NATIONAL ENERGY TECHNOLOGY LABORATORY

CarBen Version 3 Prototype: Operator's Manual

Office of Systems, Analyses and Planning

October 29, 2010

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U.S. DEPARTMENT OF ENERGY

Disclaimer

CarBen Version 3 Prototype:

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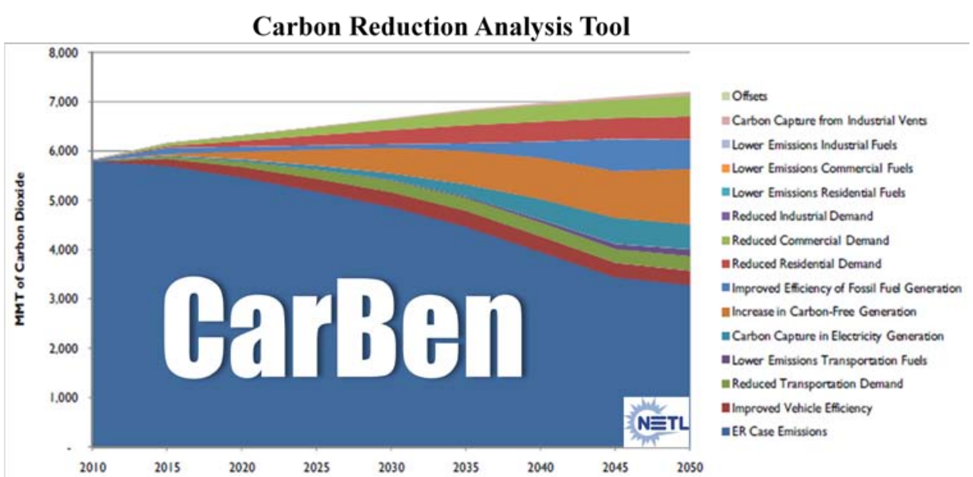
BACKGROUND

The National Energy Technology Laboratory's (NETL) CarBen model is a carbon dioxide (CO_2) emissions calculation tool that enables analysts and policymakers to evaluate the impacts that changes in the energy sector are likely to have on CO_2 emissions in the United States. The original version of CarBen (i.e., CarBen Ver.1) was developed to examine and evaluate the impacts of the technology strategy proposed in the President's Global Climate Change Initiative (GCCI), which was announced in early 2002. Several years ago CarBen was updated (i.e., CarBen Ver.2) to look at new carbon emission reduction questions and concerns; especially the role Carbon Capture and Storage (CCS) can play in reducing CO_2 emissions from the U.S. electric power sector.

The current version of CarBen (i.e., CarBen Ver. 3 Prototype) is a Microsoft Excel-based application that builds on previous versions to provide a more user-friendly interface and consolidate the reporting capabilities in a single "wedge chart," which depicts the reduction of CO_2 emissions from the energy sector as modifications are made to the CarBen Input Modules. While CarBen gives special emphasis to the electric power sector, it addresses the demand-side sectors of the energy economy—residential, commercial, industrial, and transportation—in addition to CO_2 vents and offsets.

CarBen is compatible with the Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) in that the CarBen "Reference Case" is based on the AEO 2010 Reference Case, and the CarBen "Emission Reduction Case" is designed to enable the user to modify the Reference Case assumptions and view the resulting impacts on a Wedge Chart (similar to the graph depicted in the CarBen logo on this page) and in a Summary Table. CarBen extends the AEO Reference Case to the year 2050 by linearly extrapolating the 2025–2035 growth rate to subsequent years, to provide a longer time period for evaluating the impacts of alternative CO_2 emission reduction strategies, including the development and implementation of new technologies.



GENERAL SPREADSHEET FUNCTIONS

There a number of general functions that the operator can use in all the CarBen modules. Those functions are described in this section of the manual and illustrated in the examples laced throughout the sections of the manual below.

CELL FORMATTING

- Cells displayed with a light green background are unmodified inputs. They are designed to allow modification in the Emissions Reduction case.
- As unmodified (green) cells are changed by the user, their background display changes from light green to light blue to signify modification. This enables easy tracking of modifications across the model.
- As inputs are modified in the model, in many cases, cells transition from light green to red. This signifies a data inconsistency that will need to be addressed. This can occur for several reasons:
    - A group of cells that i supposed to sum to 100 percent do not. This can be resolved by selecting the group of cells, right-clicking, and selecting "Scale Percentages."
    - In the Macroeconomic Inputs tab, more offsets were purchased than are available in a given year.
    - In the Coal Inputs tab, the Target Generation calculated using electricity demand and coal power share does not match the generation as calculated in the coal module.
    - In the Coal Inputs tab, actions for Pre-2010 power plants do not make sense. This occurs if the total retrofitted, refurbished, or retired capacities decrease over time.

SCALING PERCENTAGES

- For any block of cells that are supposed to sum to 100 percent, selecting the range, right-clicking, and choosing "Scale Percentages" will adjust the values in the cells by the following method.
- If the total value of modified cells is below 100 percent, it will scale all cells to total 100 percent.
- If the total value of modified cells is equal to or above 100 percent, all unmodified cells will be set to 0 percent, and cells will be scaled down to total 100 percent.

INTERPOLATING VALUES

- Rather than entering data for every time step, CarBen allows interpolation of values. Selecting a range of cells, right-clicking, and selecting either "Linearly Interpolate" or "Exponentially Interpolate" will, for each row in the selection, interpolate the values between the first and last cell.

RESETTING CELLS

- Right-clicking and selecting "Reset Current Sheet" will reset the value of all inputs on the sheet to the Reference Case values.
- Selecting a range of cells, right-clicking, and selecting "Reset Value(s)" will reset the selected values to the Reference Case values.

NAMING CONVERSIONS

- This model makes significant use of Named Ranges.
- The names loosely follow several conventions:
  - SD: Source Data
  - ER: Emissions Reduction Case
  - Ref: Reference Case
  - Res: Residential Module
  - Com: Commercial Module
  - Ind: Industrial Module
  - Elec: Electricity Module
  - Trans: Transportation Module
  - Lookup: A block of cells next to a mix range to be used to look up rows

WEDGE CHART

CarBen uses a "wedge chart" to illustrate the changes in CO_2 levels from the Reference Case as assumptions in the demand-side and supply-side modules are modified in the Emissions Reduction Case.[1]

If all the Emissions Reduction Case assumptions are the same as the Reference Case (i.e., the user has not modified any variables in the Emissions Reduction Case), the graph displays one blue wedge that illustrates the total CO_2 emissions forecasted in the United States from 2010 to 2050.

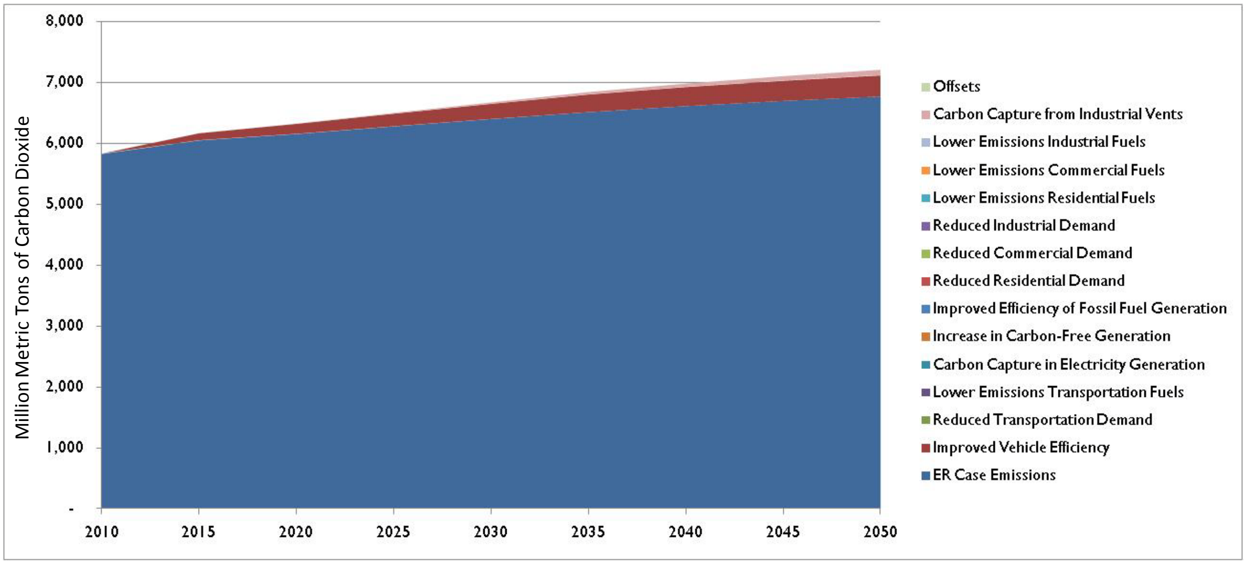
In most instances, a wedge is calculated in the graph by isolating the change in CO_2 emissions from the Reference Case due to the action(s) implemented by the user. After these are calculated, the sizes of the wedges are scaled to the total net change in CO_2 emissions to reflect double-counting that may occur to both supply- and demand-side improvements (this is explained in more detail in the paragraphs that follow).

The output from CarBen is displayed as a series of CO_2 emissions reduction "wedges" that correspond to modifications made to the inputs in the Emissions Reduction Case. For example,

[1] CarBen also includes a graphics capability for advanced Excel users to create graphs from CarBen pivot tables. These can be found in the Pivot Wedges Module.

if one were to analyze the CO_2 impacts of legislation that calls for increasing the efficiency of light-duty vehicles, this could be done in CarBen by increasing the efficiency inputs in the Emissions Reduction Case of the Transportation Inputs Module to reflect the efficiency targets in the legislation and observing the CO_2 emission changes in the “improved vehicle efficiency” wedge. The wedge chart below, Figure 1, shows the output from increasing light-duty vehicle efficiency to 50 mpg by 2050 (i.e., “50 by 50” Transportation Scenario) and linearly interpolating from 2010.

Figure 1: CO_2 Reductions under a “50 by 50” Transportation Scenario



A valuable attribute of the CarBen wedge chart is that it enables the user to understand the interaction or “ripple effects” of one action on other parts of the energy economy. This is depicted graphically in the “logic flow of wedge calculations” box below. For instance, in the “50 by 50” scenario chart above, there is a CO_2 reduction from Improved Vehicle Efficiency (the primary action resulting from the transportation policy); however, there is also a CO_2 reduction from Industrial Vents emissions due to reduced ethanol production in the industrial sector as a result of higher fuel efficiency of light-duty vehicles (which impacts the demand for ethanol, as well as gasoline).

LOGIC FLOW OF WEDGE CALCULATIONS

In addition to calculating the “ripple effects” across the energy economy from specific energy actions, CarBen scales the CO_2 impacts of multiple actions to account for interaction effects (this is also depicted in the logic flow box below). For instance, let’s assume a CarBen user changes a variable in the Commercial Input Module to “increase energy efficiency” AND changes a variable in the Electricity Input Module to increase “carbon-free generation.”

The interaction of these two actions will result in each having a different impact on CO_2 reduction than if each was done in isolation. For example, if a CarBen user were to increase energy efficiency in the commercial sector to 75 kBtu per square foot in 2050 (compared to 96 kBtu per square foot in the Reference Case), she would see a CO_2 savings of 272 MMT in 2050. However, if she were to also increase the percentage of "carbon-free electricity" generated in 2050 from 31 percent in the Reference Case to 50 percent in the Emissions Reduction Case, she would find that the CO_2 savings in the commercial sector declined from 272 MMT to 260 MMT in 2050 due to more of the nation's electricity being carbon–free; thus, actions on the demand-side that reduce electricity use are likely to have less "net" impact on CO_2 reductions because the carbon content of the nation's electricity is now lower.

Callout Box 1 below presents a sample of the actions, by energy sector and action area, that can be analyzed in the CarBen Wedge Chart.

BASE EMISSIONS REDUCTION CASE

The Base Emissions Reduction Case is a clean version of CarBen, where no data manipulation has occurred by the user. In other words, the data in the Emission Reduction Case is the same as the data in the Reference Case in each module of CarBen. (Note: It is suggested that users keep a separate file of the Base model in case the working model cannot be restored to the original values.) In the Base Emissions Reduction Case, all blocks of data on each of the input pages are highlighted in green, as shown in Figure 2. Each column in Figure 2 (and all other similar data table figures) is separated by five-year increments, beginning in 2010 and ending in 2050. As the data are manipulated within the input blocks, the cells will appear in different colors, which represent different things and will be explained in detail throughout this example. Figure 3 is located in the Wedge Chart module and represents a high-level view of the carbon baseline and reduced (or increased) emission profiles based on user inputs. When the values in the rows in Figure 3, which are currently blank (i.e., "-"), are positive, CO_2 emissions are being reduced. Conversely, when those values are negative, CO_2 emissions are increasing. Figure 4 is a graphical representation of Figure 3 that allows the user to see the temporal trends that the manipulation of data has produced. Data and visual interpretation will be highlighted as the scenarios are developed.

Figure 2: Version of a User Input Block That Has Not Been Manipulated

Generation Allocations										
Coal	(%)	47.9%	50.1%	48.8%	48.1%	47.3%	47.4%	47.0%	46.5%	45.9%
Combined Cycle	(%)	7.5%	6.0%	6.4%	6.9%	8.3%	8.4%	9.3%	10.2%	11.2%
Combustion Turbine	(%)	6.1%	4.6%	5.0%	5.8%	6.3%	6.9%	7.5%	8.1%	8.8%
Other Fossil Steam	(%)	5.2%	3.2%	3.3%	3.4%	3.6%	3.4%	3.4%	3.4%	3.4%
Nuclear	(%)	21.9%	21.1%	21.3%	20.5%	19.6%	19.2%	18.5%	17.8%	17.1%
Hydro	(%)	7.2%	7.5%	7.1%	6.9%	6.6%	6.4%	6.1%	5.9%	5.6%
Wind	(%)	3.0%	5.0%	4.7%	4.7%	4.5%	4.6%	4.5%	4.5%	4.4%
Solar	(%)	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Geothermal, MSW, etc	(%)	1.0%	1.2%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
Biomass	(%)	0.3%	1.2%	2.1%	2.5%	2.5%	2.5%	2.5%	2.5%	2.4%

Callout Box 1: Energy Sectors, Action Areas, and Sample Actions Available in CarBen

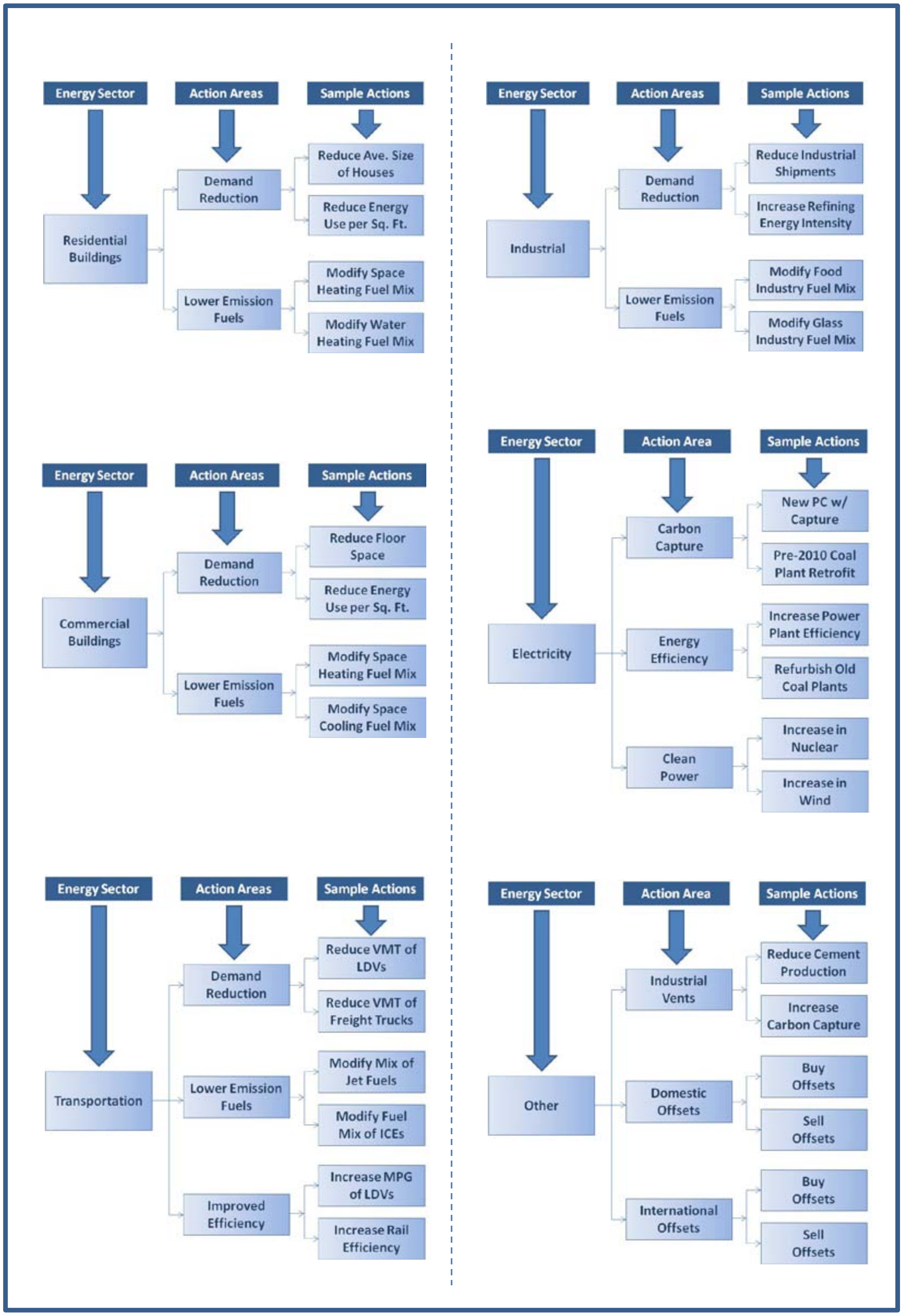
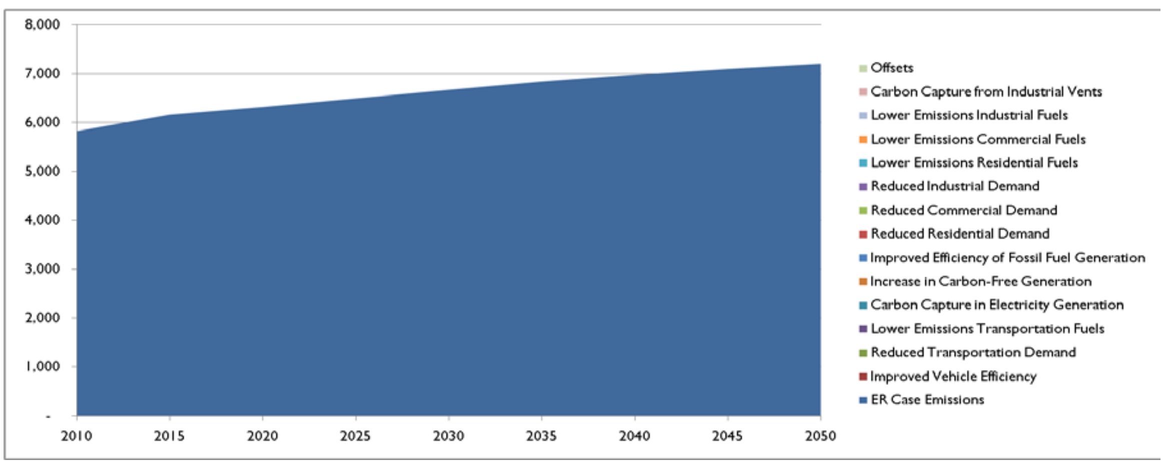


Figure 3: Rolled Up Emission Data for Base Case

	2010	2015	2020	2025	2030	2035	2040	2045	2050
ER Case Emissions	5,828	6,165	6,323	6,498	6,672	6,841	6,981	7,104	7,209
Improved Vehicle Efficiency	-	-	-	-	-	-	-	-	-
Reduced Transportation Demand	-	-	-	-	-	-	-	-	-
Lower Emissions Transportation Fuels	-	-	-	-	-	-	-	-	-
Carbon Capture in Electricity Generation	-	-	-	-	-	-	-	-	-
Increase in Carbon-Free Generation	-	-	-	-	-	-	-	-	-
Improved Efficiency of Fossil Fuel Generation	-	-	-	-	-	-	-	-	-
Reduced Residential Demand	-	-	-	-	-	-	-	-	-
Reduced Commercial Demand	-	-	-	-	-	-	-	-	-
Reduced Industrial Demand	-	-	-	-	-	-	-	-	-
Lower Emissions Residential Fuels	-	-	-	-	-	-	-	-	-
Lower Emissions Commercial Fuels	-	-	-	-	-	-	-	-	-
Lower Emissions Industrial Fuels	-	-	-	-	-	-	-	-	-
Carbon Capture from Industrial Vents	-	-	-	-	-	-	-	-	-
Offsets	-	-	-	-	-	-	-	-	-
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Calculated ER Case Emissions	5,828	6,165	6,323	6,498	6,672	6,841	6,981	7,104	7,209
Percent Reductions in 2010 Emmissions (baseline)	0.0%	-5.8%	-8.5%	-11.5%	-14.5%	-17.4%	-19.8%	-21.9%	-23.7%

Figure 4: Wedge Chart for the Base Case

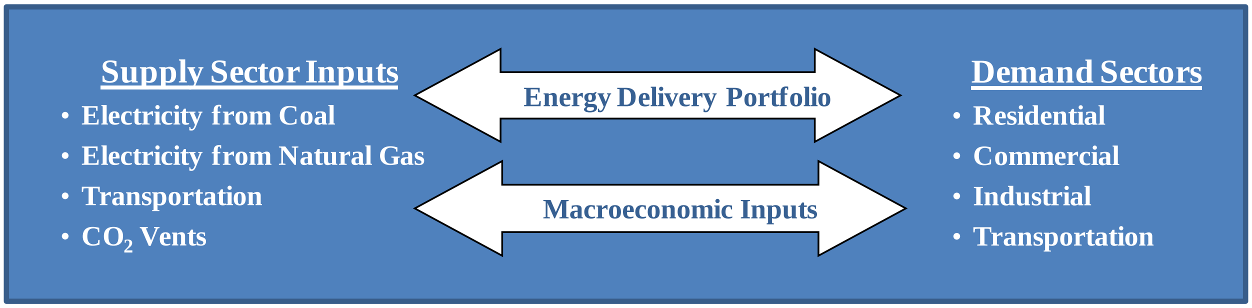


INPUT MODULES

CarBen has ten (10) input modules that cover three distinct sectors of the economy (the sectors are depicted in Figure 5). Each module is explored below, although only partially as to show procedure and results. Each module is represented on a separate tab within the CarBen spreadsheet tool. Rolled up carbon emission data and a wedge chart are on the "Wedge Chart" tab in the model.

The following sections describe the modules in detail, along with the user inputs that can be tweaked to explore various outcomes. Where appropriate, the sections also provide walk-through examples to demonstrate particular scenarios.

Figure 5: CarBen Modules



MACROECONOMIC INPUTS MODULE

Residential, Commercial, Industrial, and Transportation demand calculations are all expressed in terms of either population or GDP. By doing this, CarBen allows the user to easily examine the effects of population and GDP growth on energy use and CO_2 emissions.

- Input Guides: Expanding the "+" sign next to the US Population input will display population and GDP growth rates and ratios, in order to evaluate these inputs.
- Carbon Price: The carbon price is used to calculate the number of domestic and international offsets available, as well as the Carbon Capture rate in the Industrial CO_2 Vents Module.
- Offsets: Available offsets are calculated based on the entered carbon price and a supply curve found on the Sourced Data tab. The purchased offsets must be less than the available offsets.

EXAMPLE: MACROECONOMIC INPUTS

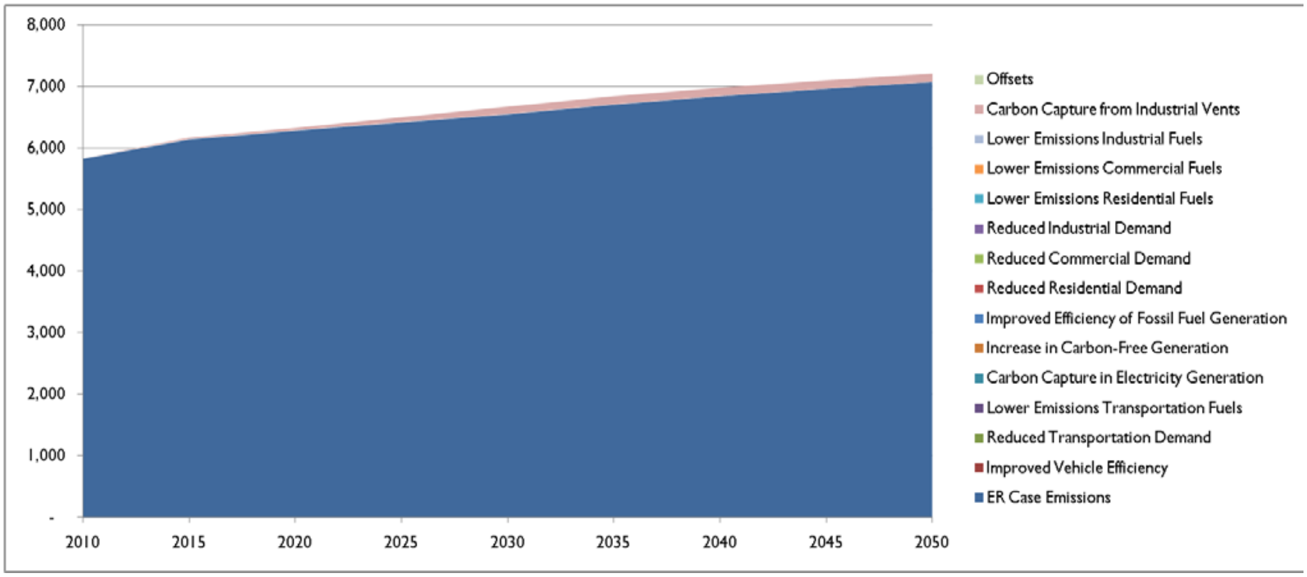
This example is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

There are only a few sets of data for the user to manipulate in the Macroeconomics Input Module. In this example, a price per unit mass (or carbon tax) is manipulated, as is the U.S. population. This is an example of both a rational and irrational hypothesis; the former being a lever that can be implemented through policy, where the latter is not. In Figure 6, a carbon tax is added in 2015, increasing in value through 2050. The values in the cells that have been changed are highlighted in blue. In this case, the values were manually changed by the user. Figure 7 shows that a carbon tax alone is not an effective measure to reduce CO_2 emissions, as the only CO_2 that is captured is that flowing from industrial vents, which is a minor contributor to the total CO_2 emission profile.

Figure 6: Addition of a Carbon Tax

US Population	(Millions)	311	327	343	359	375	391	408	426	444
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Figure 7: Addition of a Carbon Tax Results

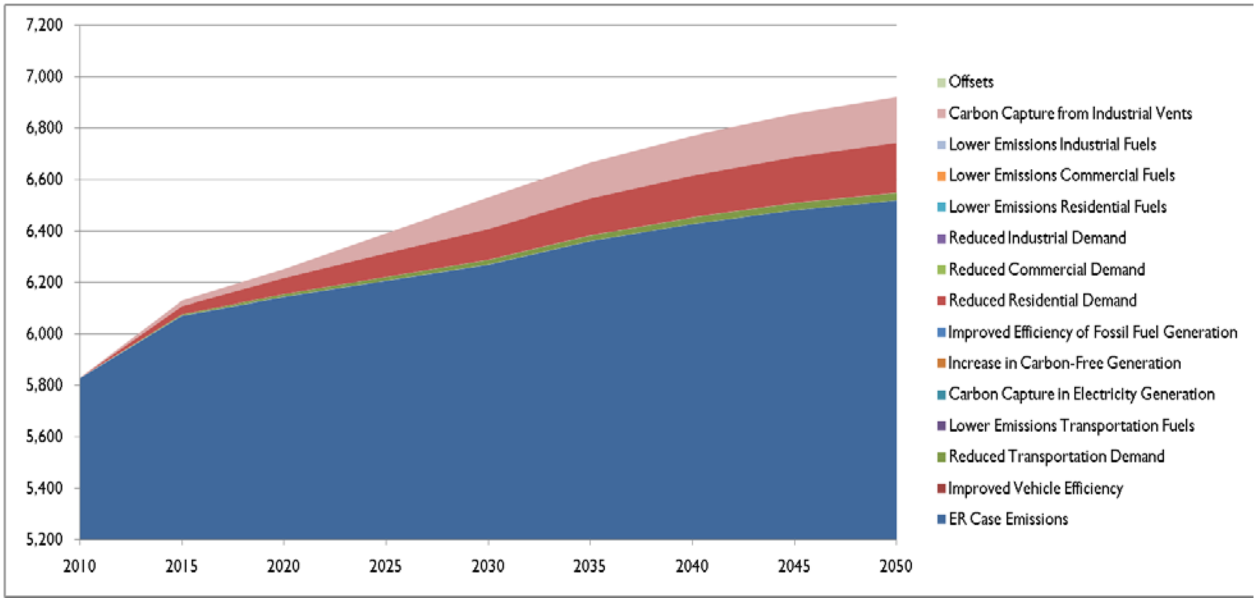


An example of an irrational manipulation is to change the U.S. population by any significant amount above and beyond traditional growth rates. In Figure 8, the population was significantly decreased in the year 2050 to a level that is 20 percent of what is predicted in the baseline (compare to the population in Figure 6, which is the baseline). The value inputted in the 2050 population cell was then interpolated back to the year 2010 using a built-in model function (Callout Box 2). The results in Figure 9 show significant reductions in CO_2 emissions, but the assumption does not withstand the proper scrutiny needed to generate plausible results.

Figure 8: 20 Percent Reduction in U.S. Population in 2050, Interpolated Back to 2010

US Population	(Millions)	311	317	322	328	333	339	344	350	355
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Figure 9: 20 Percent Reduction in U.S. Population in 2050, Interpolated Back to 2010 Results



Callout Box 2: Manipulating Data Using the Interpolation Tools in CarBen

1. Enter value desired in appropriate cell. In this example, we change the population in 2050 to 355 million.

US Population	(Millions)	311	327	343	359	375	391	408	426	355

2. Highlight the manipulated cell through the cell where you want the interpolation to take place. This case highlighted back to the first cell (311 Million).
3. Right-click on the highlighted cells.
4. At the bottom of the list of options, choose ‘Linearly Interpolate’ (note, you can also interpolate exponentially using the same procedure).

US Population	(Millions)	311	317	322	328	333	339	344	350	355

Notice that the initial value of 311 million does not change colors, as it has not changed.

RESIDENTIAL INPUTS MODULE

The general principle of the Residential Inputs Module is to express overall residential energy use in terms of U.S. population, provide the user with the ability to adjust how this energy is used, and, where sensible, provide fuel alternatives for each energy use.

ENERGY USE CALCULATION

Total residential energy usage is calculated based on four inputs:

- US Population (in the Macroeconomic Inputs tab)
- People per Household
- Average House Size
- Consumption per Square Foot.

The calculation is: (Population / People per Household) * Avg. House Size * Energy Consumption per Sq. Foot

Once the total energy use is calculated, it can then be allocated to specific uses. These inputs need to total 100 percent for each year.

While some residential energy uses, such as Personal Computers, can only be met with electricity, other needs can be met by a variety of fuels. These uses are:

- Space Heating
- Space Cooling
- Water Heating
- Cooking
- Clothes Dryers
- Other Uses

For each of these areas, the user has the ability to input a mix of fuels to meet the demand requirements. Each fuel mix must total 100 percent for each year.

EMISSIONS CALCULATION

Residential emissions are calculated for each use and fuel, and then totaled.

The calculation is: Total Residential Energy Demand * Energy Use Share % * Fuel Use Share % * Fuel Emissions Coefficient.

For electricity, the emissions coefficient is calculated in the Electricity module. These calculations are located in the Demand Calculations tab.

EXAMPLE: RESIDENTIAL INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

The Residential Inputs Module allows the user to manipulate inputs from multiple demand streams within the residential sector. These include:

- People per household
- Average home size
- Energy consumption per square foot
- How residential energy is used
- Defining the fuel mixes for multiple uses (e.g., heating, cooking, cooling)

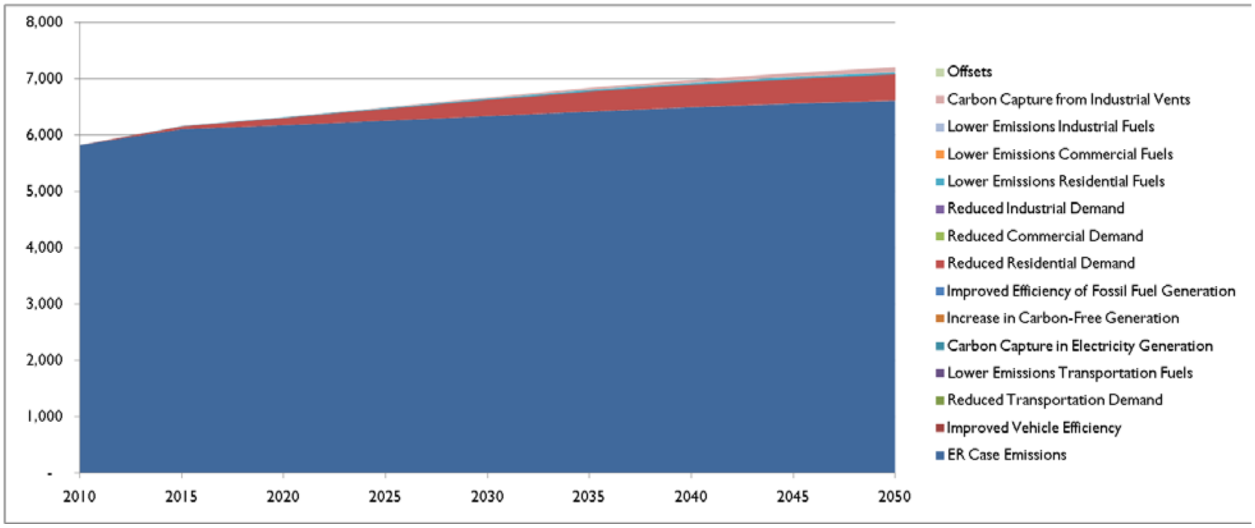
In this example, a few scenarios are performed to highlight the influences to demand dynamics. The first scenario investigated changes in the size and energy efficiency of homes. In Figure 10 the size of a home was reduced to 1,500 sq. ft. in 2050 then linearly interpolated back to 2010. In Figure 10 the energy consumption per sq. ft. was also reduced to 25 kBtu and exponentially interpolated to 2010.

Figure 10: Residential Home Size and Efficiency Sensitivities

How many people are in the average household?		2.70	2.69	2.66	2.65	2.65	2.66	2.67	2.67	2.68
How big is the average house?	(sq ft)	1,686	1,663	1,639	1,616	1,593	1,570	1,546	1,523	1,500
What is the energy consumption per square foot?	(kBtu)	58.0	52.2	47.0	42.3	38.1	34.3	30.9	27.8	25.0

The wedge chart in Figure 11 indicates that a sizeable reduction in CO_2 emissions, with home size and efficiency having close to equal influence.

Figure 11: Residential Home Size and Efficiency Sensitivities Results



The second scenario investigated changing the energy consumption mix used in space heating (the most energy intensive area of residential energy demand) by increasing the use of renewables from 10 percent to 30 percent, linearly interpolating back to 2010, and scaling the block of cells. The result from this sensitivity showed only minimal changes in CO_2 emissions and, therefore, the results are not displayed because a "reduction wedge" is visible in the chart.

COMMERCIAL INPUTS MODULE

The general principle of the commercial module is to express overall commercial energy use in terms of U.S. GDP, provide the user the ability to adjust how this energy is used, and, where sensible, provide fuel alternatives for each energy use.

ENERGY USE CALCULATION

Total commercial energy usage is calculated based on 3 inputs:

- US GDP (in the Macroeconomic Inputs tab)
- Floorspace per GDP
- Energy Consumption per Square Foot of Floorspace

The calculation is: GDP * Floorspace per GDP * Consumption per Sq. Foot

Like the Residential module, once total energy use is calculated, it can then be allocated to specific uses. These inputs need to total 100 percent for each year.

Like the Residential module, some commercial energy uses, such as Office Equipment, can only be met with electricity; other needs can be met by a variety of fuels. These uses are:

- Space Heating
- Space Cooling
- Water Heating
- Cooking
- Other Uses

For each of these, the user has the ability to input a mix of fuels to meet the required demand. Each mix must total 100 percent for each year.

EMISSIONS CALCULATION

Like the residential module, commercial emissions are calculated for each use and fuel, and then totaled.

The calculation is: Total Commercial Energy Demand * Energy Use Share % * Fuel Use Share % * Fuel Emissions Coefficient.

For electricity, the emissions coefficient is calculated in the Electricity module. These calculations are located in the Demand Calculations tab.

EXAMPLE: COMMERCIAL INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

The Commercial Inputs Module is designed very much like the Residential Inputs Module. For this example, we lowered the energy consumption per sq. ft. to 75 kBtu (see Figure 12). Additionally, we changed the mix of energy used in the "Other Uses" category to require 20 percent from renewable resources.

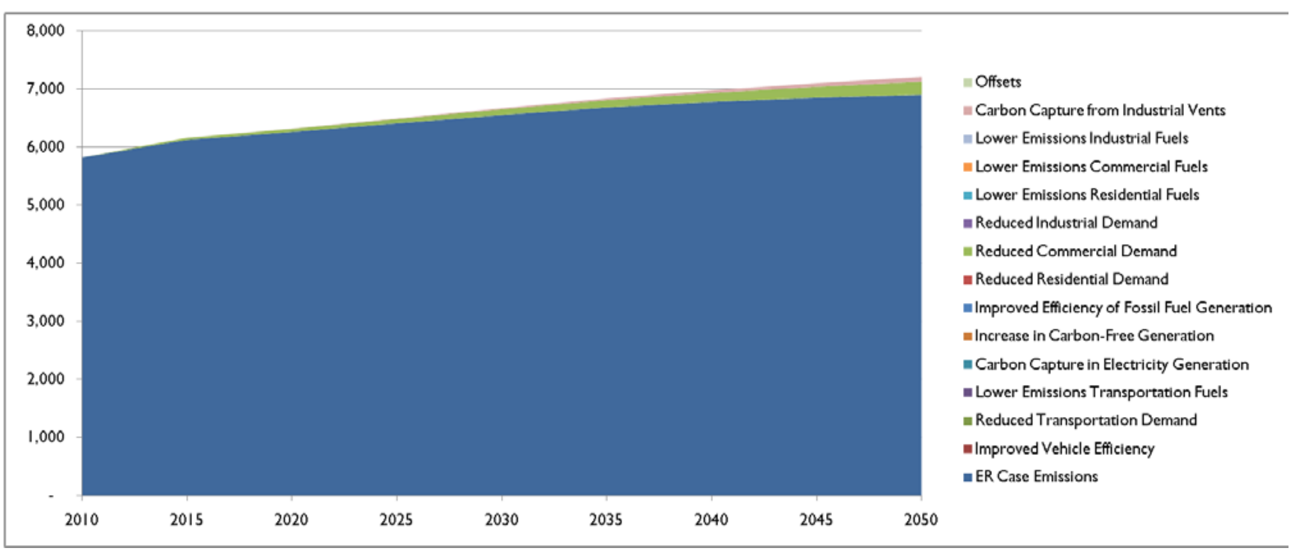
Figure 12: Commercial Inputs

How much commercial floorspace is there per thousand dollars of GDP?	(Sq ft/1000$GDP)	7.1	6.4	5.9	5.6	5.2	4.9	4.7	4.4	4.2
What is the energy consumption per square foot?	(kBtu)	106.2	102.3	98.4	94.5	90.6	86.7	82.8	78.9	75.0

What fuel mix is used for other uses?										
Electricity	(%)	48.6%	49.2%	50.6%	51.2%	51.3%	50.9%	50.5%	50.2%	49.7%
Liquefied Petroleum Gases	(%)	2.7%	2.5%	2.3%	2.2%	2.0%	1.8%	1.6%	1.5%	1.3%
Motor Gasoline	(%)	2.0%	1.8%	1.6%	1.5%	1.4%	1.2%	1.1%	1.0%	0.9%
Kerosene	(%)	0.2%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%
Distillate Fuel Oil	(%)	5.2%	4.7%	4.1%	3.7%	3.3%	2.9%	2.5%	2.2%	2.0%
Residual Fuel Oil	(%)	2.1%	2.6%	2.3%	2.1%	1.9%	1.7%	1.5%	1.4%	1.2%
Natural Gas	(%)	33.4%	31.2%	29.2%	27.7%	26.7%	26.1%	25.3%	24.5%	23.7%
Coal	(%)	2.2%	2.0%	1.8%	1.6%	1.5%	1.3%	1.2%	1.0%	0.9%
Renewable Energy	(%)	3.6%	5.6%	7.7%	9.7%	11.8%	13.8%	15.9%	17.9%	20.0%

Results in Figure 13 show a noticeable drop in CO_2 when energy consumption per sq. ft. is lowered. In addition, changing the energy supply for "Other Uses" has a non-trivial effect on CO_2. The "Other Uses" category, however, is very broad and unlikely to get much attention in CO_2 policy. Therefore, we are only showing the results from the manipulation in energy use.

Figure 13: Commercial Inputs Results



INDUSTRIAL INPUTS MODULE

The general principle of the Industrial Inputs Module is to calculate the energy consumption of each industry based on total industrial shipments, the mix of these shipments, and the energy consumption per dollar of each shipment. Each industry's emissions are then calculated based on the fuel mix for that particular industry. Total industrial energy usage is based on multiple sectors of industry, including:

- Refining
- Food
- Paper
- Bulk chemicals
- Glass
- Cement
- Iron and Steel
- Aluminum
- Fabricated metal products
- Machinery
- Computer manufacturing
- Transportation equipment
- Electrical equipment
- Wood
- Plastics, and
- Other minor industries

ENERGY USE CALCULATION

Total industrial energy usage is calculated based on the inputs above.

The calculation is: Total Industrial Energy Demand * Energy Use Share % * Fuel Use Share % * Fuel Emissions Coefficient.

In the Industrial Inputs Module, once total energy use is calculated, it can be allocated to specific uses. These inputs need to total 100 percent for each year. As with the Residential Inputs Module, some industrial energy uses can only be met with electricity; other needs can be met by a variety of fuels. These uses are:

- Residual fuel oil
- Distillate fuel oil
- Liquefied petroleum gases
- Petroleum coke
- Other petroleum
- Natural gas
- Steam coal
- Renewables
- Electricity

- Liquefied petroleum gas feedstock
- Petrochemical feedstock
- Natural gas feedstock

For each of these, the user has the ability to input a mix of fuels to meet the required demand. Each mix must total 100 percent for each year for each of the industrial sectors listed above. Note that not all of the energy inputs are an option in each of the industrial sectors.

EMISSIONS CALCULATION

For each industry, the mix of fuels can then be entered; each mix must total 100% for each year.

Emissions are then calculated for each industry and fuel, using the following formula: Industry Energy Consumption * Fuel Share % * Fuel Emissions Coefficient.

For electricity, the emissions coefficient is calculated in the Electricity Module. These calculations are located in the Demand Calculations tab.

EXAMPLE: INDUSTRIAL INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

In the Industrial example, the blend of renewable fuels supply was increased. In most cases, the 2050 value was increased to 5 percent. Although this does not seem high, it is a good approximation of reality. However, the amount of renewables in the food industry was increased to 33 percent in 2050 (see Figure 14) based on the theory that the industry's use of renewables is from burning their wastes for heat and possibly electricity generation. Results from the Industrial Inputs Module runs show that there is very little benefit to increased renewables in the industrial sector (see Figure 15).

Figure 14: Industrial Inputs

What fuel mix is used by the food industry?										
Residual Fuel Oil	(%)	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Distillate Fuel Oil	(%)	1.1%	1.0%	1.0%	0.9%	0.9%	0.8%	0.8%	0.7%	0.7%
Liquefied Petroleum Gases	(%)	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%
Other Petroleum	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	(%)	55.8%	54.3%	52.8%	51.1%	49.4%	47.6%	45.8%	43.9%	42.0%
Steam Coal	(%)	14.9%	13.4%	12.3%	11.2%	10.3%	9.4%	8.5%	7.8%	7.0%
Renewables	(%)	4.7%	8.2%	11.7%	15.3%	18.8%	22.4%	25.9%	29.5%	33.0%
Electricity	(%)	23.1%	22.6%	21.9%	21.1%	20.3%	19.5%	18.6%	17.8%	17.0%

What fuel mix is used by the iron and steel industries?										
Distillate Fuel Oil	(%)	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%
Residual Fuel Oil	(%)	0.4%	0.7%	0.6%	0.5%	0.5%	0.4%	0.4%	0.3%	0.3%
Other Petroleum	(%)	0.8%	2.3%	2.0%	1.7%	1.4%	1.1%	0.9%	0.7%	0.5%
Natural Gas	(%)	26.8%	31.0%	31.4%	30.9%	30.2%	29.9%	29.2%	28.5%	27.7%
Metallurgical Coal	(%)	54.7%	43.4%	41.6%	41.4%	41.7%	42.3%	42.5%	42.6%	42.6%
Net Coke Imports	(%)	-1.1%	0.7%	0.9%	0.8%	0.5%	-0.2%	-0.2%	-0.3%	-0.3%
Steam Coal	(%)	7.8%	5.4%	5.2%	5.3%	5.7%	6.5%	7.2%	7.9%	8.6%
Renewables	(%)	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	5.0%
Electricity	(%)	9.6%	15.0%	16.2%	16.6%	16.7%	16.1%	15.8%	15.4%	15.1%

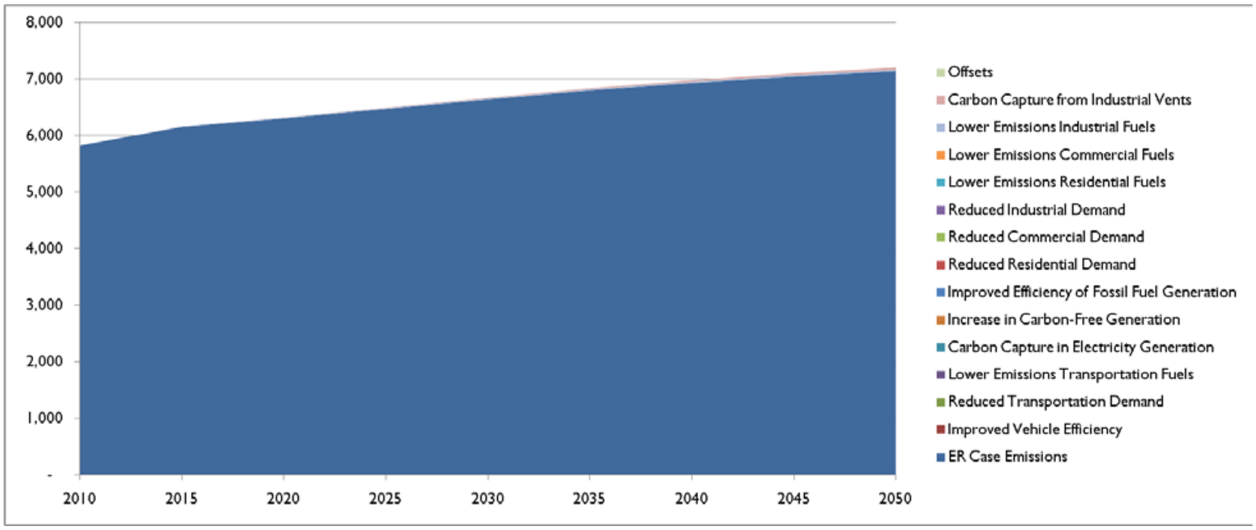
What fuel mix is used by the fabricated metal product industry?										
Liquefied Petroleum Gases	(%)	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%
Distillate Fuel Oil	(%)	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Residual Fuel Oil	(%)	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%
Petroleum Coke	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	(%)	49.9%	48.5%	47.2%	46.2%	45.1%	44.9%	44.3%	43.7%	43.0%
Metallurgical Coal	(%)	0.9%	0.9%	0.8%	0.8%	0.8%	0.8%	0.8%	0.7%	0.7%
Steam Coal	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Renewables	(%)	0.0%	0.6%	1.3%	1.9%	2.5%	3.1%	3.8%	4.4%	5.0%
Electricity	(%)	47.4%	48.3%	49.1%	49.6%	50.1%	49.7%	49.7%	49.7%	49.7%

What fuel mix is used by the machinery industry?										
Liquefied Petroleum Gases	(%)	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%
Distillate Fuel Oil	(%)	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%
Residual Fuel Oil	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Petroleum Coke	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	(%)	41.4%	39.8%	38.4%	37.0%	35.6%	35.2%	34.3%	33.4%	32.6%
Steam Coal	(%)	1.7%	1.5%	1.4%	1.5%	1.5%	1.5%	1.6%	1.6%	1.6%
Renewables	(%)	0.0%	0.6%	1.3%	1.9%	2.5%	3.1%	3.8%	4.4%	5.0%
Electricity	(%)	56.0%	57.2%	58.1%	59.0%	59.7%	59.5%	59.7%	60.0%	60.2%

What fuel mix is used by the transportation equipment industry?										
Liquefied Petroleum Gases	(%)	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Distillate Fuel Oil	(%)	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Residual Fuel Oil	(%)	0.8%	0.8%	0.7%	0.6%	0.6%	0.6%	0.7%	0.7%	0.7%
Petroleum Coke	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	(%)	47.0%	45.8%	45.2%	44.3%	43.1%	42.4%	41.5%	40.6%	39.7%
Steam Coal	(%)	1.0%	0.8%	0.8%	0.8%	0.8%	0.7%	0.7%	0.6%	0.6%
Renewables	(%)	0.0%	0.6%	1.3%	1.9%	2.5%	3.1%	3.8%	4.4%	5.0%
Electricity	(%)	50.5%	51.4%	51.6%	51.8%	52.5%	52.6%	52.9%	53.3%	53.6%

What fuel mix is used by the electrical equipment industry?										
Liquefied Petroleum Gases	(%)	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Distillate Fuel Oil	(%)	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Residual Fuel Oil	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Petroleum Coke	(%)	40.0%	39.7%	38.9%	38.3%	37.6%	37.3%	36.8%	36.3%	35.8%
Natural Gas	(%)	29.0%	28.0%	27.7%	27.4%	27.0%	26.9%	26.6%	26.4%	26.1%
Steam Coal	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Renewables	(%)	0.0%	0.7%	1.3%	1.9%	2.5%	3.1%	3.8%	4.4%	5.0%
Electricity	(%)	30.3%	31.0%	31.5%	31.9%	32.2%	32.2%	32.3%	32.4%	32.6%

Figure 15: Industrial Inputs Results



TRANSPORTATION INPUTS MODULE

The transportation section of CarBen consists of two input modules: Transportation Inputs and Transportation Fuels Inputs (see below for more details on the Transportation Fuels Inputs Module). For each mode of transportation, input the amount of activity in terms of population (or GDP as appropriate), the efficiency of that mode of transportation, and the mix of the engine types that mode of transportation employs. Then, for each engine type, allocate the mix of fuels that powers the engine.

ENERGY USE CALCULATION

The calculation for transportation energy is a function of the type of vehicle, mix of fuels, fuel efficiency, and vehicle miles traveled.

The calculation is: Total Transportation Energy Demand * Energy Use Share % * Fuel Use Share Vehicle miles traveled.

EMISSIONS CALCULATION

For each vehicle type, the mix of fuels can then be entered; each mix must total 100 percent for each year.

Emissions are then calculated for each industry and fuel, using the following formula: Transportation Energy Consumption * Fuel Share % * Fuel Emissions Coefficient * Vehicle miles traveled.

EXAMPLE: TRANSPORTATION INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

The transportation module allows the user to manipulate the activity, efficiency, and fuel mix across all sectors of transportation, including:

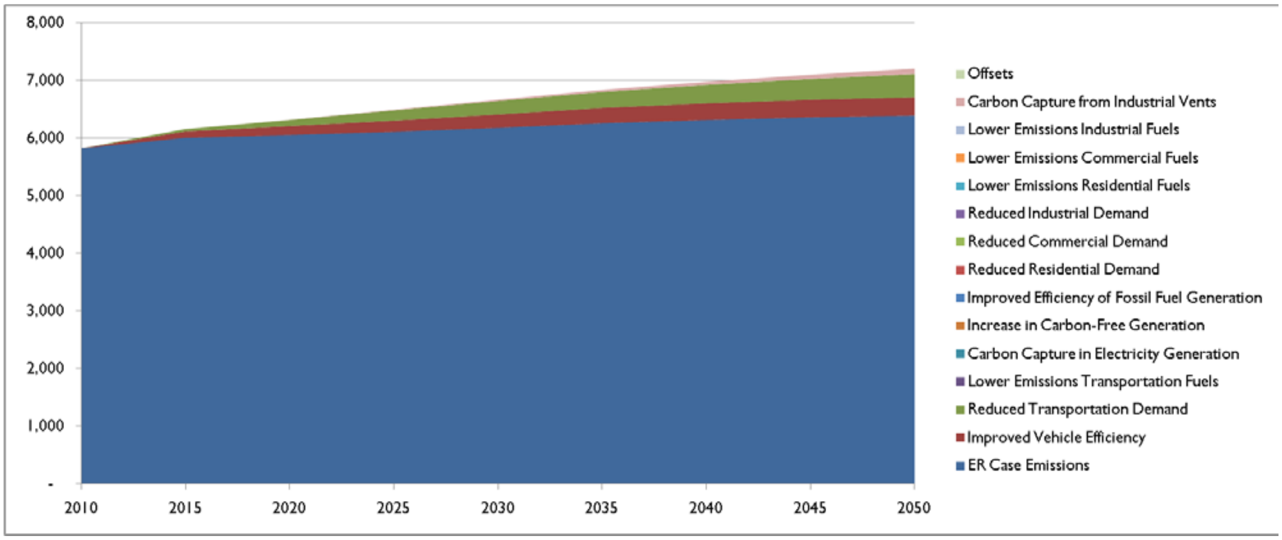
- Light duty vehicles
- Commercial light trucks
- Freight
- Air
- Rail
- Domestic shipping

The scenarios below highlight the effect of different approaches on CO_2 reduction. In the first example, the efficiency of light-duty vehicles was increased linearly from 2010 through 2050 after inputting the 2050 value and using the Interpolation Function in CarBen (see Figure 16). The vehicle miles traveled per capita was reduced using the same technique. The results in Figure 17 show measureable CO_2 reduction due to both increased efficiency and reduced transportation demand.

Figure 16 Transportation Vehicle Efficiency and Use Inputs

Light Duty Vehicles										
Activity	(VMT/Capita)	8,758	8,601	8,444	8,286	8,129	7,972	7,815	7,657	7,500
Efficiency	(Gasoline-Equiv. MPG)	21.0	24.7	28.3	31.9	35.5	39.1	42.8	46.4	50.0

Figure 17 Transportation Vehicle Efficiency and Use Inputs Results

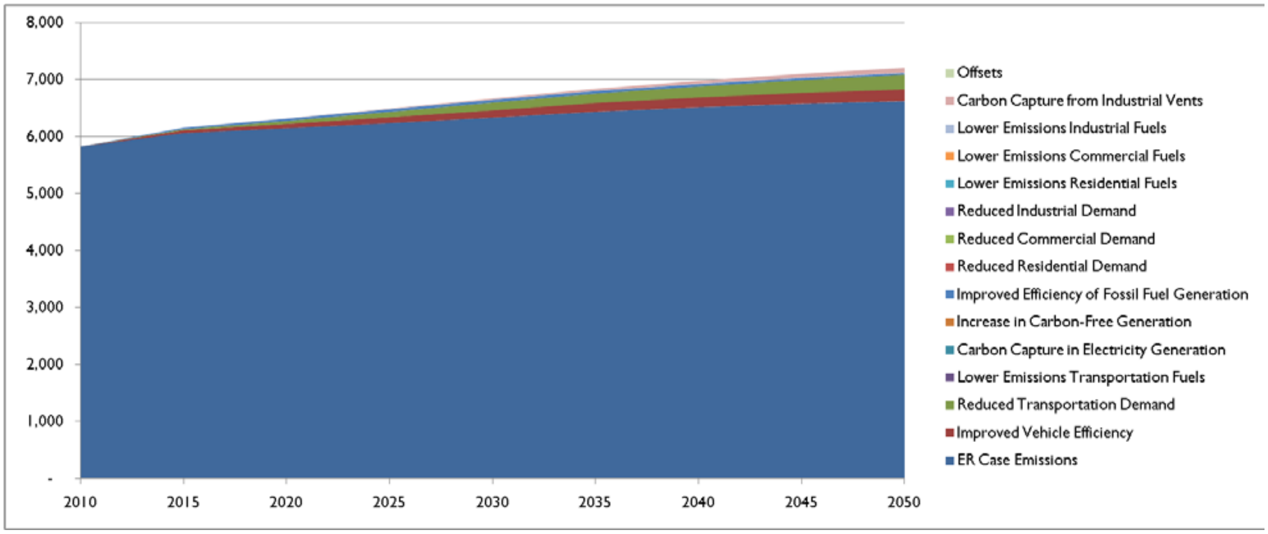


A second scenario was added to the above, where the mix of light-duty fuels was manipulated to include more plug-in hybrids and fuel cells (see Figure 18). While, on the surface, this may seem like a certain way to reduce CO_2 emissions, CO_2 reductions from this case were actually smaller than from the previous case (see Figure 19). This is due to how the energy used to power hybrids and fuel cells are coming from fossil sources that may have a higher carbon footprint than emissions from an internal combustion engine.

Figure 18: Increasing Hybrids and Fuel Cell Vehicles

Light Duty Vehicles										
Activity	(VMT/Capita)	8,758	8,601	8,444	8,286	8,129	7,972	7,815	7,657	7,500
Efficiency	(Gasoline-Equiv. MPG)	21.0	24.7	28.3	31.9	35.5	39.1	42.8	46.4	50.0
Vehicle Stock										
ICE (gasoline & alcohol fuels)	(%)	99.6%	92.2%	84.5%	76.6%	68.5%	60.6%	52.3%	43.8%	35.2%
Diesel	(%)	0.3%	0.3%	0.4%	0.9%	1.5%	1.9%	2.7%	3.7%	4.8%
Compressed Natural Gas	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plug-in Hybrid Electric Vehicle	(%)	0.0%	6.3%	12.5%	18.8%	25.0%	31.3%	37.5%	43.8%	50.0%
Fuel Cell	(%)	0.0%	1.3%	2.5%	3.8%	5.0%	6.3%	7.5%	8.8%	10.0%

Figure 19: Increasing Hybrids and Fuel Cell Vehicles Results



The above observation should lead the user to want to investigate the entire portfolio of energy supply and the influence that different scenarios may have on CO_2 reduction.

TRANSPORTATION FUELS INPUTS MODULE

The objective of this module is to calculate the CO_2 emission coefficient for each engine type. To do this, each engine type has the option to allocate which fuels they run on. In addition, the percentage of emissions captured can also be entered. This is combined with the emissions coefficients in the Sourced Data tab to determine the effective emissions coefficient of each engine.

ENERGY USE CALCULATION

The calculation for transportation energy is a function of the type of vehicle, mix of fuels, fuel efficiency, and vehicle miles traveled.

The calculation is: Total Transportation Energy Demand * Energy Use Share % * Fuel Use Share Vehicle miles traveled.

EMISSIONS CALCULATION

For each vehicle type, the mix of fuels can then be entered; each mix must total 100 percent for each year.

Emissions are then calculated for each industry and fuel, using the following formula: Transportation Energy Consumption * Fuel Share % * Fuel Emissions Coefficient * Vehicle miles traveled.

EXAMPLE: TRANSPORTATION FUELS INPUTS MODULE

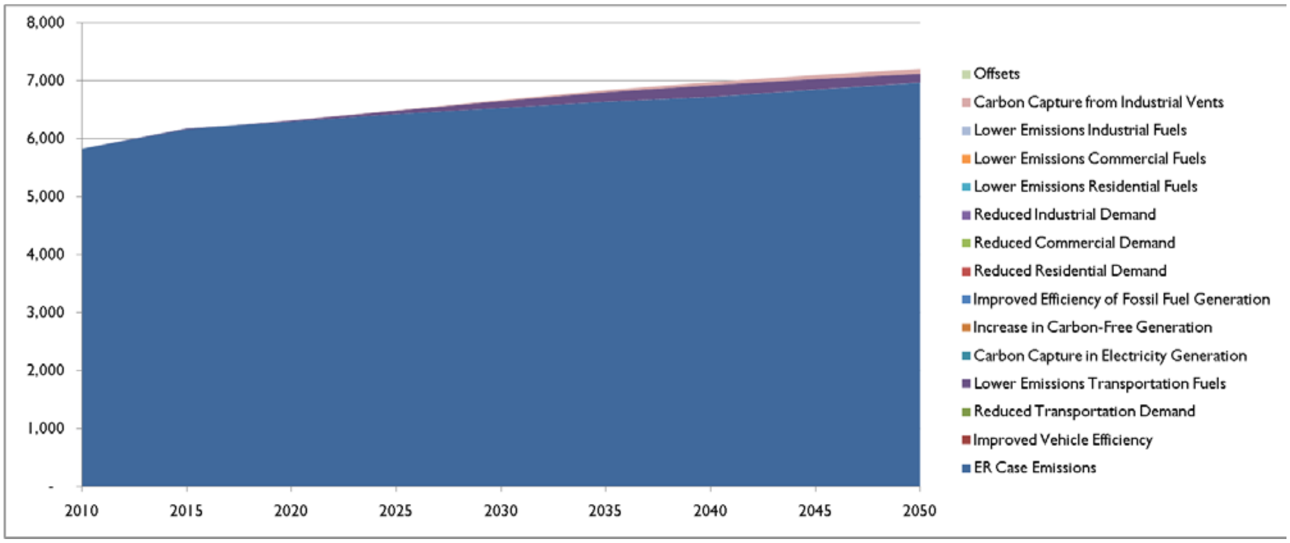
The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

In this module, the user can manipulate the source from which the transportation fuels originate. Figure 20 shows the changes made to the transportation fuels mix through 2050. In each block of cells, the biofuels portions were increased while the fossil fuels were scaled to meet the requirements. Callout Box 3 describes the process to changing inputs and scaling the remaining inputs across each column. Results in Figure 21 show that changing the fuel mix alone has a very small impact on CO_2 reduction.

Figure 20: Transportation Fuels Inputs

What fuel mix do Internal Combustion Engines run on?										
Gasoline	(%)	93.8%	89.9%	78.9%	67.9%	62.0%	56.0%	50.0%	50.0%	50.0%
Gasoline from heavy oil/tar sands	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CTL to gasoline	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CBTL to gasoline	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ethanol - corn	(%)	6.2%	10.0%	15.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Ethanol - cellulose	(%)	0.0%	0.1%	6.1%	12.1%	18.0%	24.0%	30.0%	30.0%	30.0%
What fuel mix do Diesel Engines run on?										
Conventional Diesel	(%)	98.0%	97.0%	96.0%	95.0%	94.0%	93.0%	92.0%	91.0%	90.0%
Diesel from heavy oil/tar sands	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CBTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel	(%)	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	10.0%
What percent of PHEV energy comes from Electricity?	(%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
What fuel mix are Fuel Cells made of?										
H_2 from Natural Gas	(%)	100.0%	100.0%	95.0%	90.0%	80.0%	60.0%	40.0%	40.0%	40.0%
H_2 from Coal	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
H_2 from Water and Sunlight	(%)	0.0%	0.0%	5.0%	10.0%	20.0%	40.0%	60.0%	60.0%	60.0%
What fuel mix comprises Jet Fuel?										
Jet fuel	(%)	100.0%	98.8%	97.5%	96.3%	95.0%	93.8%	92.5%	91.3%	90.0%
Jet fuel from heavy oil/tar sands	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biofuels	(%)	0.0%	1.3%	2.5%	3.8%	5.0%	6.3%	7.5%	8.8%	10.0%

Figure 21: Transportation Fuels Inputs Results



Callout Box 3: Manipulating Data using the Scaling Function

1. When a set of cells is designed to sum up to 100 percent in each column, once one cell is manipulated, the column will turn red to indicate that it is out of scale. In this case, we changed the 2050 value for biodiesel and interpolated back, so each column that does not total 100 percent is red.

What fuel mix do Diesel Engines run on?										
Conventional Diesel	(%)	98.0%	96.7%	96.8%	97.0%	96.8%	97.1%	97.1%	97.1%	97.2%
Diesel from heavy oil/tar sands	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CBTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel	(%)	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	10.0%

2. Once all of the manipulations have been made by the user, highlight the entire block of cells.
3. Right-click on the highlighted cells.
4. At the bottom of the list of options, choose "Scale Percentages". This will balance the columns keeping the inputted values from the user. The red color will disappear from the cells in the box.

What fuel mix do Diesel Engines run on?										
Conventional Diesel	(%)	98.0%	97.0%	96.0%	95.0%	94.0%	93.0%	92.0%	91.0%	90.0%
Diesel from heavy oil/tar sands	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CBTL to diesel	(%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel	(%)	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	10.0%

ELECTRICITY INPUTS MODULE

The main objective of the electricity module is to evaluate options for meeting the electricity demand calculated in the Residential, Commercial, Industrial, and Transportation modules.

ELECTRICITY GENERATION CALCULATION

Total Electricity Generation by each type of power plant is calculated based on three inputs:

- Transmission and distribution (T&D) losses
- Allocation of generation across the different types of power plants (e.g., coal, nuclear, wind)
- Generation profile (i.e., base, mid, peak) across the types of power plants

The total generation of each type of plant is calculated by the following formula: Total Demand * 1/(1-T&D Loss) * Generation Share

EMISSIONS CALCULATION

The calculation for emissions is based on fuel used, selected conversion technology, sector demand, and efficiency.

The calculation for emissions is: Energy Sector Demand * Fuel Type * Technology Type * Technology Efficiency

EXAMPLE: ELECTRICITY INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect a proposal or suggestion regarding U.S. energy policy.

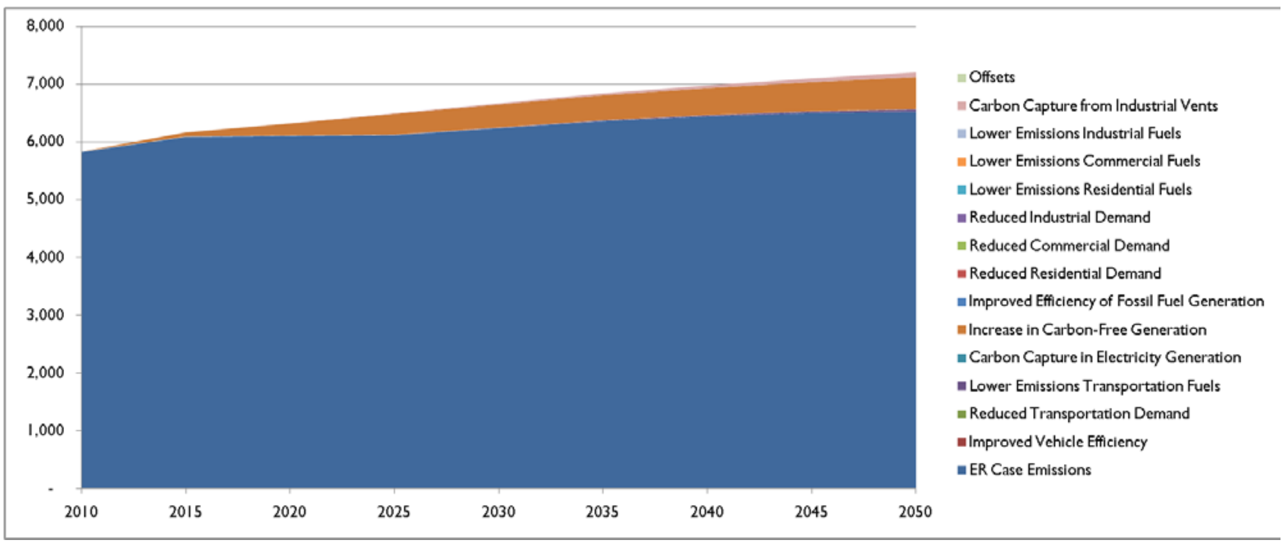
The Electricity Inputs Module allows the operator to design the electricity portfolio of his choice by choosing the contribution of specific electricity production technologies such as combined cycle, nuclear, and solar. Two scenarios are presented in the examples section of this module. The first scenario is based on a significant increase in renewable energy while scaling all other types of generation technologies. For this case, biomass was increased to 5 percent, solar to 5 percent, and wind to 20 percent in 2050, respectively, and linearly interpolated back to 2010 (see Figure 22).

Figure 22: Increased Renewable Energy Portfolio

Generation Allocations										
Coal	(%)	47.9%	48.1%	43.8%	39.9%	38.5%	37.9%	36.8%	35.7%	34.5%
Combined Cycle	(%)	7.5%	5.8%	5.7%	5.7%	6.8%	6.7%	7.3%	7.8%	8.4%
Combustion Turbine	(%)	6.1%	4.5%	4.5%	4.8%	5.1%	5.5%	5.9%	6.2%	6.6%
Other Fossil Steam	(%)	5.2%	3.1%	2.9%	2.8%	2.9%	2.7%	2.7%	2.6%	2.5%
Nuclear	(%)	21.9%	20.3%	19.1%	17.0%	16.0%	15.3%	14.5%	13.7%	12.8%
Hydro	(%)	7.2%	7.2%	6.4%	5.7%	5.4%	5.1%	4.8%	4.5%	4.2%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.2%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%	0.8%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

The results of this first case show a sizeable reduction in CO_2 from the increased use of renewables (see Figure 23). Reductions came mostly from increased carbon-free power generation, but there also was a noticeable reduction from lower transportation fuel emissions.

Figure 23: Increased Renewable Energy Portfolio Results



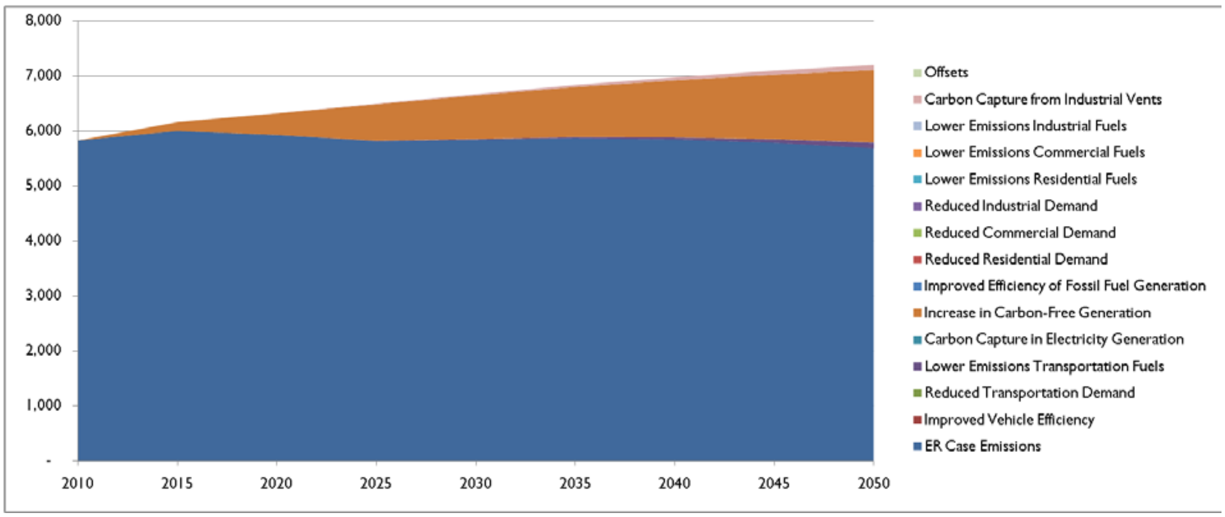
In the second case, the renewable energy inputs are repeated from the first case and nuclear power is increased to become one-third of the energy production portfolio in 2050, and linearly interpolated back to 2010 as well (see Figure 24). The results shown in Figure 25 illustrate the reduction in CO_2 emissions from increased carbon-free power generation.

Figure 24: Increased Renewable and Nuclear Energy Portfolio

Generation Allocations

Coal	(%)	47.9%	46.1%	40.1%	33.9%	31.1%	29.2%	26.9%	24.6%	22.4%
Combined Cycle	(%)	7.5%	5.5%	5.2%	4.9%	5.5%	5.2%	5.3%	5.4%	5.4%
Combustion Turbine	(%)	6.1%	4.3%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.3%
Other Fossil Steam	(%)	5.2%	3.0%	2.7%	2.4%	2.4%	2.1%	1.9%	1.8%	1.6%
Nuclear	(%)	21.9%	23.3%	24.7%	26.0%	27.4%	28.8%	30.2%	31.6%	33.0%
Hydro	(%)	7.2%	6.9%	5.9%	4.9%	4.4%	3.9%	3.5%	3.1%	2.7%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.1%	1.0%	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

Figure 25: Increased Renewable and Nuclear Energy Portfolio Results



ELECTRICITY – COAL INPUTS MODULE

The Coal Inputs Module allows the operator to examine the coal fleet, and decide whether to replace existing plants, refurbish them to improve efficiency, or retrofit them with carbon systems. In addition, the module allows for new plant construction to be either Pulverized Coal or Integrated Gasification Combined Cycle plants, with or without carbon capture.

COAL ELECTRICITY GENERATION CALCULATION

Coal Electricity generation is a function of demand. Coal technology is well known and the coal types, as well as boiler types and efficiencies, are used to calculate the electricity generation quite accurately.

Electricity generation is calculated by: Energy Demand * Mix of Coal Technologies * Technology Efficiency * Distribution and End Use Losses

EMISSIONS CALCULATION

Emission factors in coal plants have been well researched and understood for years to be a function of technology, efficiency, and coal composition.

Emissions from coal are calculated by: Energy Demand * Coal Profile * Technology Profile

EXAMPLE: ELECTRICITY – COAL INPUTS MODULE

The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect a proposal or suggestion regarding U.S. energy policy.

For this scenario, two areas were manipulated. First, the model was changed to assume that, beginning in 2030, all new coal plants would include CCS (see Figure 26). There was no change in the distribution between pulverized coal and integrated coal gasification combined cycle (IGCC) w/capture plants built.

Figure 26: Adding CCS in 2030 to All New Coal Plants

How will new coal plant construction be allocated?										
Pulverized Coal	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pulverized Coal w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Integrated gasification combined cycle	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Integrated gasification combined cycle w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%

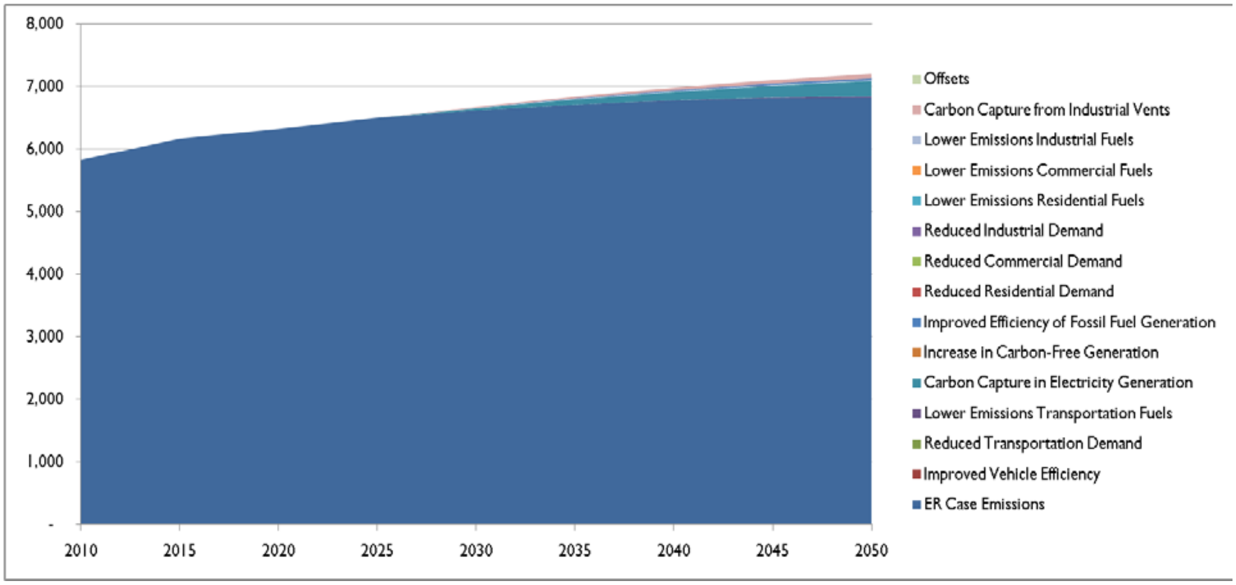
In the second scenario, the efficiency of both pulverized coal and IGCC w/capture plants were increased modestly in 2050 then linearly interpolated back to 2010 (see Figure 27).

Figure 27: Increasing Plant Efficiency

What is the thermal efficiency of newly constructed plants?										
Pulverized Coal	(%)	39.3%	39.3%	39.3%	39.3%	39.3%	39.3%	39.3%	39.3%	39.3%
Pulverized Coal w/ Capture	(%)	28.7%	29.5%	30.3%	31.1%	31.9%	32.6%	33.4%	34.2%	35.0%
Integrated gasification combined cycle	(%)	40.2%	40.2%	40.2%	40.2%	40.2%	40.2%	40.2%	40.2%	40.2%
Integrated gasification combined cycle w/ Capture	(%)	31.6%	32.5%	33.5%	34.4%	35.3%	36.2%	37.2%	38.1%	39.0%

The combined results are shown in Figure 28. As the cases were run independently, the addition of the CCS restriction far outweighed improved efficiencies with regard to reducing CO_2. The capacity factor of coal plants was increased in another case, but it had no effect and is not included. The coal cases did have a minor impact in CO_2 reduction, but alone cannot have significant impact on reducing CO_2.

Figure 28: Coal Plants Adding CCS and Increasing Efficiency



ELECTRICITY – NATURAL GAS INPUTS MODULE

Unlike the Coal Inputs Module, the Natural Gas Inputs Module does not focus on specific plants. Rather, the inputs are for the entire natural gas fleet as a whole. Thus, plant construction and retirement is not a component of this module. Demand is allocated in the Electricity Inputs tab. Efficiency, fuel choices, and capture are used to calculate CO_2 Intensity.

CO_2 INTENSITY CALCULATION

The calculation is based on the complete combustion of natural gas (mostly methane, CH_4) to CO_2 and H_2O. The calculation is: Natural Gas Demand * Technology Profile * Distribution and End Use Losses.

EXAMPLE: ELECTRICITY – NATURAL GAS INPUTS MODULE

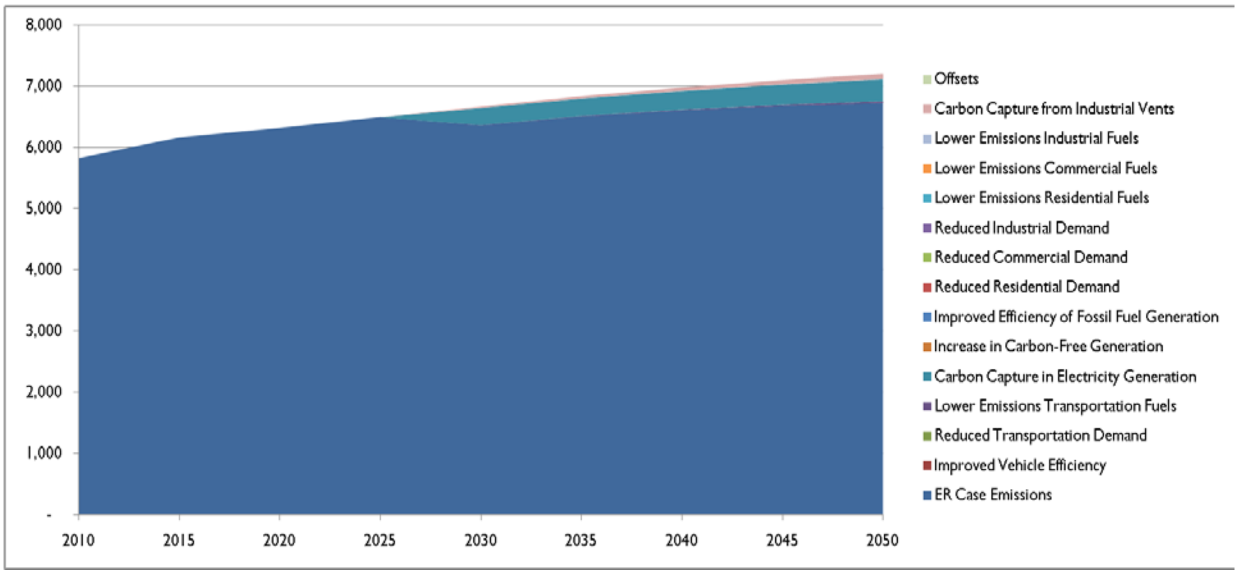
The example below is designed to help CarBen operators better understand how to modify the user inputs and interpret the results. Note that the example is presented simply for illustrative purposes and does not reflect a proposal or suggestion regarding U.S. energy policy.

Only one adjustment was made to this module in this example: starting in 2030, all natural gas facilities will have CCS (see Figure 29). The results show that there is a larger CO_2 reduction from employing CCS with natural gas than with coal (see Figure 30).

Figure 29: Manipulation to Natural Gas Module

What Percent of the fleet has Carbon Capture?										
Combined Cycle	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Combustion Turbine	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Other Fossil Steam	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 30: Manipulation to Natural Gas Module Results



CO_2 VENTS MODULE

This module is designed to look at CO_2 emissions from energy across all energy supply and demand sectors. Changes to this module have little to no effect on emissions reductions; instead, decreases are seen as a "trickle down" effect when supply and demand changes are made in other sectors that directly affect production. Therefore, there will not be an example shown here manipulating CO_2 Vent inputs, as none of them change the emissions profile.

CO_2 VENT EMISSIONS CALCULATION

The emissions calculation is: Energy Sector Demand * Percent of Chemicals Used for Each Type of Production * Technology Profile

TOTAL CO_2 EMISSIONS CALCULATION

As each supply and demand module is manipulated, CarBen calculates the direct CO_2 emissions for the changes. It also calculates the CO_2 emissions that are needed to produce the complementary chemicals needed to meet energy demand. The total CO_2 emissions are a sum of these calculations.

APPENDIX A: CARBON EMISSION SCENARIOS

CarBen can help analysts and decision makers better understand future trends for CO_2 emissions based on changes in the energy sector. It does so by enabling the operator to modify one part of the energy sector and immediately see the impacts of that change on CO_2 emissions, in that part of the energy sector as well as the energy economy as a well. For illustrative purposes, this section provides an example in which an operator incrementally adjusts the elements of the energy sector to analyze what changes would have to be made to the energy sector to reduce CO_2 emissions by 80 percent by 2050 (the emissions reduction target commonly set in climate change legislation).

Note: this section is simply for illustrative purposes and does not reflect, in any way, a proposal or suggestion regarding U.S. energy policy.

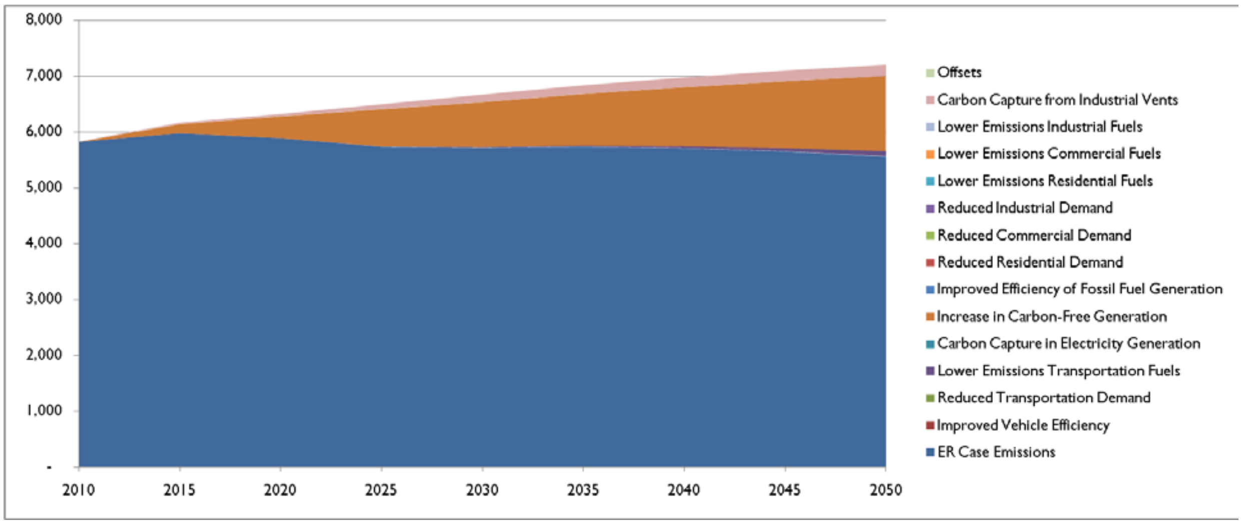
SCENARIO 1: INCREASED RENEWABLES, NUCLEAR POWER, AND A CARBON TAX

Scenario 1 Inputs

Generation Allocations										
Coal	(%)	47.9%	46.1%	40.1%	33.9%	31.1%	29.2%	26.9%	24.6%	22.4%
Combined Cycle	(%)	7.5%	5.5%	5.2%	4.9%	5.5%	5.2%	5.3%	5.4%	5.4%
Combustion Turbine	(%)	6.1%	4.3%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.3%
Other Fossil Steam	(%)	5.2%	3.0%	2.7%	2.4%	2.4%	2.1%	1.9%	1.8%	1.6%
Nuclear	(%)	21.9%	23.3%	24.7%	26.0%	27.4%	28.8%	30.2%	31.6%	33.0%
Hydro	(%)	7.2%	6.9%	5.9%	4.9%	4.4%	3.9%	3.5%	3.1%	2.7%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.1%	1.0%	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

US Population	(Millions)	311	327	343	359	375	391	408	426	444
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Scenario 1 Results

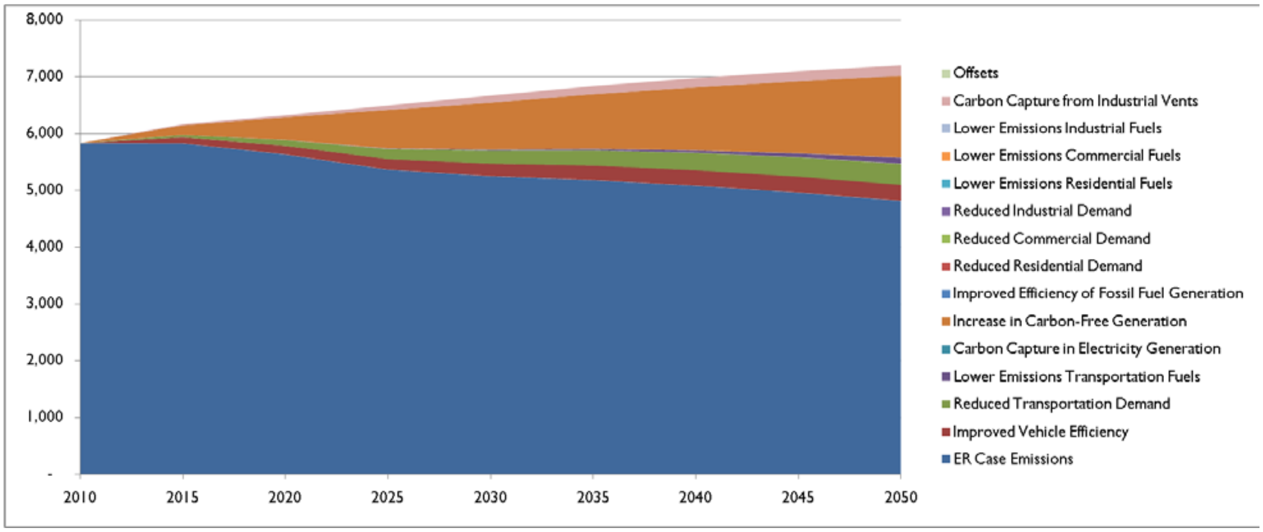


SCENARIO 2: SCENARIO 1 + INCREASED VEHICLE EFFICIENCY FOR LIGHT DUTY VEHICLES AS WELL AS REDUCTION IN MILES TRAVELED.

Scenario 2 Inputs

Light Duty Vehicles										
Activity	(VMT/Capita)	8,758	8,601	8,444	8,286	8,129	7,972	7,815	7,657	7,500
Efficiency	(Gasoline-Equiv. MPG)	21.0	24.7	28.3	31.9	35.5	39.1	42.8	46.4	50.0
Generation Allocations										
Coal	(%)	47.9%	46.1%	40.1%	33.9%	31.1%	29.2%	26.9%	24.6%	22.4%
Combined Cycle	(%)	7.5%	5.5%	5.2%	4.9%	5.5%	5.2%	5.3%	5.4%	5.4%
Combustion Turbine	(%)	6.1%	4.3%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.3%
Other Fossil Steam	(%)	5.2%	3.0%	2.7%	2.4%	2.4%	2.1%	1.9%	1.8%	1.6%
Nuclear	(%)	21.9%	23.3%	24.7%	26.0%	27.4%	28.8%	30.2%	31.6%	33.0%
Hydro	(%)	7.2%	6.9%	5.9%	4.9%	4.4%	3.9%	3.5%	3.1%	2.7%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.1%	1.0%	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
US Population	(Millions)	311	327	343	359	375	391	408	426	444
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Scenario 2 Results



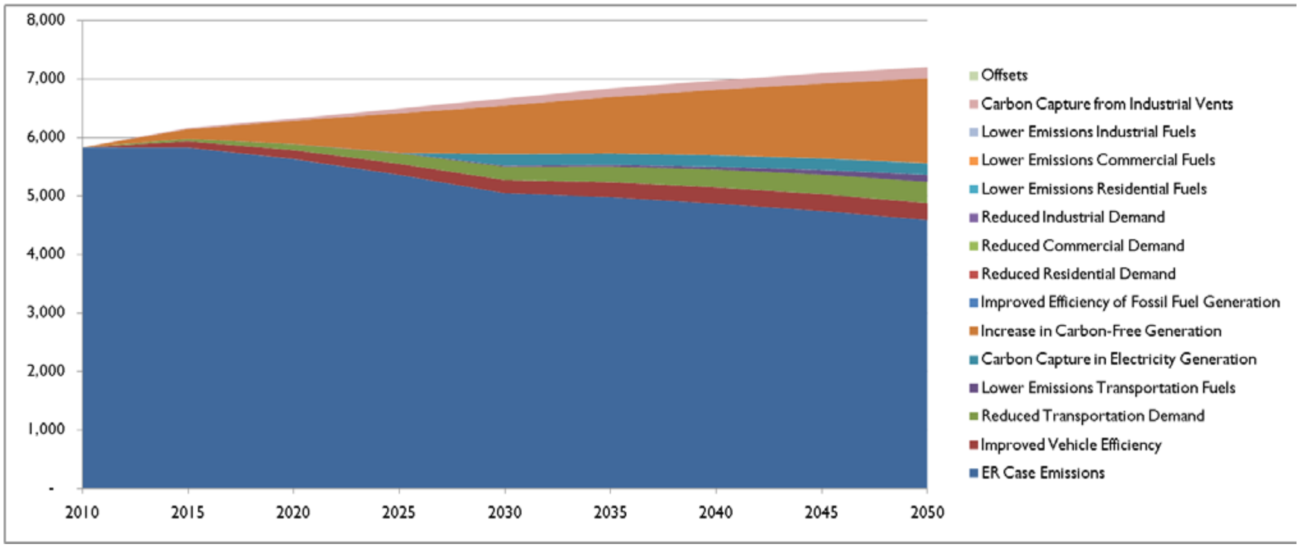
SCENARIO 3: SCENARIO 2 + CARBON CAPTURE AND STORAGE (CCS) FOR COAL AND NATURAL GAS

Scenario 3 Inputs

How will new coal plant construction be allocated?										
Pulverized Coal	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pulverized Coal w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Integrated gasification combined cycle	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Integrated gasification combined cycle w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%
What Percent of the fleet has Carbon Capture?										
Combined Cycle	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Combustion Turbine	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Other Fossil Steam	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Light Duty Vehicles										
Activity	(VMT/Capita)	8,758	8,601	8,444	8,286	8,129	7,972	7,815	7,657	7,500
Efficiency	(Gasoline-Equiv. MPG)	21.0	24.7	28.3	31.9	35.5	39.1	42.8	46.4	50.0
Generation Allocations										
Coal	(%)	47.9%	46.1%	40.1%	33.9%	31.1%	29.2%	26.9%	24.6%	22.4%
Combined Cycle	(%)	7.5%	5.5%	5.2%	4.9%	5.5%	5.2%	5.3%	5.4%	5.4%
Combustion Turbine	(%)	6.1%	4.3%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.3%
Other Fossil Steam	(%)	5.2%	3.0%	2.7%	2.4%	2.4%	2.1%	1.9%	1.8%	1.6%
Nuclear	(%)	21.9%	23.3%	24.7%	26.0%	27.4%	28.8%	30.2%	31.6%	33.0%
Hydro	(%)	7.2%	6.9%	5.9%	4.9%	4.4%	3.9%	3.5%	3.1%	2.7%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.1%	1.0%	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

US Population	(Millions)	311	327	343	359	375	391	408	426	444
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Scenario 3 Results



SCENARIO 4: SCENARIO 3 + REDUCTIONS IN ENERGY USE IN THE RESIDENTIAL AND COMMERCIAL SECTORS

Scenario 4 Inputs

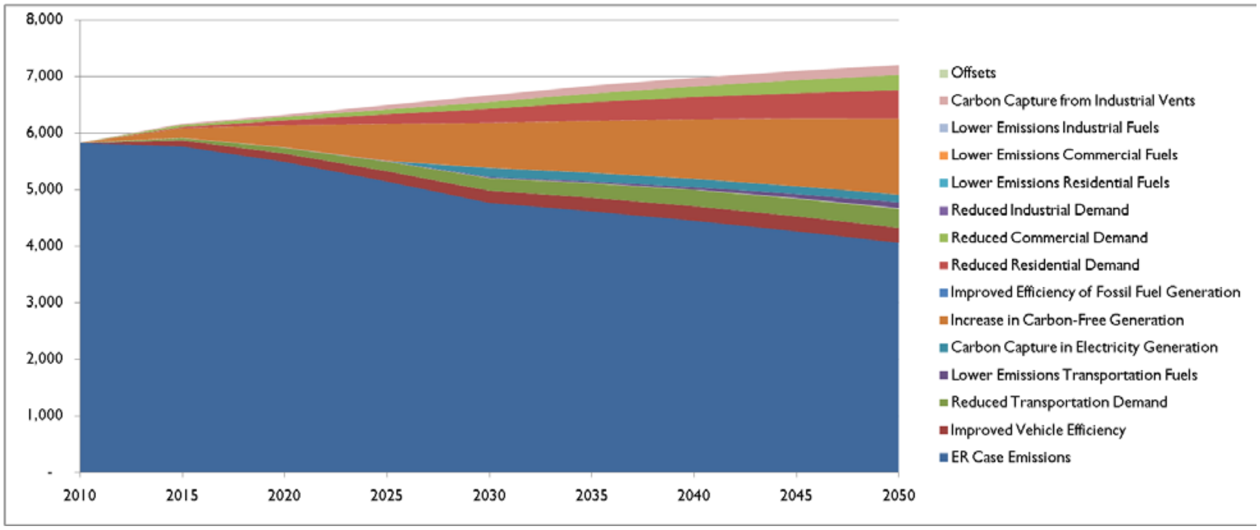
How many people are in the average household?		2.70	2.69	2.66	2.65	2.65	2.66	2.67	2.67	2.68
How big is the average house?	(sq ft)	1,686	1,663	1,639	1,616	1,593	1,570	1,546	1,523	1,500
What is the energy consumption per square foot?	(kBtu)	58.0	53.9	49.7	45.6	41.5	37.4	33.2	29.1	25.0

What is the energy consumption per square foot?	(kBtu)	106.2	102.3	98.4	94.5	90.6	86.7	82.8	78.9	75.0

How will new coal plant construction be allocated?										
Pulverized Coal	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pulverized Coal w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Integrated gasification combined cycle	(%)	50.0%	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Integrated gasification combined cycle w/ Capture	(%)	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	50.0%	50.0%	50.0%
What Percent of the fleet has Carbon Capture?										
Combined Cycle	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Combustion Turbine	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Other Fossil Steam	(%)	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Light Duty Vehicles										
Activity	(VMT/Capita)	8,758	8,601	8,444	8,286	8,129	7,972	7,815	7,657	7,500
Efficiency	(Gasoline-Equiv. MPG)	21.0	24.7	28.3	31.9	35.5	39.1	42.8	46.4	50.0
Generation Allocations										
Coal	(%)	47.9%	46.1%	40.1%	33.9%	31.1%	29.2%	26.9%	24.6%	22.4%
Combined Cycle	(%)	7.5%	5.5%	5.2%	4.9%	5.5%	5.2%	5.3%	5.4%	5.4%
Combustion Turbine	(%)	6.1%	4.3%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.3%
Other Fossil Steam	(%)	5.2%	3.0%	2.7%	2.4%	2.4%	2.1%	1.9%	1.8%	1.6%
Nuclear	(%)	21.9%	23.3%	24.7%	26.0%	27.4%	28.8%	30.2%	31.6%	33.0%
Hydro	(%)	7.2%	6.9%	5.9%	4.9%	4.4%	3.9%	3.5%	3.1%	2.7%
Wind	(%)	3.0%	7.0%	11.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%
Solar	(%)	0.0%	1.0%	2.0%	3.0%	3.4%	3.8%	4.2%	4.6%	5.0%
Geothermal, MSW, etc	(%)	1.0%	1.1%	1.0%	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Biomass	(%)	0.3%	1.8%	3.4%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

US Population	(Millions)	311	327	343	359	375	391	408	426	444
US GDP	(Billion 2000$)	11,443	13,289	15,416	17,561	19,883	22,362	25,234	28,476	32,133
Carbon Price	($/Mt CO_2)	$ -	$ 25	$ 50	$ 50	$ 60	$ 70	$ 80	$ 90	$ 100

Scenario 4 Results



The results from these four scenarios show that the CO_2 reduction goal can be met theoretically by manipulating this model. The figure below shows the 2050 CO_2 emissions to be slightly lower than the 1,166 MMt goal for 2050.

Temporal CO_2 Emissions for each Scenario Described Above