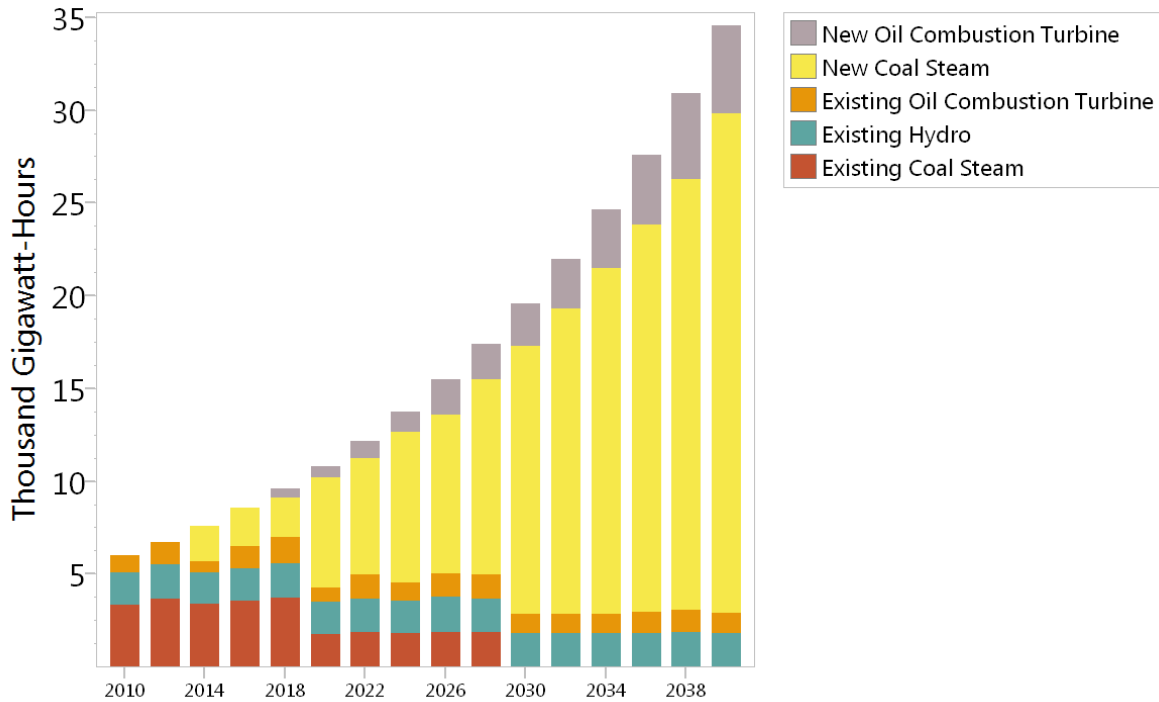
For more information on exogenous and endogenous capacity, please refer to the help file, found in LEAP under Help: Contents.

### 1.4.3 Viewing Results



Click on the **Results View** to see the results of the Reference scenario. Select the Transformation\Electricity Generation branch and view the results for categories such as capacities, energy outputs, and module reserve margins. Compare your results to the tables and charts provided below.

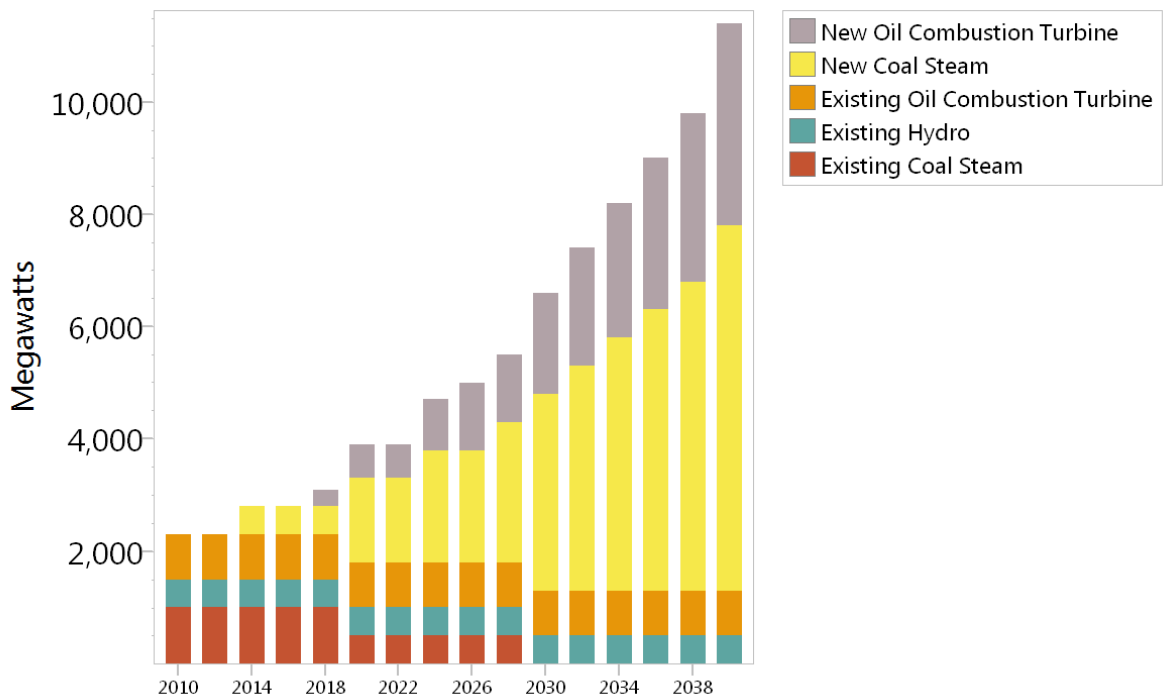
**Electricity Generation in Freedonia: Reference Scenario (Thousand GWh)**



Notes: base year = 5,970 GWh, 2040 = 34,583 GWh

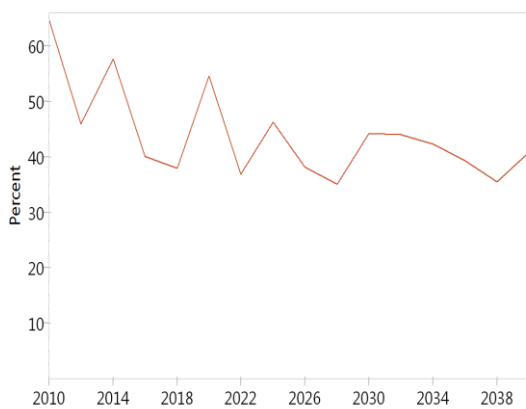
**Hint:** To get this chart, click on the Processes under the Electricity Generation module in the Tree, select **Transformation: Outputs by Output Fuel**. Next, choose Every Two Years on the X-axis, and on the chart legend select All Branches. Use the chart toolbar on the right to select a stacked bar chart. Finally, make sure units are set to Gigawatt-hours on the Y-axis. To save all these settings for future reference, click on the Favorites menu and choose Save Chart as Favorite. Note that the order of processes is based on their order in the tree you set up in **Analysis View**.

## Electricity Generation Capacity: Reference Scenario (MW)

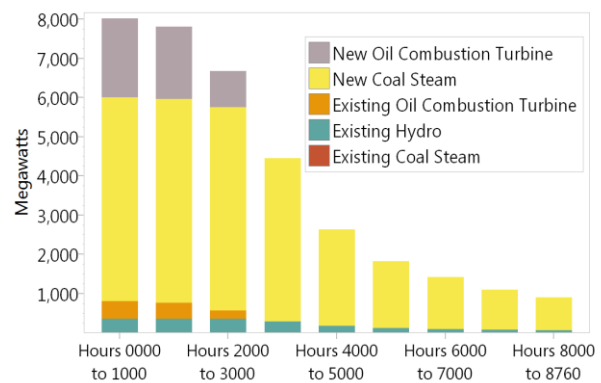


Notes: base year = 2300 MW, 2040 = 11,400 MW

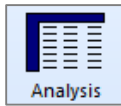
## Reserve Margin (%)





## Power Dispatched in 2040 (MW)



## 1.5 Emissions

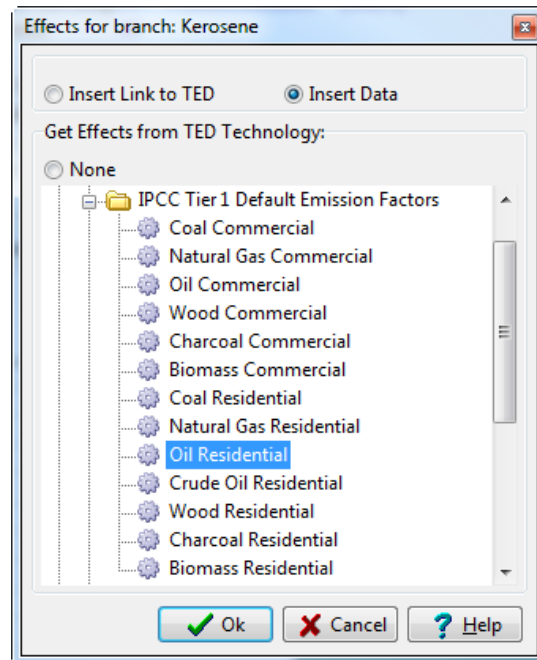


You will now use LEAP to estimate the emissions of major pollutants in the Reference scenario. To do this, first you must return to **Analysis View** and go to **Basic Params** to switch on Energy Sector Effect Loadings. Now select Current Accounts and then create *links* between each relevant technology branch (those marked with the ) and matching or similar technologies contained in the Technology and Environmental Database (TED). You create links to the data in TED by first selecting the **Environmental Loading** tab, and then clicking the TED button () . This will display the box shown on the right.

For this exercise you will make use of the default Tier 1 emission factors suggested by the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report. To create the links, first click on an appropriate technology branch under the category “IPCC Tier 1 Default Emission Factors” for each sector, then click OK.

Make sure the input fuels to the TED technology are similar to fuels used by the LEAP technology. In some cases, the IPCC Tier 1 technologies do not contain entries for all fuels. In this case you will need to pick the closest matching entry (e.g. the IPCC “Oil Residential” category can be linked to the LEAP “Kerosene Lighting” category).

You do NOT need to add environmental loading data for any demand-side devices that consume electricity, such as lights or refrigerators, since their environmental impacts occur upstream (e.g. in the power plants that produce the electricity).

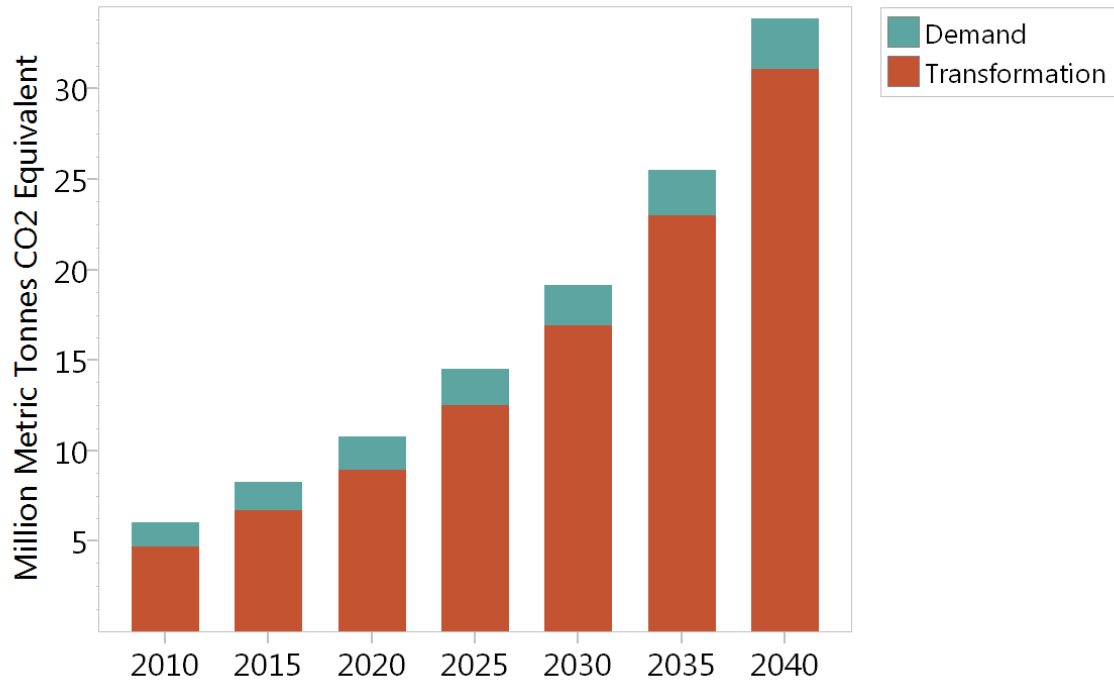


### 1.5.1 Viewing Results



Click on the **Results View** to see environmental results for the Reference scenario. Click on the top-level branch “Freedonia” and select the result **Environment: 100-Year GWP: Direct (At Point of Emissions)**. Compare your results to those shown below. Also check the results for other non-greenhouse gases, such as sulfur and nitrogen oxides.

#### One Hundred Year Global Warming Potential of Emissions from Freedonia Reference Scenario (all greenhouse gases)

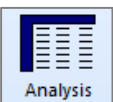
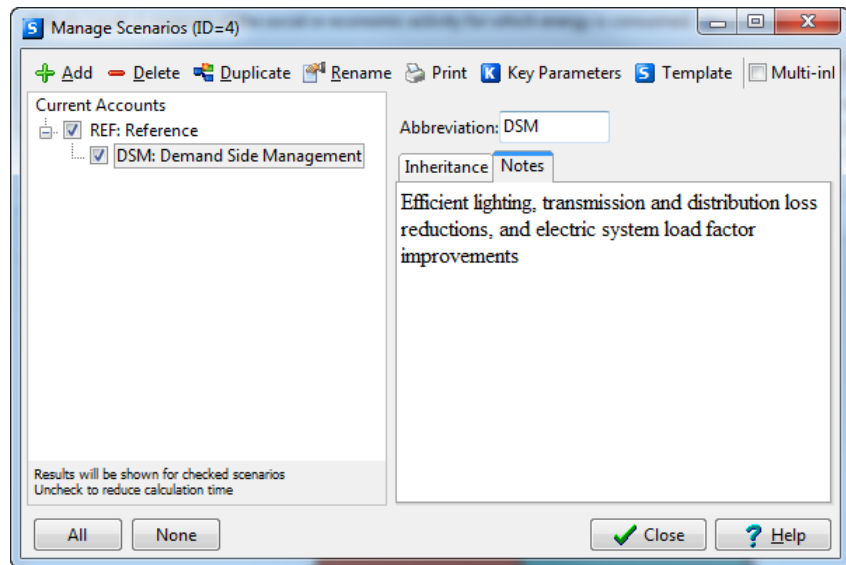


Note: Base Year = 6.0, 2040 = 33.9 Million Tonnes CO<sub>2</sub>-equivalent.

## 1.6 A Second Scenario: Demand-Side-Management

You will now create a second scenario to explore the potential for electricity conservation in Freedonia. Enter the **Scenarios** (S) screen to add a new scenario. Add the scenario under the Reference scenario so that by default it inherits all of the Reference scenario assumptions and modeling expressions.

Give the new scenario the name “Demand Side Management”, the abbreviation “DSM”, and add the following notes: “Efficient lighting, transmission and distribution loss reductions, and electric system load factor improvements.”



Exit the scenario manager and select the Demand Side Management scenario on the main screen, and then edit the data for the scenario to reflect the following notes:

**Hint:** Remember you must be in **Analysis View** to change scenarios. Use the View Bar to select it if you are not.

The DSM scenario consists of four policy measures:

1. **Refrigeration:** Proposed new efficiency standards for refrigerators are expected to cut the average energy intensities of refrigeration in urban households by 5% in 2020 compared to Current Accounts values, and by 20% in 2040. In rural households intensities are expected to remain unchanged.


**Hint:** You can enter this information in several ways.

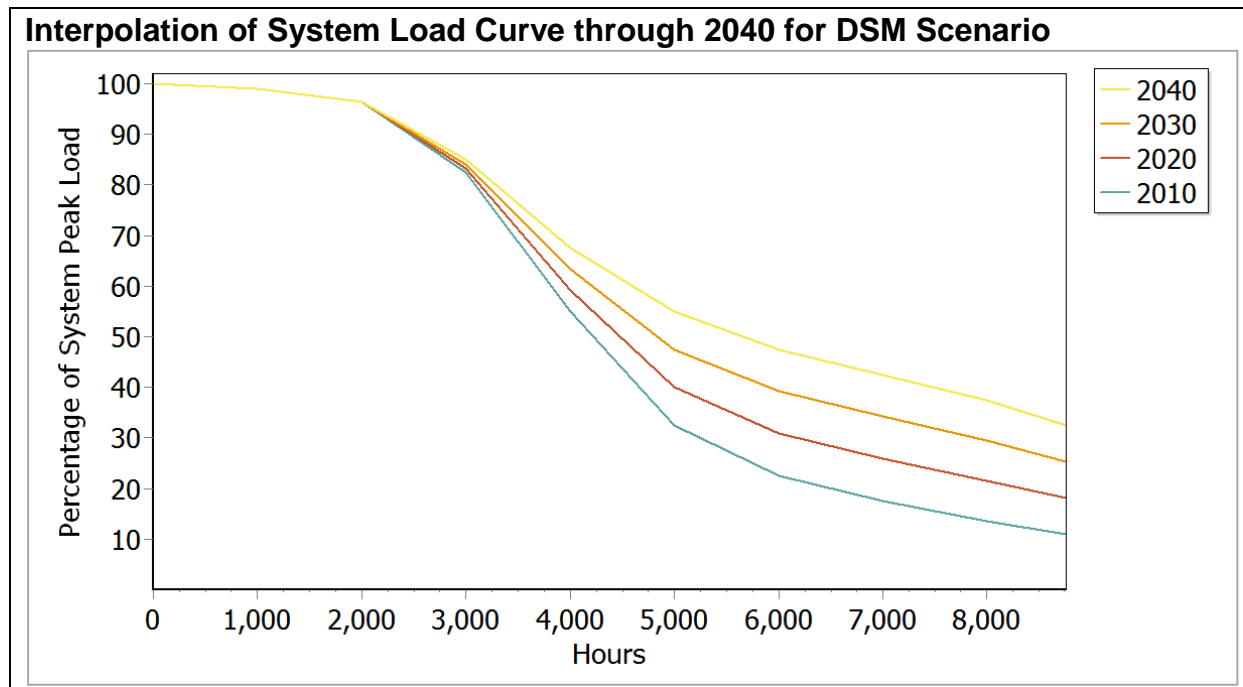
- Use the Time Series Wizard, select interpolation, and enter the values for refrigerator energy intensity in future years (calculate the values on your own), or
  - enter an expression which calculates the value for you, such as **Interp(2020, BaseYearValue \* 0.95, 2040, BaseYearValue \* 0.8)**
2. **Lighting:** A range of measures including new lighting standards and utility demand-side-management programs are expected to reduce the energy intensity of electric lighting in urban households by 1% per year (-1%/year), and to reduce the expected growth in electric lighting intensity in rural areas from 1% (Reference scenario) to 0.3% per year (+0.3%/year).

3. **Transmission and Distribution:** Under the planned DSM program, electric transmission and distribution losses are expected to be reduced to 12% by 2025 and to 9% by 2040%.

4. **Electric System Load Factor Improvements:** Various load-leveling measures in the DSM plan are expected to lead to gradual improvements in the system load factor, which increases to about 64% in 2040. Do not enter this load factor explicitly in LEAP; instead, to represent this new load factor create a second yearly shape with the data shown on the right.

Yearly Shape: DSM Load Shape		
Shape Type: Peak Load Shape (% of peak load)		
Name	Hours	Avg. Value
Hours 0000 to 1000	1000	99.0
Hours 1000 to 2000	1000	96.5
Hours 2000 to 3000	1000	85.0
Hours 3000 to 4000	1000	67.5
Hours 4000 to 5000	1000	55.0
Hours 5000 to 6000	1000	47.5
Hours 6000 to 7000	1000	42.5
Hours 7000 to 8000	1000	37.5
Hours 8000 to 8760	760	32.5
9 Slices		Tot=8760
Minimum:		30.0

***Hint:** Create a new yearly shape called “DSM Load Shape” (see section 1.4.2 to remind you how to do this). In the DSM scenario go to the **System Peak Load Shape** variable at the Electricity Generation module, click on the  button to the right of the expression field and choose YearlyShape for the curve you just created. The chart below will show how LEAP interpolates between the load curve in 2010 (System Load Curve) and the load curve in 2040 (DSM Load Curve).*

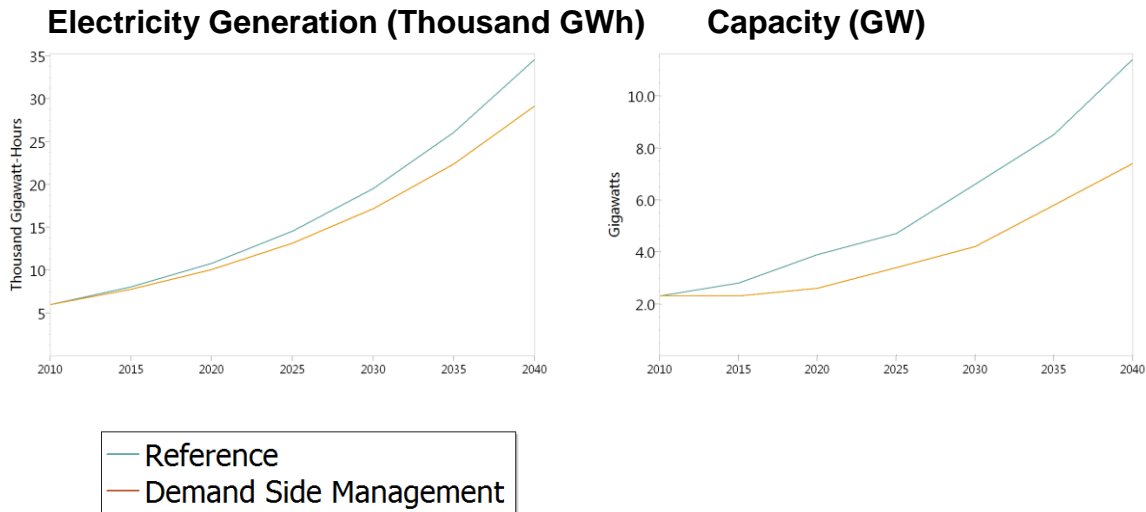


### 1.6.1 DSM Scenario Results



Click on the **Results View** to see the results of the DSM scenario. Compare your results with those shown below:

#### Electricity Generation: Reference Scenario Compared to DSM Scenario



Generation in DSM scenario in 2040 = 29,159 GWh. Capacity = 7,400 MW.

**Hint:** To recreate the electricity generation graph in the results view, go to **Transformation: Outputs by Output Fuel**, and set units and scenarios to match the above graph. Make sure that the highlighted branch on the tree matches the results that you want to see (in this case you should have *Transformation\Electricity Generation\Processes* selected). Show results on the X-axis Every Five Years. Check the table view to see exact values in a given year.



## Exercise 2: Demand

Exercise 2 further develops the demand analysis begun in Exercise 1 covering three other sectors: industry, transport, and commercial buildings. Use the information in section 2 to complete the tree structure, Current Accounts data and Reference scenario analysis for these sectors.

### 2.1 Industry

#### 2.1.1 Current Accounts



There are two principal energy-intensive industries in Freedonia: Iron and Steel, and Pulp and Paper.

All other industries can be grouped into a single category. The adjoining table shows the output of each subsector. Industrial energy analysis is typically done in either economic (e.g., value added) or physical (e.g. tonnes) terms. The choice generally depends on data availability and the diversity of products within a subsector. In this exercise, both methods are used.

#### **Industrial Output (2010)**

Iron and Steel	600,000 tonnes
Pulp and paper	400,000 tonnes
Other Industry	1.8 billion USD

***Hint:** When adding the branch for “Industry”, set the activity level unit to “No Data” (since for this sector you are specifying different activity level units for each subsector).*

Energy use in the Iron and Steel and Pulp and Paper industries can be divided into two end-uses: process heat and motive power.

#### **Iron and Steel**


- Currently, process heat requirements average 24.0 GJ per tonne, and boilers using bituminous coal produce all of this.
- Each tonne of steel requires an average of 2.5 GJ of electricity use.

#### **Pulp and Paper**

- Wood-fired boilers meet all process heat requirements of 40.0 GJ per tonne of pulp and paper products.
- Each tonne of pulp & paper requires 3 MWh of electricity use.

#### **Other Industry**

- Freedonia’s other industries consumed a total of 36 Million GJ of energy in 2010.
- 40% of this energy was electricity and the remainder was residual fuel oil.

***Hint:** When adding the branch for “Other Industry”, set the branch type to the  green category icon. This indicates that you want to enter an aggregate energy intensity at this branch. You can then add two more branches for electricity and fuel oil below this branch. These lower branches will only contain fuel shares, not energy intensities. Note that*

you will also need to calculate the energy intensity in GJ/US Dollars using the total value added for the “Other” subsectors (see above).

## 2.1.2 Reference Scenario

### Iron and Steel

- Total output is not expected to change: all plants are operating at maximum capacity and no new plants are planned within the analysis period.
- Natural gas is expected to provide for 10% of process heat requirements by 2040.
- Natural gas boilers are 10% more efficient than coal boilers.

**Hint:** You will need to switch back to Current Accounts to add a new branch for Natural Gas. You can use the following simple expression to calculate natural gas energy intensity as a function of coal energy intensity:

$$\text{Coal} * 0.9$$

**Hint:** Remember to use the Interp and Remainder functions to help you calculate boiler shares.

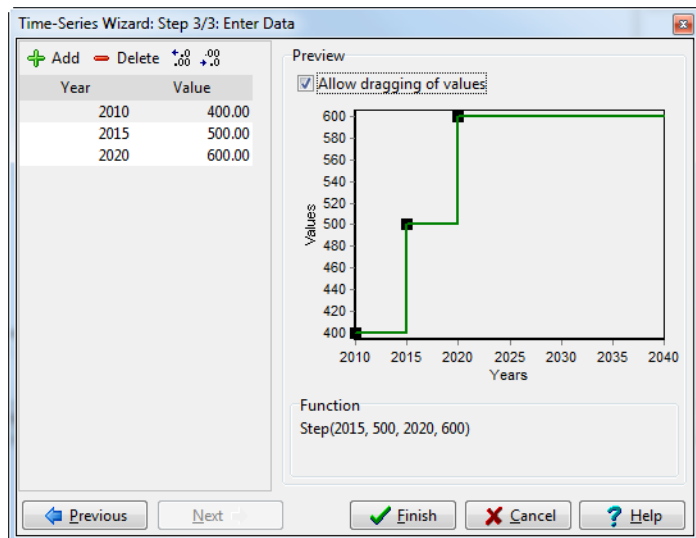
### Pulp and Paper

- Two new paper plants are expected: one in 2015 and one in 2020. Each will add 100 thousand tonnes per year to the total output of this industry.

**Hint:** Use the Step function in the Time Series Wizard to specify discrete changes in activity levels or other variables (see right).

### Other Industry

- Output of other industries is expected to grow at a rate of 3.5% per year.
- The fuel share of electricity is expected to rise to 55% by the year 2040.



## 2.1.3 Viewing Results



Now review your results and compare to the answer sheet shown below.

### Industrial Energy Demand in Freedonia: Reference (Million GJ)

Fuels	2010	2040	Subsectors	2010	2040
Coal (bituminous)	14.4	13.0	Iron and Steel	15.9	15.8
Electricity	20.2	63.6	Other	36.0	101.0
Natural Gas	-	1.3	Pulp and Paper	20.3	30.5
Residual Fuel Oil	21.6	45.5			
Wood	16.0	24.0			
<b>Total Industry</b>	<b>72.2</b>	<b>147.3</b>	<b>Total Industry</b>	<b>72.2</b>	<b>147.3</b>

## 2.2 Transport

### 2.2.1 Current Accounts



#### Passenger Transport

- All passenger transportation in Freedonia is either by road (cars and buses) or rail. You may ignore air and water transport for this exercise.
- In the year 2010, cars were estimated to have traveled about 8 billion km; buses traveled about 1 billion km.
- Surveys also estimate that cars have a (distance-weighted) average number of occupants (load factor) of 2.5 people, while the similar average for buses is 40 passengers.
- Surveys have found that the current stock of cars has a fuel economy of about 12 km/liter of gasoline (roughly 28 MPG). Buses, in contrast, travel about 3 km/liter of diesel.
- The national railroad reports 15 billion passenger-km traveled in 2010.

#### Calculating Passenger-Km

A	Car Use (billion veh-km)	
B	Load Factor (pass-km/veh-km)	2.5
$C=A*B$ = Total Car Pass-km		
D	Bus Use (billion veh-km)	
E	Load Factor (pass-km/veh-km)	40.0
$F=D*E$ Total Bus Pass-km		
$G=F+C$ Road Passenger-km		
H	Rail Passenger-km	
$I=G+H$ Total Passenger-km		

#### Calculating Energy Intensities

J	Car Fuel Economy (veh-km/l)	12.0
K	Load Factor (pass-km/veh-km)	2.5
$L=1/(J*K)$ Energy Intensity (liters/pass-km)		
M	Bus Fuel Economy (veh-km/l)	3.0
N	Bus Load Factor (pass-km/veh-km)	40.0
$O=1/(M*N)$ Energy Intensity (liters/pass-km)		

### Hints:

- Assume that all current cars use gasoline fuel and all current buses use diesel fuel.
  - You may wish to enter total population as the activity level at the sector level (see section 1.3 for population data).
  - Use the information above to calculate the total number of passenger-kms, the percentage for each mode, and the average energy intensity (per passenger-km). Fill out the form above to help you.
- 20% of rail transit is by electric trains, the remainder by diesel trains. The energy intensity of electric trains is 0.1 KWh per passenger-km. The energy intensity of diesel trains is 25% higher than that of electric trains.

### Freight Transport

- An average of 250 tonne-km of freight is transported per capita.
- 85% of freight transport is by road, the rest by rail.
- Road transport uses an average of 4 MJ of diesel fuel per tonne-km.
- Diesel freight trains have an energy intensity of 3 MJ/tonne-km.

#### Units Cancellation in LEAP

When specifying freight transport activities, notice how LEAP automatically cancels out the numerator and denominator units of your data as you step down through the branches of the tree.

In this example, start by specifying population at the sector level, at the next level you then specify tonne-km/person. In other words, LEAP cancels the units

$$\frac{\text{[People]}}{\text{[person]}} \times \frac{\text{[tonne-km]}}{\text{[person]}}$$

### 2.2.2 Reference Scenario

#### Passenger Transport

- The unit demand for passenger travel (passenger-km/person) is expected to rise slightly faster than average income levels (the elasticity of demand for travel with respect to income is 1.1).
- At the same time the total population is growing at 2.5% per year.
- Average income per capita is expected to grow from its current level, \$3000, at a rate of 3.5% per year through 2040.
- Cars are expected to account for 75% of passenger road traffic by 2040.

**Hint:** create new branches called “Income” and “Population” under “Key Assumptions” on the Tree, then calculate future transport demands as a function of these variables. Use the following expression to model the growth in per capita transport demand, under the Reference scenario:

**GrowthAs(Key\Income, 1.1)**

## Freight Transport

- The per capita demand for freight transport is expected to grow at a rate of 2% per year over the analysis period.
- The energy efficiency of all transport modes (both passenger and freight) is expected improve by 0.5% per year through 2040, except for cars, which are expected to improve by 1% per year.

### 2.2.3 Viewing Results



Now switch to **Results View** and compare your results with the tables shown below.

#### Transport Energy Demand in Freedonia: Reference (Million GJ)

Branches	2010	2040	Fuels	2010	2040
<b>Freight</b>	38.5	125.9	Diesel	56.5	182.6
<b>Rail</b>	4.5	14.7	Electricity	1.1	6.1
<b>Road</b>	34.0	111.1	Gasoline	22.1	240.1
<b>Passenger</b>	41.1	303.0			
<b>Rail</b>	6.5	36.4			
<b>Diesel</b>	5.4	30.3			
<b>Electric</b>	1.1	6.1			
<b>Road</b>	34.7	266.6			
<b>Diesel Buses</b>	12.6	26.5			
<b>Gasoline Cars</b>	22.1	240.1			
<b>Total Transport</b>	<b>79.6</b>	<b>428.8</b>	<b>Total Transport</b>	<b>79.6</b>	<b>428.8</b>


## 2.3 Commerce: Useful Energy Analysis

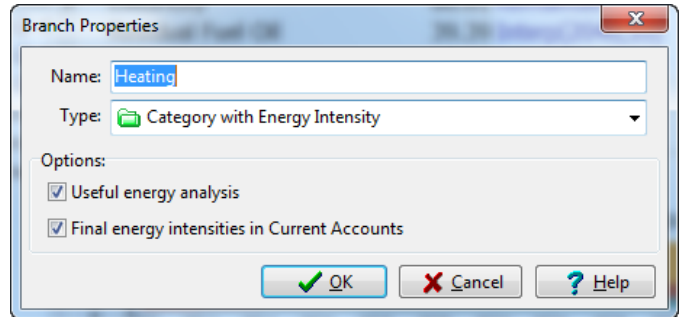


This exercise considers space-heating uses in commercial buildings, and serves to introduce the application of useful energy analysis techniques. Useful energy analysis is particularly helpful where multiple combinations of fuels and technologies can provide a common service at (such as heating), and in situations where you want to independently model device efficiencies, and overall energy service requirements.

### 2.3.1 Current Accounts

- Commercial buildings in Freedonia utilized a total of 100 million square meters of floor space in 2010.
- Total final energy consumption for heating purposes was 20 million GJ in 2010.
- Residual fuel oil and electricity each currently supply half of the total heating energy. Natural gas is expected to be introduced in the near future
- Electric heaters have an efficiency of nearly 100%, while fuel oil boiler efficiencies average 65%, and natural gas boilers have 80% efficiency.

**Hint:** For this exercise, you need to setup a  Category with Energy Intensity branch for heating. Check the boxes to indicate that you wish to conduct a useful energy analysis and that you wish to enter final energy intensities in Current Accounts. Use the branch properties screen to set this up as shown right.



The image shows a 'Branch Properties' dialog box. The 'Name' field is set to 'Heating'. The 'Type' dropdown is set to 'Category with Energy Intensity'. Under the 'Options' section, both 'Useful energy analysis' and 'Final energy intensities in Current Accounts' are checked. At the bottom, there are 'OK', 'Cancel', and 'Help' buttons.

### 2.3.2 Reference Scenario

- Floor space in the commercial sector is expected to grow at a rate of 3% per year.
- Due to expected improvements in commercial building insulation standards, the *useful* energy intensity (i.e. the amount of heat delivered per square meter<sup>1</sup>) is expected to decline by 1% per year, until 2040.
- By 2040, natural gas boilers are expected to have reached a market penetration (i.e. share of floor space) of 25%, while fuel oil boilers are expected to decline to only a 10% market share. Electricity heating fills the remaining requirements. Notice that in future scenarios, the **Activity Level** shares are different from the **Fuel Share** percentages that you entered for Current Accounts to account for the different devices efficiencies.
- Finally, gradually improving energy efficiency standards for commercial boilers are expected to lead to improvements in the average efficiency of fuel oil and natural gas boilers. Fuel oil systems are expected to reach an efficiency of 75% by 2040, and natural gas systems are expected to reach an efficiency of 85% by 2040.

### 2.3.3 Viewing Results



After entering the above data, switch to **Results View** and compare your results with the table shown below.

#### Commercial Space Heating Energy Demand: Reference (Million GJ)

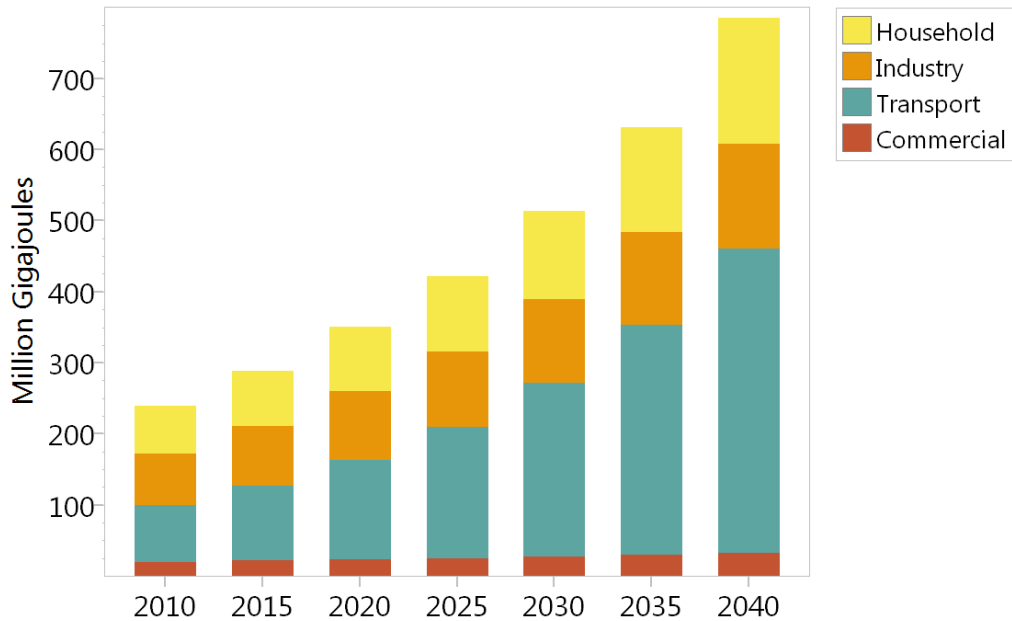
Fuel	2010	2040
Electricity	10.0	19.3
Natural Gas	-	8.7
Residual Fuel Oil	10.0	3.9
<b>Total Commercial</b>	<b>20.0</b>	<b>31.9</b>

<sup>1</sup> As opposed to the *final* energy intensity: the amount of fuel used per square meter.

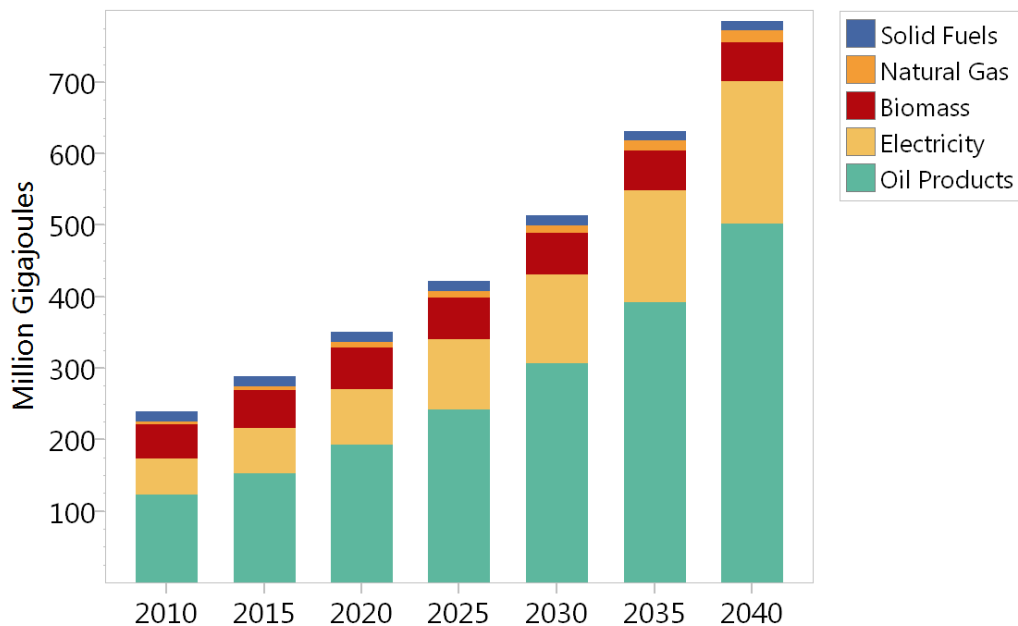
## 2.4 Total Final Demands

Before proceeding to the Transformation exercises, check your overall energy demand results by comparing with these charts.

**Energy Demand by Sector: Reference Scenario (Million GJ)**

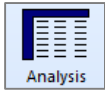


**Energy Demand by Fuel Group: Reference Scenario (Million GJ)**



***Hint:** To see the energy demand by fuel group graph above, choose **Demand: Energy Demand Final Units** and choose fuels on the right legend drop down menu and then select the **Group Fuels** check box.*

## Exercise 3: Transformation



In this third exercise you will further develop the simplified Transformation data set you constructed in Exercise 1. In this exercise you will add new modules to examine charcoal production, oil refining and coal mining.

### 3.1 Charcoal Production

No charcoal is imported or exported. It is all produced by conversion from firewood. All charcoal in Freedonia is currently made using traditional earth mounds. These have a conversion efficiency (on an energy basis) of around 20%. In the future, more efficient “brick beehive” kilns are expected to be available. These have a conversion efficiency of 47%. They are expected to be used to meet 5% of total charcoal demand by 2020, 20% of charcoal demand by 2040.

*Hint: Create a standard (i.e. not a simple) module and select the option to enter efficiency data as efficiencies (to match the data above).*

### 3.2 Electricity Generation

With the addition of the extra demand sectors in Exercise 2, the demand for electricity generation triples to around 16,200 GWh. Thus, you now need to specify a larger and more realistic electric generation system to match the additional demand for electricity. Change the data you entered in Exercise 1 in Current Accounts for the Electricity Generation module to match those below:

Plant Type	Year 2010 Capacity (MW)	Base Year Output (% of GWh)
Existing Hydro	1,000	34%
Existing Coal Steam	2,500	44%
Existing Oil Combustion Turbine	2,000	22%
<b>Total</b>	<b>5,500</b>	<b>100% (16,200 GWh)</b>

In addition, in the Reference scenario, assume the capacity of “Existing Coal Steam” plants decreases, with 1500 MW retired in 2020 and the remaining capacity all retired in 2030. You can enter this in the **Exogenous Capacity** variable under the Reference scenario using the *Step* expression as follows:

**Step(2020, 1000, 2030, 0)**



### 3.3 Oil Refining

In 2010, Freedonia's oil refineries had the capacity to handle 6 million tonnes of crude oil feedstocks<sup>2</sup>. The efficiency of the refineries (on an energy basis) was about 95%. There are currently no plans to increase refining capacity.

The refineries used only one feedstock fuel: crude oil, and produced seven types of products: gasoline, avgas, kerosene, diesel, residual/fuel oil, LPG, and lubricants. The refineries can be operated with sufficient flexibility that the mix of refinery products matches the mix of requirements for those products. Any oil product requirements that cannot be produced from the refinery are imported into Freedonia.

To set up oil refining in LEAP, first create a new module named "Oil Refining" and set the properties to be a standard module that includes capacity data. Leave all other checkboxes unchecked. Once the module has been created, add one process to represent all refining in Freedonia. In Current Accounts, set the **Dispatch Rule** for this process to *PercentShare*. Also set the **First Simulation Year** variable to *BaseYear* and make sure the **Process Share** is equal to 100.

### 3.4 Coal Mining

All coal mined in Freedonia is bituminous. In the base year, the country's coal mines produced 3.41 million tonnes of coal, mining capacity stood at 6 million tonnes, and the efficiency of coal mining (including coal washing plants) was 80%.

The Reference scenario assumes that coal mining capacity will increase, reaching 14 million tonnes by 2020, and 23 million tonnes by 2040. It is assumed that mine capacity will expand linearly in years between these data years. In spite of this expansion program, it is expected that sometime after 2030 imports of coal will be needed to meet domestic requirements, not because of resource limits, but because the capacity of the mines is unable to expand as fast as demand for coal grows.

***Hint:** Known capacity should be entered in the **Exogenous Capacity** variable. Imports of coal should not be entered as capacity, but instead are governed by the **Output Properties** variable at the "Coal Mining\Output Fuels" branch. Make sure that the Shortfall Rule is set to Import fuel to meet shortfall to meet the modeling demands described above.*

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<sup>2</sup> Note: you are limited to entering capacity data in energy units (i.e. tonnes of oil equivalent per year). For the purposes of this exercise, assume 1 tonne of crude oil = 1 TOE.

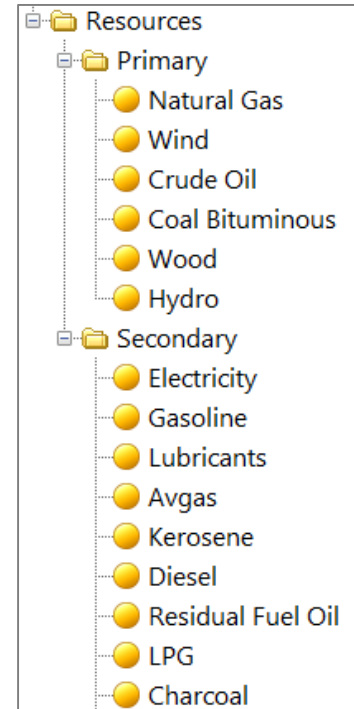
### 3.5 Resources

The final step in entering data is to specify which primary resources are produced domestically and which need to be imported. In LEAP you can specify the base year reserves of fossil fuels and the maximum annual available yield of renewable energy forms such as hydro and wind. Unless you indicate otherwise, LEAP will assume that any resources not available domestically are imported.

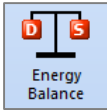
Data on resources are stored under the “Resources” branches. Notice that one branch is listed for each fuel used in the Fredonia data set. These branches are updated automatically as you edit the rest of the tree structure in LEAP. You cannot add or delete branches in the resources part of the tree.

In Fredonia, the only domestic energy resources are coal, hydropower, biomass (wood) and wind. All natural gas and oil resources have to be imported. No detailed data are available yet on the coal, hydropower, biomass and wind resource base, so for this analysis assume that these resources are essentially unlimited.

To reflect this in LEAP, go to the “Resources” branches and enter base year reserves (for coal) and yields (for wood, hydropower and wind) of *Unlimited* GJ for each. Enter zeros for the reserves of crude oil and natural gas. Notice that, by definition, you do not need to enter resource availability data for any of the secondary fuels.



### 3.6 Viewing Results



Switch to the **Energy Balance View** and check your base and end year energy balances against the following tables:

#### Energy Balance of Freedonia in 2010 (Million GJ)

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Biomass	Electricity	Oil Products	Total
Production	124.9	-	-	19.8	81.3	-	-	226.1
Imports	-	3.5	183.6	-	-	-	-	187.1
Exports	0.0	-	-	-	-	0.0	-	0.0
Total Primary Supply	124.9	3.5	183.6	19.8	81.3	0.0	-	413.2
Coal Mining	-25.0	-	-	-	-	-	-	-25.0
Oil Refining	-	-	-183.6	-	-	-	174.4	-9.2
Charcoal Production	-	-	-	-	-32.2	-	-	-32.2
Electricity Generation	-85.5	-	-	-19.8	-	58.3	-51.3	-98.4
Transmission and Distribution	-	-0.1	-	-	-	-8.7	-	-8.8
Total Transformation	-110.5	-0.1	-183.6	-19.8	-32.2	49.6	123.1	-173.6
Household	-	3.4	-	-	33.1	18.3	13.0	67.8
Industry	14.4	-	-	-	16.0	20.2	21.6	72.2
Transport	-	-	-	-	-	1.1	78.6	79.6
Commercial	-	-	-	-	-	10.0	10.0	20.0
Total Demand	14.4	3.4	-	-	49.1	49.6	123.1	239.6

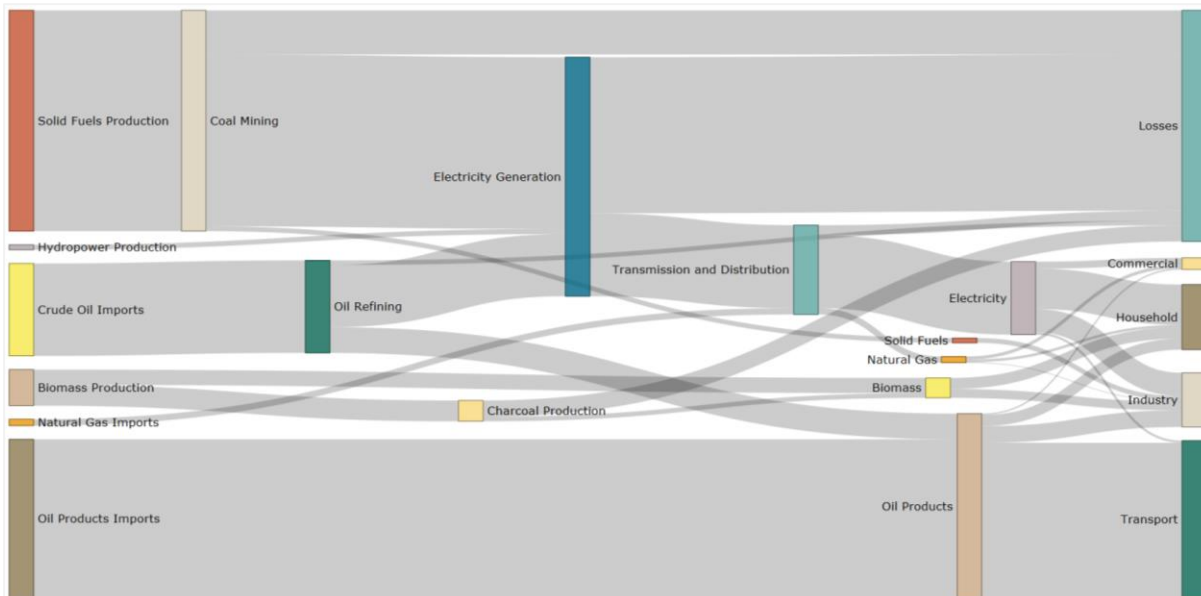
#### Reference Scenario Energy Balance of Freedonia in 2040 (Million GJ)

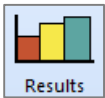
	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Biomass	Electricity	Oil Products	Total
Production	600.0	-	-	13.6	98.0	-	-	711.7
Imports	-	17.2	251.4	-	-	-	432.6	701.2
Exports	-	-	-	-	-	-	-	-
Total Primary Supply	600.0	17.2	251.4	13.6	98.0	-	432.6	1,412.9
Coal Mining	-120.0	-	-	-	-	-	-	-120.0
Oil Refining	-	-	-251.4	-	-	-	238.9	-12.6
Charcoal Production	-	-	-	-	-43.8	-	-	-43.8
Electricity Generation	-467.0	-	-	-13.6	-	225.5	-169.1	-424.3
Transmission and Distribution	-	-0.3	-	-	-	-27.1	-	-27.3
Total Transformation	-587.0	-0.3	-251.4	-13.6	-43.8	198.4	69.7	-628.0
Household	-	6.9	-	-	30.2	109.6	30.1	176.8
Industry	13.0	1.3	-	-	24.0	63.6	45.5	147.3
Transport	-	-	-	-	-	6.1	422.8	428.8
Commercial	-	8.7	-	-	-	19.3	3.9	31.9
Total Demand	13.0	17.0	-	-	54.2	198.4	502.3	784.8

**Hint:** If your energy balance does not seem correct, troubleshoot demand and Current Accounts (in this case 2010) before addressing any errors in your scenarios. Some other tips for troubleshooting energy balances include:

1. *If the value of energy requirements (independently of whether they are imported/exported/domestically produced) does not match the results, it is good to trace your results to see if you can localize which demand, transformation and resources branches are not functioning as you expect.*
2. *If the energy requirements seem correct, but imports, exports and/or domestic production seems incorrect, then it is possible that numbers have been input correctly, but branch properties are not set correctly. Here are some things to check:*
  - *Check the output properties of each transformation module. This can be found in **Analysis View**, in the "Output Fuels" folder in each transformation module (i.e. Transformation\Oil Refining\Output Fuels). Check the **Output Properties**, **Import Target** and **Export Target** variables to make sure those make sense.*
  - *Check the **Base Year Reserves** and **Yield** variables in the "Resources" branches to ensure that you have sufficient primary and secondary resources to produce resources and energy domestically.*
  - *Check the import and export target variables at the Primary and Secondary Resources branch. These variables add additional imports and exports for resources that have not been already specified as outputs of one or more Transformation modules.*

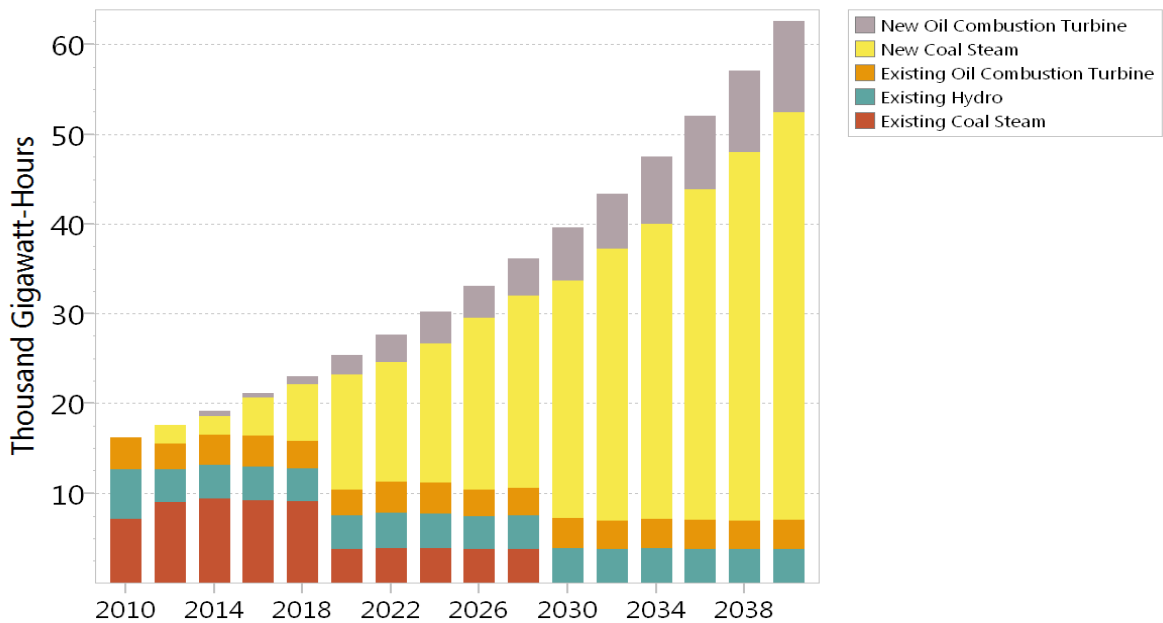
Within the **Energy Balance View**, switch from the Table display to show a Sankey Diagram. This diagram is a representation of the flows through different elements of your energy system.





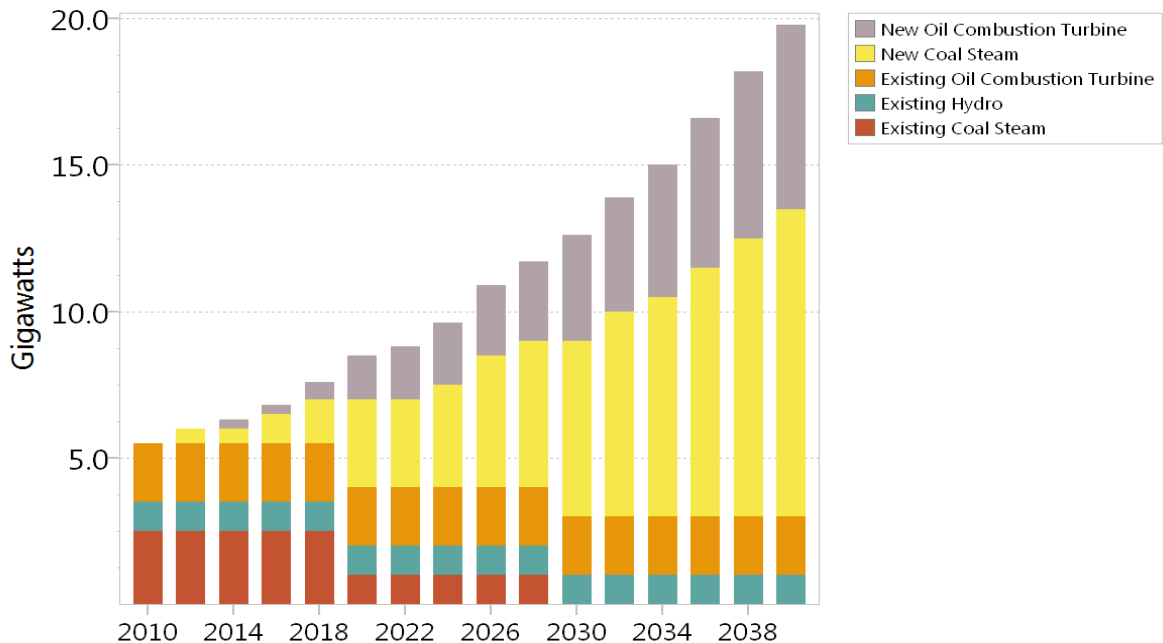
Now switch to **Results View** and compare your results with the charts shown below.

### Electricity Generation: Reference Scenario (Thousand GWh)



Notes: Base Year = 16,200 GWh, 2040 = 62,637 GWh

### Electricity Generation Capacity: Reference Scenario (GW)



Notes: Base Year = 5.5 GW, 2040 = 19.8 GW

## Exercise 4: Cost-Benefit Analysis

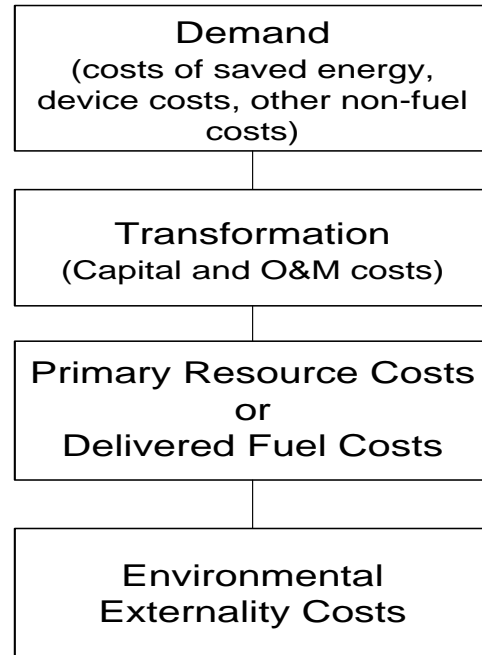
In this exercise you are going to enter data to describe the costs of various demand and supply-side technologies. You are then going to use LEAP to do an integrated cost-benefit analysis of various policy scenarios.

Make sure you start with a data set that has all of the data entry completed through Exercise 3.

### 4.1 Cost-Benefit Analysis in LEAP: A Brief Introduction

LEAP performs cost-benefit calculations from a societal perspective by comparing the costs of any two policy scenarios. LEAP can include all of the following cost elements:

- Demand costs, capital and operating and maintenance costs expressed as total costs, costs per activity, or costs of saving energy relative to some scenario,
- Transformation capital costs,
- Transformation fixed and variable operating and maintenance costs,
- Costs of indigenous resources,
- Costs of imported fuels,
- Benefits of exported fuels,
- Externality costs from emissions of pollutants,
- Other miscellaneous user-defined costs such as the costs of administering an efficiency program.

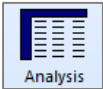



To set-up a costing analysis in LEAP it is first necessary to draw a consistent boundary around your system, so that LEAP will not double-count costs and benefits. For example, if you count the costs of fuels used to generate electricity you should not also count the cost of the electricity in an overall cost-benefit calculation.

If you have not already done so, switch on costing by going to the Scope & Scale tab of the **Basic Params** screen and enable the check box next to Costs. Now go to the Costing tab and select the boundary that will be drawn around the system for the purposes of costing. For this exercise you should select *Complete Energy System* as the boundary, meaning that fuel costs are accounted for only when they are imported or exported or when indigenously produced fuels are extracted as primary resources. Set the *Discount Rate* to 5%.

You will now start by constructing a series of policy scenarios that will be analyzed. Next you will enter the cost data relevant for these scenarios including Demand, Transformation and Resource costs. Finally, you will examine some costing results including an overall cost-benefit comparison of the various scenarios.

## 4.2 Creating Policy Scenarios

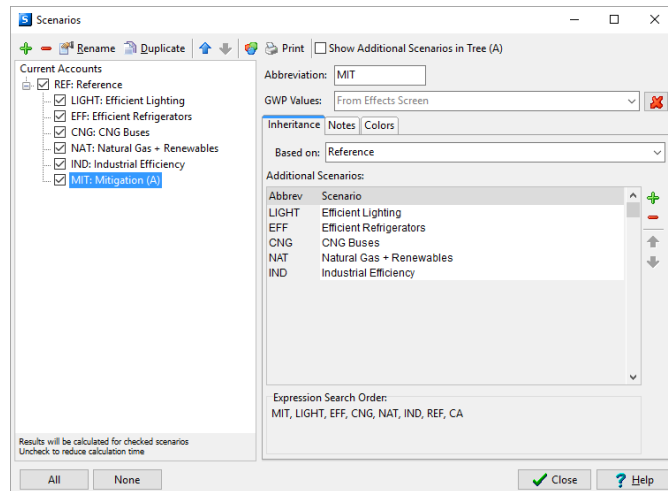


Go to the **Scenarios** screen (  ) and create the following five scenarios:

- Efficient Lighting
- Efficient Refrigerators
- CNG Buses
- Natural Gas + Renewables
- Industrial Efficiency

**Hint:** You can delete the *DSM* scenario that you created in Exercise 1.6

The **Scenarios** screen should look like the one shown right. Make sure each of the new policy scenarios is created beneath the Reference scenario. In this way the scenarios will inherit the expressions already entered for the Reference scenario.



Finally, create a “Mitigation” scenario under the Reference scenario that is a combination of the five policy scenarios listed above. Use the Inheritance tab to set that this scenario also inherits its expressions from these five policy scenarios.

## 4.3 Entering Costing Data

Next you will enter the data that that will be used to evaluate how these scenarios differ from the Reference scenario.

*In general, the unit costs of different technologies are the same for different scenarios, but the scenarios will differ in terms of how much of each technology is implemented or how much of each fuel is consumed.* Thus, you first need to enter cost data in the Current Accounts scenario. After that you will enter data describing the penetration of the technology in the different policy scenarios.

You will start by specifying cost data for demand-side options. In general, you need to enter three types of data describing:

- **Technology Penetration:** how many of the new (efficient) types of devices will be installed in each policy scenario?
- **Technology Performance:** how efficient are the new devices?
- **Technology Cost:** how much do the new devices cost? You may either specify the total costs of competing devices used in the Reference and policy scenarios or you can simply

enter the incremental cost of the new devices introduced in the policy scenarios relative to the costs of the device used in the Reference scenario.

#### 4.3.1 Efficient Lighting Scenario

*Hint: Before entering in data, create a new technology branch under the urban lighting category folder for your new efficient technology.*

- **Technology Penetration:** A program to install efficient lighting systems could reduce electricity consumed in urban households, using compact fluorescent (CFL) and other technologies. Assume that the program starts in 2012 and is capable of reaching 40% of all households by 2017 and 75% by 2040. Enter this data in the Efficient Lighting scenario for the **Activity Level** variable.
- **Technology Performance:** Efficient lighting can be assumed to consume only 30% of the electricity used by conventional lighting in urban households. Enter this data in the Current Accounts scenario for the **Final Energy Intensity** variable.
- **Technology Cost:** Standard light bulbs cost 1\$ each but have a lifetime of only one year. Efficient light bulbs cost \$6 each but are assumed to last for 3 years. Each household is assumed to have 5 working lights. Enter this data in the Current Accounts scenario for the **Demand Cost** variable. You will be entering data per household so make sure you first select the “Activity Cost” method. You will also need to use the *AnnualizedCost* function to specify the annualized cost of both the existing and the efficient technology per household per year. So for example the annualized cost per household for efficient light bulbs would be written as:

**AnnualizedCost(6\*5, 3)**

This uses a standard mortgage formula to annualize the cost per household (5 bulbs at \$6 per bulb) over the 3-year life of the bulb. Write a similar formula for standard/existing light bulbs.

*Hint: The Function Wizard (Ctrl+F) is helpful when entering arguments into functions such as AnnualizedCost.*

#### 4.3.2 Efficient Refrigerators Scenario

- **Technology Penetration:** Government is considering introducing a new efficiency standard for refrigerators. This would start in 2014. By 2025 all urban refrigerators in the country (not rural) can be assumed to meet the new standard.
- **Technology Performance:** The standard would require that manufacturers produce refrigerators with an average energy intensity of 380 kWh/year.
- **Technology Cost:** The cost of improving refrigerator efficiency to 380kWh is approximately \$100 US per fridge. Both current and efficient fridges have a lifetime of about 10 years. In this example you only have data describing the *incremental cost*



of the new efficient device. Thus, when entering data for the **Demand Cost** variable in the Current Accounts scenario, you will need to specify a cost of zero for the existing refrigerator and then annualize the \$100 incremental cost over the 10-year lifetime of the efficient refrigerator. It is perhaps worth noting that to do a cost-benefit analysis you do NOT need to specify all of the costs of a scenario. You need only specify how one scenario's costs differ from another's.

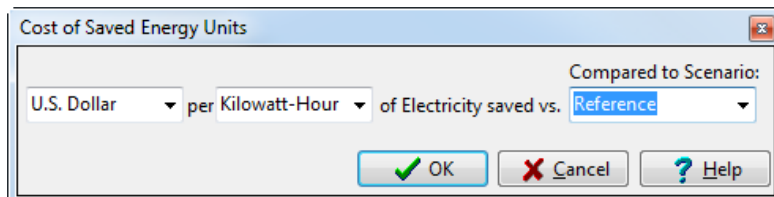
### 4.3.3 Industrial Energy Efficiency Scenario

In the “Other Industrial” sector of Freedonia energy is used in a wide variety of different processes. An energy audit of selected industries has estimated that energy consumption can be reduced through variety of measures at an average cost of about 5 cents per KWh saved (for both electricity and oil). These measures have the potential to save up to 30% of the energy consumed in the “Other Industry” sector by 2040.

Unlike in the previous two examples, for this type of analysis the cost information is not available in a form that allows you to count up the number of new devices that will be installed. Instead you will have to specify the costs by entering the cost per unit of saved energy.

In Current Accounts, select the **Demand Cost** variable for the Electricity and Fuel Oil branches under the “Other Industry” branch. Now select the “Cost of Saved Energy” method. When you select this method a dialog box will appear. In it choose units of *U.S. dollars per Kilowatt-Hour saved versus the Reference scenario*. The dialog should look like the one shown here.

Once you have set the units, click OK and then enter the data of \$0.05/KWh saved. Repeat this for each fuel.



Now select the Industrial Efficiency scenario, and specify the energy savings that can be expected. One easy way to do this is to select the **Final Energy Intensity** variable (specified at the “Other Industry” branch) and then enter the following formula which tells LEAP that the energy intensity will be 30% less than in the baseline Reference scenario by 2040:

$$\text{BaselineValue} * \text{Interp}(2010, 1, 2040, 0.7)$$

### 4.3.4 CNG Buses Scenario

Switching buses from diesel to CNG is seen as a good option both for improving air quality in densely populated and polluted cities as well as being a good way of mitigating CO<sub>2</sub> emissions.

- **Technology Penetration:** CNG buses could start to be introduced in 2012. By 2017 they could meet 7% of total bus passenger-kms, and by 2040 this could reach 70%.

- **Technology Performance:** Natural gas powered CNG buses use 0.29 MJ/passenger-km: slightly less than the final energy intensity of diesel buses in the base year.
- **Technology Cost:** CNG buses cost US\$0.1 per passenger-km more than existing buses but these costs are annualized over the 15-year lifetime of the buses.

#### 4.3.5 Transformation Costs

Wind and natural gas combined cycle (NGCC) plants will all be included in the last mitigation scenario. Before entering in costing data, you must create new branches for both technologies and specify their performance characteristics. Use the table below to set this up in Current Accounts.

##### Performance Characteristics for Future Electric Generation Facilities

	New Wind	New NGCC
Feedstock Fuel	Wind	Natural Gas
Dispatch Rule	MeritOrder	MeritOrder
Merit Order	1	1
First Simulation Year	FirstScenarioYear	FirstScenarioYear
Process Efficiency [%]	100	55
Maximum Availability [%]	35	80
Capacity Credit [%] <sup>1</sup>	30	100
Historical Production [GWh]	0	0
Exogenous Capacity [MW]	0	0
Lifetime [years]	30	30

<sup>1</sup> The **Capacity Credit** variable takes into account the portion of capacity that is fixed due to the intermittency of renewable technologies. This means that the all technologies other than wind will have a capacity credit of 100%.

Each of your demand side policy options will have a variety of impacts on the size and operation of the Transformation sectors. Therefore, unlike for the demand-side options where you only needed to enter cost data to describe the new options you were studying, for Transformation you need to specify costs for all of the various power plants and fuels that may be affected.

Start by specifying the capital costs and the fixed and variable operating and maintenance costs of the various electric generation power plants in your system. Use the following table for the data you need in LEAP.

### Costs for Existing and Future Electric Facilities

	Capital (\$/kW)	Fixed O&M (\$/kW)	Variable O&M (\$/MWh)	Interest Rate (%)
<b>Existing Plants</b>				
Existing Coal Steam	1000	40	3	5
Existing Hydro	2000	0	1	5
Existing Oil Combustion Turbine	400	10	0.7	5
<b>New Plants</b>				
New Coal Steam	1000	40	3	5
New Oil Combustion Turbine	400	10	0.7	5
New NGCC	500	10	0.5	5
New Wind	800	25	0	5

Important: these costs do NOT include fuel costs. You will deal with fuel costs below when you specify resource cost data.

#### 4.3.6 Natural Gas and Renewables Scenario

In the Reference scenario, Coal Steam and Oil Combustion turbines are assumed to be the main types of power plants to be built in the future. Recall that these data were specified for the **Endogenous Capacity** variable (located under the Electric Generation module's list of processes).

In this policy scenario you will instead examine the impact of building a different mix of power plants in the future. This scenario will analyze the impact of building a mix of natural gas combined cycle and wind power plants for our base load plus some oil combustion turbines to meet our peak load requirements.

Select the Natural Gas + Renewables scenario, and in the **Endogenous Capacity** screen, replace the Reference scenario data with the following:

#### Capacity Addition Sizes in the Natural Gas and Renewables Scenario

Process	Addition Order	Addition Size (MW)
New NGCC	1	400
New Oil Combustion Turbine	2	200
New Wind	3	200

**Hint:** Make sure you enter these technologies directly into the Mitigation scenario as well. You do not have to add the addition size (this value will be inherited), but you do need to create the structure with the correct *Addition Order* as above.

#### 4.3.7 Resource Costs

Under the Resources section of the tree, you will specify the unit costs for indigenously produced and imported primary resources and secondary fuels. Use the following information to enter these costs.

**Primary Resources (Indigenous production and imports):**

- Coal - \$20/tonne in 2010, rising to \$30/tonne in 2040
- Natural gas - \$0.1/m<sup>3</sup> in 2010, rising to \$0.2/m<sup>3</sup> in 2040
- Crude Oil - \$30/tonne in 2010, rising to \$50/tonne in 2040

**Secondary Resources (Indigenous production and imports):**

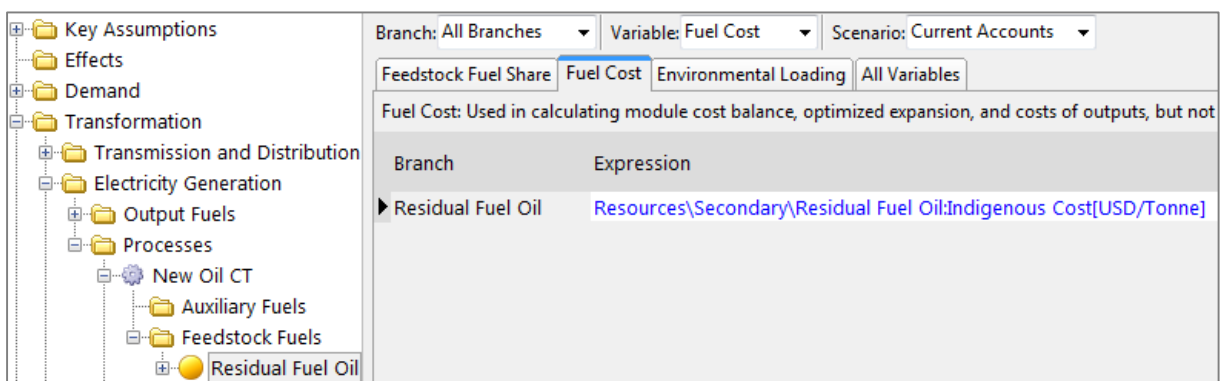
- Diesel, Gasoline, LPG, Kerosene, Residual Fuel Oil, Avgas and Lubricants - \$300/tonne in 2010, rising to \$400/tonne in 2040
- Electricity is not priced here since you are modeling electricity costs instead on the basis of input fuel and power plant costs.

Enter this base year cost data in Current Accounts, since all of the scenarios assume the same unit costs. Cost projections need only be entered once, under the Reference scenario.

Make sure that the **Fuel Cost** variable for each of the feedstock fuels associated with each Electricity Generation process refers to the **Indigenous Cost** variables in the Resources branches. For example, the **Fuel Cost** variable for the “New Oil Combustion Turbine” feedstock fuel should be the following expression:

**Resources\Secondary\Residual Fuel Oil:Indigenous Cost[USD/Tonne]**

The screenshot below illustrates this:



**Hint:** You can add this type of expression by pressing **Ctrl-B** and using the Branch/Variable selection wizard.

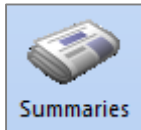
### 4.3.8 Environmental Loadings

In order to accurately calculate the cost of avoided emissions in your scenarios, you must ensure that appropriate emission factors have been assigned wherever a fuel is combusted in LEAP.

As you did in section 1.5, add emission factors to all branches by right-clicking on the tree, and selecting *Add IPCC Tier 1 Factors to All Branches*, checking each branch for which you want to add emission factors. In this exercise, we focus only on combustion-related emissions – therefore, add emission factors only to Demand branches and to the Electricity Generation module. You should not add any emission factors in the Transmission and Distribution, Charcoal Production, Oil Refining or Coal Mining modules.

## 4.4 Cost-Benefit Results

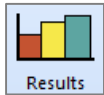
In the **Scenarios** screen you can click the check boxes on the tree to indicate which scenarios should be calculated. To keep the results reasonably simple at first you may want to check only the Reference and Mitigation scenarios.



In the Summaries view you can display the *Net Present Value* (NPV) of the Mitigation scenario relative to another selected scenario (in this case the Reference scenario). The NPV is the sum of all discounted costs and benefits in one scenario minus another (summing across all years of the study).

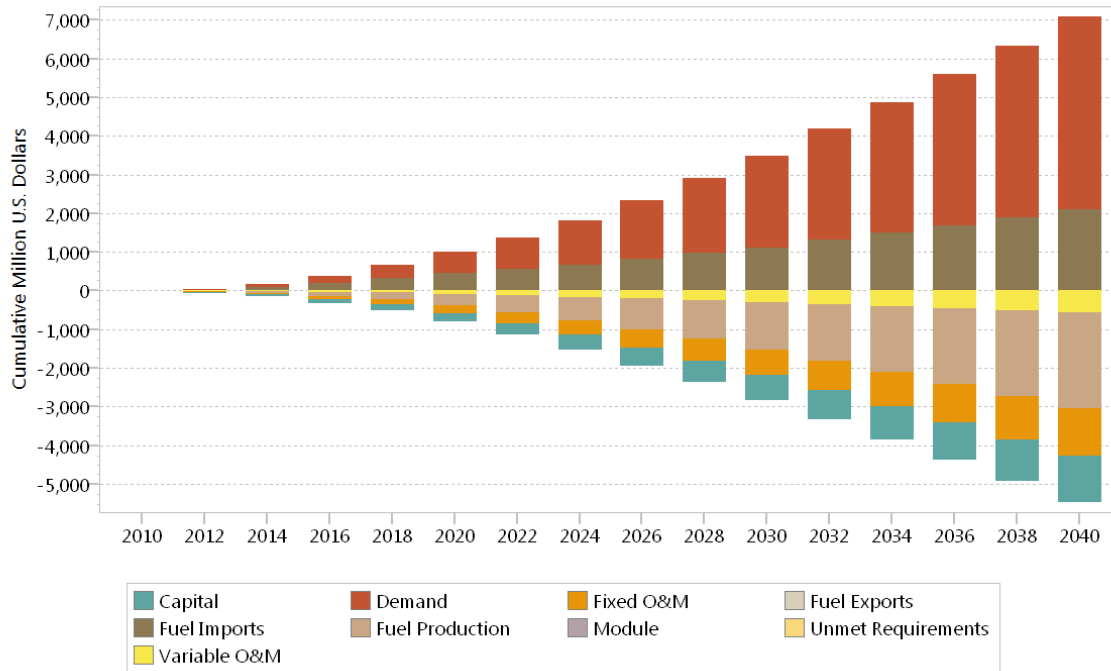
You should see results similar to those shown here. Notice that these indicate that on the demand side the Mitigation scenario costs more than the Reference scenario (since here you are investing into energy efficiency measures) but that this is somewhat offset by savings in the Transformation module and in avoided fuel requirements due to the energy saved on the demand side. The overall NPV of \$1.62 billion is how much more the Mitigation scenario costs versus the Reference scenario. The cost of avoided GHG emissions (3.40 \$/tonne CO<sub>2e</sub>) is given by dividing the NPV by the tonnes of CO<sub>2e</sub> avoided.

<b>Cumulative Costs and Benefits of Mitigation Scenario, 2010-2040</b>	
Billion 2010 US Dollars. Discounted at 5.0% to year 2010, Compared with the Reference Scenario	
	Mitigation
<b>Demand</b>	<b>5.00</b>
Household	0.73
Industry	1.70
Transport	2.56
Commercial	-
<b>Transformation</b>	<b>-3.00</b>
Transmission and Distribution	-
Electricity Generation	-3.00
Charcoal Production	-
Oil Refining	-
Coal Mining	-
<b>Resources</b>	<b>-0.38</b>
Production	-2.48
Imports	2.10
Exports	-
Unmet Requirements	-
<b>Environmental Externalities</b>	<b>-</b>
<b>Net Present Value</b>	<b>1.62</b>
GHG Savings (Mill Tonnes CO <sub>2e</sub> )	474.88
Cost of Avoiding GHGs (U.S. Dollar/Tonne CO <sub>2e</sub> )	3.40



You may also want to look at cost results graphically. You can do this in the **Results View**. Select the top branch in the tree and show the result **Costs: Social Costs**. In the chart legend, show *All Costs*. Often it is most useful to view costs in terms of differences versus the Reference scenario. For example, try to display the following chart that shows the incremental cumulative discounted costs in each year of the Mitigation scenario versus the Reference scenario.

**Cumulative Discounted Costs: Mitigation vs. Reference Scenario**  
(discounted to 2010 at 5% per year)




Notice how the Mitigation scenario is more expensive than the Reference scenario in terms of demand-side costs and in terms of imported fuels (these items appear above the X-axis), but this is somewhat offset by savings in transformation capital costs, fuel production and operating and maintenance (O&M) costs (these items appear as negative values below the X-axis).

## Exercise 5: A Transportation Study

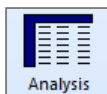
In Exercise 5 you will use LEAP's transportation analysis features to construct a range of scenarios that examine different policies for passenger cars and sport utility vehicles (SUVs). SUVs are the kind of large energy-intensive vehicles, the popularity of which is causing rapidly growing fuel consumption and greenhouse gas emissions, especially in the USA.

You will first use LEAP to construct a Current Accounts inventory of fuel use and selected emissions from these vehicles. Next, you will create a "Business as Usual" scenario that projects fuel use and emissions into the future under the assumption of no new policies to reduce fuel use and emissions. Finally, you will create and compare a range of scenarios that examine measures designed to reduce fuel use and emissions.

As with other exercises, you will start by creating a new area and then setting up the Basic Parameters of the study.

Select menu option Area: New Area, or click on the  **New** button on the main toolbar. Call the new area "Transportia" (or any other name you like). Check the radio button to create the area from default data then click OK.

### 5.1 Basic Parameters and Structure



Go to **Basic Params.**

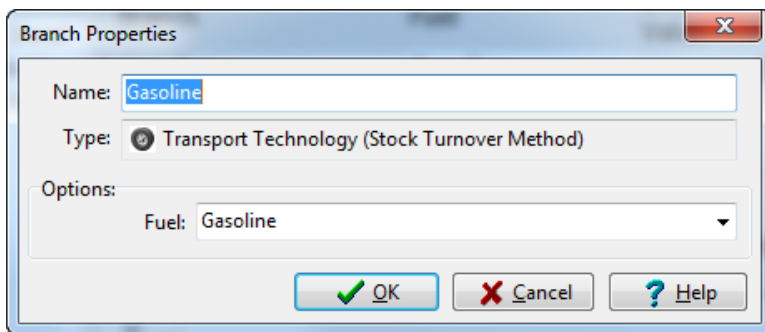
- On the Scope & Scale tab, make sure only the Energy Sector Effect Loadings box is checked. This study will not make use of Transformation, Costs or Resource data.
- On the Years tab, enter 2010 as the *Base Year*, 2011 as the *First Scenario Year* and 2030 as the *End Year*.
- Transportia uses U.S. measurement units rather than the International S.I. units, so you will need to set different default units for your study. On the Default Units tab select "Gallons of Gasoline Equiv (US)" as the default energy unit, "Miles" as the default distance unit, "Pound/Million BTU" as the default energy-based emissions unit and "Gramme/Vehicle-Mile" as the default transport-based emissions unit.
- On the Stocks tab, make sure the Top-down sales and stock data box is checked and that the number of vintage years is 22.

You are now ready to enter your Tree structure. First, you will create two major categories, one for “Cars” and one for “Sport Utility Vehicles” (SUVs). To add each of these click on the *Add* button (+) above the tree and create each as a category branch (📁).

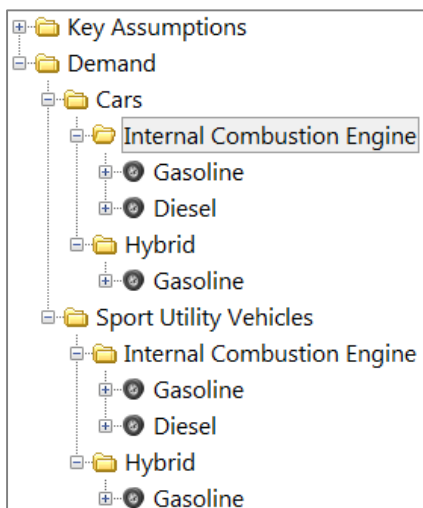
Under each category create subcategories for conventional “Internal Combustion Engine” (ICE) vehicles and one for the new type of “Hybrid-Electric Vehicles” (see box).

Under each of the conventional Internal Combustion Engine categories you will consider two alternative technologies, “Gasoline” and “Diesel”, so create two technologies.

When adding these technologies, make sure you create them as *Transport Technology (Stock Turnover Method)* branches (⚙️), and select the correct fuel for each as shown below. Under each of the hybrid categories you will only consider gasoline vehicles.



Your completed tree structure should look something like this:



## Hybrid-Electric Vehicles

Hybrid vehicles combine a small internal combustion engine with an electric motor and battery to reduce fuel consumption and tailpipe emissions. Energy lost during braking is captured and returned to the battery in a process called "regenerative braking."

Unlike electric vehicles, hybrids have the advantage that they do not need to be “plugged-in” to the electric supply. Hybrid engines operate more efficiently and produce less pollution than conventional internal combustion engines.

Hybrids should be competitively priced when all the costs over the life of the vehicle are included. This is because any cost premium is likely to be offset by fuel savings.

By combining gasoline with electric power, hybrids will have the same or greater range than traditional combustion engines. Hybrids offer similar performance compared to conventional internal combustion engine vehicles.



**The Toyota Prius: one of the available hybrid-electric cars.**



## 5.2 Current Accounts Data

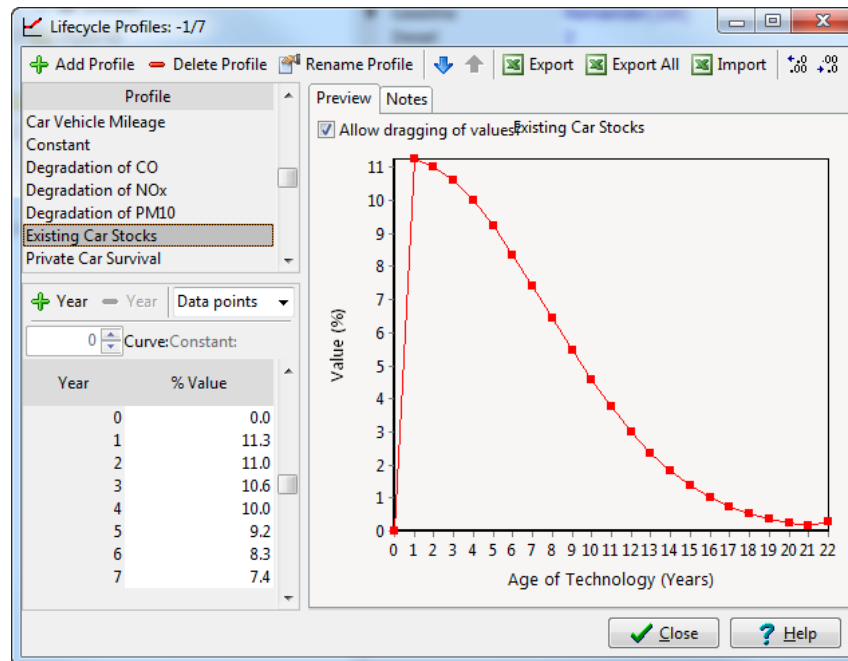
You are now ready to enter the following base year (Current Accounts) data for your analysis.

- There were 6 million cars and 4 million SUVs on the road in the base year (2010), not including new cars sold in that year.
- The existing stock of cars and SUVs is made up of vehicles of different ages (vintages). The percent share of each of these vintages is given in the table on the right.

**Hint:** Create a new Lifecycle Profile named “Existing Car Stocks” to represent the distribution of vintages within the base year stock. The Lifecycle Profiles screen is accessed under the General menu. First add a profile then enter the data shown on the right. The figure below shows how this information will look when entered into the lifecycle profile screen. Back in **Analysis View**, go to the **Stock share** tab for each technology branch and in the Stock Vintage Profile column, select the “Existing Car Stocks” profile.

**Important:** Note that LEAP requires that all stock vintage profiles have zero vehicles of age zero years. This is because the data you enter for base year stocks should not include those new vehicles sold in the base year. These vehicles are specified using the **Sales** variable.

Age (Years)	% of Stock
0	0.00
1	11.26
2	11.04
3	10.60
4	9.99
5	9.22
6	8.34
7	7.40
8	6.43
9	5.48
10	4.58
11	3.75
12	3.01
13	2.37
14	1.82
15	1.38
16	1.02
17	0.74
18	0.53
19	0.37
20	0.25
21	0.17
22	0.27



- In the base year, 0.8 million cars were sold, and 0.5 million SUVs. As these and other vehicles age they will gradually be retired from the vehicle stock (taken off the road). A survival profile describing this retirement of vehicles can be represented by an exponential function of the following type:

$$S_t = S_{t-1} \cdot e^{-0.02t}$$

where  $S_t$  is the fraction of surviving vehicles of age  $t$  (in years).

**Tip:** Create another Lifecycle Profile named “Private Car Survival” to represent the percent survival of vehicles as they get older. First add a profile then create an exponential curve with the constant parameter  $-0.02$ . Back in **Analysis View**, go to the **Sales share** tab for each technology branch and in the Survival Profile column, select the “Private Car Survival” profile.



- Among internal combustion engine cars and SUVs, 2% of sales and 2% of the base year stock is diesel vehicles. The remainder was gasoline vehicles.
- 0.05% of the base year stock of cars is Hybrid vehicles. 0.5% of the cars sold in the base year were Hybrids.
- All new cars and new SUVs are assumed to be driven 15,000 miles in their first year on the road. As the age of vehicles increases they are driven less. This decrease in driving can be represented by an exponential function, similar to the one above, and also with the constant parameter  $-0.002$ .
- The base year fuel economy of the different types of vehicles is shown in the following table. Fuel economy is assumed to stay constant as a vehicle’s age increases.
- No hybrid SUVs are currently available.

Fuel Economy in 2010 (Miles per Gallon)

	Gasoline ICE	Diesel ICE	Gasoline Hybrid
Cars	25	28	40
SUVs	15	17	23

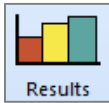
### 5.3 Business as Usual Scenario

You are now ready to create a “Business and Usual” scenario (BAU) that projects fuel use into the future under the assumption of no new policies to reduce fuel use and emissions.

Go to the **Scenarios** screen () and click the **Add** button () to add a new a new scenario named “Business as Usual” (BAU). Then enter the following data:

- Sales of vehicles are expected to double, reaching 2 million vehicles/year in 2030. However, all this growth is expected within the SUV market segment. Annual car sales remain at 0.8 million/year in 2030, while annual SUV sales more than double, reaching 1.2 million in 2030.
- Hybrid market penetration remains constant in the BAU scenario. No hybrid SUVs are introduced.
- In the absence of new standards, fuel economy of all vehicles remains unchanged in the future.

## 5.4 Business as Usual Results



You are now ready to view BAU results for sales, stocks, mileage and fuel use. Check your results against each of the following categories for the years 2010, 2020, and 2030.

**Device Sales (thousands of vehicles)**

Branches	2010	2020	2030
Cars	800	800	800
Internal Combustion Engine	796	796	796
Gasoline	780	780	780
Diesel	16	16	16
Hybrid	4	4	4
Gasoline	4	4	4
Sport Utility Vehicles	500	850	1,200
Internal Combustion Engine	500	850	1,200
Gasoline	490	833	1,176
Diesel	10	17	24
Hybrid	-	-	-
Gasoline	-	-	-
Total	1,300	1,650	2,000

**Device Stocks (thousands of vehicles)**

Branches	2010	2020	2030
Cars	6,800	7,031	7,106
Internal Combustion Engine	6,793	6,999	7,071
Gasoline	6,657	6,859	6,929
Diesel	136	140	141
Hybrid	7	32	35
Gasoline	7	32	35
Sport Utility Vehicles	4,500	6,068	9,063
Internal Combustion Engine	4,500	6,068	9,063
Gasoline	4,410	5,947	8,882
Diesel	90	121	181
Hybrid	-	-	-
Gasoline	-	-	-
Total	11,300	13,099	16,170

**Vehicle Mileage (billion vehicle-miles)**

Branches	2010	2020	2030
Cars	96.8	100.7	101.7
Internal Combustion Engine	96.7	100.2	101.2
Gasoline	94.8	98.2	99.1
Diesel	1.9	2.0	2.0
Hybrid	0.1	0.5	0.5
Gasoline	0.1	0.5	0.5
Sport Utility Vehicles	64.1	87.6	130.8
Internal Combustion Engine	64.1	87.6	130.8
Gasoline	62.8	85.9	128.2
Diesel	1.3	1.8	2.6
Hybrid	-	-	-
Gasoline	-	-	-
Total	160.9	188.3	232.5

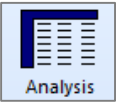
**Energy Demand (million gallons gasoline eq.)**

Branches	2010	2020	2030
Cars	3,864	4,012	4,051
Internal Combustion Engine	3,862	4,001	4,038
Gasoline	3,792	3,929	3,966
Diesel	69	72	72
Hybrid	3	12	13
Gasoline	3	12	13
Sport Utility Vehicles	4,261	5,827	8,700
Internal Combustion Engine	4,261	5,827	8,700
Gasoline	4,186	5,724	8,546
Diesel	75	103	154
Hybrid	-	-	-
Gasoline	-	-	-
Total	8,125	9,840	12,751

***Hint:** if your results differ by more than a few percent from those shown above, first check, and if necessary debug, your Current Accounts data.*

*First eliminate the possibility of errors in your Current accounts data before trying to debug future values.*

## 5.5 Emissions Factors



Next, you will enter environmental loadings data describing some of the pollution loadings associated with the vehicles you are studying. To keep data entry to a minimum, for this short exercise you will examine only four pollutants: the greenhouse gas, Carbon Dioxide (CO<sub>2</sub>) and three pollutants contributing to local air pollution: Nitrogen Oxides (NO<sub>x</sub>), Carbon Monoxide (CO), and Particulate Matter of size less than 10 microns (PM<sub>10</sub>).

CO<sub>2</sub> emissions from vehicles are dependent only on the type of fuel used and the efficiency (fuel economy) of the vehicle. Therefore, they can be specified in terms of emissions per unit of energy consumed. The measurement units used are pounds of CO<sub>2</sub> per MMBTU of fuel consumed.

Local air pollutants are much more dependent on the type of control technology used in the vehicle, and also tend to be regulated by the Government at certain levels. For this reason, these emission factors tend to be specified per vehicle-mile traveled. The units used are grammes of pollutant per vehicle-mile traveled. Because emissions of these pollutants depend critically on the performance of the catalytic converter or other control technology used in the vehicle, they can also be expected increase per vehicle-mile quite substantially as vehicles get older. For this reason, in addition to specifying the emission factors for new vehicles, you will also need to specify degradation factors for each pollutant that specify how emissions increase as vehicles get older.

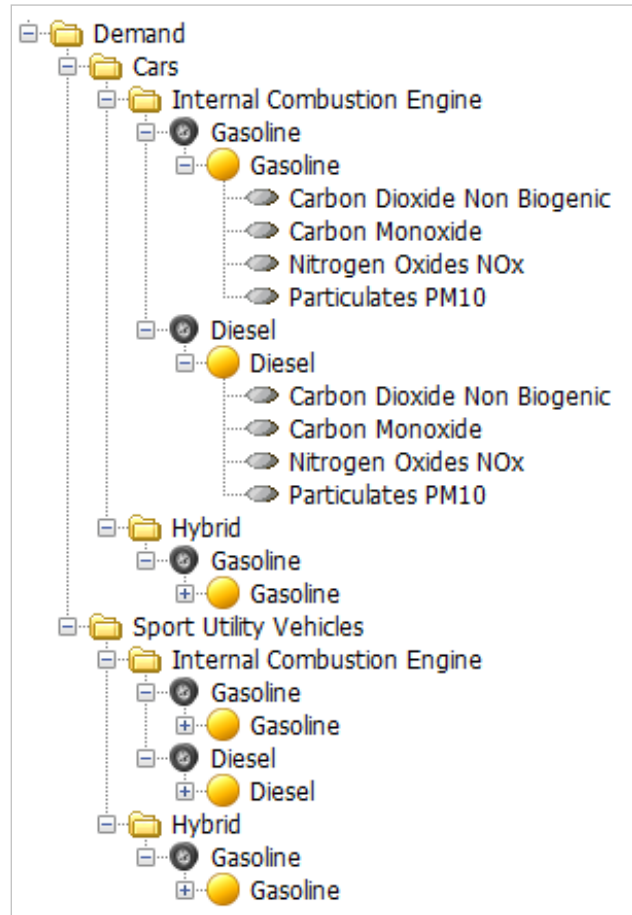
The Government of Transportia is continually reviewing and improving its regulations for vehicle emissions, based on recommendations from its Environmental Protection Agency. Since 2000, the emissions standards for new vehicles have been tightened a number of times. The following table specifies how average emission factors for each type of new vehicle have evolved since 2000.

Car	Pollutant	Units	2000	2005	2014	New Standard?
Gasoline	CO <sub>2</sub>	lbs/MMBTU	159.50			
	CO	g/veh-mile	6.20	5.30	3.50	1.70
	NO <sub>x</sub>	g/veh-mile	0.44	0.35	0.04	0.03
	PM <sub>10</sub>	g/veh-mile	0.40	0.30	0.20	0.05
Diesel	CO <sub>2</sub>	lbs/MMBTU	161.00			
	CO	g/veh-mile	1.05	0.54	0.20	
	NO <sub>x</sub>	g/veh-mile	0.60	0.27	0.08	
	PM <sub>10</sub>	g/veh-mile	1.50	1.50	0.50	0.20

Data on emissions from hybrid vehicles are not yet available. However, because they are regulated in the same way as conventional internal combustion engine gasoline vehicles they are assumed to have the same emission factors as that type of vehicle.

One set of standards is due to come into force for vehicles manufactured in 2014, the Government is also considering introducing a new set of emissions regulations, with the proposed new emission factors, listed in the final column. This proposed set of regulations has not yet been approved and thus, the date when this will come into law and affect new vehicles being manufactured has not yet been decided.

To enter the above data into LEAP you will first need to create a series of *Environmental Loading* branches (●) under each of your technologies (●). Go to the **Environmental Loading** tab, and use the *Add* button (+) to add CO<sub>2</sub>, CO, NO<sub>x</sub> and PM<sub>10</sub> effects. Once complete, your tree structure should appear as shown on the right.



It is important to set the correct units for each pollutant. For CO<sub>2</sub>, set the *Method* to “Per unit energy consumed” and then select units *Pound per Million BTU*. For the other pollutants select type “Per unit travel” and then select units: *Gramme per Vehicle-mile*.

Since the above data represent emissions standards that came into force governing the manufacture of new vehicles in a specific year, you will need to enter the data for 2000, 2005, and 2014 using a step function. Since the year for the new standard has not yet been decided you can specify that year using a Key Assumption named “New Reg Year”. Set the value of this variable to 2050 so that the new standards will, in effect, not be used in any initial scenario calculations.

So for example, you might create an expression to represent CO emissions from gasoline vehicles as follows:

**Step(2000, 6.2, 2005, 5.3, 2014, 3.5, Key\New Reg Year, 1.7)**

Finally, for the three local air pollutants you will also need to specify how the emission factors increase over time, as each vintage of vehicles on the road gets older. To do this you will again need to go to General: Lifecycle Profiles and create three named profiles to represent degradation of CO, NO<sub>x</sub> and PM<sub>10</sub>. The degradation of these can each be represented by exponential curve with the following constant parameters: 0.006 for CO, 0.008 for NO<sub>x</sub>, and 0.005 for PM<sub>10</sub>. Back in **Analysis View**, go to the **Environmental Loading** tab for each technology branch and in the final *Degradation Profile* column, select the appropriate profiles.

Emissions of carbon dioxide (CO<sub>2</sub>) depend only on the amount of fuel burnt in the vehicle. Therefore, a single constant emission factor can be used, and no degradation curve is required. Hence, for CO<sub>2</sub> emission factors leave the *Degradation Profile* set to constant.

*Hint: To avoid entering the above step function under every technology branch, you may choose to create key assumptions for each set of emission factors and link to them under each technology.*

## 5.6 Business as Usual Emissions



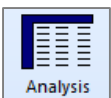
Projecting emissions into the future is simple for BAU, since this scenario assumes no new policies to reduce emissions. Check your emissions results for the years 2010, 2020, and 2030 against the following table.

Pollutant Emissions	2010	2020	2030
CO <sub>2</sub> (millions of tonnes)	70	85	110
CO (thousands of tonnes)	1079	881	929
NO <sub>x</sub> (thousands of tonnes)	82	36	14
PM <sub>10</sub> (thousands of tonnes)	68	52	54


## 5.7 Policy Scenarios

You are now ready to examine a series of policy scenarios. You will start by examining a range of different measures individually, and then later combine them into different combinations of integrated scenarios.

### 5.7.1 Improved Fuel Economy (IFE)



The first policy being considered by the Government is to introduce stricter fuel economy standards for conventional (i.e. non-hybrid) internal combustion engine gasoline and diesel vehicles. The proposed new standard will require new cars and SUVs to increase their fuel economy by 5% in 2015, by 10% in 2020 and by 20% in 2025 (all values relative to the base year fuel economy).

To model this policy, first go to the **Scenarios** screen () and then create a new scenario below the BAU scenario called “Improved Fuel Economy”. To reduce data entry, you may want to create a new Key Assumption to represent the above improvements. For example, you could create a variable called “Target Economy”, set its Current Accounts value to 1.0 and then in the Improved Fuel Economy scenario, specify its future values using the following expression:

**Step(2015, 1.05, 2020, 1.1, 2025, 1.2)**

Next, go to the **Fuel Economy** tab for each appropriate vehicle type and enter the following expression for the Improved Fuel Economy scenario:



## **BaselineValue \* Key\Target Economy**

This will cause future fuel economy to be calculated as the product of the BAU fuel economy and the target fuel economy.

### **5.7.2 Increased Market Penetration of Hybrid-Electric Vehicles (HYB)**

A second policy being considered is to increase the market penetration of hybrid-electric vehicles. This is likely to be done through a range of consumer and producer tax incentives and subsidies. It is expected that with these incentives hybrids can increase their market penetration so that by 2030, 50% of the market for cars and SUVs is for hybrids.

Hybrid fuel economy is expected to improve as the technology matures. Hybrid Gasoline cars reach a fuel economy of 60 MPG by 2030, while Hybrid SUVs reach 35 MPG.

Create a new scenario called “Hybrids” and enter an *Interp* function to specify how the future sales of cars and SUVs will be split between conventional ICEs and Hybrids.

### **5.7.3 Increased Market Penetration of Diesel Cars and SUVs (DSL)**

Because of their higher efficiency and GHG benefits, the Government is also considering a policy to increase the market penetration of diesel cars and SUVs. However, it is not clear that whether these benefits are justified given that diesel vehicles have higher emissions of local air pollutants, especially particulates. It is expected that with various incentives diesels could increase their market penetration to 30% of the market for conventional ICEs by 2030.

Create a new scenario called “Diesel” and enter an *Interp* function to specify how the future sales of ICE cars and SUVs will be split between diesel and gasoline vehicles.

### **5.7.4 New Tailpipe Emissions Standards (TAIL)**

As noted above in section 5.3, the Government is also considering introducing a new and more stringent tailpipe emissions standard. The Government wants to see what the emissions reductions benefits will be of introducing this new standard in 2020, both as a standalone policy and also as part of a wider package of measures to reduce pollution and combat climate change.

***Hint:** Create a new scenario called “Tailpipe Standard” then simply edit the value of the Key Assumption named “New Reg Year” that you created earlier for this new scenario. This variable represents the date when the new tailpipe emissions standard will be introduced. Change it to 2020.*

### **5.7.5 Promotion of Cars over SUVs (CAR)**

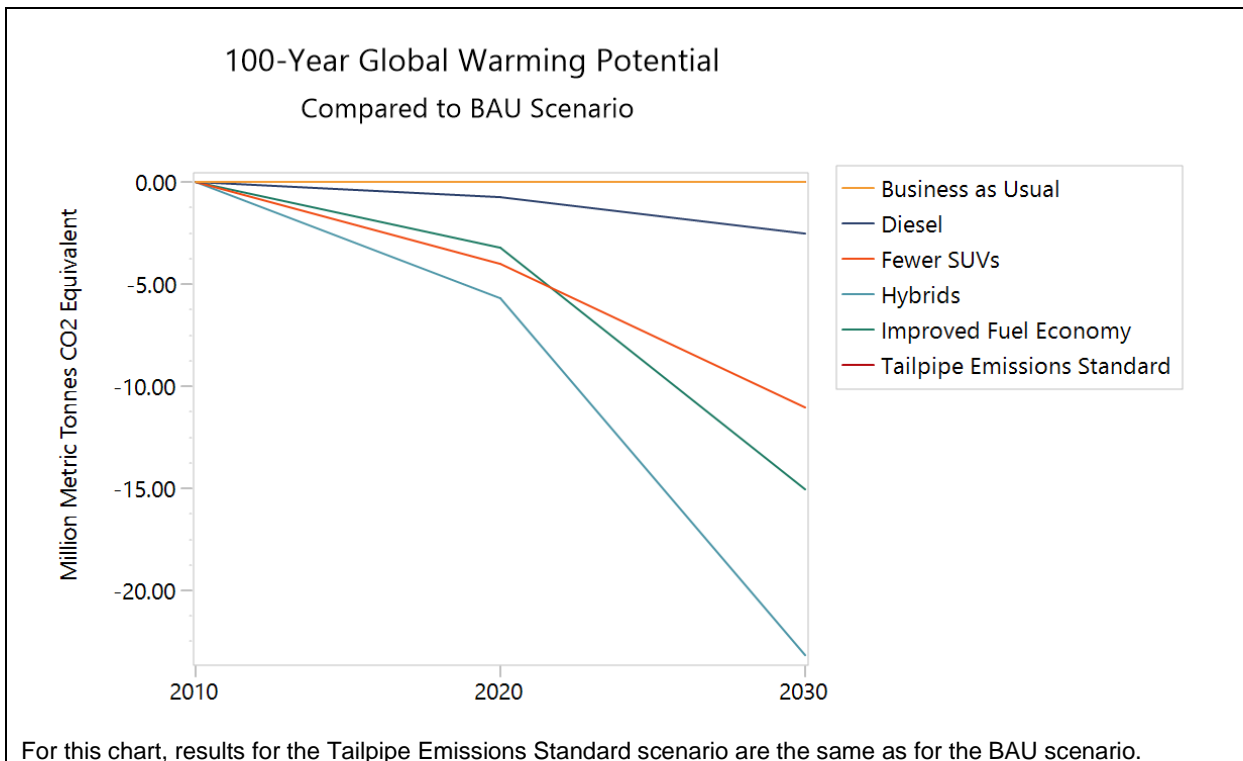
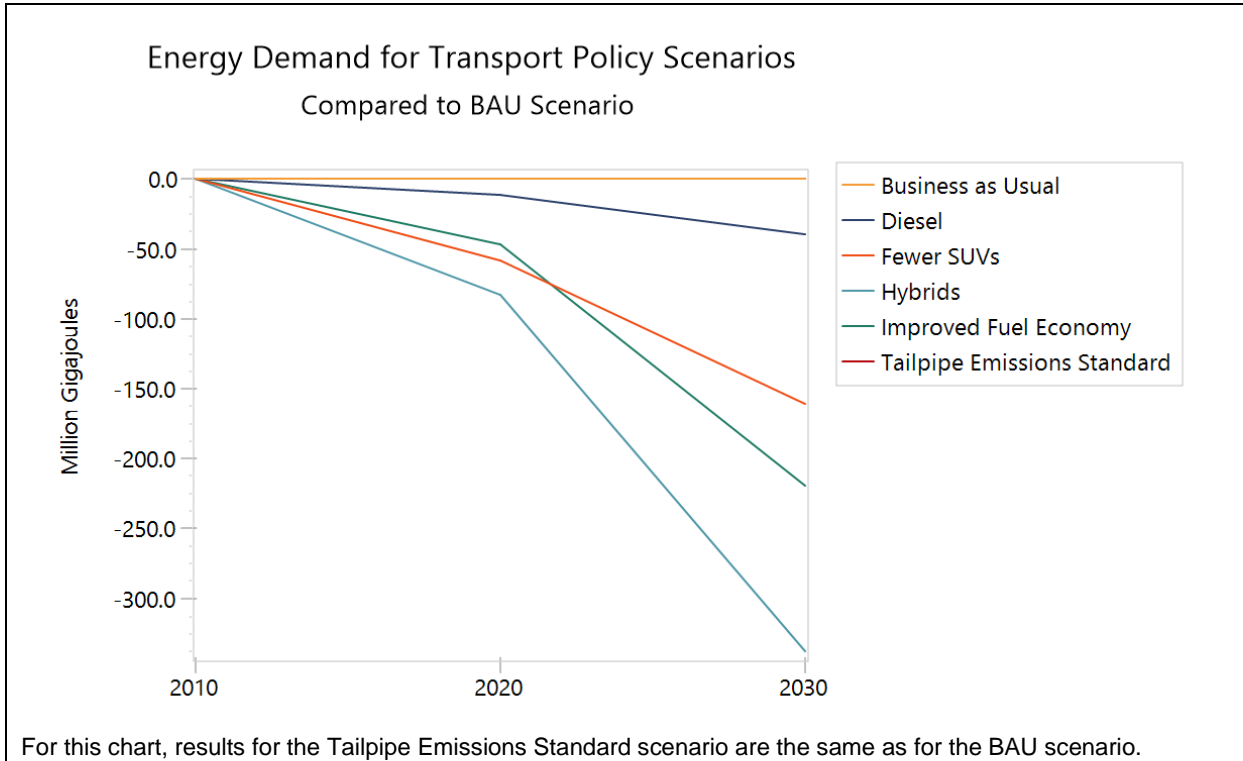
The Government is also considering a series of measures to discourage consumers from purchasing large and fuel-inefficient SUVs. Using a series of policies such as fuel or carbon taxes and motor vehicle insurance based on vehicle weight or fuel economy, it is expected that annual SUV sales can be reduced to 700,000 vehicles by the year 2030, with car sales increasing to 1,300,000 vehicles.

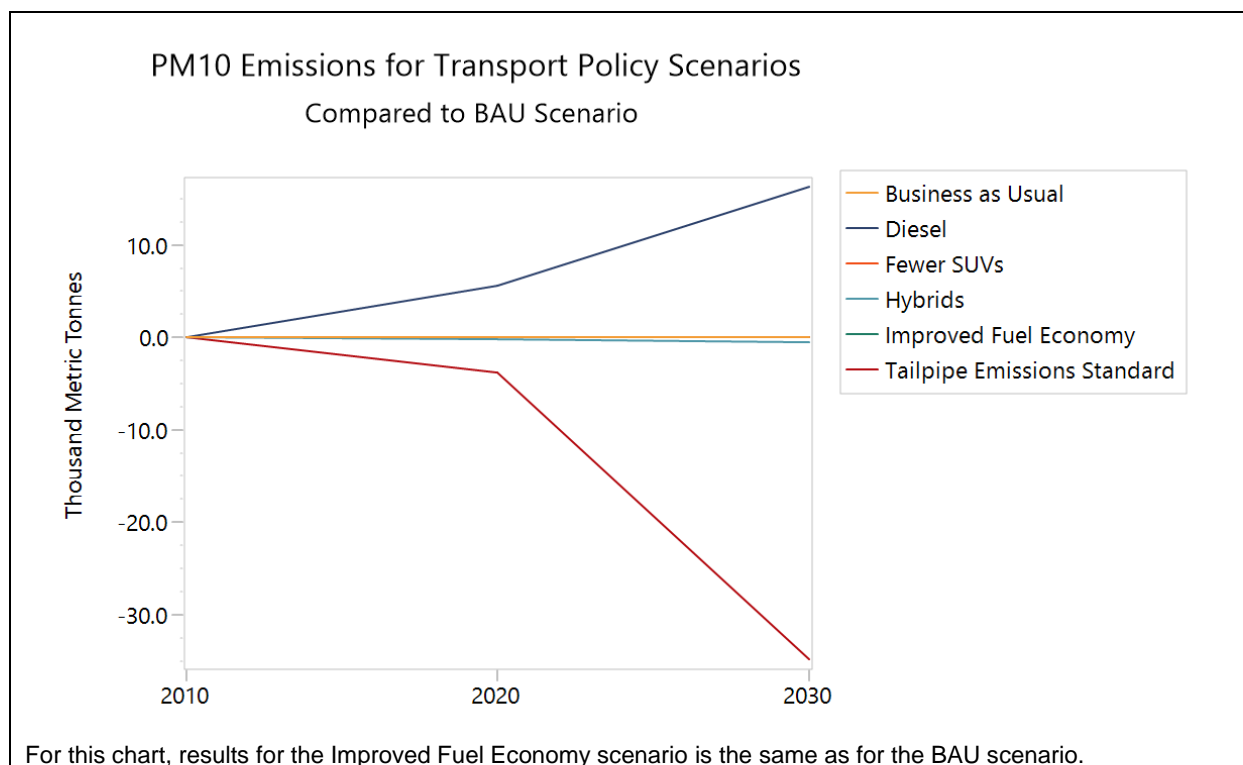


## 5.8 Results



You are now ready to view the results of your scenarios. Compare the results you get to the charts on the following pages.







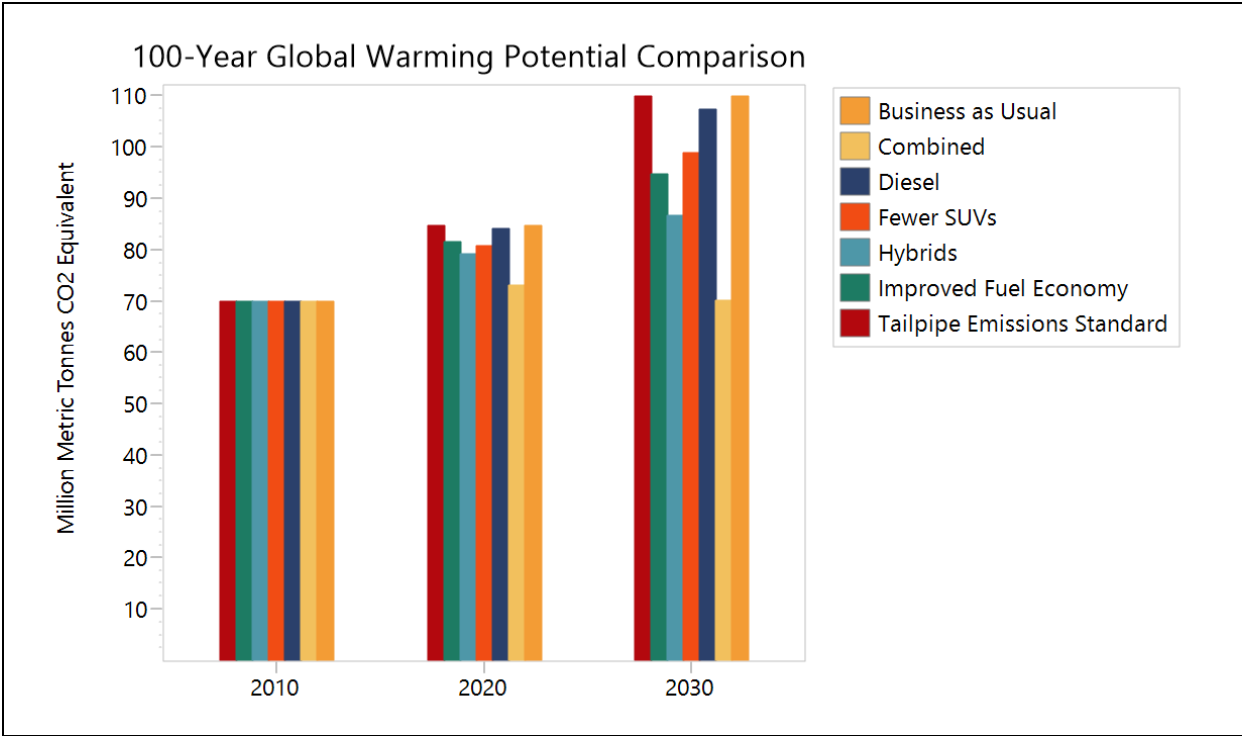
Notice that some scenarios result in environmental trade-offs. In particular, notice that increased use of diesel vehicles leads to reductions in CO<sub>2</sub> emissions but to significant increase in PM<sub>10</sub>. You may also wish to check results for NO<sub>x</sub>.

You can try creating your own combinations of scenarios. Start by combining the following scenarios:

- Improved Fuel Efficiency Standards for Conventional Gasoline Vehicles.
- Introduction of a new Tailpipe Emissions Standard.
- Increased Market Penetration of Hybrid-Electric Vehicles.
- Promotion of Cars over SUVs.

Go to the **Scenarios** screen (  ) and create a new scenario named “Combined” that inherits from the BAU scenario. On the inheritance tab, click on the *Add* button (  ) to add each of the above named scenarios to the area marked *Additional Scenarios*. You do not need to enter new data for this scenario, as it will automatically inherit the data entry expressions used in each of the scenarios from which it inherits.

Now compare the results for this new combined scenario to the individual policy scenarios and to the BAU scenario.



## Exercise 6: Least-Cost Electric Generation

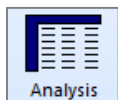
In this simple exercise you will use LEAP's optimization features to investigate a range of different technologies for generating electricity. You will compare the costs of generating electricity including the capital, operating and maintenance and fuel costs of those technologies and you will perform sensitivity analyses to examine which options are the cheapest when the externality costs of local air pollution are either included or excluded. You will then go on to explore the implications of a cap on CO<sub>2</sub> emissions – how it alters the set of technologies chosen and how it affects the overall cost of the scenario.

This exercise will also show you how to import a year's worth of hourly electrical load data into LEAP, as a way of describing how demands vary among seasons and times of the day.

*Please note that this exercise is a highly simplified representation of an electric generating system and the data values provided are not intended to be realistic. **Please do not cite or use the data shown in this exercise in any real study.***

 **NB: this exercise requires Microsoft Excel as well as LEAP.**

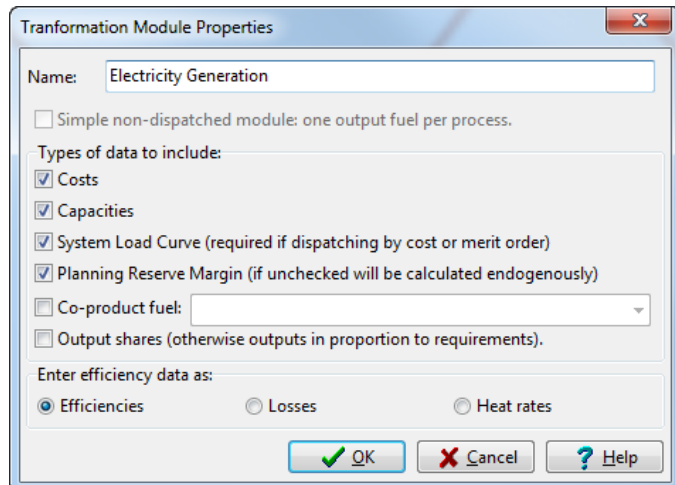
### 6.1 Entering Electric Generation Data



Start by opening the LEAP area “Optimization Exercise”, by clicking Area: Open, and then clicking Area: Revert to Version, selecting “Optimization Exercise Start”. This data set is partially completed already.

Under the Demand branches, a single branch specifies that the demand from electricity grows from nothing in the base year (2010) to 200 Thousand GWh in the end year (2020). This information is entered in the **Total Energy** variable of a single *Technology with Total Energy* (⚙️) branch in the Current Accounts scenario. In this simple exercise the same energy demand assumptions will be used in all scenarios.

Now look at the Transformation tree branches. You will see a single module describing transmission and distribution losses. Here we have created a simple Transformation module containing the simple assumption of 10% electrical losses. This value is assumed to stay the same in all years and across all scenarios. Your first data entry task is to create a new module that will be used to describe the various possible electric generation technologies.



Start by adding a new Transformation module called “Electricity Generation” and set its properties are set to include costs, capacities, a system load curve and a planning reserve margin. Efficiency data should be set to be entered

directly (as percentage efficiency values). Make sure the new module appears below the “Transmission and Distribution” module in the tree’s branch structure.

Once you have created the module you can start to enter the basic data describing its various technologies. Enter all of the following data for the Current Accounts scenario. Set the planning reserve margin to 25% and make sure the module has electricity as a single output fuel.

You can leave the default properties for the output fuel unchanged. No data should be entered for import and export targets for this output fuel.

Next you can specify the set of electric generation technologies to be evaluated. Create each one as a separate process within the Electricity Generation module, and do this while editing the Current Accounts scenario. The following table provides the data you will need to define these processes.



Process	Feedstock	Efficiency (%)	Max Availability (%)	Capacity Credit (%)	Capital Cost (Thousand \$/MW)	Fixed O&M (Thousand \$/MW)	Variable O&M (\$/MWh)	Fuel Costs	Lifetime (yrs)
NGCC	Natural Gas	45	85	100	1900	10	3	\$7/MMBTU	30
Wind	Wind	100	30	20	2300	20	4	n/a	25
Coal	Coal Bituminous	35	90	100	2200	40	3	\$100/Tonne	30
Hydro	Hydro	100	60	50	9000	30	5	n/a	40

Most of the above data in this table needs to be entered for the various variables defined for each process. Feedstock fuel costs need to be specified within the Resource branches of the tree. Enter the natural gas and coal fuel costs at both the **Indigenous Cost** and **Import Cost** variables (under the Resources\Primary branches). Ensure that these cost variables are correctly referenced in the **Fuel Cost** variable for each power plant feedstock fuel, as you did in section 4.3.7.

Finally, to ensure the energy balances are correctly calculated, make sure that you specify very large reserves of natural gas and coal bituminous and very large availability of wind and hydro power. In Current Accounts, enter *Unlimited* GJ as the **Base Year Reserves** for these fuels under the Resources\Primary branches. Enter the same value for wind and hydro availability in the **Yield** variable.

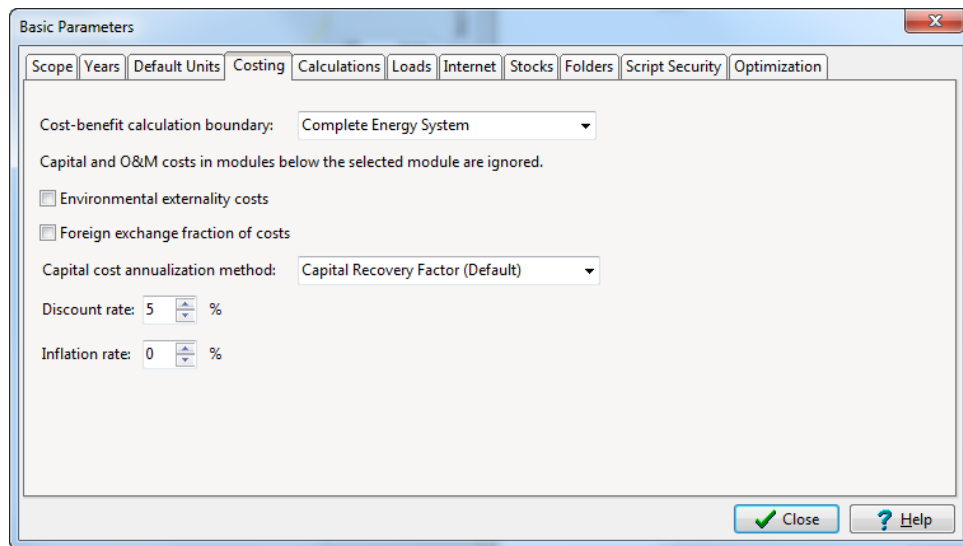
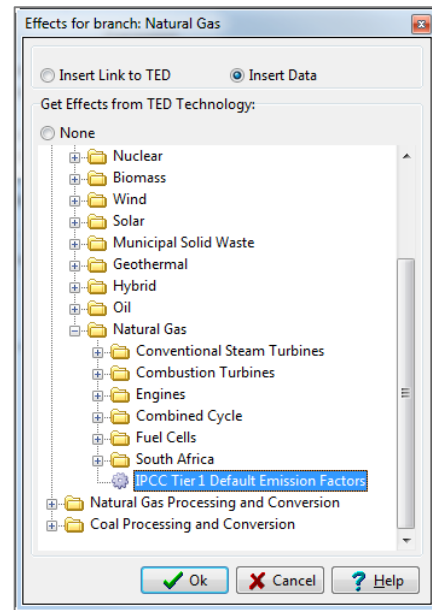
In addition to the data in the above table, ensure that the **Interest Rate** variable is equal to the model’s discount rate of 5%. Make sure the **Exogenous Capacity** variables are all set to zero. Finally, set the **Dispatch Rule** to *RunningCost*.

In this simple exercise we are not trying to represent actual historical patterns of dispatch, and thus we will not be using the **Historical Production** variable to tell LEAP how much of each process to dispatch. Instead we will be using LEAP’s optimization calculations to calculate process capacity values consistent with minimizing costs while meeting demands. Setting the **First Simulation Year** to a date equal to or before the base year of the study tells LEAP to ignore the **Historical Production** variable. To accomplish this, you may enter the expression *BaseYear* into the **First Simulation Year** for all processes.

Before leaving the processes branches make sure you have specified a set of emission factors for each process. Using the techniques you first followed in Exercise 1.5, add IPCC Tier 1 emission factors for the coal and NGCC (natural gas) power plants. Connect each relevant feedstock fuel branch (those marked with the ) and the IPCC Tier 1 technologies the **Environmental Loading** tab, and then clicking the TED button () . This will display the box shown on the right.

Finally, visit the Cost tab of **Basic Params** (shown below). Here you will need to set a few options that will be used to calculate cost results. Make sure this screen has the following settings:


- The *Cost-benefit calculation boundary* should be set to “Complete Energy System”.
- *Environmental externality costs* can initially be switched off. Also, foreign exchange costs are not used in this exercise so that can also be left off.
- Set the *Discount rate* to 5%
- The *Capital cost annualization method* should be set to “Capital Recovery Factor (Default)”. This method is required when using optimization.




## 6.2 Creating Load Shapes by Importing Hourly Load Data

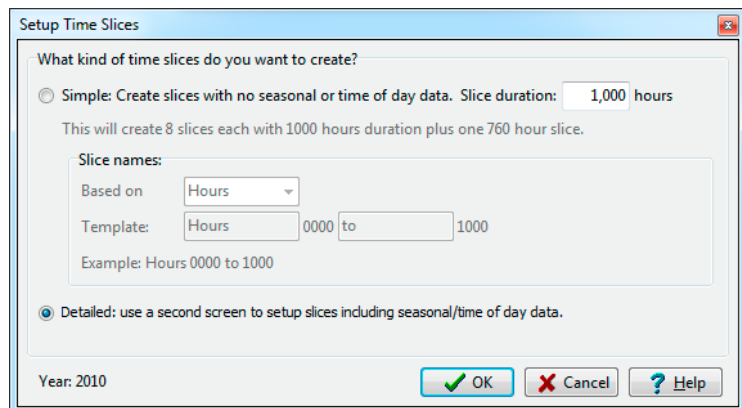
Next you will create a set of data that describe how the electric generation load varies among different seasons and times of day. The variations in the electric load are important in determining what mix of base load or peak load plants make should be built and operated.

Creating and using this load shape in LEAP is a four-step process.

1. **Time Slices:** First you will specify a set of time slices into which each year will be divided. In this example we will divide each year into four seasons and each season will be further divided into days and nights.
2.  **Hourly Data Spreadsheet:** Second, you will select a set of predefined hourly data that describes how the electric load varied across all 8760 hours of a single year. This hourly data is predefined and stored in a separate Microsoft Excel spreadsheet provided to you.
3. **Yearly Shape:** Third, you will use LEAP's **Yearly Shapes** screen to import the hourly data contained in the spreadsheet and automatically map it to the time slices you have created.
4. **System Energy Load Shape:** Finally, you will use this newly created load shape in your LEAP data set by assigning it to the **System Energy Load Shape** variable in your analysis.

Let's follow each of those steps in detail.

1. **Time Slices:** First let's create a detailed set of time slices. Go to the General: Time Slices screen and click the Setup toolbar button (). Choose "Detailed: use a second screen to setup slices including seasonal/time of day data."



Setup Time Slices

What kind of time slices do you want to create?

☐ Simple: Create slices with no seasonal or time of day data. Slice duration: 1,000 hours

This will create 8 slices each with 1000 hours duration plus one 760 hour slice.

Slice names:

Based on: Hours

Template: Hours 0000 to 1000

Example: Hours 0000 to 1000

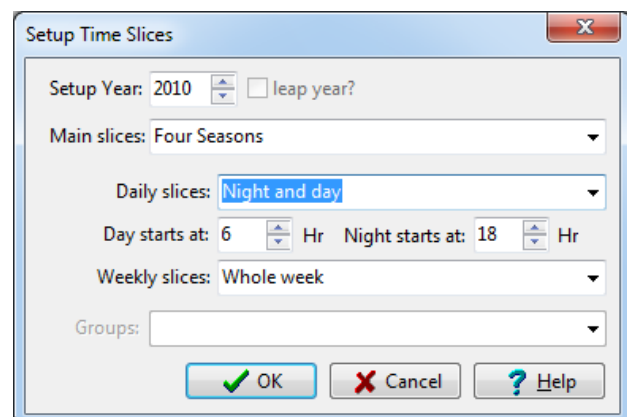
☐ Detailed: use a second screen to setup slices including seasonal/time of day data.

Year: 2010

OK Cancel Help

Set up the time slices as shown here so that the main slices are four seasons (spring, summer, autumn, winter) and the daily slices are day and night. In this exercise we will not use any weekly slicing.

Once you click OK, LEAP will generate the detailed set of time slices shown below. Each slice will include data describing its number of hours, its start and end dates and the days of the week covered by each slice. You can click the *More* button on the toolbar to see this detailed information. Notice that for non-leap years the total number of hours in all time slices will be 8760 hours. This automatically generated time slice data can be edited manually on this screen but typically that is not necessary, which is the case in this example. You can now return to the main screen.



Setup Time Slices

Setup Year: 2010 ☐ leap year?

Main slices: Four Seasons

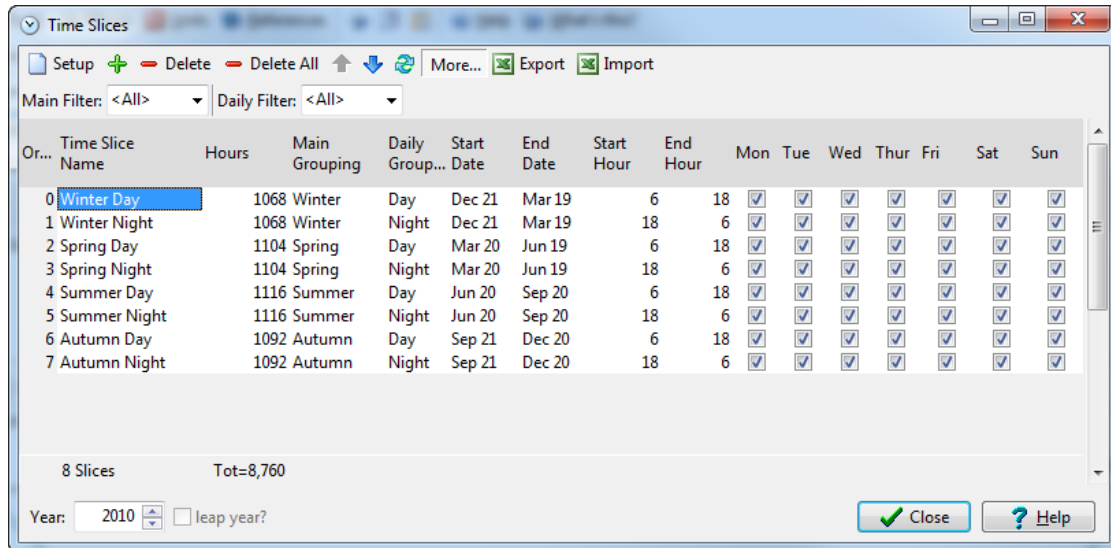
Daily slices: Night and day

Day starts at: 6 Hr Night starts at: 18 Hr

Weekly slices: Whole week

Groups:

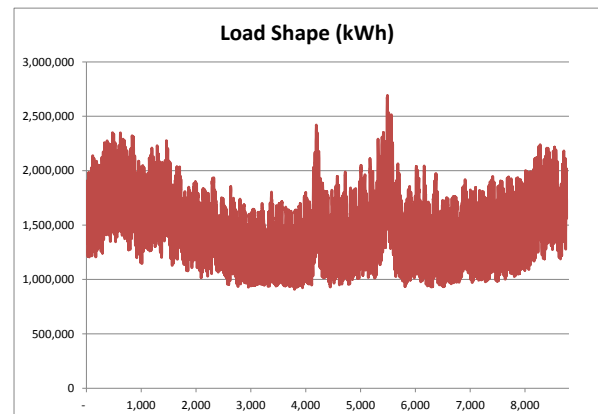
OK Cancel Help



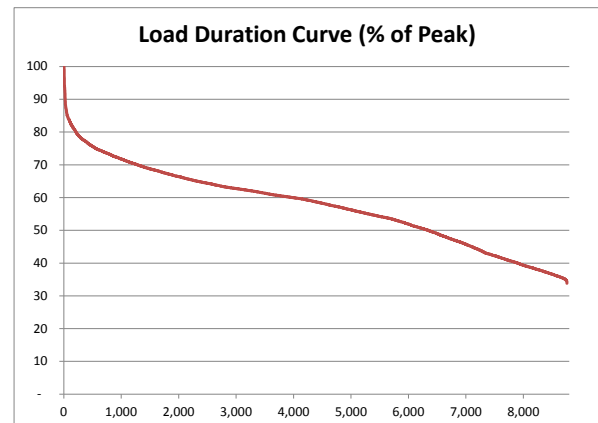
2. **Hourly Spreadsheet Data:** Next, open up a copy of Microsoft Excel and load the spreadsheet from the area folder, which typically is found here:

**Document\LEAP Areas\Optimization Exercise\Sample Load Shape.xlsx**


Notice that this spreadsheet contains hourly data for all 8760 hours of a single year, from the first hour of January 1<sup>st</sup> to the last hour of December 31<sup>st</sup>. The numbered hours are listed in the “Hour” column (column A) from 1 to 8760 while the corresponding electric demands are listed in the “kWh” column (column B). These values are plotted in the “Load Shape” chart in the spreadsheet (shown here). Notice the large variations both among seasons and between different times of the day and days of the week.

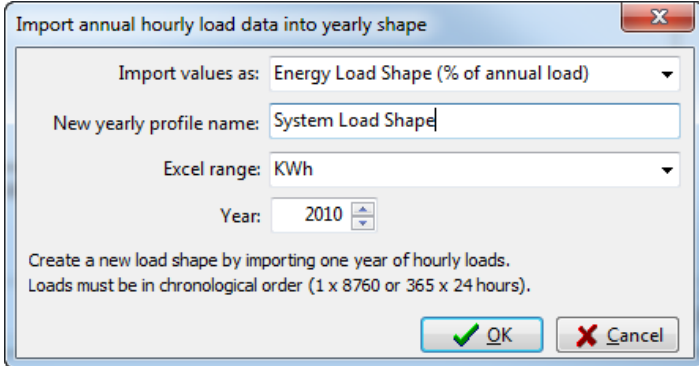


In columns C, D and E these same data have been reorganized by sorting the values from high to low and normalizing them in percentage terms against the annual peak value in order to produce a standard load duration curve that shows how demand varies from the hour with the highest demand to the hour with the lowest. This load duration curve is also shown here. Notice that as a result of the sorting operation, the load duration curve loses any information about seasons, days of the week or times of the day.





3. **Yearly Shape:** You will now import this hourly data into LEAP. Keeping Excel open, go to the General: Yearly Shapes screen and select the toolbar option  *Import Hourly Shape*. A dialog box will appear as shown here. Set this up to import values as an “Energy Load Shape (% of annual load)”, since this type of load shape is required when using optimization in LEAP. Choose the Excel range named “kWh” as the import range: this range contains the kWh values in column B of the spreadsheet. Finally, remember to enter a name for the new yearly shape. We suggest you name it “System Load Curve”.



Import annual hourly load data into yearly shape

Import values as: Energy Load Shape (% of annual load)

New yearly profile name: System Load Curve

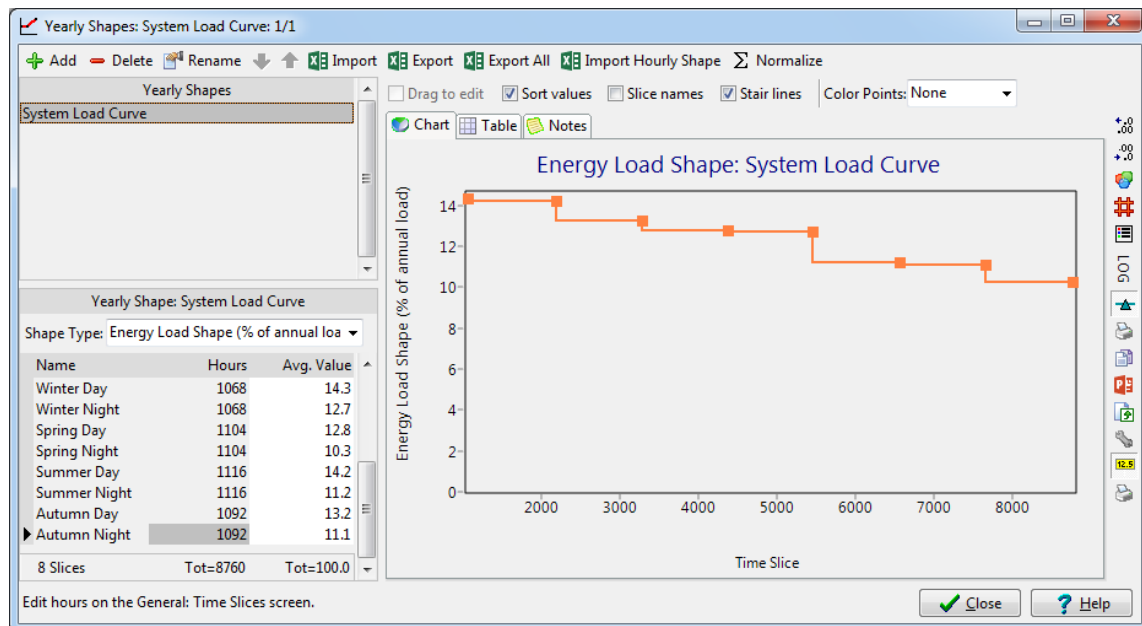
Excel range: kWh

Year: 2010

Create a new load shape by importing one year of hourly loads.  
Loads must be in chronological order (1 x 8760 or 365 x 24 hours).

OK Cancel

When you click OK, LEAP will import all of the hourly values in the spreadsheet and automatically map these values to the time slices you specified in step 1 above. The result will be a yearly shape that should look like the one shown below. Notice that in this screen shot we have used the chart options to organize the chart so that it shows values sorted from high to low.

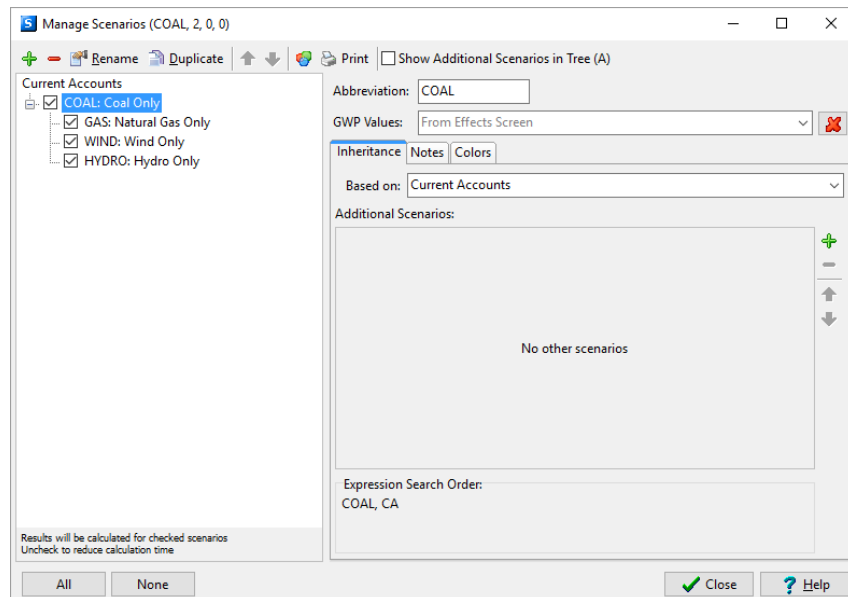


4. **System Energy Load Shape:** The final step in using this is data requires that you assign this newly created load shape to the **System Energy Load Shape** variable. Exit the **Yearly Shapes** screen and then in **Analysis View** locate the Transformation\Electric Generation branch. In Current Accounts, enter the following expression for the **System Energy Load Shape** variable:

**YearlyShape(System Load Curve)**

### 6.3 Simulation Scenarios to Explore Technology Characteristics

You are now ready to explore the costs and emissions associated with different technologies. Before exploring a least-cost scenario using LEAP's optimization features, let's first set up some very simple scenarios, each of which looks at just a single generation technology. Go to the **Scenarios** screen (S) and create a first scenario named "Coal Only" that inherits from your Current Accounts data.



Next create three more scenarios each of which directly inherits from the Coal scenario. Name these: "Natural Gas Only", "Wind Only", and "Hydro Only". Once these have been created, the **Scenarios** screen will look like the screen shown above. NB: to minimize data entry it is important that the three additional scenarios inherit directly from the Coal Only scenario.

Once you have created these four scenarios return to the main screen and then select the **Endogenous Capacity** variable for the Coal Only scenario. Use the *Add* button (+) on the right of this screen to add the Coal process to this list and enter the value of 100 MW for the *Addition Size Expression* for this variable.

Doing this tells LEAP that in this scenario LEAP should automatically add coal capacity whenever it is needed. In LEAP's standard **simulation** calculations, it is up to you to tell LEAP *what* types of power plants to add, although LEAP will decide *when* to add them. Later on, when we come to use LEAP's optimization calculations, you will see that LEAP will decide both of these questions: *what* processes to add and *when* to add them.

Repeat this same process for the three other scenarios: Natural Gas Only, Wind Only, and Hydro Only. In each case, add only the one process relevant for that scenario, and using 100 MW as the *Addition Size Expression*.

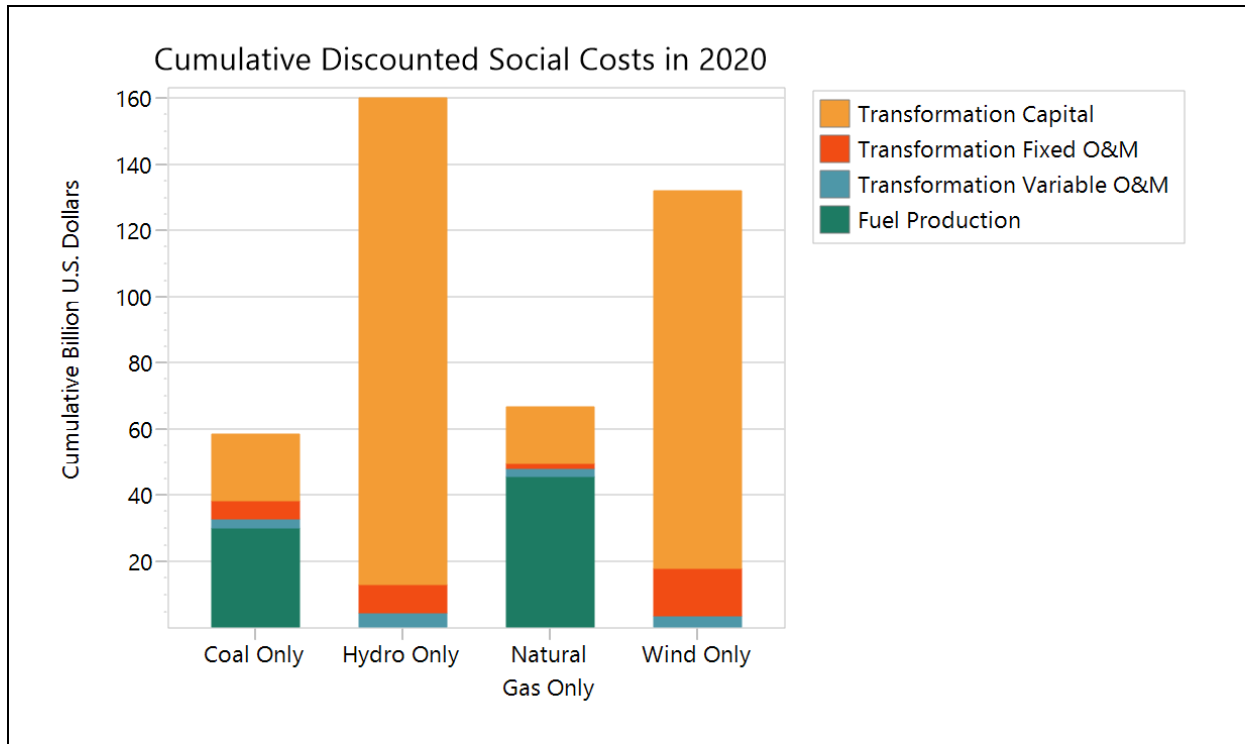
### 6.3.1 Results

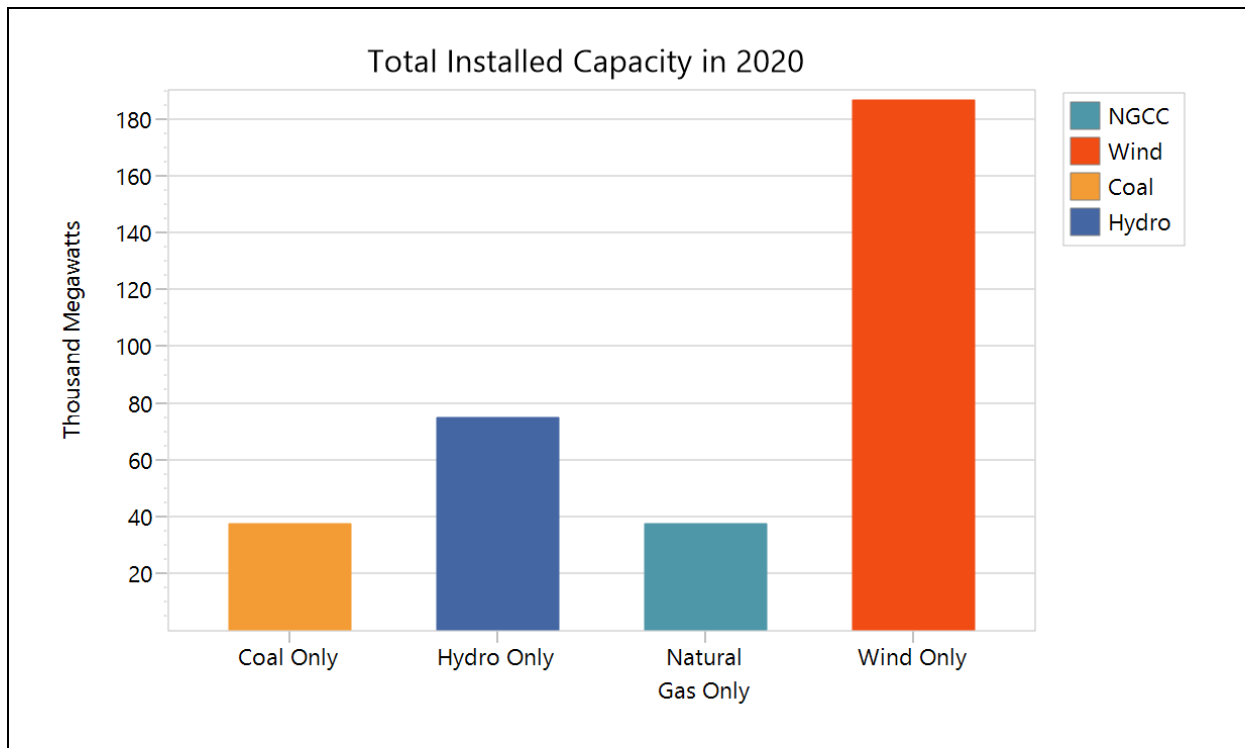


You are now ready to see some results for these scenarios. Go to the **Results View** and create two different charts as follows:

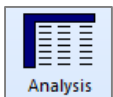
1. **Social Costs:** First create a chart comparing the total cumulative, discounted social costs in 2020 (at the top area branch) for each scenario. Make sure you configure the chart to show *All Scenarios* on the X-axis and *All Social Cost Categories* in the legend. Save this chart as a favorite chart called “Costs by Scenario”.
2. **Capacity:** Next create a chart showing total installed capacity in 2020 in each scenario. Save this chart as a favorite chart called “Capacity by Scenario”.

These two charts should look like those shown below:





## 6.4 Incorporating Externality Values

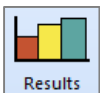


The results you obtained above are influenced by the fact that we have so far ignored a crucial factor: the damage costs associated with pollution associated with burning fossil fuels. These costs are often ignored because they are not directly monetized in most energy systems. However, they are a real cost and cause real economic impacts such as damage to human health and crops.

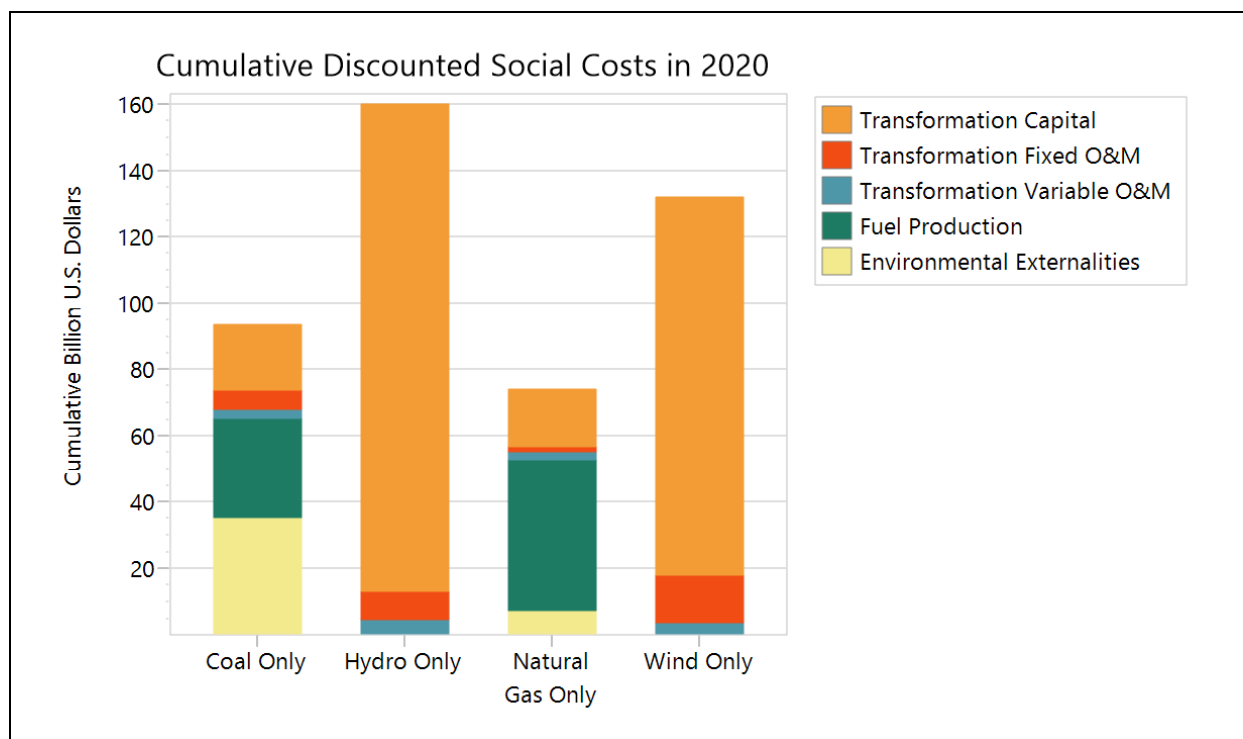
Next you will enter data that describes these externality values. Go back to the **Basic Params** Costing screen and make sure that *Environmental Externality Costs* is checked on. Now return to the **Analysis View** and under the top level “Effects” branch in the tree, add two new branches for the effects nitrogen oxides (NO<sub>x</sub>) and sulfur dioxide (SO<sub>2</sub>).

Externality	
Pollutant	Value (\$/kg)
NOx	7
SO2	2

Now in the **Externality Cost** variable, enter the externality values given in the table above in \$/kg. Enter this data for the Current Accounts scenario so that these externality values are used by all of the scenarios.



Now select the **Results View** again. Once LEAP has recalculated its results, show the favorite result **Costs by Scenario**. You should see a chart like the one below. Notice that LEAP has now calculated a new set of costs corresponding to externality costs.

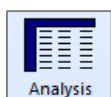
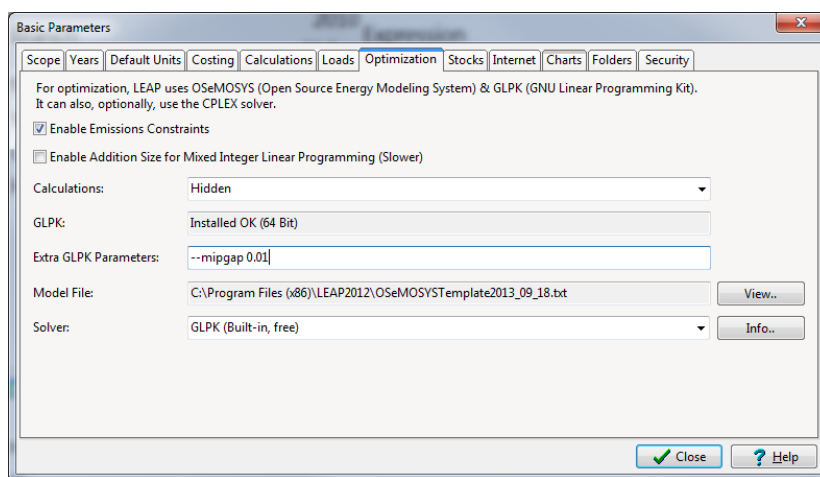


## 6.5 Using Optimization to Identify a Least-Cost Scenario

You are now ready to try out LEAP's optimization capabilities. These will allow LEAP to automatically decide what combination of power plants will meet demands at the lowest cost.

First, visit the Optimization tab in **Basic Params** and check that optimization is properly installed within LEAP. You should see a screen like the one shown on the right.

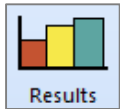
Now set up a new scenario in which you can use these optimization features. Go to the **Scenarios** screen and create a new scenario called "Optimization" that inherits directly from Current Accounts.



Return to the main screen in analysis view and select the Optimization scenario. You only need to set a simple setting to use optimization since you have already entered all of the basic data needed by the optimization calculations. LEAP will automatically make use of the same data you already entered in your simulation calculations.

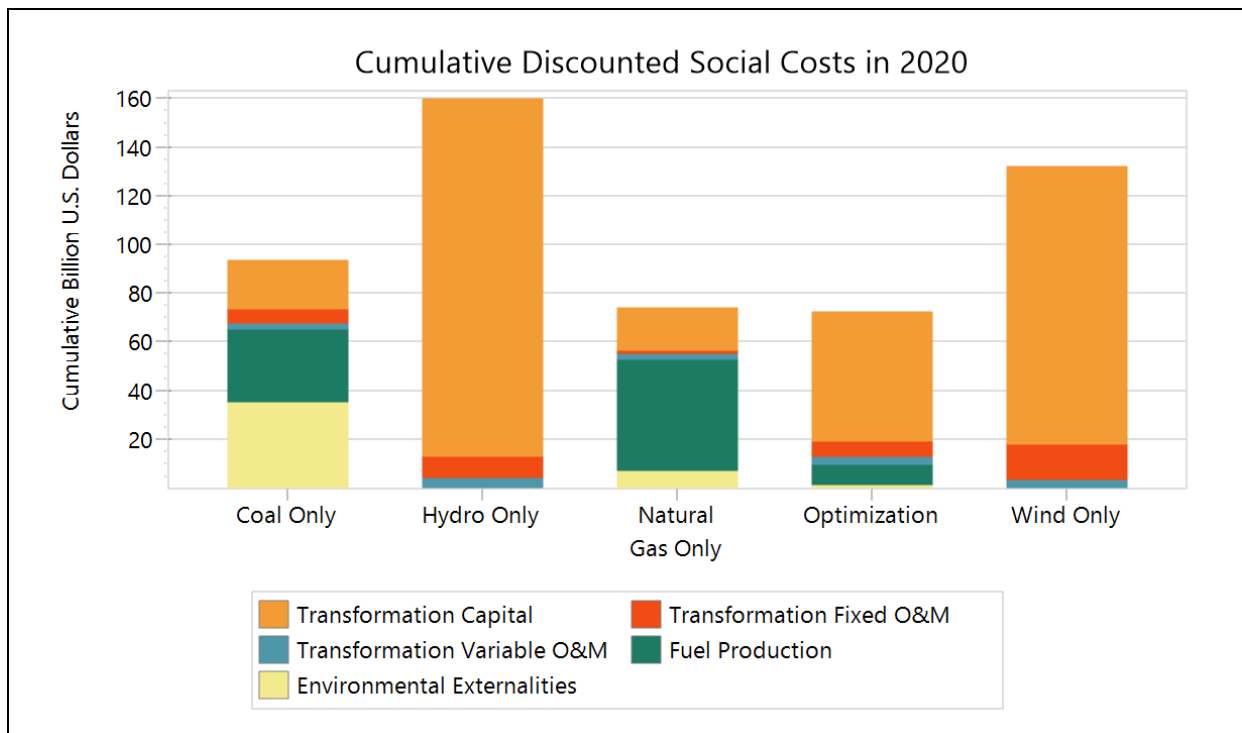
Select the Transformation\Electric Generation branch and then select the **Optimize** variable. Change its value from *No* to *Yes*. If you don't see this variable, check that you are currently editing the Optimization scenario (this variable does not appear in Current Accounts).

Note also that you don't need to set the **Dispatch Rule** for this scenario, since LEAP will use the optimization calculations to decide how much to dispatch each process. Thus, the **Dispatch Rule** is hidden for any scenarios using optimization. That's all you have to do!



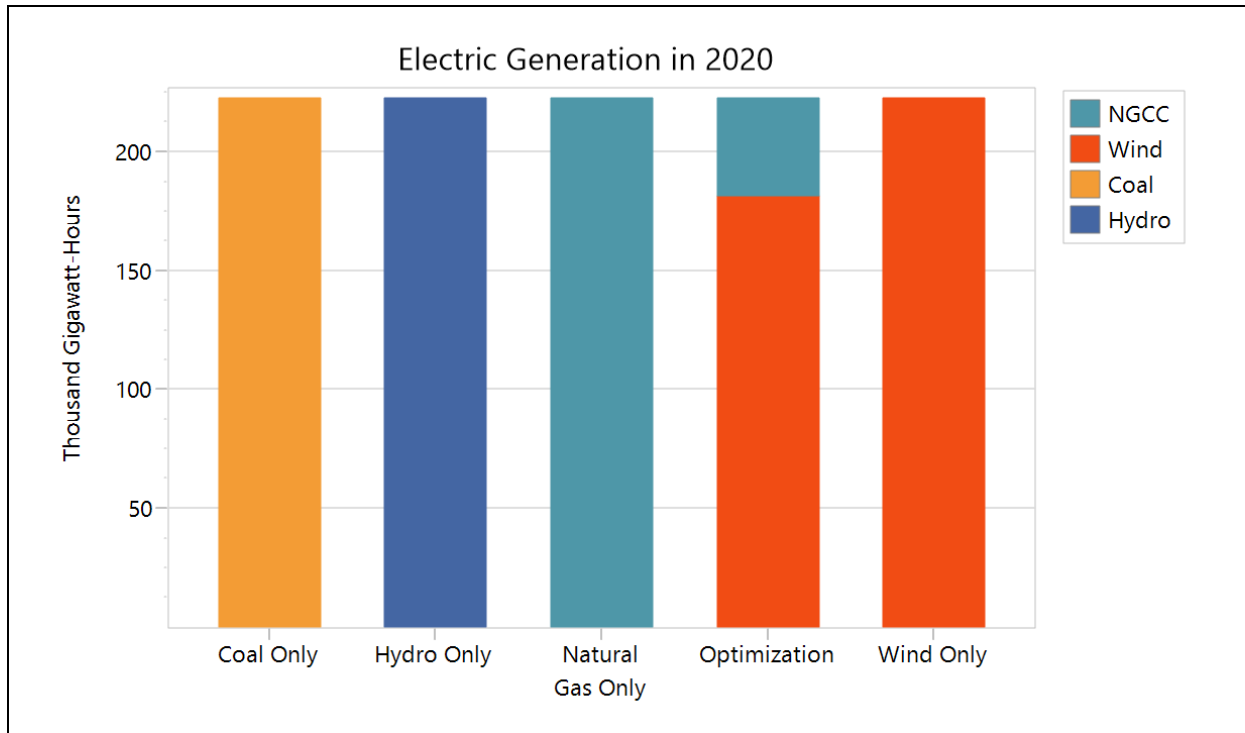
Now select the **Results View** again. LEAP will again recalculate its results. You may notice that during its calculations LEAP's calculations will appear to pause during which time it will run the OSeMOSYS optimization model, which is used to calculate the optimization scenario.

Once calculations are complete you can again show the favorite result Costs by Scenario. You should see a chart like the one show below. Notice that LEAP has now created results for this new optimization scenario. You should see that total social costs are slightly cheaper than even the cheapest of the other scenarios you created previously.





To see how this is possible, let's look at another chart showing **Transformation: Outputs by Output Fuel** by process for each scenario in 2020.



Notice that unlike in the other single-technology simulation scenarios, in the Optimization scenario LEAP has chosen a mix of power plants. Since the load shape we entered earlier varies by season and time of day there will be some periods where a very high peak demand exists. These periods favor power plants that are relatively cheap to build but expensive to operate (NGCC). Base load periods favor power plants that are more capital intensive but which have low running costs (e.g. wind).

## 6.6 Using Constraints to Specify a CO<sub>2</sub> Cap

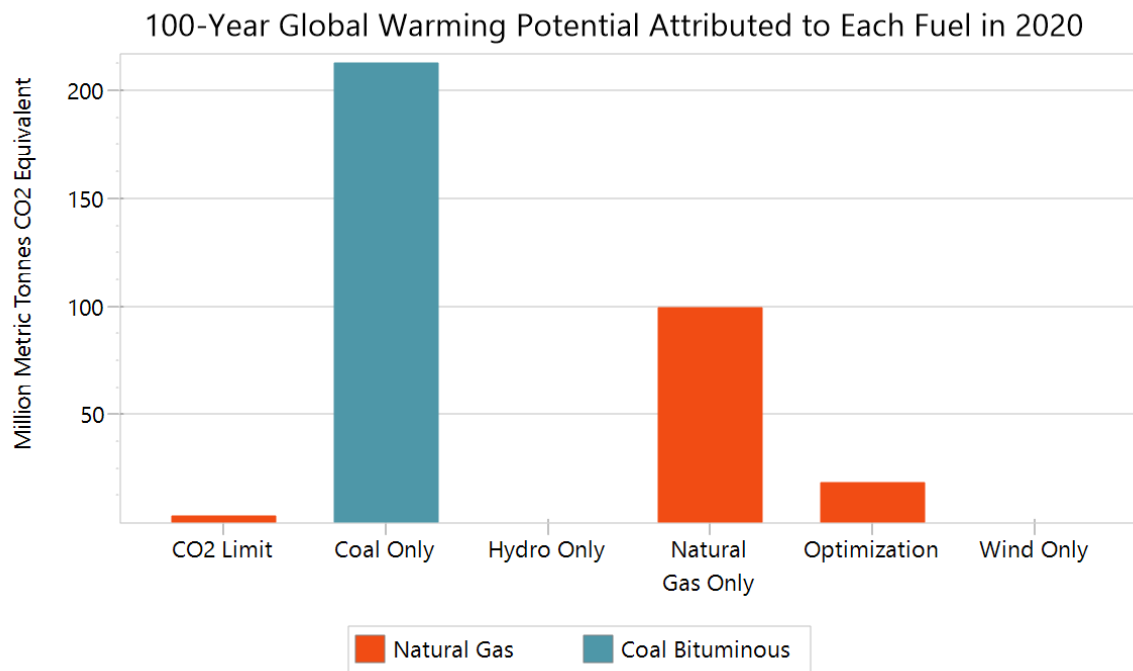
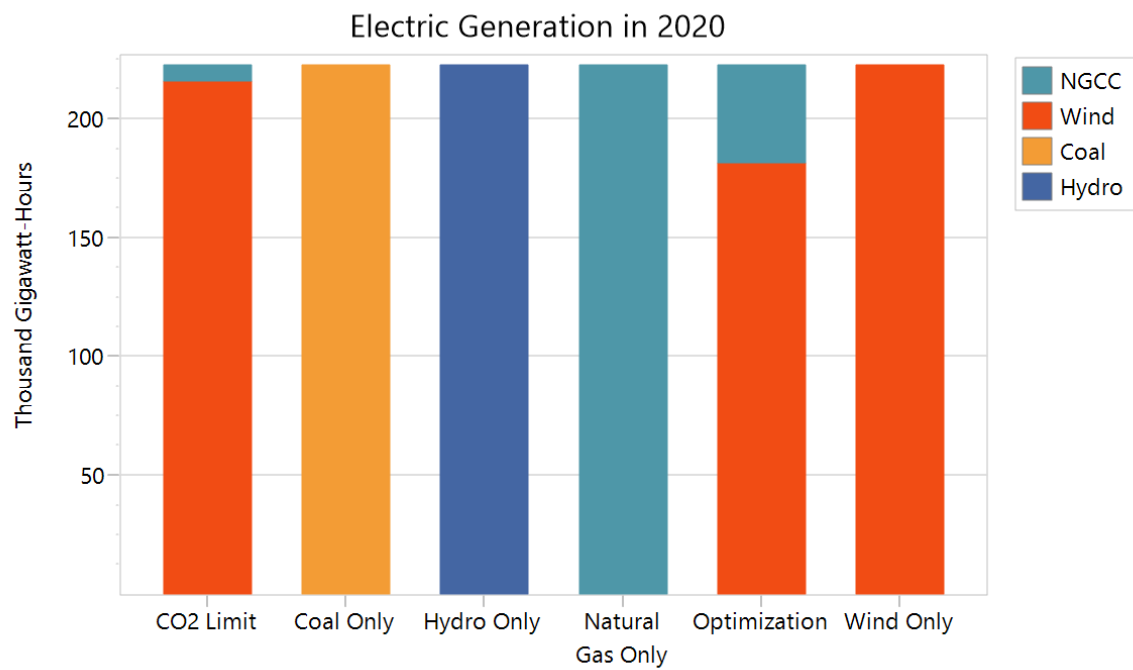
In this next exercise you will create an additional scenario that looks at how the least cost choice of technologies will change if a maximum level of CO<sub>2</sub> emissions is imposed on the system.

To create an emissions constraint, first return to the Optimization tab in **Basic Params** and make sure that the *Enable Emissions Constraints* box is checked on.

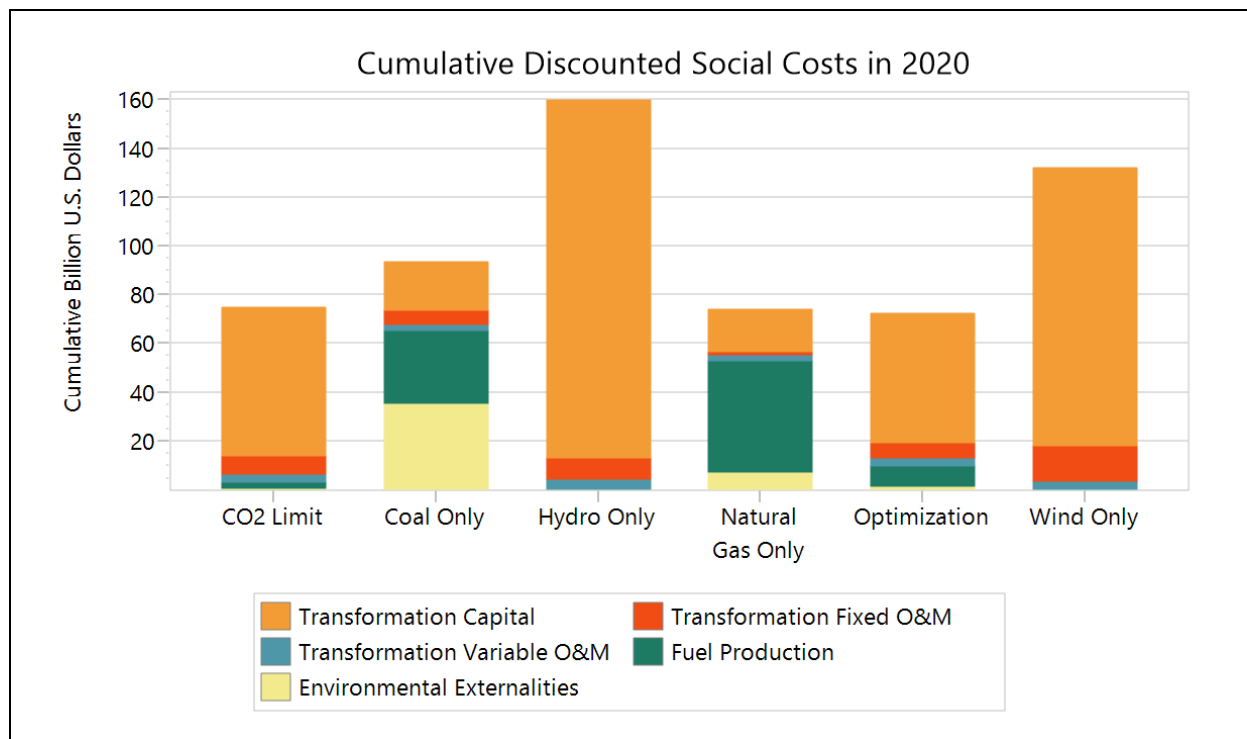
Now return to the main screen and add a new effect under the Effects branch for Carbon Dioxide. For Currents Accounts and all existing scenarios, no constraint is needed so simply leave the default *Unlimited* expression in the **Annual Emission Constraint** variable.

Next, go to the **Scenarios** screen and create a new scenario called “CO<sub>2</sub> Limit” that inherits from the Optimization scenario. Return to main screen and for this scenario enter a value of 3 Million Metric Tonnes in the **Annual Emission Constraint** variable for Carbon Dioxide.

Finally, select **Results View** again and look at results for electricity generation, total GHG emissions and total social costs. You should see charts like those below.







## 6.7 Using Your Own Data

Now go back and review the capital, O&M and fuel costs used in this exercise, as well as the technical parameters including lifetime, efficiency, maximum availability and capacity credit.

Bear in mind that the values used in this exercise are only sample values: they are not necessarily intended to be realistic (and of course you should not use them in any real study!)

- How do these values compare to the costs of electric generation in your country?
- Try replacing the capital and fuel costs used in this exercise with your own data (if available). How does the optimal mix of power plants change?
- Finally, think about which of these variables are likely to change in the future. For example, you may want to consider how many renewable technologies such as solar and wind energy have been getting significantly cheaper in recent decades, while fossil fuel prices (especially oil) generally have been rising. Try entering some growth expressions to describe these trends. What impact do these changes have on the optimal mix of power plants?