LEAP

Low Emissions Analysis Platform

Training Exercises

(Now with links to video walk-throughs on LEAP YouTube Channel)

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TRAINING EXERCISES FOR LEAP

Introduction

These training exercises will introduce you to LEAP, the Low Emissions Analysis Platform, 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. A video walk-through of exercise 1 is available at: https://youtu.be/cW87lWDABgc.

- **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 to 2 to 4 days to complete fully. Video walk-throughs of these exercises are available at: https://youtu.be/brSaqo0cV8I (exercise 2) and https://youtu.be/MwIqXQW1t8E (exercise 3)

- **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. A video walk-through of exercise 4 is available at: https://youtu.be/au99KzpHmio

- **Exercise 5** demonstrates how LEAP can be used to examine non-energy sector greenhouse gases, using the examples of high global warming substances such as HFCs and methane from agriculture. This exercise also shows how to import data from Excel and introduces the use of "user variables", as a way of extending the capabilities of LEAP. Exercise 5 builds upon Exercise 4. A video walk-through of exercise 5 is available at: https://youtu.be/tHD3TifBhAk

Each of these five 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 6** 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 this exercise without having completed any of the previous exercises.

- **Exercise 7** 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_2 emissions – including how a cap might alter the set of technologies chosen and the overall costs of a scenario. You can begin this exercise without having completed any of the previous exercises.

Hardware Requirements: To complete these exercises, you will need a standard Windows-based computer with at least 2 GB of RAM and with Microsoft Windows 7 or later 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 with LEAP

If LEAP is installed, start LEAP from the desktop icon or the Windows Start menu. If not, run the installation program directly from the setup.exe file or download and run LEAP from https://leap.sei.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 https://leap.sei.org/license.

The main screen of LEAP consists of seven 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 above the tree to switch views.*

- The **Analysis View** is where you enter or view data and construct your models and scenarios.
- The **Results View** is where you examine the outcomes of the various scenarios as graphs and tables.
- The **Energy Balance View** lets you see energy results calculated in LEAP as specially formatted energy balances and Sankey diagrams.

For information on the other views, click on Help.

The Analysis View
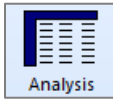
The **Analysis View** (shown below) contains a number of controls apart from the view bar mentioned above. On the left is a tree in which you view or edit your data structures. On the right are two linked panes. At the top is a table in which you edit or view data and create the modeling relationships. Below it is an area containing charts and tables that summarize the data you entered. Above the data entry 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 menu and toolbar give access to major options.

Data are organized in a tree.

Edit data by typing here.

Select scenarios here.

Switch between views of the Area here.

Select units and scaling factors here.

The status bar notes the current Area and View.

Data can be reviewed in chart or table format.

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 normally have an energy intensity associated with them. Demand technology branches appear differently depending on the type of demand analysis methodology chosen. These methodologies are activity analysis (⚙), total energy consumed (✳), stock analysis (🔋) and transport analysis (⚫). In the first exercise, you will conduct an activity level-based analysis using technology branches (⚙). Later, in exercise six, you will conduct a transport analysis using transportation technology branches (⚫).

- 🄺 **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 contains data for the historical years in your study. Different scenarios in LEAP all begin with the same Current Accounts information. 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 (⑤)**. 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**).

1   Introduction to LEAP

A video walk-through of exercise 1 is available at: https://youtu.be/cW87lWDABgc.

1.1   Overview of Freedonia

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 several 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   Settings

[1] Before beginning the exercises, edit the settings 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 **Settings** screen ( ) under the **General** menu option. In the Years tab, choose 2010 as the *Base Year*, 2011 as the *First Scenario Year* and 2040 as 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 with their default values. Note: in this exercise, you will be using only one year of historical data (2010).

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[1] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=151

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 Baseline 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

[2] The first step in an 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 do not 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.

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[2] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=265

First Sketch of Demand Tree	Second Sketch of Demand Tree

After reading though 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* (⚙️).
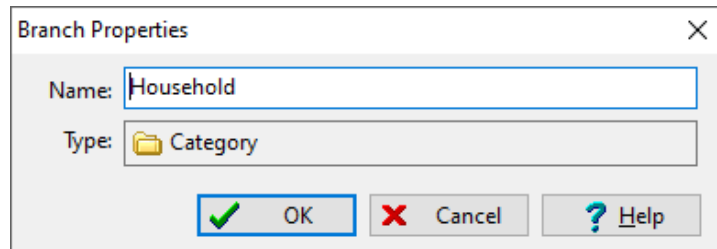
1.3.2 Current Accounts

In the year 2010, Freedonia's 40 million people are living in 8 million households. Of these households, 30% are in urban areas.

Urban Households

- 30% of urban households 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.
- All urban households use electricity for lighting. The average urban household annually consumes 400 kWh for lighting.
- 95% of urban households have refrigerators, which consume 500 kWh per year on average.
- Other devices such as computers, televisions, and fans annually consume 800 kWh per urban 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 **Final Energy Intensity** for each branch (scaling factors can be left blank).*

> *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. 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.*

For stoves, specify "Share" as the unit of activity for each cooking stove (natural gas or electric), and enter 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 3: *Expressions entered into the **Final Energy Intensity** variable are interpreted by LEAP as annual values. For example, this means if you enter a value of 400 kWh per household, LEAP will understand this as 400 kWh per household, per year.*

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 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
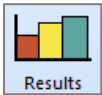
[3]Click on the **Results View** to check your results for Current Accounts. Notice that at this stage we will only be viewing result for a single base year: 2010. Results can be viewed in either chart or table format. For this exercise, click on the Table tab at the top of the display window. On the 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 option. 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 set the number of levels to three (both of these options are in the toolbar at the top of **Results View**).

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[3] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=1548

Current Accounts Energy Demand in 2010 (Million GJ)
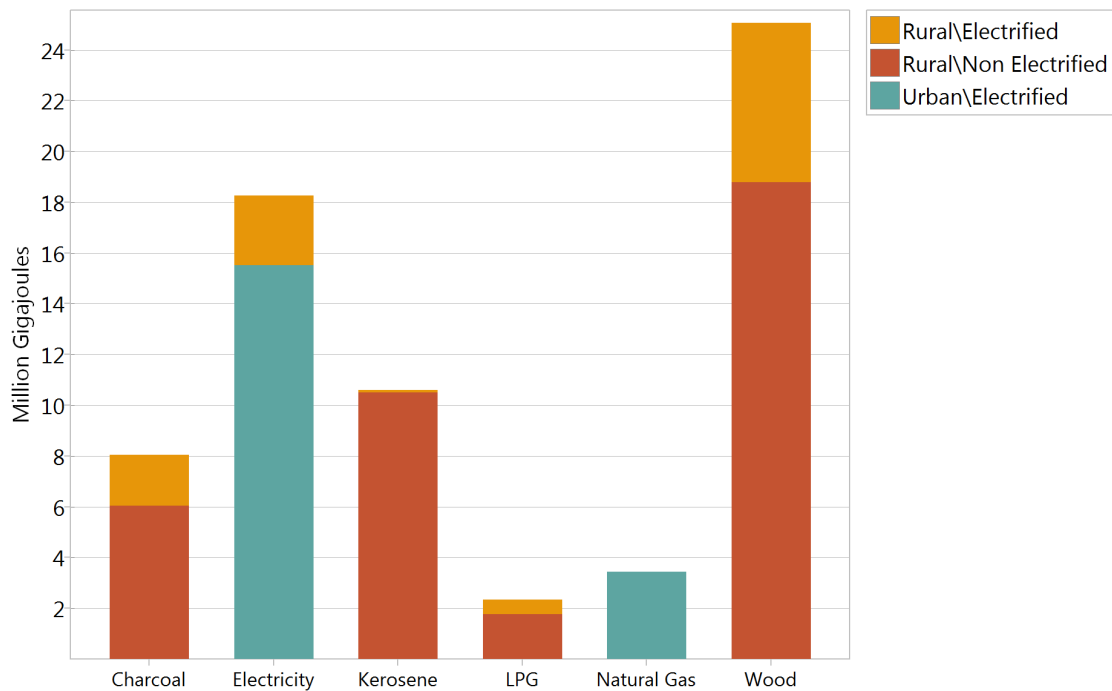
*Hint: to get this chart in **Results View**, select* All Fuels *on the X-axis and* All Branches *on the legend. Show two levels of detail for branches.*

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 1.3.3

1.3.4 Baseline Scenario

[4] 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 Scenarios screen to add a first scenario. Give it the name "Baseline" 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 screen and, if necessary, select the Baseline 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.

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[4] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=1717

*Hint: To enter a growth rate, press **Ctrl-G** or click on the* *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 create an* Interp *function 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 your computer's 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**.*

1.3.5 Baseline Results

[5] Click on the **Results View** again and 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.

Energy Demand by Fuel in the Baseline Scenario (Million GJ)
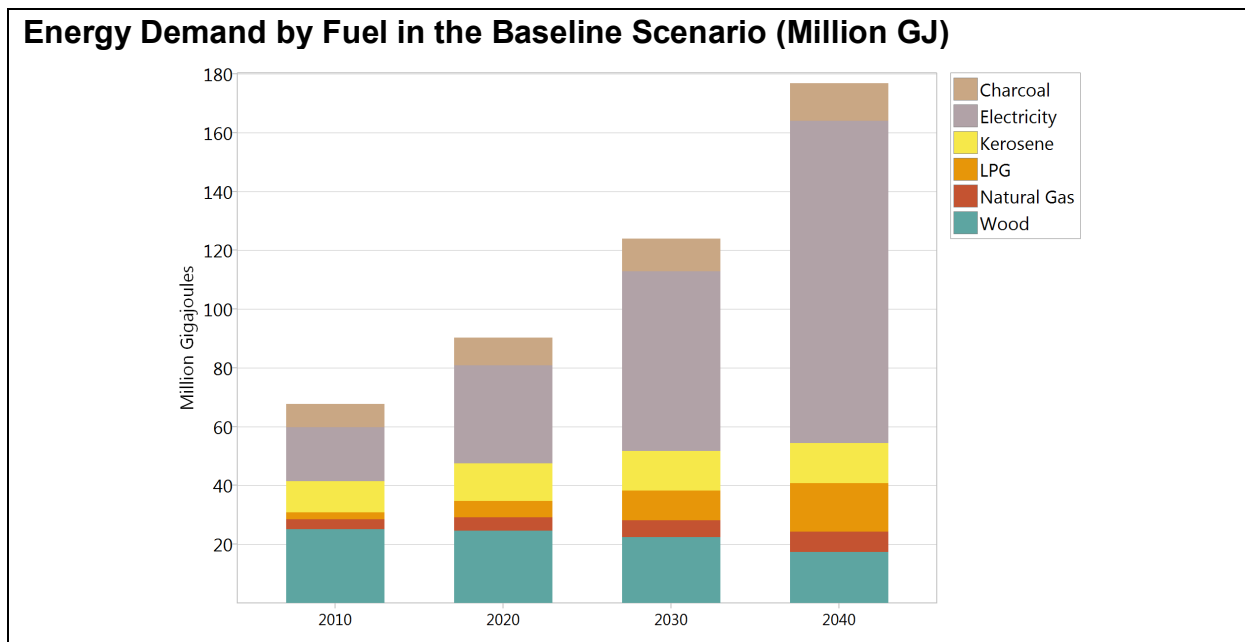
Compare your projections with the tables shown below (note that tables in LEAP are formatted slightly differently than those shown here, but you should be able to find all of the relevant information by adjusting the number of branch levels). Start by checking results at the highest levels (i.e. start 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 in the Baseline Scenario (Million GJ)

By Fuel

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

By Branch

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

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 1.3.4.

> *Explore different results in LEAP and try to answer the following questions:*
>
> *1. What is the share of electricity use in urban areas and rural areas in 2010? How does this change in 2040?*
>
> *2. What end-use predominates residential electricity consumption in 2010 and 2040?*
>
> *3. Overall, does the energy use of biomass (wood and charcoal) increase or decrease? To what extent?*

1.4 Transformation

[6] 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:

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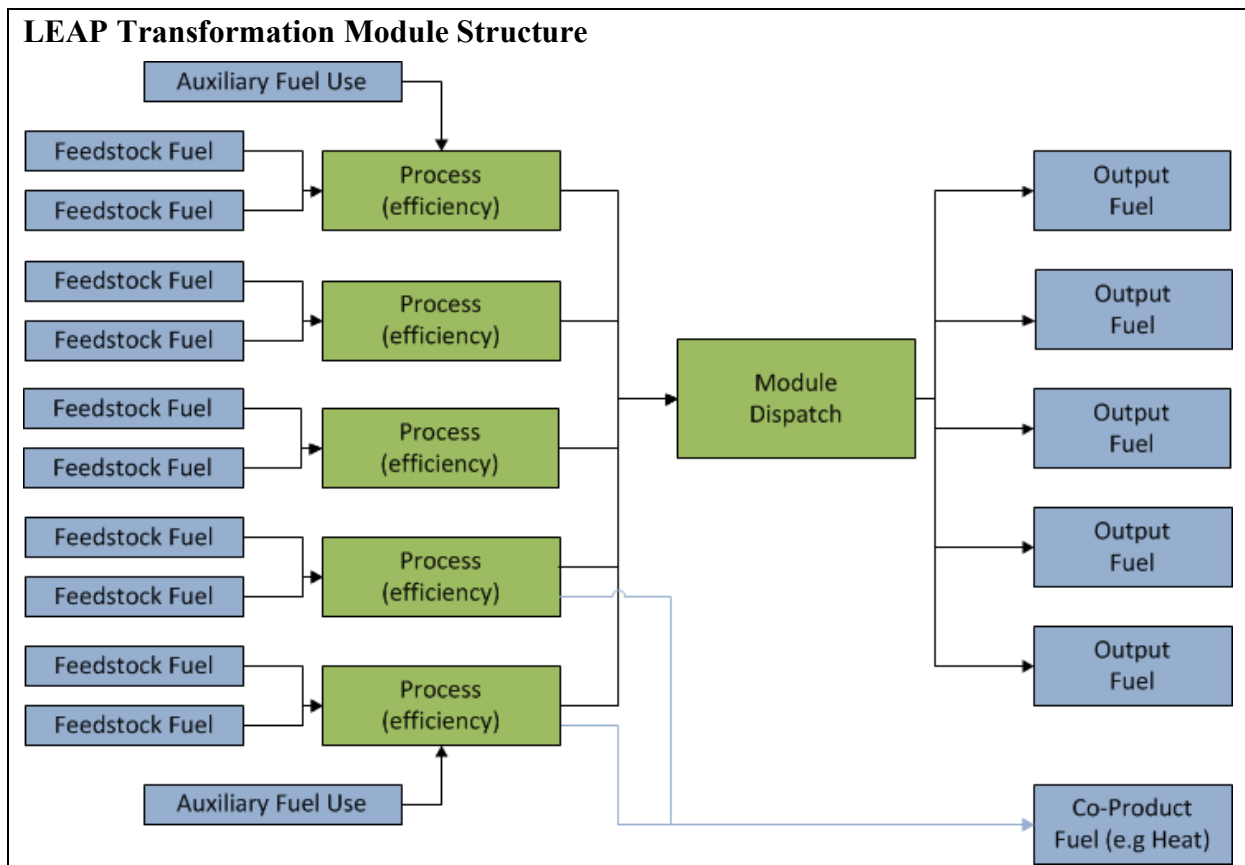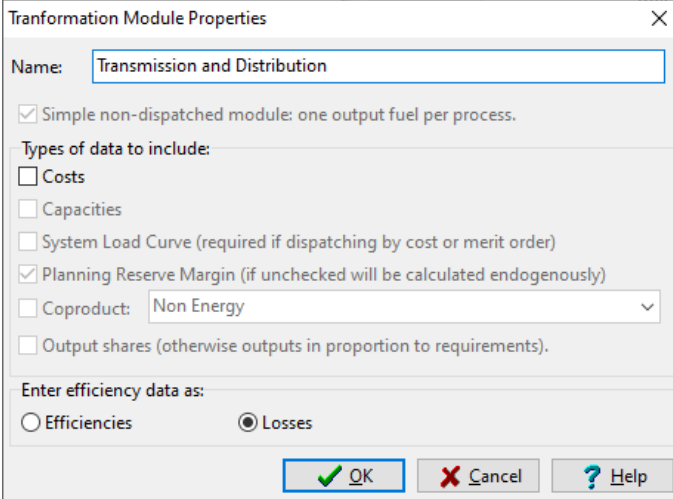
In this exercise you will develop a simplified model of the electricity transmission and generation sectors in Freedonia. This model will be the basis for the more detailed and realistic model you will create in Exercise 3.

Return to the **Settings** screen ([icon]) 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

[7] 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 Baseline 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 Baseline scenario.

To create a simple module, right-click

on the Transformation branch on the Tree and select the *Add* command ([icon]). 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 Baseline scenario and use the* Interp *function to specify how electric losses change over time.*

---

[7] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=2587

1.4.2 Electricity Generation

[8]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.

Make sure that you set correct *Properties* (🖼) for Electricity Generation module (see above). Since you will be specifying data on plant Capacities, Efficiencies, and a System Load Curve, be sure that these items are checked. Also check the Planning Reserve Margin option. For now, you can leave costs unchecked. You will enter cost data later.

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 **Dispatch Rule** to *MeritOrderDispatch* 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.

---

[8] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=2780

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 here.
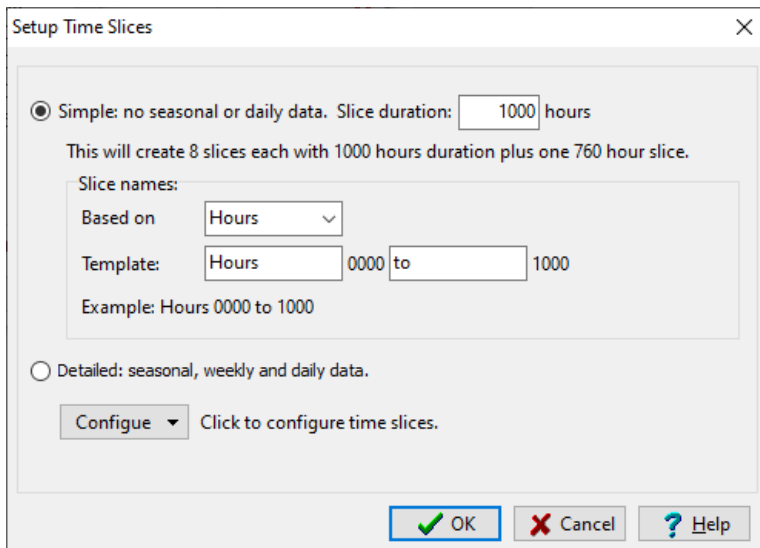
The time slices screen should then look like this:
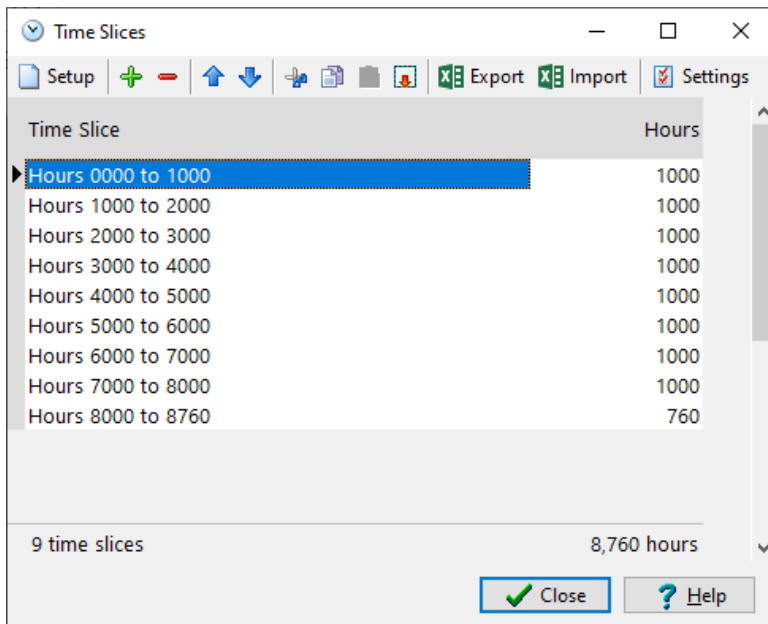
2. Next, you need to create a yearly load shape with values for each of the hourly slices you just specified. To do this, go to the General: Yearly Shapes screen (shown below)

and enter a "Peak Load Shape" for the entire system. Enter the values as shown in the screen below. We suggest you call the shape **SystemShape**
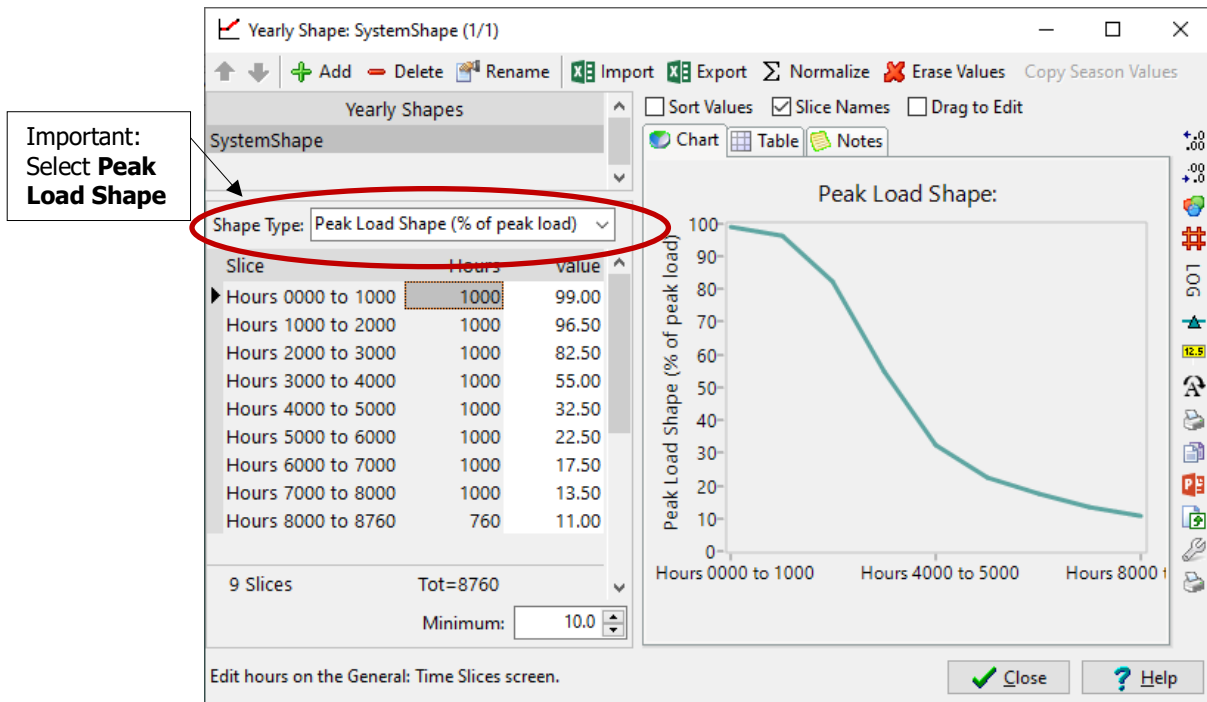
Hint: The value in hour 0 implicitly is always 100%. This does need to be entered explicitly. Make sure you enter the minimum value of 10% in the Minimum: *box at the bottom of the screen, which corresponds to the hour 8760.*

3. Finally, return 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 ![E] button attached to the expression field and select the *YearlyShape: SystemShape* option, or simply type the expression YearlyShape(SystemShape).

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

1.4.2.1 The Baseline Scenario

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

- In the Baseline 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 *MeritOrderDispatch* (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 Baseline 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 Build Order	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

[9] Click on the **Results View** to see the results of the Baseline 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: Baseline Scenario (Thousand TWh)
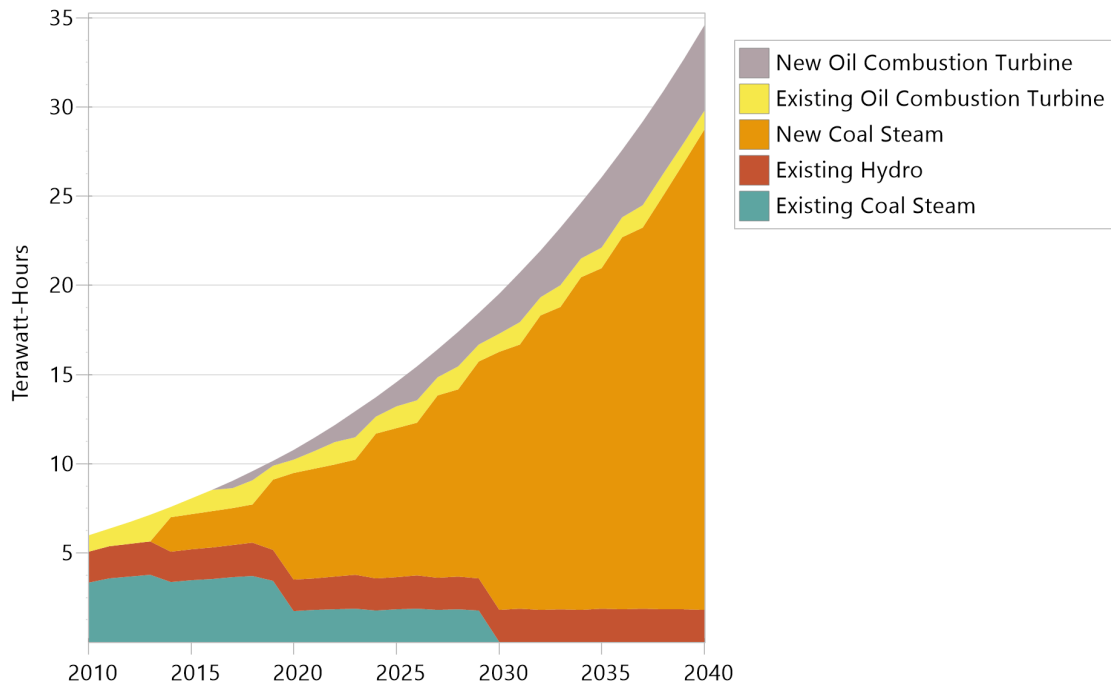
Notes: base year = 5.97 TWh, 2040 = 34,58 TWh

*Hint: To get this chart, click on the Processes under the Electricity Generation module in the Tree, select **Transformation: Outputs by Output Fuel**. Next, on the chart legend, select All Branches. Use the chart toolbar on the right to select an area chart. Finally, make sure units are set to Terawatt-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**.*

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[9] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=3722

Electricity Generation Capacity: Baseline Scenario (MW)
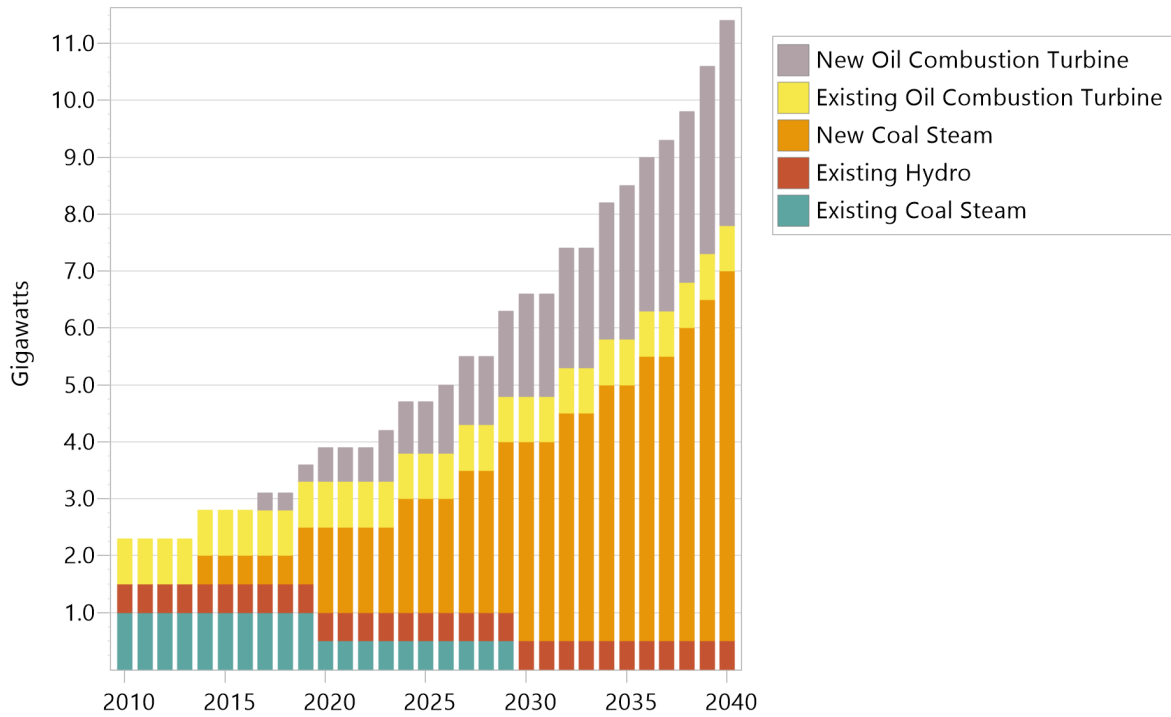
Notes: base year = 2300 MW, 2040 =11,400 MW

Reserve Margin (%)
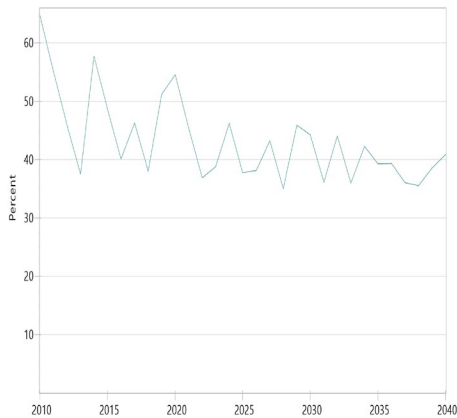
Power Dispatched in 2040 (MW)
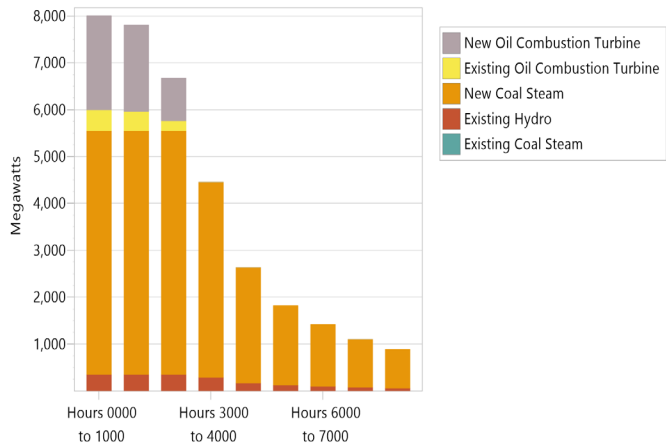
Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 1.4.3.

1.5 Emissions
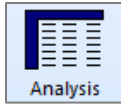
[10] You will now use LEAP to estimate the emissions of major pollutants in the Baseline scenario. To do this, first you must return to **Analysis View** and go to **Settings** to switch on Energy Sector Effect Loadings. Now select Current Accounts and then create *Effect* branches immediately under each relevant demand technology (those marked with the ⚙ icon) and under each relevant Transformation feedstock fuel (those marked with the 🟡 icon).

You can create these branches by selecting from the default IPCC Tier 1 emission factors stored in the TED database. To do this, right-click on a technology and then select the *Add multiple effects* option (✥). This will display the box shown on the right.
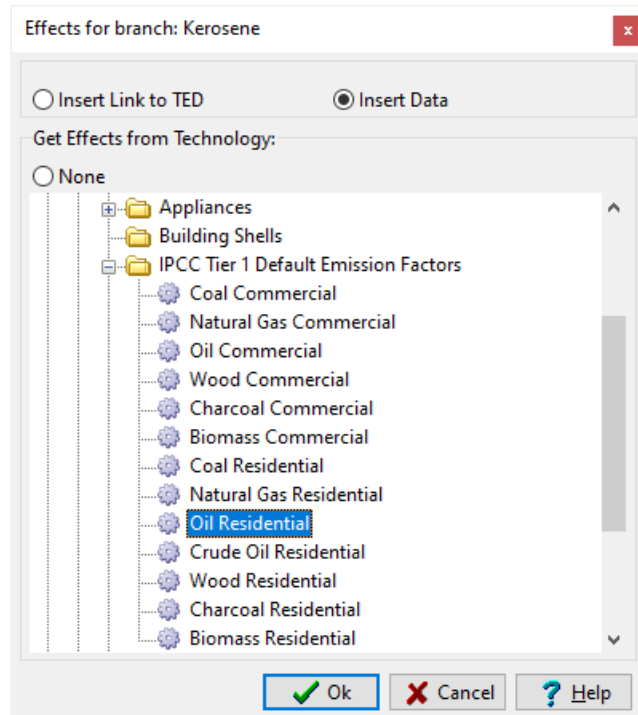
Make sure the input fuels to the TED technology are similar to fuels used by the LEAP technology. In some cases, the IPCC Tier 1 technologies do not contain entries for all fuels. In this case you will need to pick the closest matching entry (e.g. the IPCC "Oil Residential" category can be linked to 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).

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[10] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=3910

1.5.1 Viewing Results

[11] Click on the **Results View** to see environmental results for the Baseline 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.
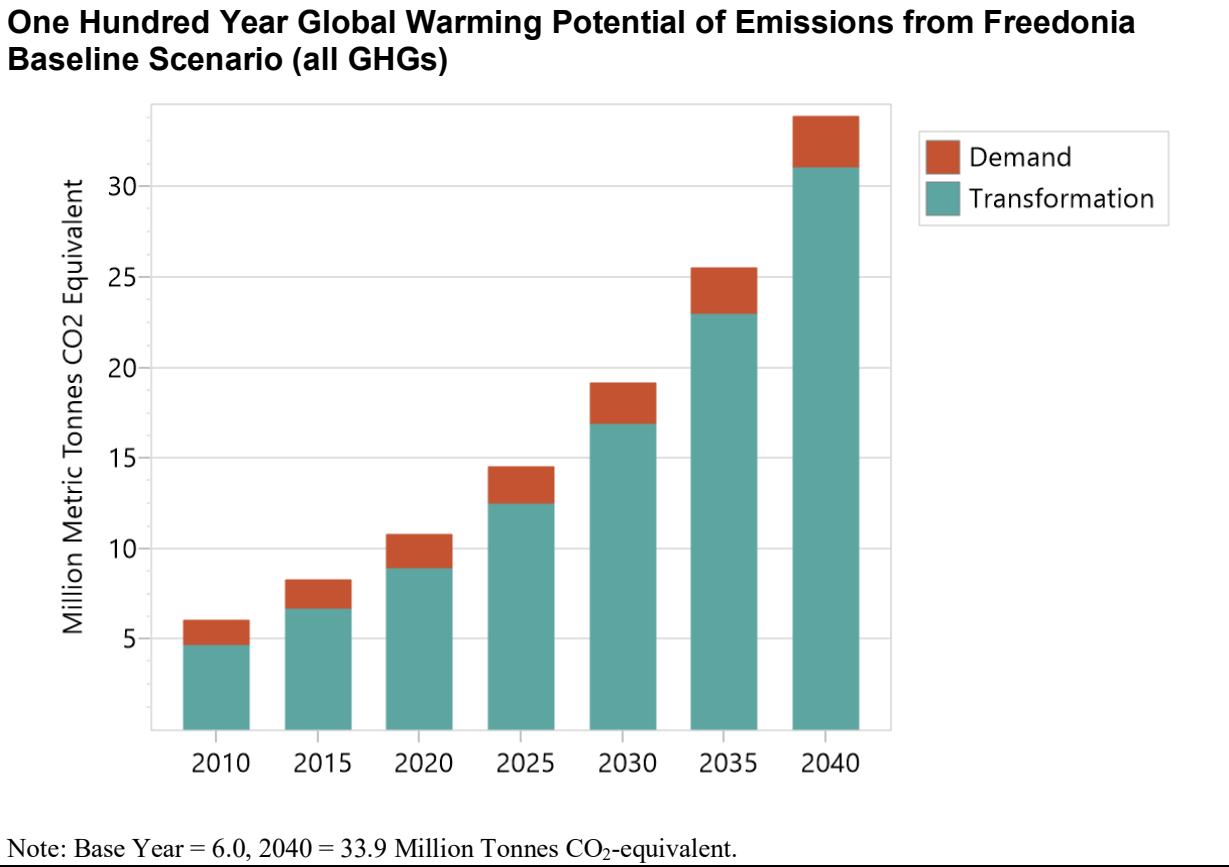
One Hundred Year Global Warming Potential of Emissions from Freedonia Baseline Scenario (all GHGs)

Note: Base Year = 6.0, 2040 = 33.9 Million Tonnes CO_2-equivalent.

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 1.5.1.

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[11] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=4221

1.6 A Second Scenario: Demand-Side-Management

[12] 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 Baseline scenario so that by default it inherits all of the Baseline scenario assumptions and modeling expressions.
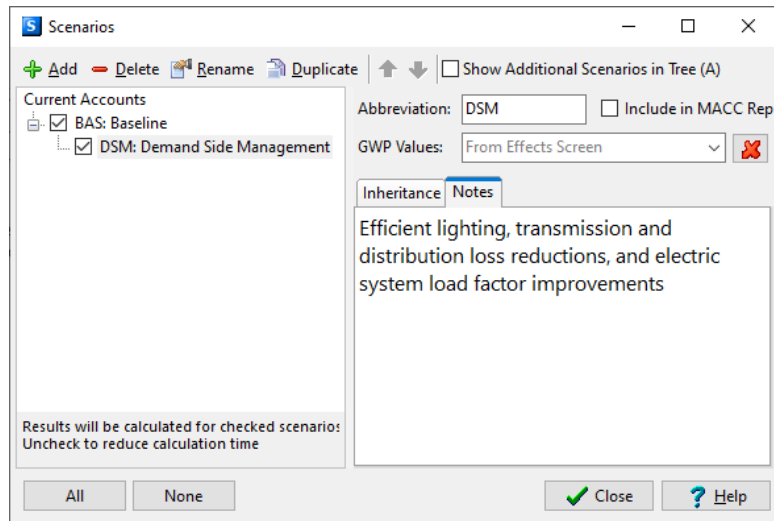
Give the new scenario the name "Demand Side Management", the abbreviation "DSM", and add the following notes: "Efficient lighting, transmission and distribution loss reductions, and electric system load factor improvements."

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% (Baseline scenario) to 0.3% per year (+0.3%/year).

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[12] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=4326

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 and named DSMShape.

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 "DSMShape" (see section 1.4.2 to remind you how to do this), which will represent the load shape of the system in 2040. Then, you will have to tell LEAP to interpolate between the base and end year load curves. 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: DSMShape *or enter expression* YearlyShape(DSMShape). *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).*

Interpolation of System Load Curve through 2040 for DSM Scenario
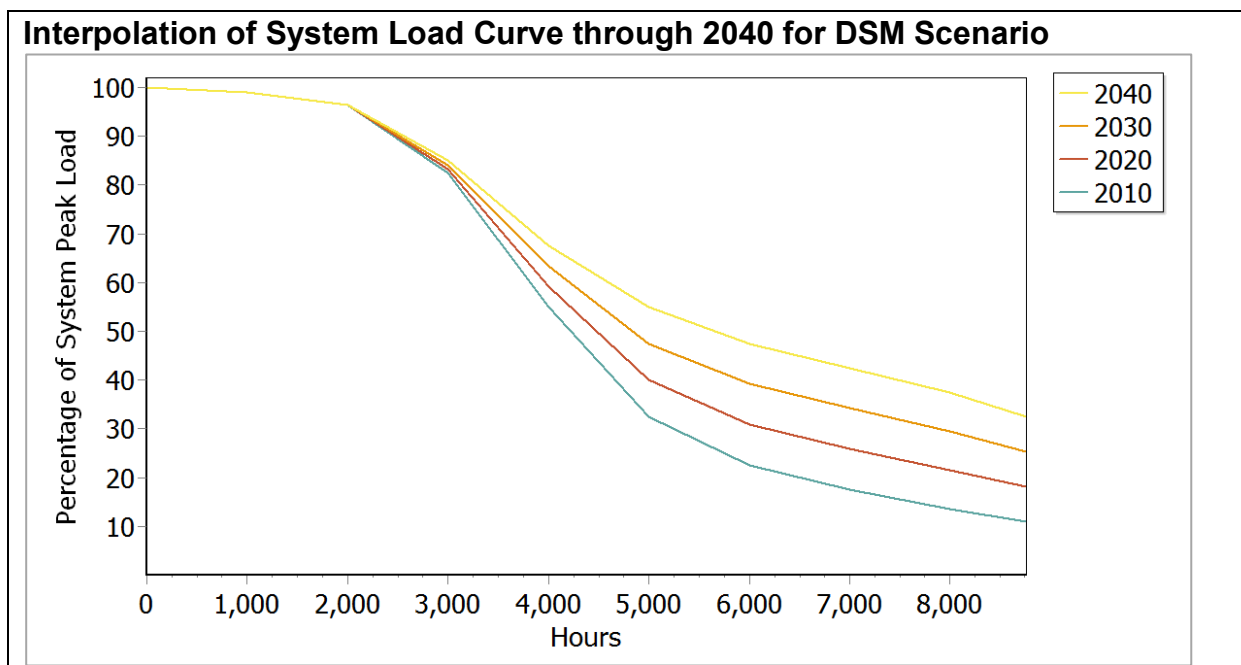
1.6.1 DSM Scenario Results

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

Electricity Generation: DSM Scenario vs. Baseline Scenario

Electricity Generation (TWh)
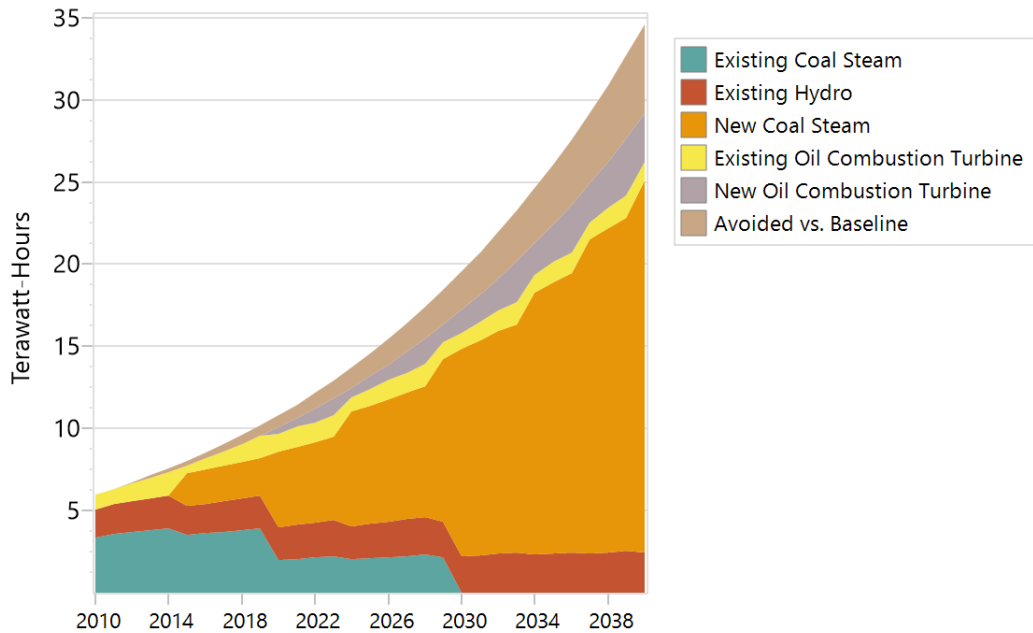
Capacity (GW)
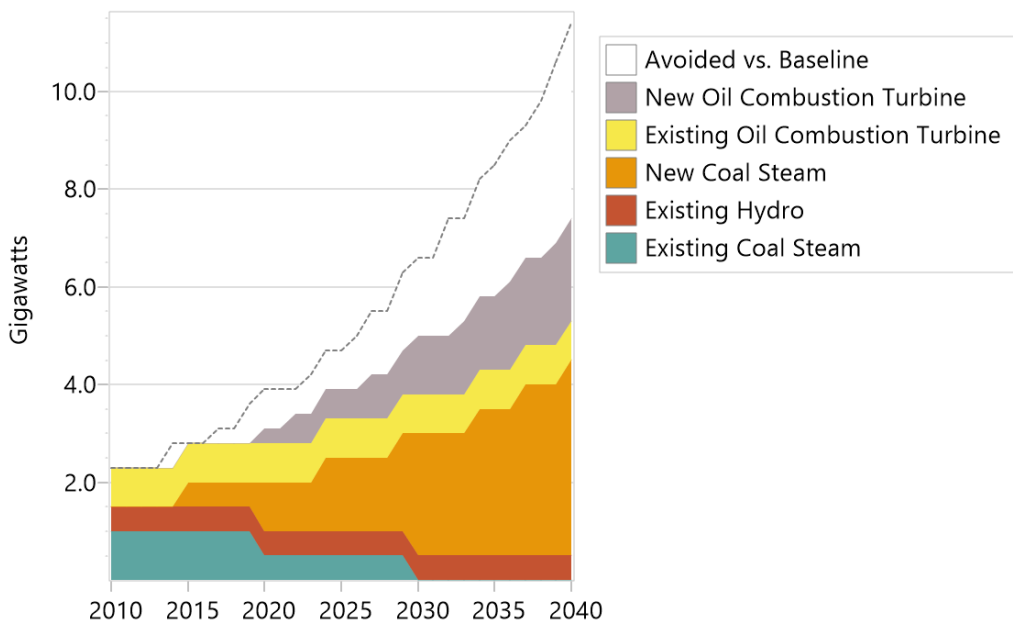
Generation in DSM scenario in 2040 = 29.16 TWh. Capacity = 7.40 GW.

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[13] Video walk-through of this section: https://youtu.be/cW87lWDABgc?t=4855

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.*

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 1.6.1.

Explore different results in LEAP and try to answer the following questions:

1. *In the DSM scenario, what is the percent reduction in electricity demand in 2040 compared to the Baseline scenario? What is the reduction in lighting demand and cooling demand?*

2. *How much less power generation (GWh) and generation capacity (MW) are required in 2040 in the DSM, compared to the Baseline scenario?*

3. *How many tons of SO_2 emissions are avoided in 2040?*

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 Baseline scenario analysis for these sectors.

2.1 Industry

2.1.1 Current Accounts

[14] 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*

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[14] Video walk-through of this section: https://youtu.be/brSaqo0cV8I?t=50

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 Baseline 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:

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.
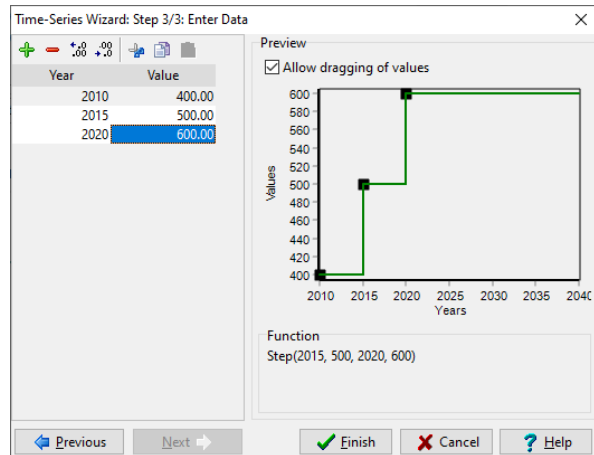
2.1.3 Viewing Results

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

Industrial Energy Demand in Freedonia: Baseline (Million GJ)

By Fuel

Fuel	2010	2040
Electricity	20.2	63.6
Natural Gas	-	1.3
Residual Fuel Oil	21.6	45.5
Coal Bituminous	14.4	13.0
Wood	16.0	24.0
Total	72.2	147.3

By Branch

Branch	2010	2040
Iron and Steel	15.9	15.8
Heat	14.4	14.3
Electricity	1.5	1.5
Pulp and Paper	20.3	30.5
Heat	16.0	24.0
Electricity	4.3	6.5
Other Industry	36.0	101.0
Electricity	14.4	55.6
Residual Fuel Oil	21.6	45.5
Total	72.2	147.3

2.2 Transport

2.2.1 Current Accounts

[16] **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.

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[15] Video walk-through of this section: https://youtu.be/brSaqo0cV8I?t=722
[16] Video walk-through of this section: https://youtu.be/brSaqo0cV8I?t=794

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 below to help you.*

	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)**	

- 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.

2.2.2 Baseline 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 Baseline 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

Results [17] Now switch to **Results View** and compare your results with the tables shown below.

Transport Energy Demand in Freedonia: Baseline (Million GJ)

By Branch

Branch	2010	2040
Passenger	41.1	303.0
Road	34.7	266.6
Cars	22.1	240.1
Buses	12.6	26.5
Rail	6.5	36.4
Diesel	5.4	30.3
Electricity	1.1	6.1
Freight	38.5	125.9
Road	34.0	111.1
Diesel	34.0	111.1
Rail	4.5	14.7
Diesel	4.5	14.7
Total	79.6	428.8

By Fuel

Fuel	2010	2040
Electricity	1.1	6.1
Gasoline	22.1	240.1
Diesel	56.5	182.6
Total	79.6	428.8

Explore different results in LEAP and your knowledge to try to answer the following questions:

1. *Which transport subsectors have the largest potential to reduce the consumption of oil products over the next 30 years?*

2. *List three measures that could be implemented to achieve these reductions and indicate how they could be modeled in a transport scenario.*

2.3 Commerce: Useful Energy Analysis

Analysis [18]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.
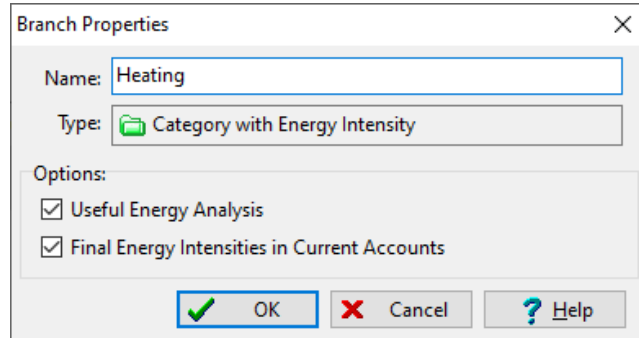
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[17] Video walk-through of this section: https://youtu.be/brSaqo0cV8I?t=2844
[18] Video walk-through of this section: https://youtu.be/brSaqo0cV8I?t=2910

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 later.
- 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.*

Branch Properties ✕

Name: Heating

Type: 📁 Category with Energy Intensity

Options:
☑ Useful Energy Analysis
☑ Final Energy Intensities in Current Accounts

✔ OK   ✗ Cancel   ? Help

2.3.2 Baseline 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[19]) 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 device 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.

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[19] As opposed to the *final* energy intensity: the amount of fuel used per square meter.

Commercial Space Heating Energy Demand: Baseline (Million GJ)

Fuel	2010	2020	2030	2040
Electricity	10.0	12.4	15.5	19.3
Natural Gas	-	2.0	4.9	8.7
Residual Fuel Oil	10.0	8.7	6.7	3.9
Total	20.0	23.2	27.1	31.9

2.4 Total Final Demands

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

Energy Demand by Sector: Baseline Scenario (Million GJ)

Energy Demand by Fuel Group: Baseline Scenario (Million GJ)
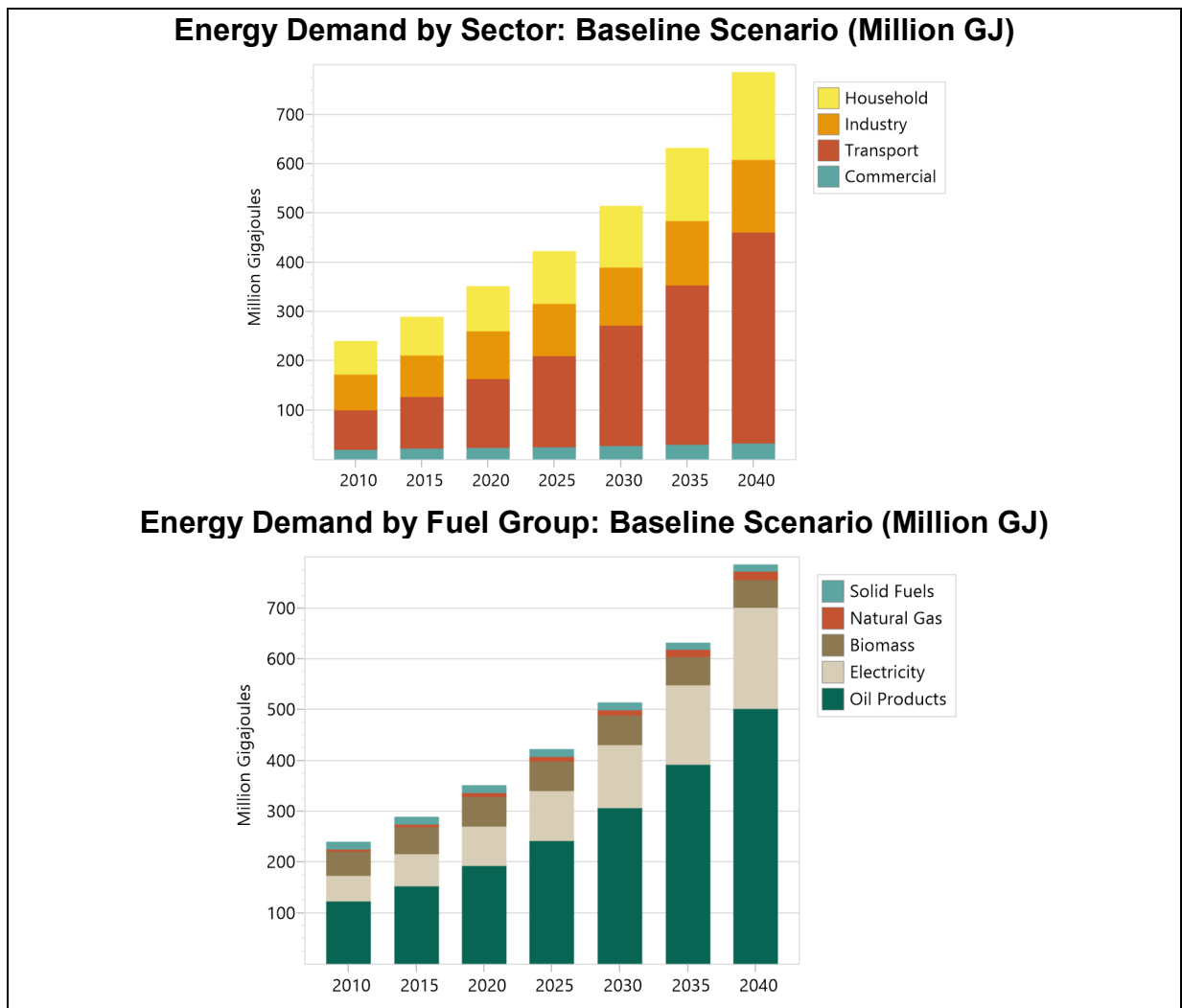
*Hint: To see the energy demand by fuel group graph above, choose **Demand: Energy Demand Final Units** and choose fuels on the right legend drop down menu and then select the Fuel Groups check box from the menu above the chart.*

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 2.4.0.

Think about LEAP's functionality to develop a demand analysis in your country, and try to answer the following questions:

1. *In what other situations might it be convenient to apply useful energy analysis techniques?*

2. *What problems might be encountered when applying useful energy analysis techniques in your country?*

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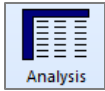
In this third exercise you will further develop the simplified Transformation data set you constructed in Exercise 1. In this exercise you will add new modules to examine charcoal production, oil refining and coal mining.

3.1 Charcoal Production

[21] 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.

Tranformation Module Properties ✕

Name: Charcoal Production

☐ 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)
☐ Coproduct: ▼
☐ Output shares (otherwise outputs in proportion to requirements).

Enter efficiency data as:
◉ Efficiencies   ○ Losses   ○ Heat rates

✔ OK   ✗ Cancel   ? Help

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

[22] 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%
Total	**5,500**	**100% (16,200 GWh)**

In addition, in the Baseline scenario, assume the capacity of "Existing Coal Steam" plants decrease with 1,500 MW retired in 2020 and the remaining capacity all retired in 2030. You can enter this in the **Exogenous Capacity** variable under the Baseline scenario using the *Step* expression as follows:

Step(2020, 1000, 2030, 0)

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[21] Video walk-through of this section: https://youtu.be/MwIqXQW1t8E?t=47
[22] Video walk-through of this section: https://youtu.be/MwIqXQW1t8E?t=348

3.3 Oil Refining

[23] In 2010, Freedonia's oil refineries had the capacity to handle 6 million tonnes of crude oil feedstocks[24]. 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

[25] 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 Baseline 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 variables at the "Coal Mining\Output Fuels" branch. Make sure that the **Shortfall Rule** is set to* Import to meet shortfall *to meet the modeling demands described above.*

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[23] Video walk-through of this section: https://youtu.be/MwIqXQW1t8E?t=581
[24] 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.
[25] Video walk-through of this section: https://youtu.be/MwIqXQW1t8E?t=871

3.5   Resources

[26] 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. 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 Freedonia 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 Freedonia, the only domestic energy resources are coal, hydropower, and biomass (wood). All natural gas and oil resources have to be imported. No detailed data are available yet on the coal, hydropower and biomass 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 and hydropower) 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.
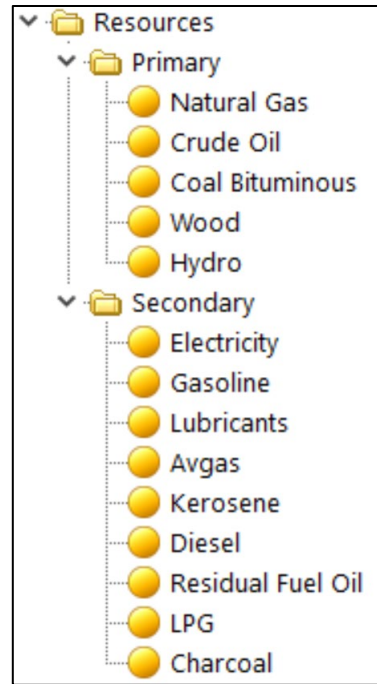
3.6 Viewing Results
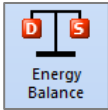
Switch to the **Energy Balance View** and check your base and end year energy balances against the following tables:

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

Baseline 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:*

   o *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 **Import Target** and **Export Target** variables to make sure those make sense.*
   o *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.*
   o *Check the import and export 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 for 2040. This diagram is a representation of the flows through different elements of your energy system.
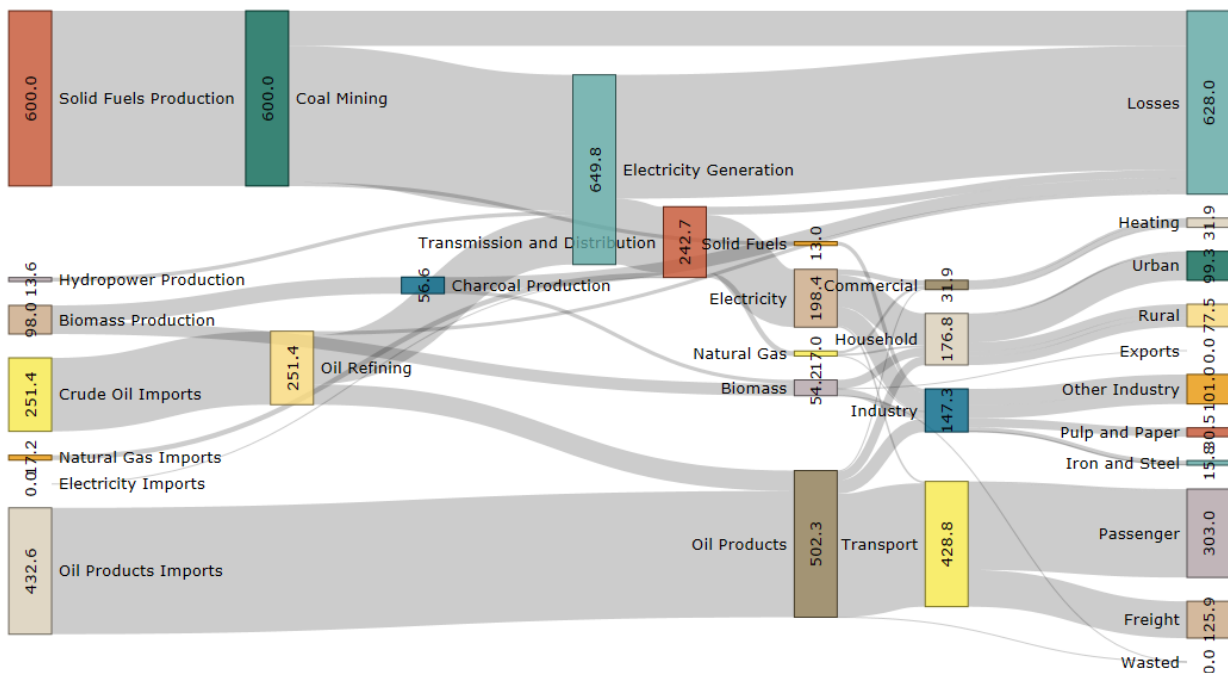
Now switch to **Results View** and compare your results with the charts shown below.

Electricity Generation: Baseline Scenario (TWh)
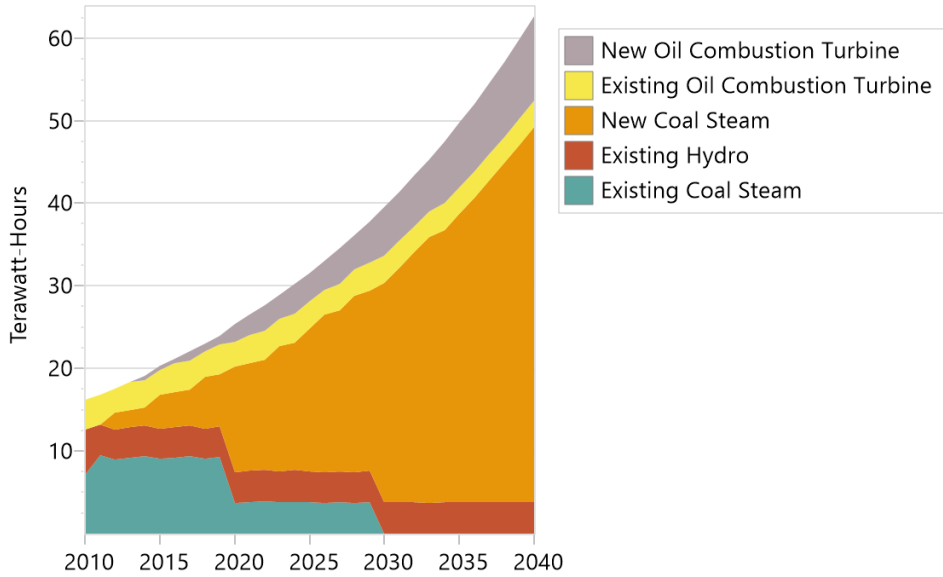
Notes: Base Year = 16.2 TWh, 2040 = 62.6 TWh

Electricity Generation Capacity: Baseline Scenario (GW)
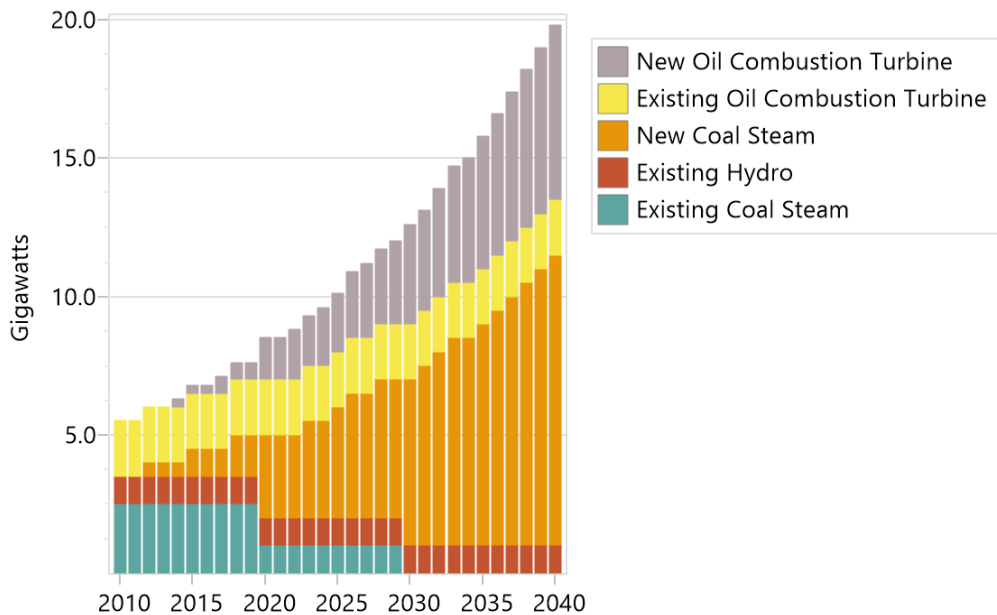
Notes: Base Year = 5.5 GW, 2040 = 19.8 GW

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 3.6.0.

> *Explore different results in LEAP and try to answer the following questions:*
>
> 1. *In what year do refineries and coal plants reach their maximum capacity?*
>
> 2. *Assuming that additional requirements are covered through imports, what is the projection of the total imports of petroleum products in 2040 (in millions tonnes of oil equivalentl)?*

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

[27] 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.

Demand
(costs of saved energy, device costs, other non-fuel costs)

Transformation
(Capital and O&M costs)

Primary Resource Costs
or
Delivered Fuel Costs

Environmental
Externality Costs

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.
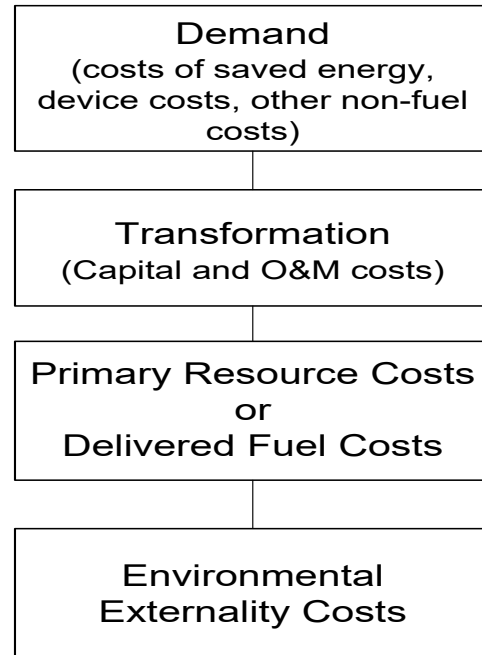
If you have not already done so, switch on costing by going to the Scope & Scale tab of the **Settings** screen and enable **Costs**. Now go to the Costing tab and select the boundary that will be drawn around the system for the purposes of costing. For this exercise you should select *Complete Energy 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.

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[27] Video walkthrough of this section: https://youtu.be/au99KzpHmio?t=56

4.2 Creating Policy Scenarios

Analysis
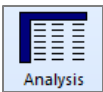
[28] Go to the **Scenarios** screen (🅂) and create the following five scenarios:

- 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 Baseline scenario. In this way the scenarios will inherit the expressions already entered for the Baseline scenario.
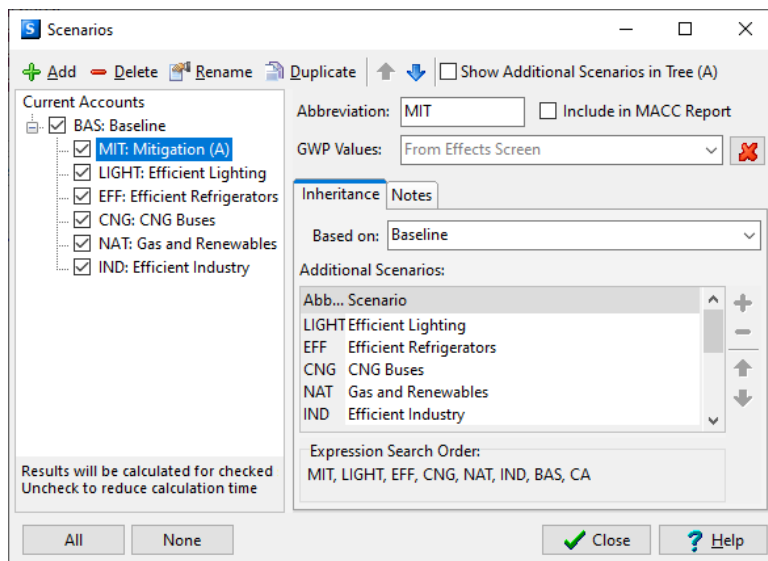
Finally, create a "Mitigation" scenario under the Baseline scenario that is a combination of the five policy scenarios listed above. Use the Inheritance tab to set that this scenario also inherits its expressions from these five policy scenarios.

4.3 Entering Costing Data

[29] Next you will enter the data that that will be used to evaluate how these scenarios differ from the Baseline 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?

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[28] Video walkthrough of this section: https://youtu.be/au99KzpHmio?t=261
[29] Video walkthrough of this section: https://youtu.be/au99KzpHmio?t=433

- **Technology Cost:** how much do the new devices cost? You may either specify the total costs of competing devices used in the Baseline 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 Baseline 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 can reach 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. 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 Baseline 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 scenario by 2040:

BaselineValue * 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_2 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 [%][1]	30	100
Historical Production [GWh]	0	0
Exogenous Capacity [MW]	0	0
Lifetime [years]	30	30

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

Additionally, you can assume that the wind resource is unlimited. Go to the "Resources" branch and enter *Unlimited* as the annual available yield for wind.

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 (%)
Existing Plants				
Existing Coal Steam	1000	40	3.0	5
Existing Hydro	2000	0	1.0	5
Existing Oil Combustion Turbine	400	10	0.7	5
New Plants				
New Coal Steam	1000	40	3.0	5
New Oil Combustion Turbine	400	10	0.7	5
New NGCC	500	10	0.5	5
New Wind	800	25	0.0	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 Baseline 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 Baseline 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^3$ in 2010, rising to $0.2/$m^3$ 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 Baseline 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:
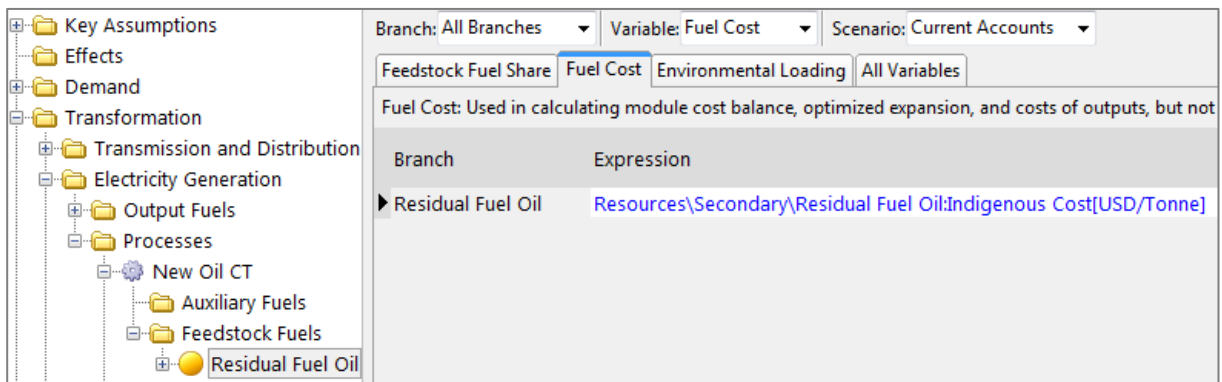
Hint: *You can add this type of expression by pressing* **Ctrl-B** *and using the Branch/Variable selection wizard.*

4.3.8 Environmental Loadings

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

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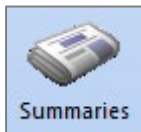
In the **Summaries** view you can display the *Net Present Value* (NPV) of the Mitigation scenario relative to another selected scenario (in this case the Baseline scenario). The NPV is the sum of all discounted costs and benefits in one scenario minus another (summing across all years of the study).

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 Baseline 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 $1.03 billion is how much more the Mitigation scenario costs versus the Baseline scenario. The cost of avoided GHG emissions (2.16 $/tonne CO_2e) is given by dividing the NPV by the tonnes of CO_2e avoided.

Cumulative Costs and Benefits of Mitigation Scenario, 2010-2040
Billion 2010 US Dollars. Discounted at 5.0% to year 2010, Compared with the Baseline Scenario

Sector	Mitigation
Demand	5.00
Household	0.73
Industry	1.70
Transport	2.56
Commercial	-
Transformation	-3.59
Transmission and Distribution	-
Electricity Generation	-3.59
Charcoal Production	-
Oil Refining	-
Coal Mining	-
Resources	-
Production	-2.48
Imports	2.10
Exports	-
Other Costs	
Unmet Requirements	-
Environmental Externalities	-
Non Energy Sector Costs	-
Total Net Present Value	1.03
GHG Savings (Mill Tonnes CO2e)	474.88
Cost of Avoided GHGs (USD/Tonne CO2e)	2.16

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[30] Video walkthrough of this section: https://youtu.be/au99KzpHmio?t=3076
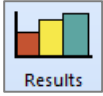
You may also want to look at cost results graphically. You can do this in the **Results View**. Select the top branch in the tree and show the result **Costs: Social Costs**. In the chart legend, show *All Costs*. Often it is most useful to view costs in terms of differences versus the Baseline scenario. For example, try to display the following chart that shows the incremental cumulative discounted costs in each year of the Mitigation scenario versus the Baseline scenario.

Cumulative Discounted Costs: Mitigation vs. Baseline Scenario (discounted to 2010 at 5% per year)
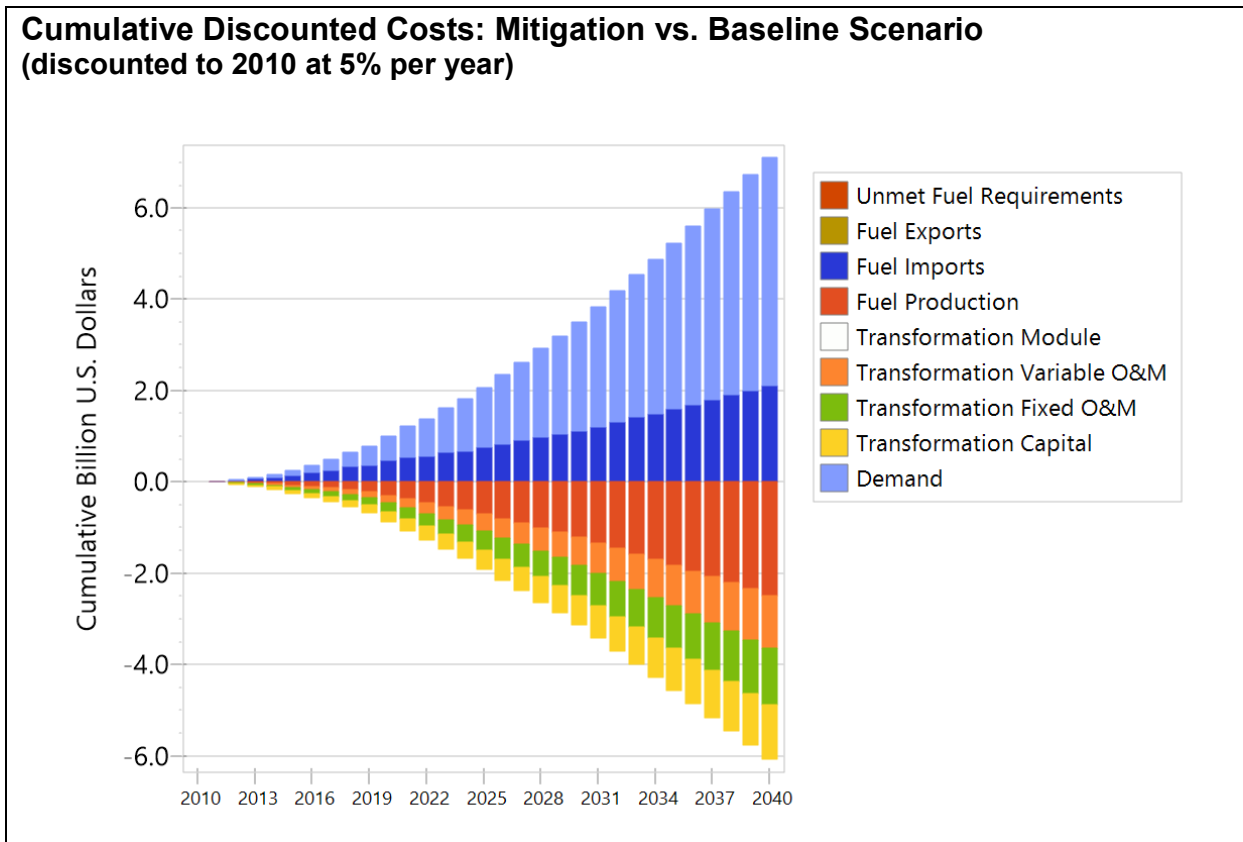
Notice how the Mitigation scenario is more expensive than the Baseline scenario in terms of demand-side costs and in terms of imported fuels (these items appear above the X-axis), but this is somewhat offset by savings in transformation capital costs, fuel production and operating and maintenance (O&M) costs (these items appear as negative values below the X-axis).

Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 4.4.0.

Explore the results for the other scenarios in LEAP and try to answer the following questions:

1. *Are there any individual scenarios that result in lower costs compared to the Baseline?*

2. *If analyzed individually, which measure has the highest potential for reducing GHG emissions?*

3. *If analyzed individually, which scenario has the lowest cost of avoided GHG emissions? And the highest? How do you interpret a negative and a positive cost?*

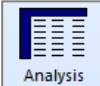# 5   Including Emissions from Non-Energy Sources

LEAP is primarily a tool for energy sector planning and for conducting emissions assessments from the energy sector. However, it also allows you to include total emissions of pollutants from outside the energy sector, so that your model can cover the complete inventory of a country's emissions all from within the LEAP interface. Following Intergovernmental Panel on Climate Change (IPCC) GHG inventory guidelines[31], these "non-energy" sources include:

- Industrial Processes and Product Use (IPPU),
- Agriculture, Forestry and Other Land Use (AFOLU),
- Waste

Often, historical emissions of pollutants from these non-energy sectors would be determined outside of LEAP using special software. Projections of future emissions can also be estimated in the same way and incorporated into LEAP's scenarios. In either case, once you choose to include non-energy emission data within LEAP, you may then use all of its basic modeling and mathematical functions to perform simple calculations or make scenario projections for the non-energy sector from within LEAP itself.

In this exercise, you will expand your model of Freedonia to include total emissions of methane and nitrous oxide from manure management, a subcategory of AFOLU. You will then also include hydrofluorocarbon (HFC) emissions arising from refrigeration and air conditioning activities, a subcategory of IPPU. Finally, you will create a new scenario to show how biogas electricity from an agricultural waste digester can be modeled in LEAP, which affects emissions from both the energy sector (arising from the power sector) as well as the non-energy sector (arising from agriculture).

5.1   Current Accounts

[32] Begin by enabling both the Non-Energy Sector Effect Loadings and Complex Effects options from within **Settings**. You will then see a new category branch called "Non Energy" at the bottom of the tree. For this exercise, both of the options are needed because LEAP classifies HFCs as complex effects, which are enabled separately.

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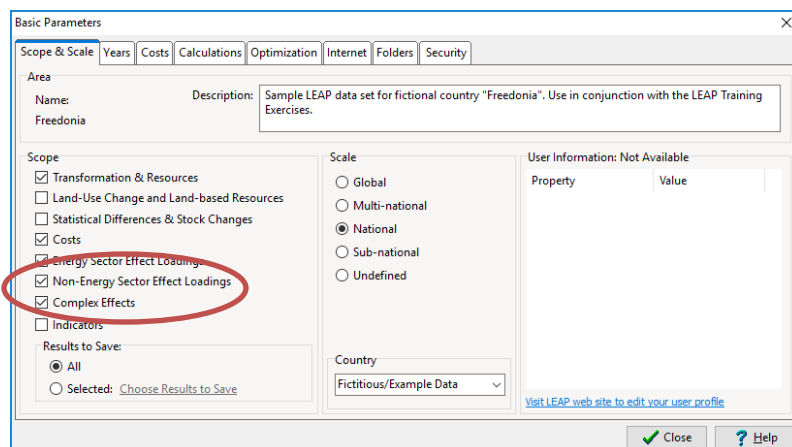
[31] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.
[32] Video walkthrough of this section: https://youtu.be/tHD3TifBhAk?t=71

Within the Non-Energy category, you may decide on any branch structure that suits your needs. For clarity, it is recommended that you use the same category names that are outlined in IPCC inventory guidelines. Use the ✚ to re-create the branch structure shown below, choosing *Category* in the screen that appears.
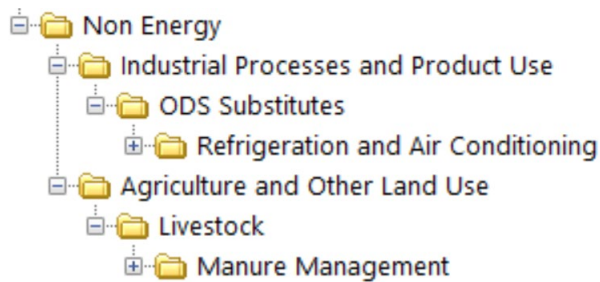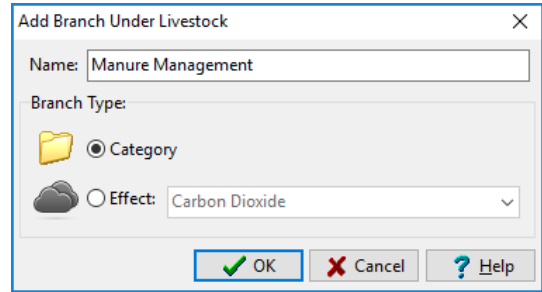
2	Industrial Processes and Product Use
2.F	Product Uses as Substitutes for Ozone Depleting Substances (ODS)
2.F.1	Refrigeration and Air Conditioning
3	Agriculture, Forestry, and Other Land Uses
3.A	Livestock
3.A.2	Manure Management

The relevant IPCC Inventory categories are shown to the right of the tree structure to emphasize their compatibility. To keep this exercise brief, we will include only emissions from IPCC Inventory categories 2.F.1 and 3.A.2.

5.1.1 HFCs from Refrigeration and Air Conditioning

[33] Freedonia's historical emissions of HFCs from category 2.F.1 are contained in an accompanying Microsoft Excel document titled *"HFC_Emissions.xlsx",* which can be found under the *LEAP Areas\Freedonia* folder in your computer. Under the "Refrigeration and Air Conditioning" branch in the tree, use the ✚ to add eight branches (choosing *Effect* in the screen that appears), each representing the emission of a different HFC compound found in the accompanying workbook.

> **Hint:** *When adding these branches, if you first select the effect from the list menu then LEAP will automatically assign a name to the branch based on the name of the effect.*

Regular audits of HFC emissions from refrigerators and air conditioners in Freedonia mean that annual inventories for these pollutants are available all the way back to the year 2000. Sometimes it is useful to include large amounts of historical data within LEAP, for as many years as are available. So, we will use this opportunity to learn how to input a time series of data from Excel quickly and easily into LEAP. To do this, follow the steps below.

1. **Copy source data from Excel.** Viewing the *"HFC_Emissions.xlsx"* document, select the whole range of cells containing historical emissions of HFC-23 (fluoroform). Copy the range to the clipboard, either right-clicking and selecting "Copy" or using **Ctrl-C**.

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[33] Video walkthrough of this section: https://youtu.be/tHD3TifBhAk?t=369

2. **Paste data into LEAP.** Return to LEAP and place your mouse cursor in the **Non Energy Effect Loading** variable for the HFC-23 branch, and press **Ctrl-V** to paste the data. You will see the screen shown right.
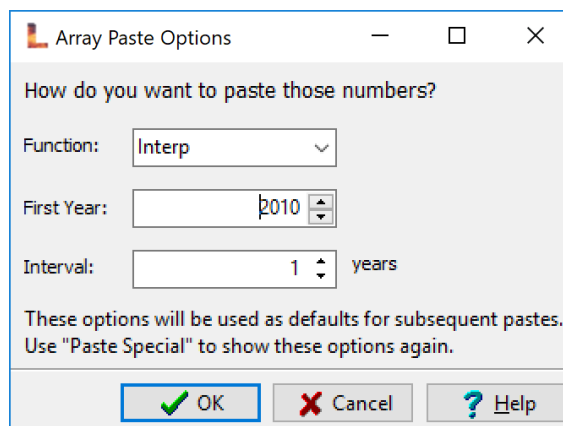
LEAP will recognize that your clipboard contains information from an Excel range, and will guess that the numbers in this range contain time-series data. This screen helps you to paste these data as arguments into a LEAP function. Choose LEAP's *Interp* function in the first box and change the *First Year* to 2000 since your data begin in the year 2000. Since your historical data are separated by one year, leave the *Interval* option unchanged.

3. **Finalize.** Click OK, and LEAP will write the following function into the variable:

    Interp(2000, 14.3, 2001, 15.4, 2002, 15.9, 2003, 16.9, 2004, 18.2, 2005, 19, 2006, 19.7, 2007, 21, 2008, 21.6, 2009, 22.8, 2010, 23.9)

    Repeat this process for all other HFC compounds.

    Note: Values for years prior to the base year do not appear in any of LEAP's charts. However, they may still be included in expressions, and conveniently remain inside the model should you decide to change the base year to an earlier year.

5.1.2 Methane and Nitrous Oxide from Manure Management

[34]Under "Manure Management", use the ➕ again to add two branches representing emissions of methane and nitrous oxide found under category 3.A.2. In 2010, Freedonia's 65 million livestock consisted mainly of poultry, but also of a mixture of cattle, swine and other animals. Farms employed a number of different manure management practices. On average, manure from these animals emitted 0.07 kg of CH_4 and 0.1 kg of N_2O per year for every head of livestock[35].

In this exercise, the annual emissions of each GHG can then be calculated by multiplying the number of livestock by the average emission factor. If we wish to perform this multiplication in LEAP, we can create a special user-defined variable to hold our assumption for the total number of livestock. To do this, follow the steps below. There are many different configuration options while setting up user-defined variables. Unless described specifically in the steps below, you may ignore these many additional options by leaving them at their default settings.

---

[34] Video walkthrough of this section: https://youtu.be/tHD3TifBhAk?t=653

[35] The annual emissions of methane and nitrous oxide vary widely among different types of livestock. Furthermore, the way that their manure is managed (whether in an anaerobic lagoon, dry lot, pasture, etc.), the climate, and other factors will affect the annual production of these gases. To keep this exercise simple, we provide only an average emission factor for manure from all animals.

1. **Open the User Variables Manager.** From the main menu, select Analysis: User Variables. Use the *Add* button to add a new user variable.

2. **Configure basic information for your variable**. Give your variable a name, such as "Livestock". In the Basic Info tab, type a unit name in the *Scale/Units* box, and enter a short description of the variable in the *Notes* section. An example screen is shown to the right.
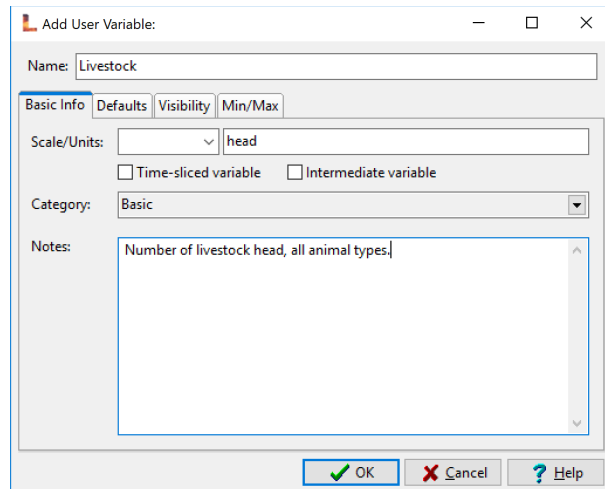
3. **Configure the visibility for your variable.** In the Visibility tab, use the *Branch Visibility* section to control where the variable appears in the tree. Configure your screen so that the variable appears for branches of type *Non Energy Sector Categories*, at the branch called "Non Energy\Agriculture Forestry and Other Land Use\Livestock" and no branches beneath it. When finished, your screen should look like the following:
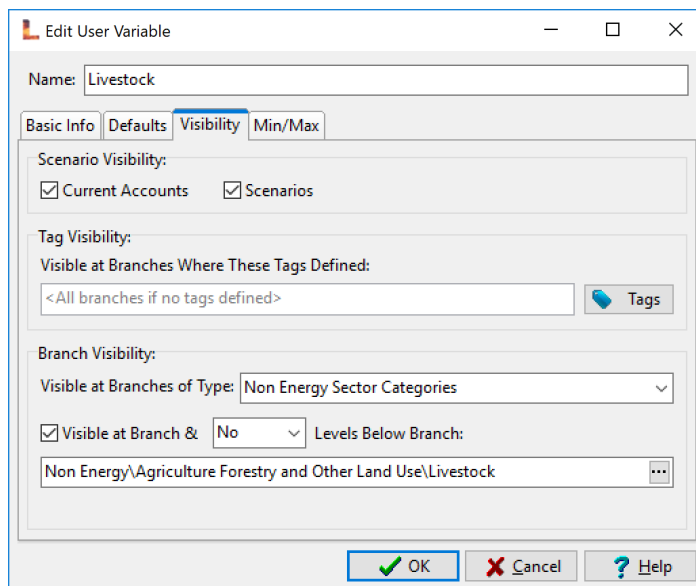
Click OK, and then close the User Variables Manager window**.**

You should now see your new **Livestock** variable when you click on the Non Energy\Agriculture Forestry and Other Land Use\Livestock branch. Use it to include the number of livestock in Freedonia for the base year.

Finally, write an expression into each of the Methane and Nitrous Oxide *Effect* branches to calculate total annual emissions in Current Accounts.

> ***Hint:*** *Multiply the average emission factor provided earlier by the number of livestock, creating a reference to the **Livestock** variable as needed. For example, the **Non Energy Effect Loading** variable for methane should contain the following expression:*
>
> **0.07 * Non Energy\Agriculture Forestry and Other Land Use\Livestock: Livestock[head]**

5.2   Baseline Scenario

[36] In the Baseline scenario, we will include two simple assumptions that relate changes in non-energy emissions to Key Assumptions which we have already created.

Refrigeration and air conditioning activities are expected to increase with rising incomes, and with them, emissions of HFCs. For all HFC emissions from refrigeration and air conditioning, enter the expression *GrowthAs(Key\Income)* into the **Non Energy Effect Loading** variable.

If Freedonian's diets do not change, then the number of livestock head can be expected to increase at the same rate as the national population. Using the **Livestock** variable, enter a similar expression to that above, which increases the number of livestock at the same rate as population.

---

[36] Video walkthrough of this section: https://youtu.be/tHD3TifBhAk?t=1013

5.2.1 Viewing Results

Switch to the **Results View** and examine the result **Environment: 100-Year GWP: Direct (At Point of Emissions)**. Compare your results to those shown below.

One Hundred Year Global Warming Potential, Baseline Scenario, all greenhouse gases
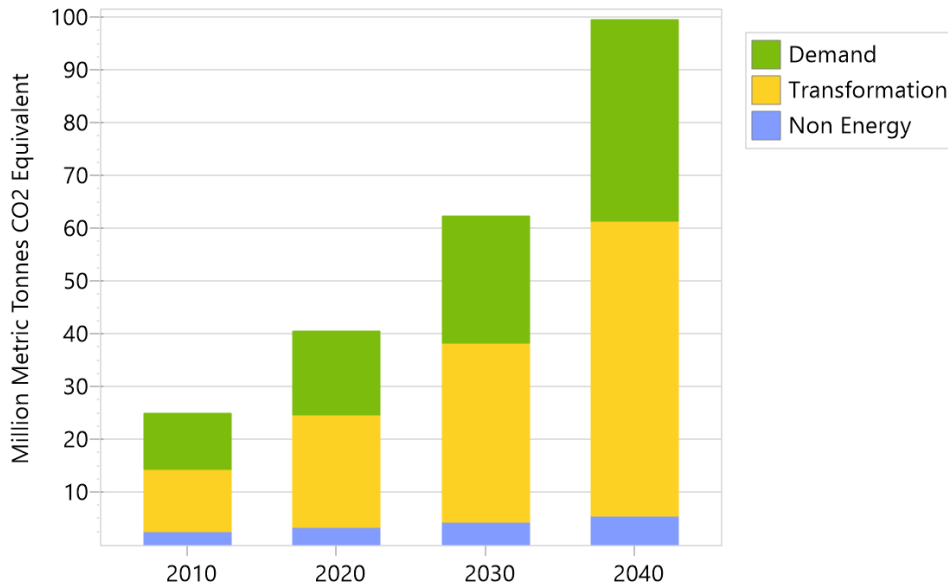
One Hundred Year Global Warming Potential, Baseline Scenario, Non-Energy Emissions Only
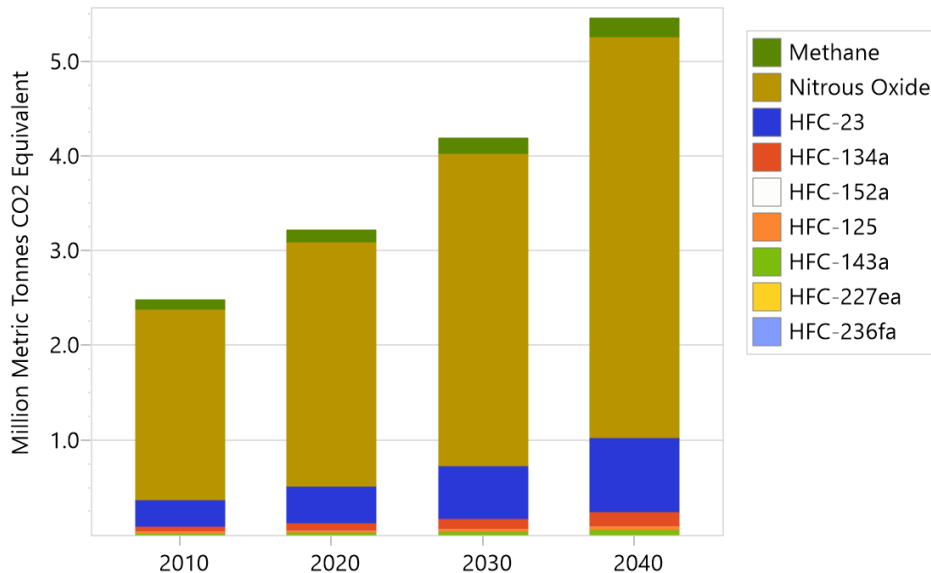
Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 5.2.1.

5.3   Policy Scenario: Digesting Animal Wastes for Power Generation

[37] To develop a source of natural fertilizer and to reduce greenhouse gas emissions, the government of Freedonia is evaluating a small power plant project which consumes methane-rich biogas to produce electricity.

First, add a new process into the Electricity Generation module, called "Animal Waste Digestion". The technical and cost parameters for this technology are given in the table below (leave all other parameters at their default values). Be sure to enter these under Current Accounts.

Technical Parameters	
Feedstock Fuel	Biogas
Dispatch Rule	FullCapacity
Process Efficiency [%]	30
Maximum Availability [%]	85
Cost Parameters	
Capital Cost ($/kW)	5800
Variable O&M Cost ($/MWh)	5
Fixed O&M Cost ($/kW)	150

You will also need to include a set of emission factors for the combustion of biogas in the generator. Using the ➕ to add *Effect* branches beneath the process' fuel, add each one of the pollutants from the table below.

Pollutant	Emission Factor (kg/TJ)
Carbon Dioxide Biogenic	54600
Carbon Monoxide	2.5
Methane	1
Non-Methane Volatile Organic Compounds	5.6
Nitrogen Oxides	20
Nitrous Oxide	0.1
Sulfur Dioxide	4

Visit **Scenarios** (🅂) to create a new scenario which inherits from the Baseline scenario, called "Animal Waste Digestion". This scenario is characterized by two changes:

- The utility in Freedonia will construct a 30 MW pilot project biogas generator, which is expected to be completed in 2021.
- For each gigajoule of energy that the biogas generator consumes, 1.14 kg of methane and 1.39 kg of nitrous oxide emissions are avoided annually from manure management practices.

---

[37] Video walkthrough of this section: https://youtu.be/tHD3TifBhAk?t=1312

Hint: *In your new scenario, adjust the baseline non-energy emissions by subtracting the avoided amount, calculated using the following LEAP expression[38]:*

BaselineValue – (Transformation\Electricity Generation\Processes\Biogas:Inputs[GJ] * 1.14)

5.3.1 Viewing Results

If you have set up your model correctly, you should be able to use LEAP's **Results View** to show emissions from two different parts of your tree: the Electricity Generation sector and the Manure Management category. Reductions in GHG emissions arise from both the energy (since biogas is used to displace other forms of fossil fuel generation) and non-energy sectors (since producing and combusting the biogas means that it is not vented to the air, and improves manure management practices).

One Hundred Year Global Warming Potential, Avoided Emissions of Animal Waste Digestion vs. Baseline Scenario
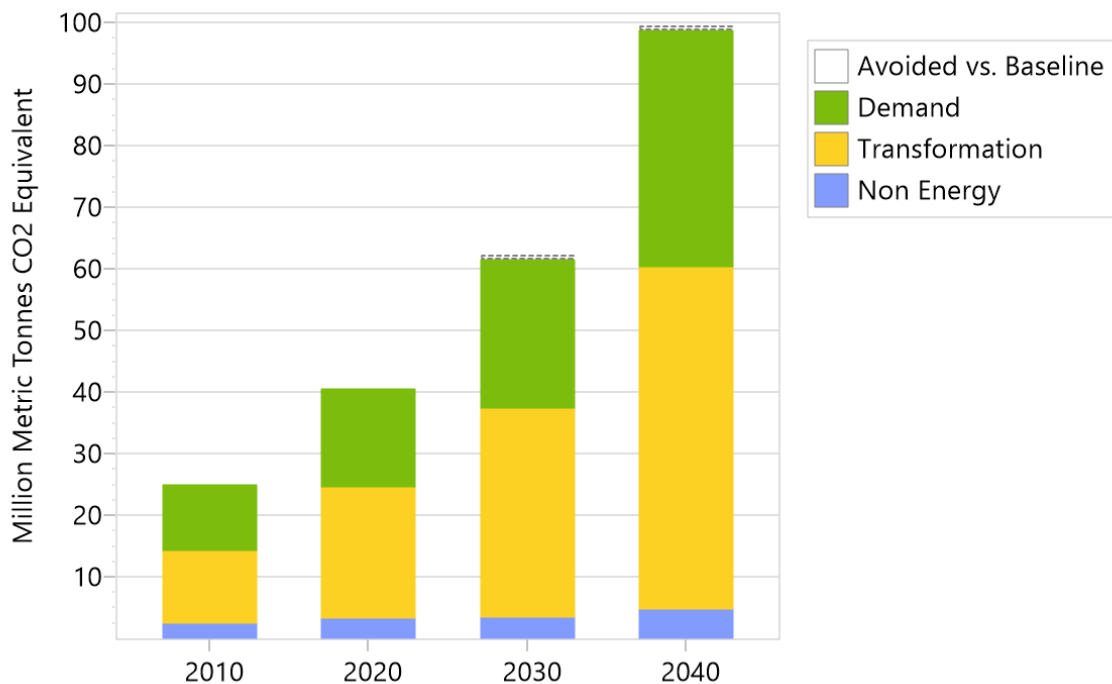
Note: Avoided emissions in 2040 = 0.9 Million Tonnes CO_2-equivalent.

The get the same chart as above, make sure you are positioned at the top-level branch in the tree. This shows the total avoided emissions compared to the Baseline scenario for all sectors in Freedonia. As show below you can also explore the avoided emissions per pollutant, specifically in the livestock sector.

---

[38] Under some circumstances, LEAP will allow you to refer to "Result"-type variables (variables which are calculated when you switch to the **Results View**) in your expressions. Use the "Result"-type variable called **Inputs** in your calculation, which returns the energy inputs to a transformation process. When using "Result"-type variables, always check that LEAP is using the variable in the way that you expect.

One Hundred Year Global Warming Potential, Avoided Emissions of Animal Waste Digestion vs. Baseline Scenario in the Livestock sector
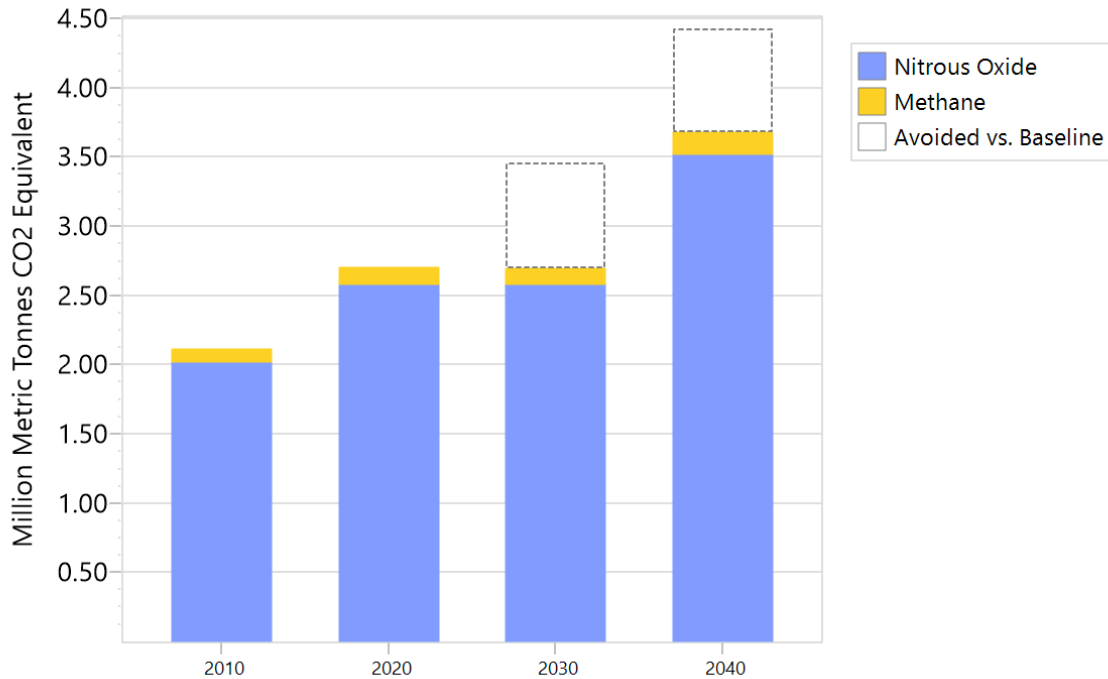
Tip: to see a version of Freedonia matching the results shown here, first open the standard Freedonia area in LEAP then use **Area: Revert to Version** and select version 5.3.1.

Explore additional results in LEAP and try to answer the following questions:

1. *Which sectors give rise to the emissions abatement found under the Animal Waste Digestion scenario?*

2. *What is the abatement of each pollutant in 2030 and 2040, in thousand metric tonnes of CO_2 equivalent?*

3. *In what other cases do you think it might be useful to make use of user-defined variables?*

6 A Transportation Study

In this exercise 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 **Baseline** 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 edit the **Settings** 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.

6.1 Settings and Structure
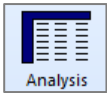
Go to the Scope & Scale tab on the **Settings** screen and make sure only the Energy Sector Effect box is checked. This study will not make use of Transformation, Costs or Resource data.

- On the Years tab, enter 2010 as the *Base Year*, 2011 as the *First Scenario Year* and 2030 as the *End Year*.

- On the Calculations tab, make sure the *Top-down sales and stock data* box is checked.

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.
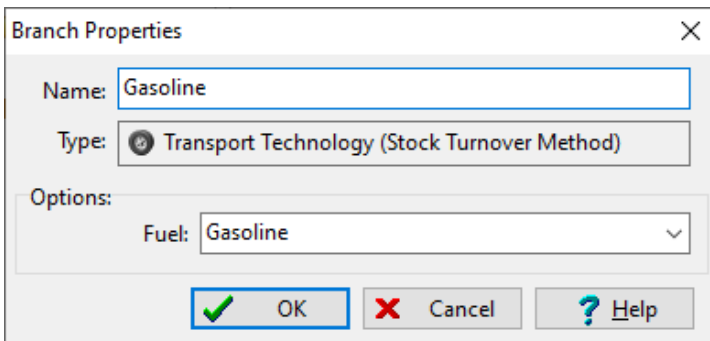
Your completed tree structure should look something like this:
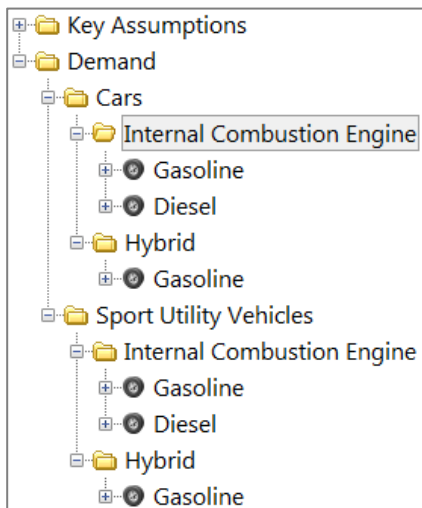
Hybrid-Electric Vehicles

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.

6.2   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. Enter this data in the **Stock** variable at the Demand branch.

- 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
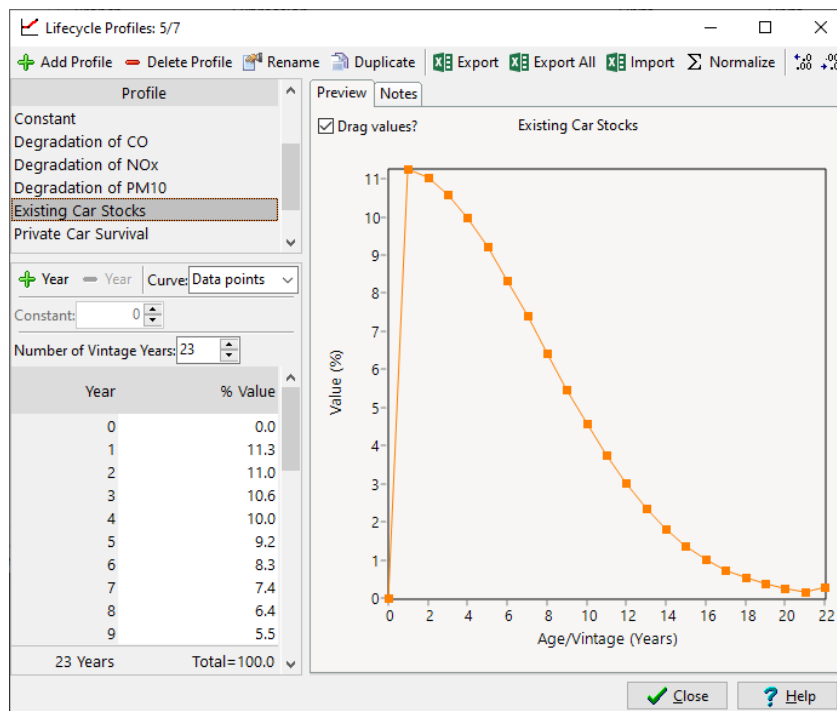
- In the base year, 0.8 million cars were sold, and 0.5 million SUVs. Enter this data in the **Sales** variable at the Demand branch. As these and other vehicles age they will gradually be retired from the vehicle stock (taken off the road). A survival profile describing this retirement of vehicles can 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 increase, 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. Create a new Lifecycle Profile and link it to the Degradation Profile column under the Mileage variable for each technology.

- 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. Stock share and Sales share variables for SUVs should be set to 0 in Current Accounts.

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

6.3 Baseline Scenario

You are now ready to create a Baseline scenario (BAS) 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 Baseline (BAS). 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 Baseline scenario. No hybrid SUVs are introduced.
- In the absence of new standards, fuel economy of all vehicles remains unchanged in the future.

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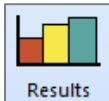
You are now ready to view Baseline results for sales, stocks, mileage and fuel use. Check your results against each of the following categories for the years 2010, 2020, and 2030.

Device Sales (thousands of vehicles)

Branch	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)

Branch	2010	2020	2030
Cars	6,800	7,051	7,123
Internal Combustion Engine	6,793	7,020	7,088
Gasoline	6,657	6,879	6,946
Diesel	136	140	142
Hybrid	7	32	35
Gasoline	7	32	35
Sport Utility Vehicles	4,500	6,082	9,075
Internal Combustion Engine	4,500	6,082	9,075
Gasoline	4,410	5,960	8,893
Diesel	90	122	181
Hybrid	-	-	-
Gasoline	-	-	-
Total	11,300	13,133	16,198

Vehicle Mileage (billion vehicle-miles)

Branch	2010	2020	2030
Cars	96.8	101.0	101.9
Internal Combustion Engine	96.7	100.5	101.4
Gasoline	94.8	98.5	99.4
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	87.8	131.0
Internal Combustion Engine	64.1	87.8	131.0
Gasoline	62.8	86.1	128.4
Diesel	1.3	1.8	2.6
Hybrid	-	-	-
Gasoline	-	-	-
Total	160.9	188.8	232.9

Energy Demand (million gallons gasoline eq.)

Branch	2010	2020	2030
Cars	3,864	4,024	4,060
Internal Combustion Engine	3,862	4,013	4,048
Gasoline	3,792	3,941	3,975
Diesel	69	72	72
Hybrid	3	12	13
Gasoline	3	12	13
Sport Utility Vehicles	4,261	5,840	8,711
Internal Combustion Engine	4,261	5,840	8,711
Gasoline	4,186	5,737	8,557
Diesel	75	103	154
Hybrid	-	-	-
Gasoline	-	-	-
Total	8,125	9,865	12,772

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.

6.5 Emissions Factors
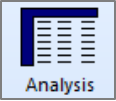
Next, you will enter environmental loadings data describing some of the pollution loadings associated with the vehicles you are studying. To keep data entry to a minimum, for this short exercise you will examine only four pollutants: the greenhouse gas, Carbon Dioxide (CO_2) and three pollutants contributing to local air pollution: Nitrogen Oxides (NO_x), Carbon Monoxide (CO), and Particulate Matter of size less than 10 microns (PM_{10}).

CO_2 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_2 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	CO2	lbs/MMBTU	159.50			
	CO	g/veh-mile	6.20	5.30	3.50	1.70
	NOx	g/veh-mile	0.44	0.35	0.04	0.03
	PM10	g/veh-mile	0.40	0.30	0.20	0.05
Diesel	CO2	lbs/MMBTU	161.00			
	CO	g/veh-mile	1.05	0.54	0.20	
	NOx	g/veh-mile	0.60	0.27	0.08	
	PM10	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 *Effect* branches (☁) under each of the fuels (🟡) below your technologies (⚙). Use the *Add* button (➕) to add CO_2, CO, NO_x and PM_{10} 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_2, 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

```
📁 Demand
  📁 Cars
    📁 Internal Combustion Engine
      ⊟ ◉ Gasoline
        ⊟ 🟡 Gasoline
          ☁ Carbon Dioxide Non Biogenic
          ☁ Carbon Monoxide
          ☁ Nitrogen Oxides NOx
          ☁ Particulates PM10
      ⊟ ◉ Diesel
        ⊟ 🟡 Diesel
          ☁ Carbon Dioxide Non Biogenic
          ☁ Carbon Monoxide
          ☁ Nitrogen Oxides NOx
          ☁ Particulates PM10
    📁 Hybrid
      ⊟ ◉ Gasoline
        ⊞ 🟡 Gasoline
  📁 Sport Utility Vehicles
    📁 Internal Combustion Engine
      ⊟ ◉ Gasoline
        ⊞ 🟡 Gasoline
      ⊟ ◉ Diesel
        ⊞ 🟡 Diesel
    📁 Hybrid
      ⊟ ◉ Gasoline
        ⊞ 🟡 Gasoline
```

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)

> *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.*

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_x and PM_{10}. The degradation of these can each be represented by exponential curve with the following constant parameters: 0.006 for CO, 0.008 for NO_x, and 0.005 for PM_{10}. Back in **Analysis View**, go to the **New Device Environmental Loading** tab
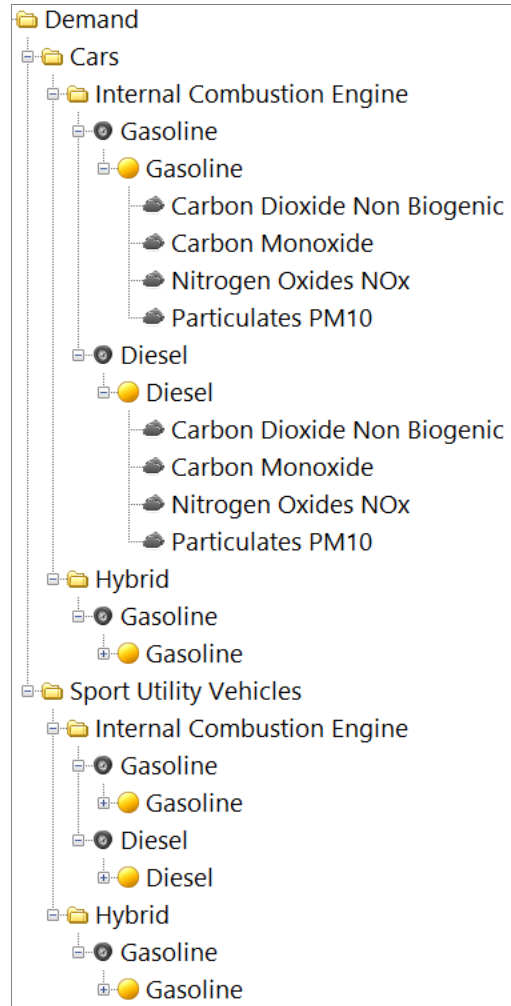
for each technology branch and in the final *Degradation Profile* column, select the appropriate profiles.

Emissions of carbon dioxide (CO_2) 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_2 emission factors leave the *Degradation Profile* set to constant.

6.6 Baseline Emissions

Projecting emissions into the future is simple for the Baseline, 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
CO2 (millions of tonnes)	70	85	110
CO (thousands of tonnes)	1079	884	931
NOx (thousands of tonnes)	82	36	14
PM10 (thousands of tonnes)	68	52	54

6.7 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.

6.7.1 Improved Fuel Economy (IFE)
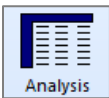
The first policy being considered by the Government is to introduce stricter fuel economy standards for conventional (i.e. non-hybrid) internal combustion engine gasoline and diesel vehicles. The proposed new standard will require new cars and SUVs to increase their fuel economy by 5% in 2015, by 10% 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 (⑤), and then create a new scenario below the Baseline 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 Baseline fuel economy and the target fuel economy. Remember that you can drag and drop the Target Economy variable from Key Assumptions.

6.7.2 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.

6.7.3 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.

### 6.7.4 New Tailpipe Emissions Standards (TAIL)

As noted above in section 6.5, 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.*
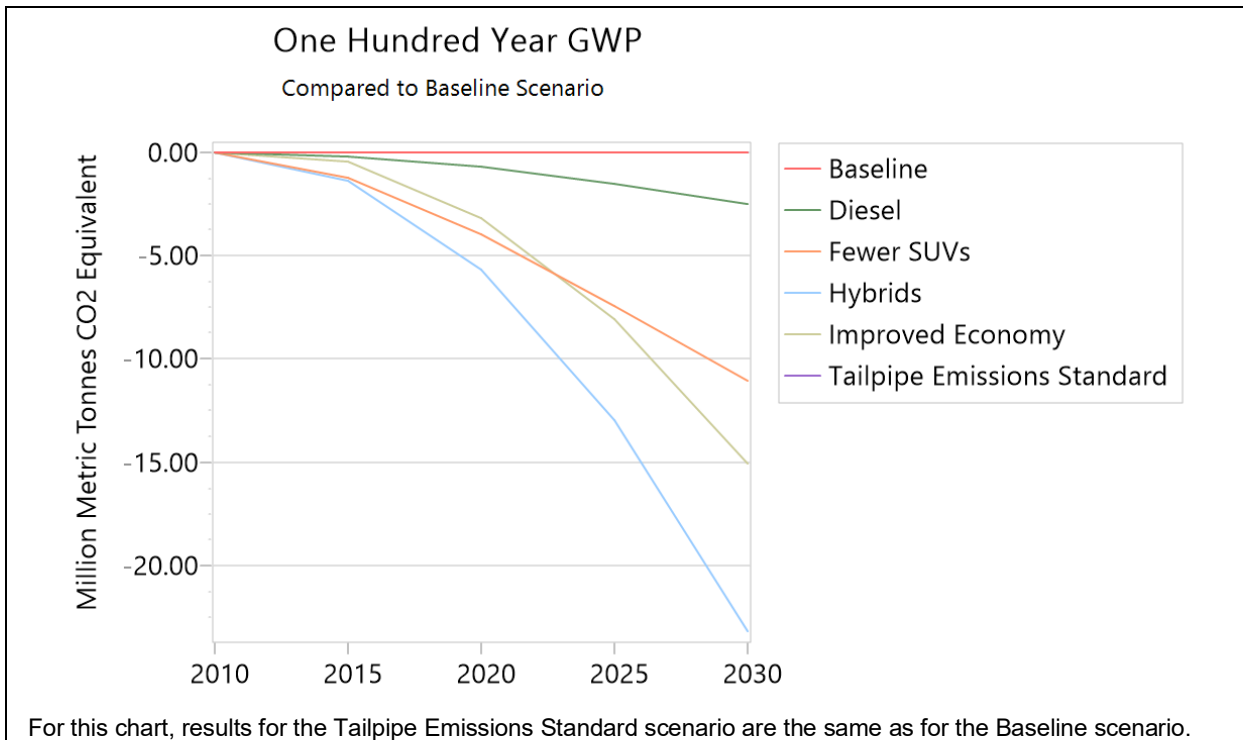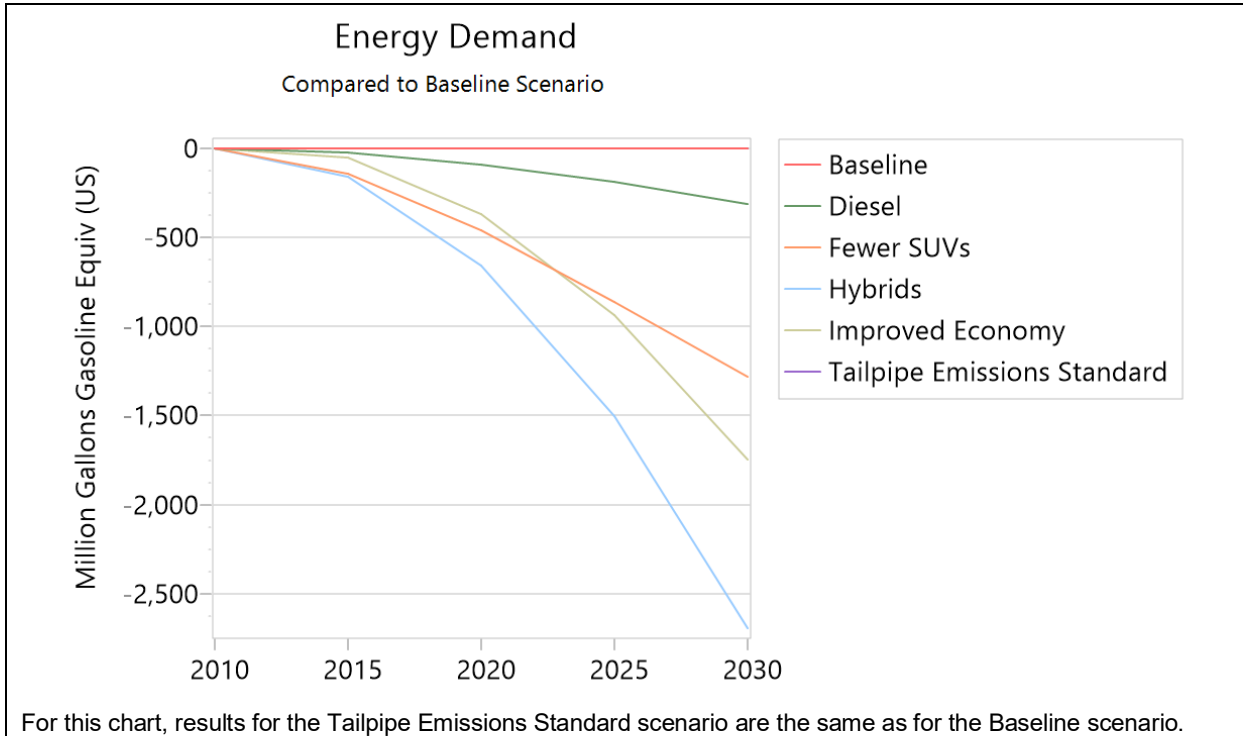
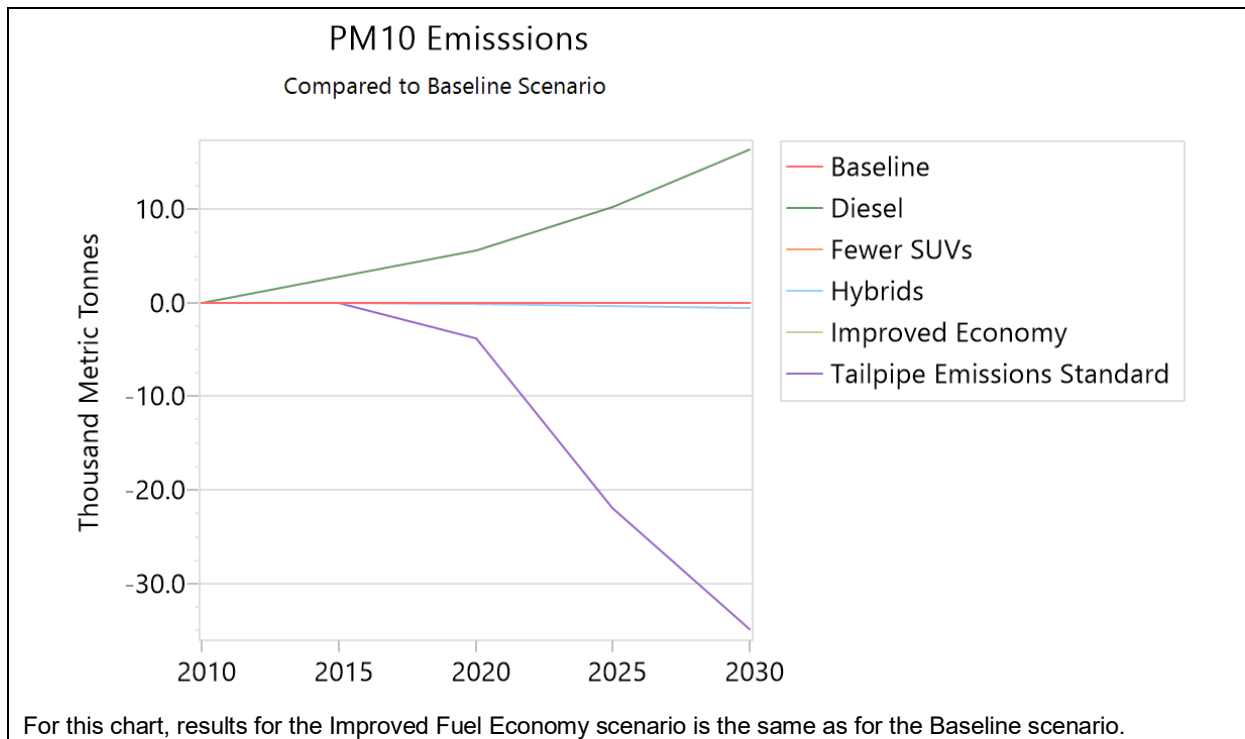### 6.7.5 Promotion of Cars over SUVs (CAR)

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.

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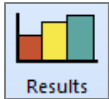
You are now ready to view the results of your scenarios. Compare the results you get to the charts on the following pages.

Energy Demand
Compared to Baseline Scenario

For this chart, results for the Tailpipe Emissions Standard scenario are the same as for the Baseline scenario.

One Hundred Year GWP
Compared to Baseline Scenario

For this chart, results for the Tailpipe Emissions Standard scenario are the same as for the Baseline scenario.

PM10 Emisssions

Compared to Baseline Scenario

For this chart, results for the Improved Fuel Economy scenario is the same as for the Baseline scenario.

Notice that some scenarios result in environmental trade-offs. In particular, notice that increased use of diesel vehicles leads to reductions in CO_2 emissions but to significant increase in PM_{10}. You may also wish to check results for NO_x.

You can try creating your own combinations of scenarios. Start by combing 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 (⑤) and create a new scenario named "Combined" that inherits from the Baseline 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 Baseline scenario.

One Hundred Year GWP

All Fuels, All GHGs
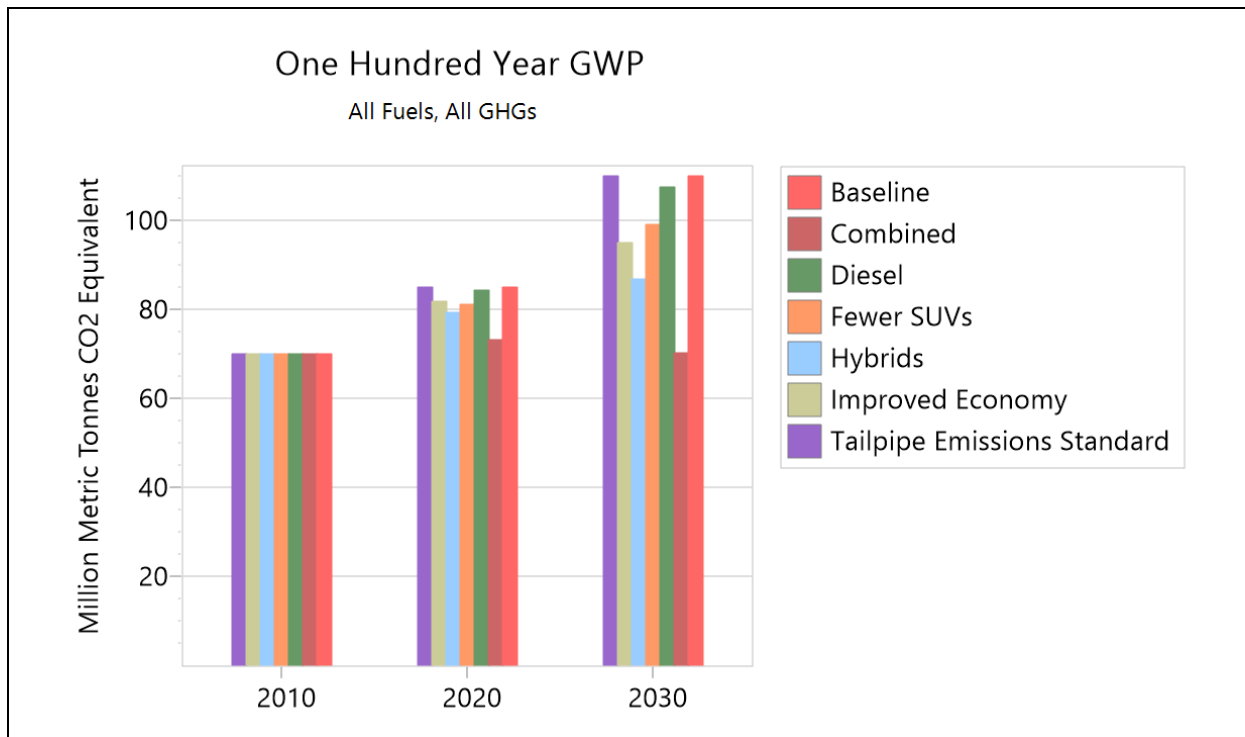
Tip: to see results matching those shown here, first open the standard "Transport Exercise" area in LEAP then use **Area: Revert to Version** and select version "Transport Exercise Complete".

Explore additional results in LEAP and try to answer the following questions:

1. *In the "Combined" scenario, what are the avoided emissions (compared to the Baseline) in 2030 that resulted from lower consumption of gasoline?*

2. *What additional measures could be implemented to further decrease the emissions from the transport sector?*

3. *How do the mitigation measures in the transport sector affect the emissions from other sectors upstream? What would you need to do in order to capture them in the model?*

# 7   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_2 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.*
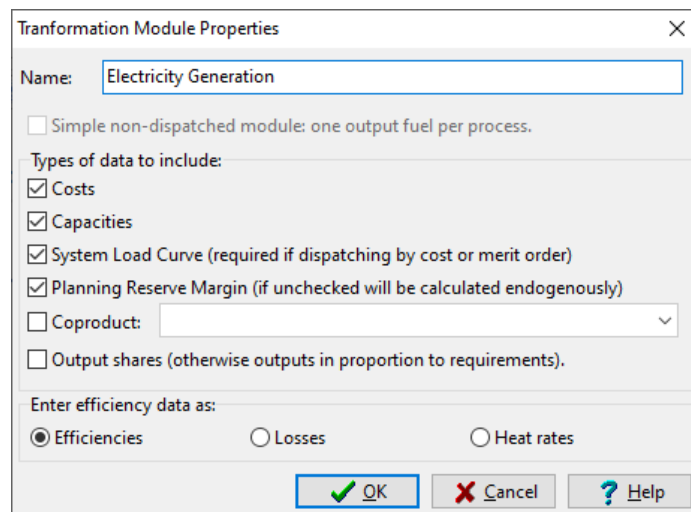
7.1   Entering Electric Generation Data
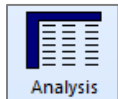
Start by opening the LEAP area "Optimization Exercise", by clicking Area: Open, and then clicking Area: Revert to Version, selecting "Optimization Exercise Start". This data set is partially completed already.

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.

Tranformation Module Properties   ✕

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)
☐ Coproduct: | ⌄|
☐ Output shares (otherwise outputs in proportion to requirements).

Enter efficiency data as:
◉ Efficiencies   ○ Losses   ○ Heat rates

[✔ OK]   [✗ Cancel]   [? Help]

Start by adding a new Transformation module called "Electricity Generation" and set its properties 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 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	Effic-iency (%)	Max Availab-ility (%)	Capacity Credit (%)	Capital Cost (Thousand $/MW)	Fixed O&M (Thousand $/MW)	Variable O&M ($/MWh)	Fuel Costs	Lifetime (yrs)
NGCC	Natual 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.

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. Right-click each relevant feedstock fuel branch (those marked with the 🟡 icon), and then select the *Add multiple effects* option (⁺⊕). This will display the box shown on the right. Select the appropriate emission factors stored in the TED database.
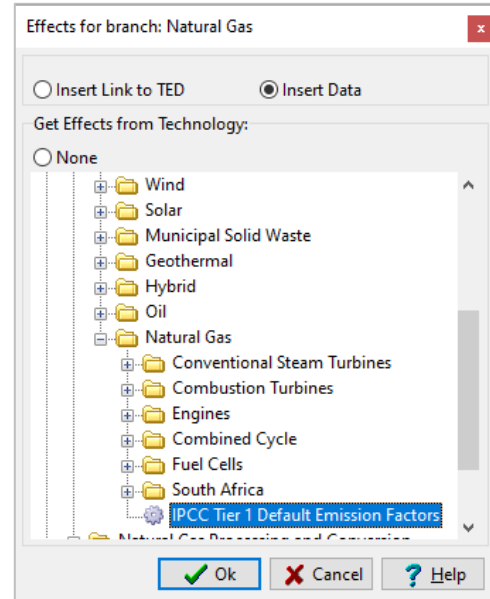
Finally, visit the Cost tab of **Settings** (shown below). Here you will need to set a few options that will be used to calculate cost results. Make sure this screen has the following settings:

- 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.
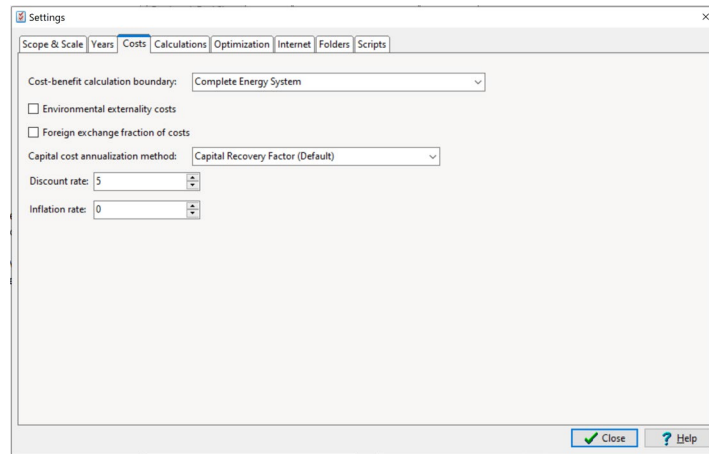
7.2 Creating Load Shapes by Importing Hourly Load Data

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 day will be divided into 24 hours.

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.
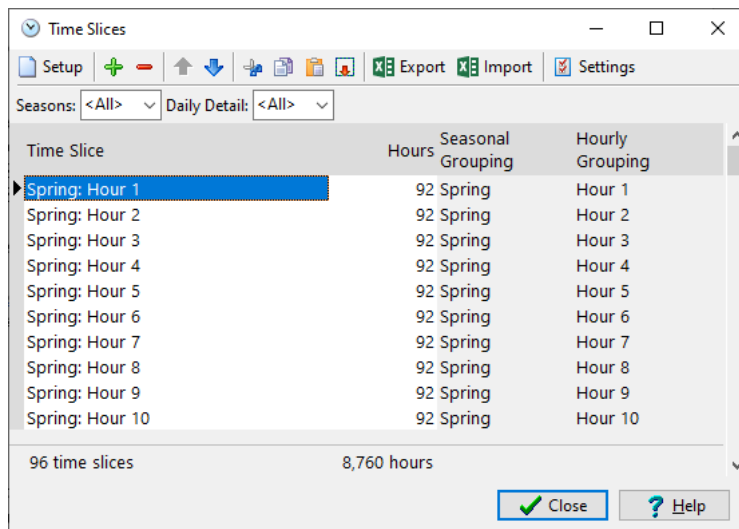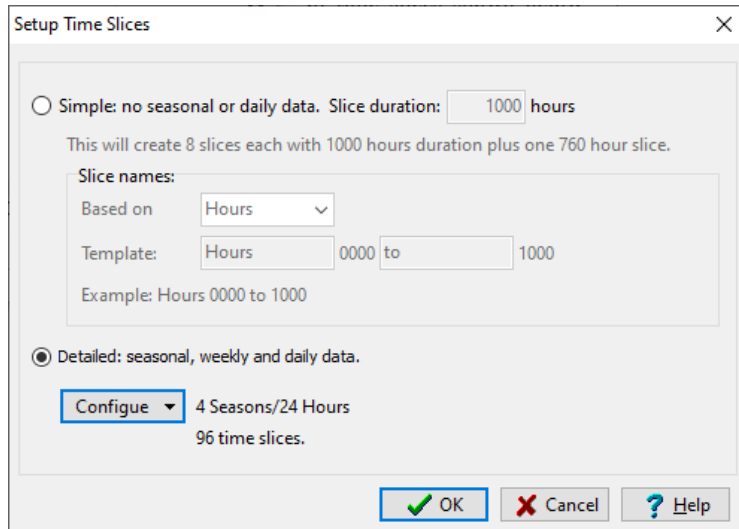
3. **Yearly Shape:** Third, you will use LEAP's **Yearly Shapes** screen to import the hourly data contained in the spreadsheet and automatically map it to the time slices you have created.

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** and then set up slices to include four seasons and 24 hourly slices. In this exercise we will not use any weekday/weekend slicing.

Once you click OK, LEAP will generate the detailed set of time slices shown to the right. Each slice will include data describing its number of hours. You can now return to the main screen.

2. ▣ **Hourly Spreadsheet Data:** Next, open up a copy of Microsoft Excel and load the spreadsheet **Sample Load Shape.xlsx** found in the Optimization exercise area folder.

Setup Time Slices ✕

○ Simple: no seasonal or daily data. Slice duration: [1000] 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: seasonal, weekly and daily data.
   [Configue ▾]   4 Seasons/24 Hours
                    96 time slices.

   [✔ OK] [✕ Cancel] [? Help]

Time Slices — ☐ ✕

[🗋 Setup] ➕ ➖ ⬆ ⬇ ... | ▣ Export ▣ Import | ☑ Settings

Seasons: [<All> ▾] Daily Detail: [<All> ▾]

Time Slice	Hours	Seasonal Grouping	Hourly Grouping
Spring: Hour 1	92	Spring	Hour 1
Spring: Hour 2	92	Spring	Hour 2
Spring: Hour 3	92	Spring	Hour 3
Spring: Hour 4	92	Spring	Hour 4
Spring: Hour 5	92	Spring	Hour 5
Spring: Hour 6	92	Spring	Hour 6
Spring: Hour 7	92	Spring	Hour 7
Spring: Hour 8	92	Spring	Hour 8
Spring: Hour 9	92	Spring	Hour 9
Spring: Hour 10	92	Spring	Hour 10

96 time slices   8,760 hours

[✔ Close] [? Help]

Notice that this spreadsheet contains hourly data for all 8760 hours of a single year, from the first hour of January 1st to the last hour of December 31st. 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.
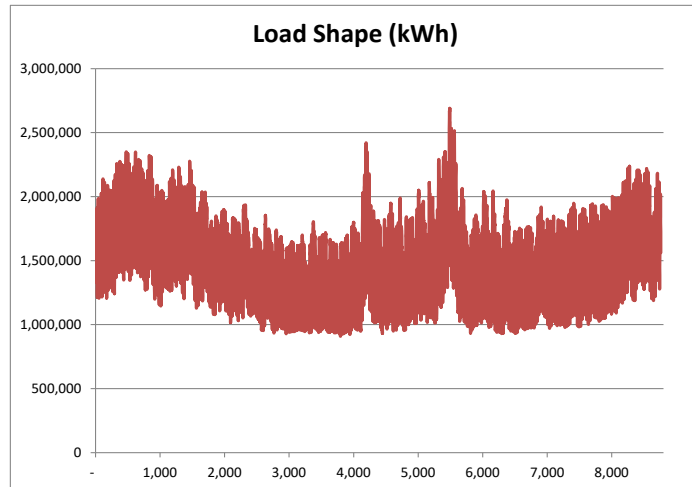
In columns C, D and E these same data have been reorganized by sorting the values from high to low and normalizing them in percentage terms against the annual peak value to produce a standard load duration curve that shows how demand varies from the hour with the highest demand to the hour with the lowest. 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.
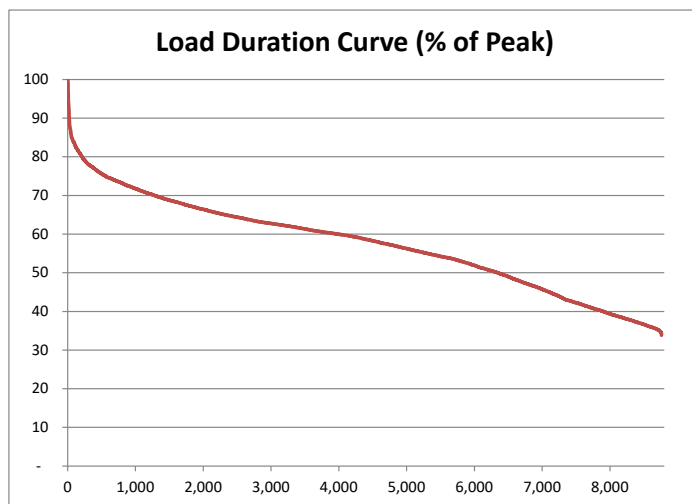
3. **Yearly Shape:** You will now import this hourly data into LEAP. Keeping Excel open, go to the General: **Yearly Shapes** screen and select the toolbar option 📊 *Import Hourly Shape.* A dialog box will appear as shown here. Set this up to import values as an "Energy Load Shape (% of annual load)", 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 "SystemShape".

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.
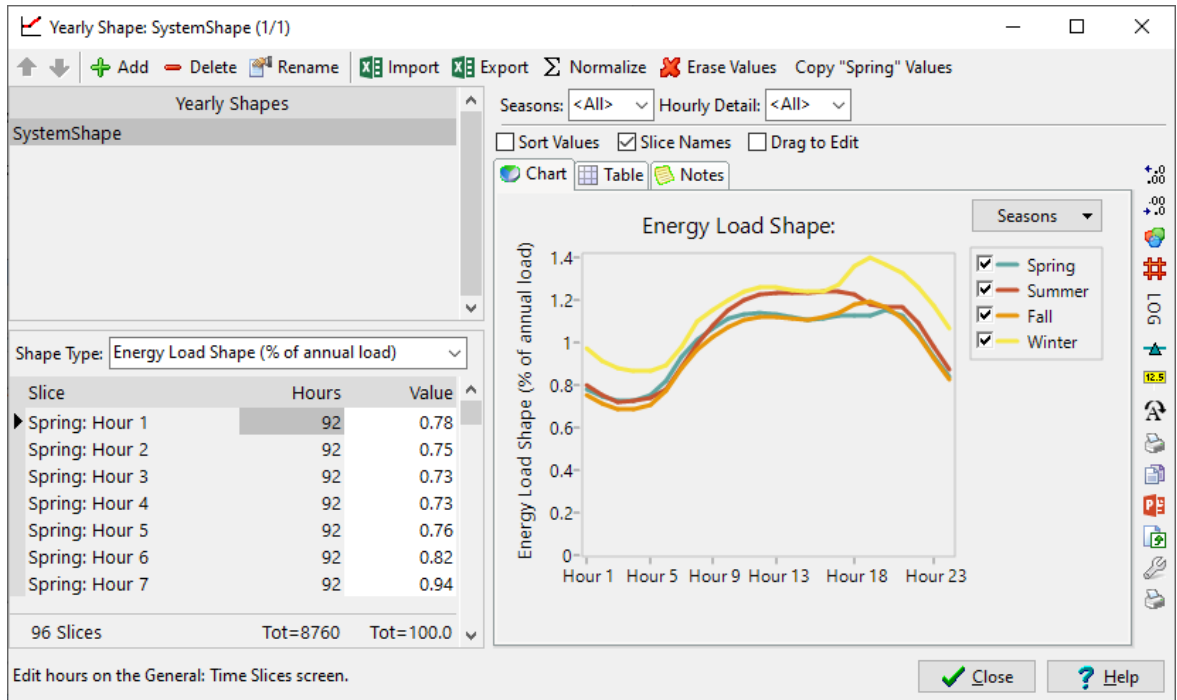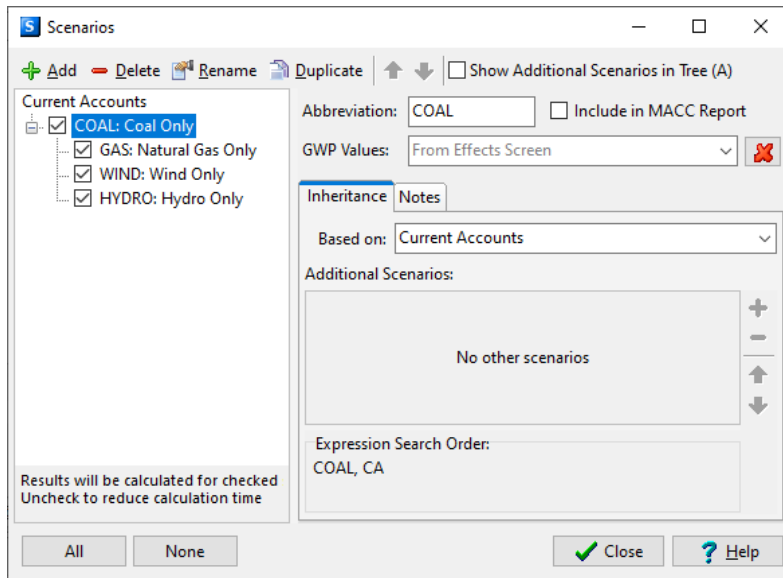

4. **System Energy Load Shape:** The final step in using this is data requires that you assign this newly created load shape to the **System Energy Load Shape** variable. Exit the **Yearly Shapes** screen and then in **Analysis View** locate the Transformation\Electric Generation branch. In Current Accounts,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

YearlyShape(SystemShape)

7.3 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*.

7.3.1 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:
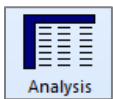
Installed Capacity in 2020
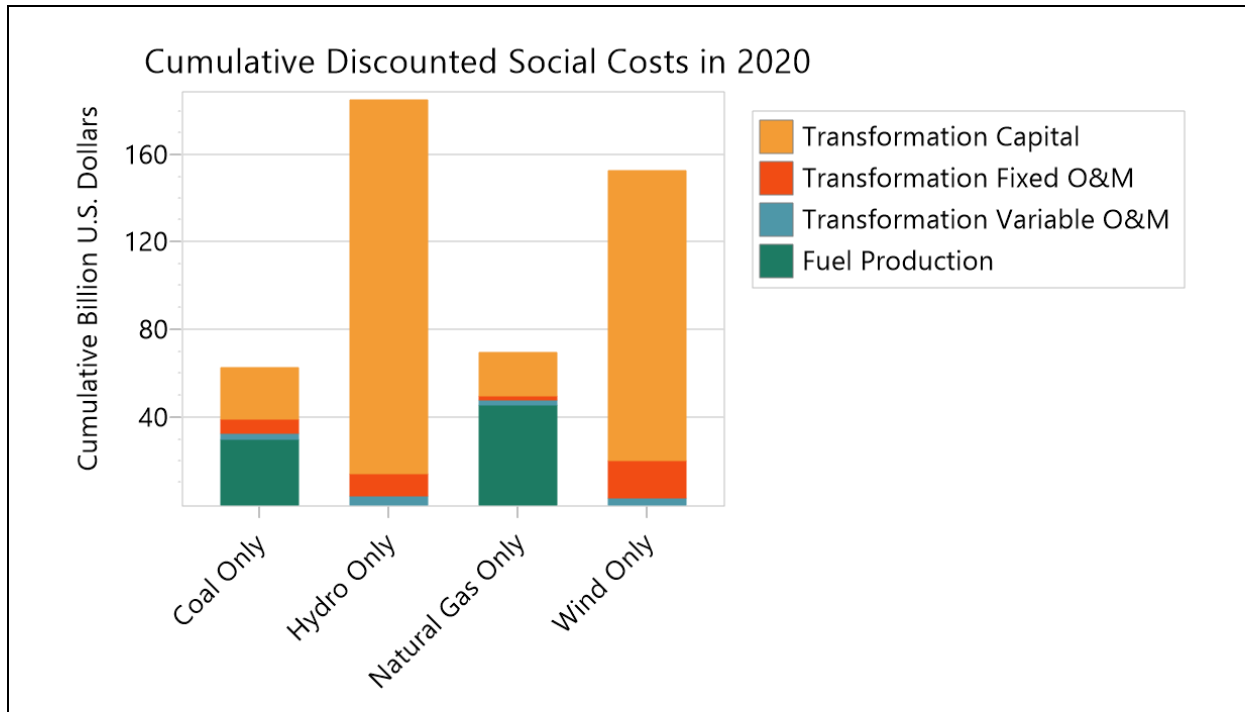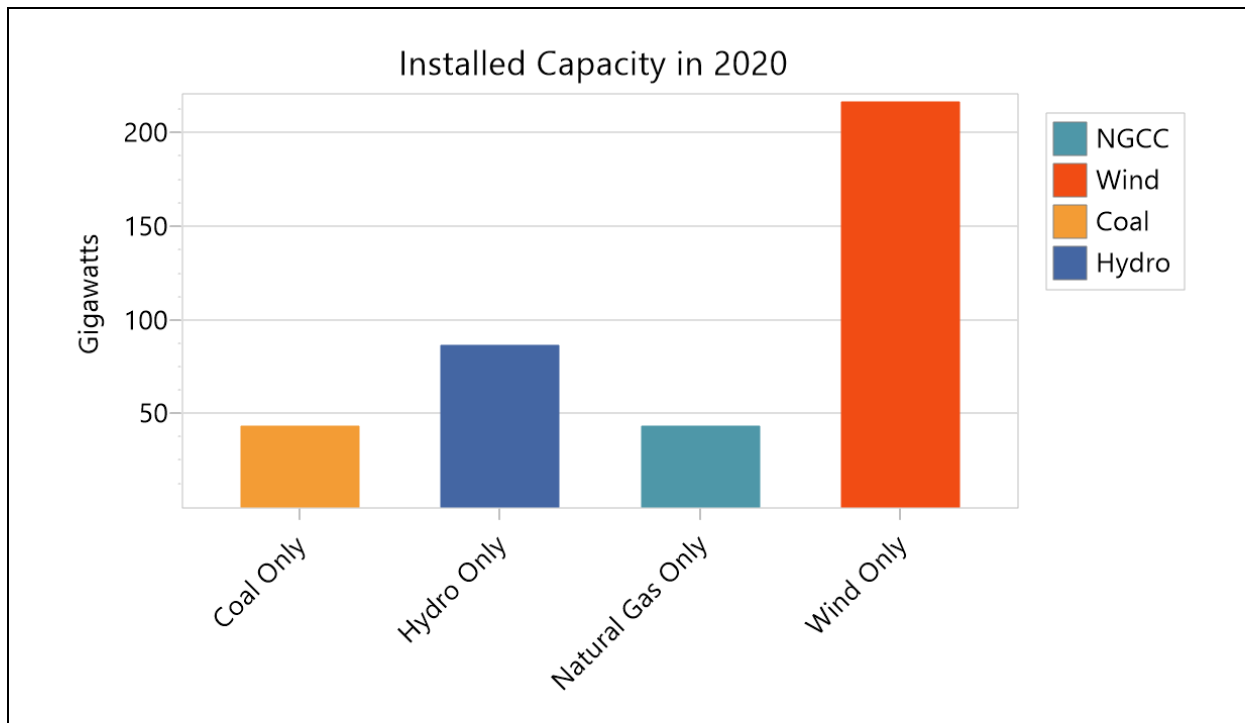
Use LEAP to analyze the results and try to answer the following questions:

1. Why is coal the cheapest option?

2. Why does LEAP incorporate more capacity for the Wind Only and Hydro Only scenarios if the electricity demand is the same in all scenarios?

7.4   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 **Costing** tab on the **Settings** 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_x) and sulfur dioxide (SO_2).

Pollutant	Externality 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 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.

Cumulative Discounted Social Costs in 2020
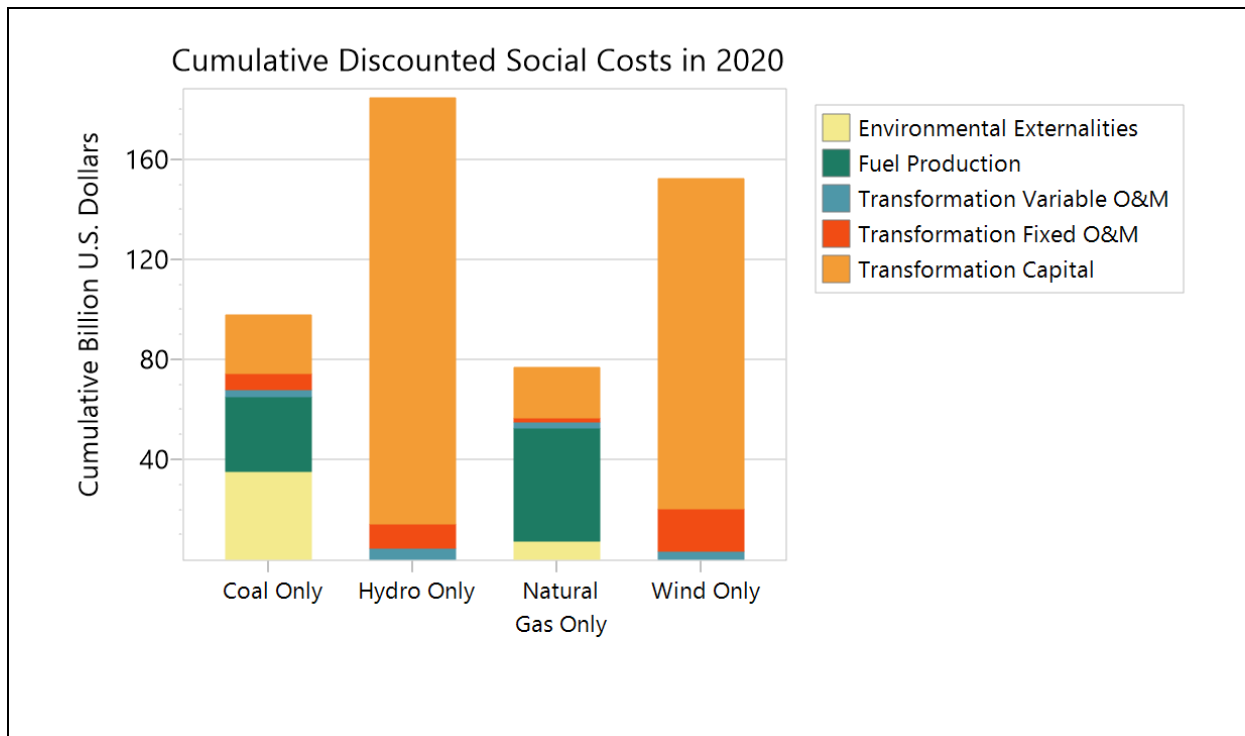
Use LEAP to analyze the results and try to answer the following questions:

1. How did the results change and why?

2. Why do externalities vary so much between different types of plants?

3. What other important types of externalities have we ignored in these calculations?

7.5   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 the **Settings** screen and check that optimization is properly installed within LEAP. Make sure also that "Enable Emission Constraints" is switched on.

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.
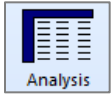
Return to the main screen in analysis view and select the Optimization scenario. You only need to set a simple setting to use optimization since you have already entered all of the basic data needed by the optimization calculations. LEAP will automatically make use of the same data you already entered 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 do not see this variable, check that you are currently editing the Optimization scenario (this variable does not appear in Current Accounts).

Note also that you do not 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.
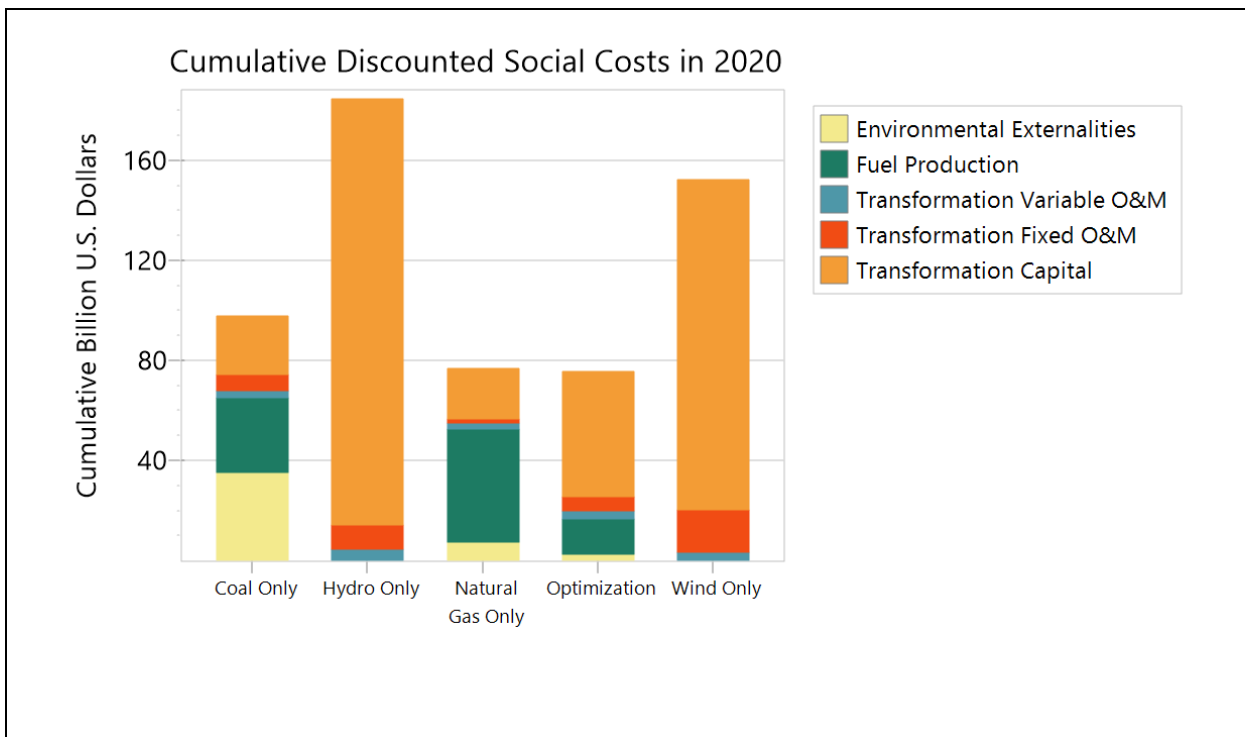
To see how this is possible, let's look at another chart showing **Transformation: Outputs by Output Fuel** by process for each scenario in 2020.

Electric Generation in 2020
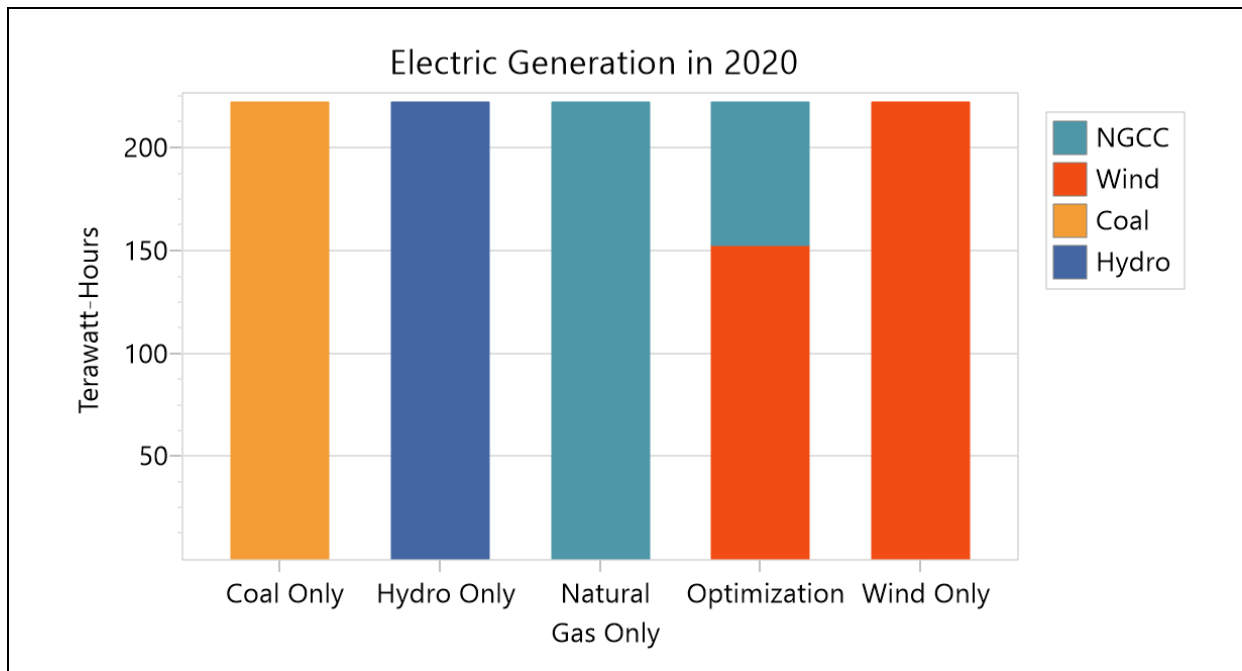
Notice that unlike in the other single-technology simulation scenarios, in the Optimization scenario LEAP has chosen a mix of power plants. Since the load shape we entered earlier varies by season and time of day there will be some periods where a very high peak demand exists. These periods favor power 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).

> *Use LEAP to analyze the results and try to answer the following question:*
>
> - *How would the optimal expansion of the power system change if the value of externalities is not considered?*

## 7.6   Using Constraints to Specify a CO_2 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_2 emissions is imposed on the system.

To create an emissions constraint, first return to the Optimization tab in **the Settings** screen 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 "CO2 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.

Cumulative Discounted Social Costs in 2020
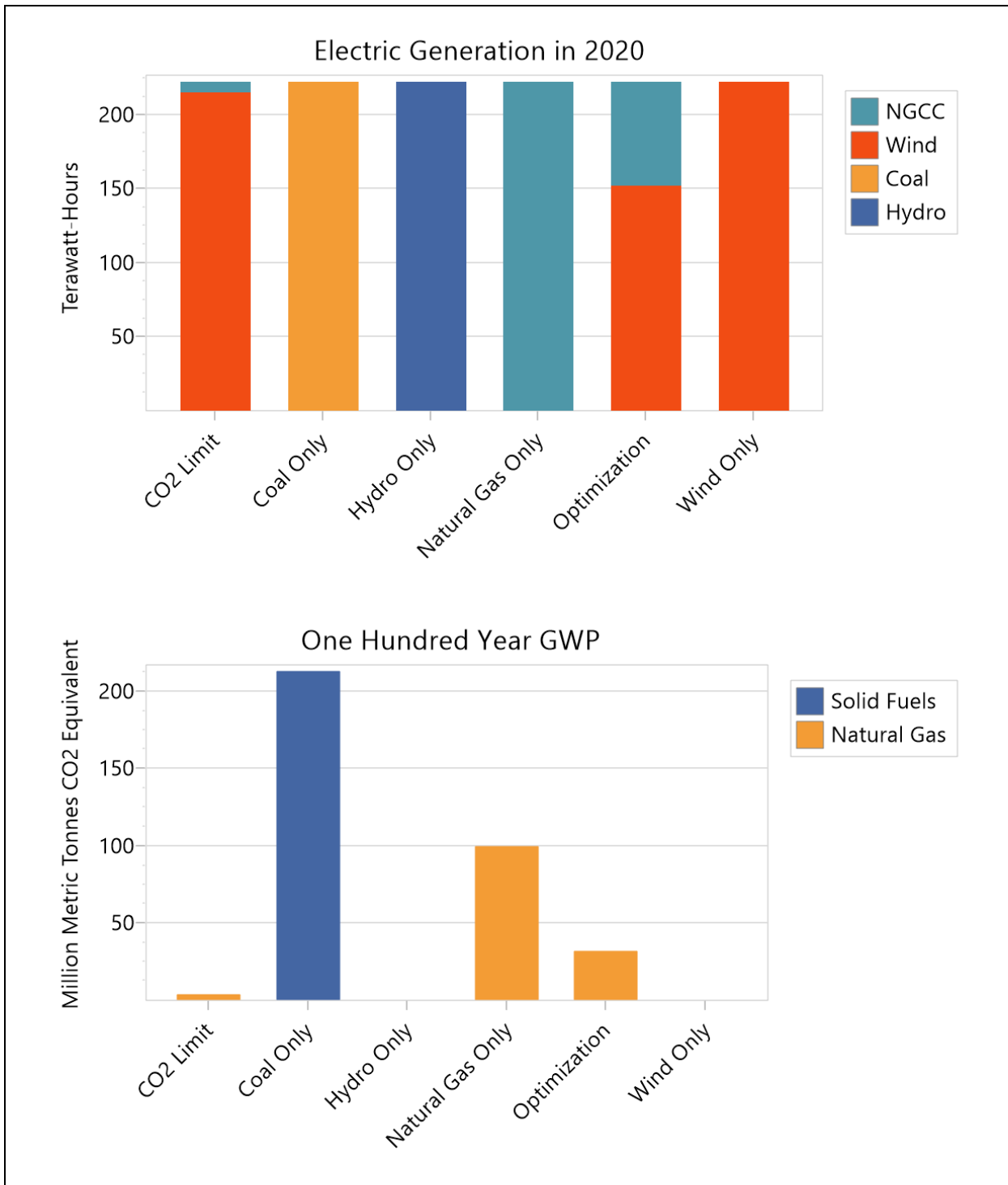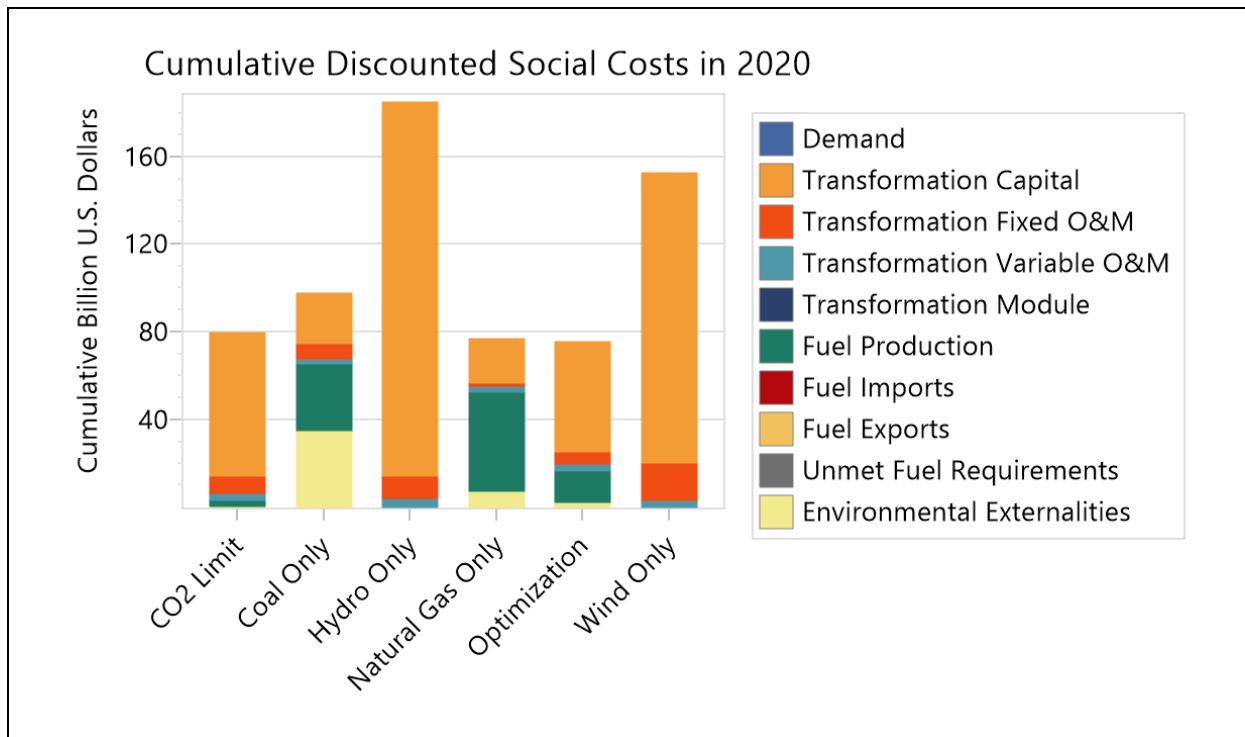
Tip: to see results matching those shown here, first open the standard "Optimization Exercise" area in LEAP then use **Area: Revert to Version** and select version "Optimization Exercise Complete".

Use LEAP to analyze the results and try to answer the following questions:

1. *What effect does the emissions cap have on the power capacity incorporated into the system?*

2. *How does it change the profile of the optimal installed capacity?*

3. *Is there an effect on the power dispatch?*

7.7   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?