Title

Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase (LIGHTEnUP) – Analysis Tool User’s Guide:

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Publication Date
2016-06-22

LBNL-1005777

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Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase (LIGHTEnUP) – Analysis Tool User's Guide

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June 2016

This work was supported by the U.S. Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231

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Acronyms and abbreviations

Acronym or Abbreviation	Definition
AEO	Annual Energy Outlook (Produced by EIA)
AMO	Advanced Manufacturing Office within EERE
BAU	Business As Usual
Btu	British Thermal Units (Btu)
DOE	U.S. Department of Energy
dropdown menus	Allows the user to choose one value from a list of values allowed as inputs for the cell
$E\ (REI)_{t=EY}$	Relative Energy Impact at End Year
$E\ (TAP)_{t=EY}$	Energy Technical Adoption Potential at End Year
$E_{t=0}$	Energy consumption in the Base Year (e.g., 2010)
$E_{t=EY}$	Energy forecasted at the End Year (EY)
EERE	Office of Energy Efficiency and Renewable Energy within DOE
EIA	Energy Information Administration within DOE
EPA	U.S. Environmental Protection Agency
GR	Growth Rate driver
HR	Heat Rate – the conversion efficiency of electricity generation technologies (typically in units of btu/kWh, but in this report it is primary/final energy)
ICE	Internal Combustion Engine
kg	kilogram = 1,000 grams
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-Cycle Assessment
LDV	Light-Duty Vehicles
LIGHTEnUP	Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase
LPG	Liquefied Petroleum Gas
MECS	Manufacturing Energy Consumption Survey
Mill MtCO2	Million Metric Ton of CO_2
NAICS	North American Industry Classification System
NG	Natural Gas
Quad	1,000 TBtu
R&D	Research and Development
REI	Relative Energy Impact (typically in units of energy)
REI %	Relative Energy Impact percentage
SOA	state-of-the-art
TAP	Technical Adoption Potential (typically in units of energy)
TAP %	Technical Adoption Potential percentage
Tbtu	Trillion British Thermal Units (Btu)
TEC	Total Energy Consumption
tool	Refers to the LIGHTEnUP Tool
TWh	Trillion Watt-hours of electricity
Type-E	Externally Developed Type-E Scenarios
Type-I1	Internally Developed Type-I1 Scenarios
Type-I2	Internally Developed Type-I2 Scenarios
U.S.	United States
VB	Microsoft Visual Basic Programming Code for Excel
VMT	Vehicle Miles Traveled

Abstract

The LIGHTEnUP Analysis Tool (Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase) has been developed for The United States Department of Energy's (U.S. DOE) Advanced Manufacturing Office (AMO) to forecast both the manufacturing sector and product life-cycle energy consumption implications of manufactured products across the U.S. economy.

The tool architecture incorporates publicly available historic and projection datasets of U.S. economy-wide energy use including manufacturing, buildings operations, electricity generation and transportation. The tool requires minimal inputs to define alternate scenarios to business-as-usual projection data. The tool is not an optimization or equilibrium model and therefore does not select technologies or deployment scenarios endogenously. Instead, inputs are developed exogenous to the tool by the user to reflect detailed engineering calculations, future targets and goals, or creative insights. The tool projects the scenario's energy, CO_2 emissions, and energy expenditure (i.e., economic spending to purchase energy) implications and provides documentation to communicate results. The tool provides a transparent and uniform system of comparing manufacturing and use-phase impacts of technologies.

The tool allows the user to create multiple scenarios that can reflect a range of possible future outcomes. However, reasonable scenarios require careful attention to assumptions and details about the future. This tool is part of an emerging set of AMO's life cycle analysis (LCA) tool such as the Material Flows the Industry (MFI) tool [1] [2], and the Additive Manufacturing LCA tool [3].

Introduction

The United States Department of Energy's (U.S. DOE) Advanced Manufacturing Office (AMO) supports new, energy-efficient processing and materials technologies in order to reduce the energy consumption of manufactured goods in the U.S. economy. The U.S. industrial and manufacturing sector is pivotal for achieving economy wide energy efficiency through its ability to not only create processes and technologies that impact its own energy consumption, but also through its ability to manufacture more efficient products that impact energy consumption in all other sectors of the U.S. economy. Examples of this are manufacturing more efficient lighting materials or lightweight vehicle components, where an increase in manufacturing consumption creates a product that reduces energy consumption during its use-phase. Due to the potential vast effects of these technologies across time and economic sectors, a comprehensive view of their associated energy impacts is required.

Environmental Life Cycle Assessment (LCA) is a methodology predicated on ISO 14040 [4] that examines the impacts (e.g., material consumption, pollutant emissions, or energy consumption) of a product or process throughout its entire lifetime. LCA typically consists of five phases: Raw material extraction and refinement, Manufacturing, Freight & Distribution, Use, and End of Life (e.g., disposal, recycling, re-use). When conducting a life cycle assessment of an existing product, it can be straightforward to trace back through the manufacturing and materials required to create the product. A process or technology, on the other hand, can have a much more complex life cycle chain as the single technology may go into the creation of many products spanning multiple economic sectors and sub-sectors. Traditionally, LCA examines products or processes that currently exist, enabling LCA practitioners to use historic data and information to evaluate a product or process over these five phases. A prospective LCA approach, in contrast, describes anticipated situations or changes that could happen in the future. Because AMO's mission is to support new processing and materials technologies that have the potential to reduce net energy consumption across the U.S. economy in the future, AMO must take a prospective LCA approach.

Prospective LCA is speculative and challenging because the future is uncertain. In the early stages of technology research, development, and deployment (RD&D), it can be difficult to predict a technology's energy consumption performance, let alone estimate how it might compare to incumbent technologies, or affect future technology and product development. A technology researcher or analyst (referred to herein as the user) can use fundamental engineering principles to estimate energy performance, but must still anticipate the technology's deployment and effect on products – which can have high degrees of uncertainty. However, bounding this inevitable uncertainty with scenarios to describe how technologies and products might be utilized in both the manufacturing and use-phase stages serves as a constructive way of thinking through plausible future outcomes. Scenarios can be simple – such as a new steel process which only impacts steel sector energy consumption. Or scenarios can be complex enough to capture inter-related technologies and products that allows for a single topic of analysis to reflect impacts across multiple sectors. Scenarios can reflect detailed analysis and calculations, future targets and goals, or creative insights. In this respect, scenarios help prospective LCA practitioners and policy makers anticipate potential future outcomes and therefore scenarios must be derived transparently and communicated clearly.

The U.S. Department of Energy's Energy Information Administration uses the National Energy

Modeling System (NEMS) [5] as a comprehensive model for the U.S. economy to develop the Annual Energy Outlook [6], but NEMS is not easily accessible and too complex for most analysts. Other models are designed for analysis of specific products and systems such as the Argonne National Lab's GREET model for vehicle technologies and alternative fuels [7]. With GREET the user can examine changes in materials or efficiencies and estimate the life cycle greenhouse implications for a particular vehicle type but this does not indicate the economy wide impacts from deployment. Similarly Lawrence Berkeley National Lab's Home Energy Saver tool [8] allows users to explore strategies for energy conservation for residential buildings with but it doesn't have the capabilities for assessing impacts for a specific economy wide penetration scenario.

The LIGHTEn-UP tool and framework, referred to herein as the "tool", is a more streamlined tool that allows users to explore energy transformation strategies across the whole U.S. economy. It provides a prospective LCA approach through use of publically available historic and projection datasets for the U.S. economy. The tool uses these datasets as a backbone to help users anticipate, characterize, and communicate a new technology's potential energy-related impacts by projecting impacts across the U.S. economy over time. The primary goal of the tool is to provide analysts in academia, industry, government agencies and research laboratories, and policymakers with insights about manufacturing sector measures and impacts that can reduce energy consumption and emissions across the U.S. economy and over long-term projection periods. The tool is not an optimization or equilibrium model and therefore does not select technologies or deployment scenarios endogenously. Instead, it enables users to develop scenarios of future impacts and provides documentation to help communicate these scenarios. While the tool is designed to be straight forward to use with transparent calculations, providing defensible results depends upon careful attention to assumptions and details about the future.

This guide presents an overview of the LIGHTEn-UP tool with detailed instructions for its use in creating scenarios of future technology impacts. It briefly presents some of the assumptions, weaknesses, and next steps for the tool. And it concludes with two case study examples.

The LIGHTEnUP Tool Overview

Development Goals

The LIGHTEnUP tool's evolution is guided by the goal of developing a tool that is substantive, resilient, transparent, and intuitive to use.

- Substantive – capable of U.S. economy-wide prospective energy analysis.
- Resilient – evolves as new data become available. And provides a repository of past and future technology analysis.
- Transparent – methods and calculations are open to review by users.
- Intuitive – logically structured such that the user's attention can focus on analysis.

In its current version, the LIGHTEn-UP tool is a Microsoft Excel-based tool that documents and communicates prospective energy impact analysis over a multi-year (2010 – 2050) projection period. Projections out to 2050 can be helpful when performing analysis of early stage R&D technologies whose impacts are not expected until many years in the future.

Each of the following core concepts are presented in greater detail in the next section. However, they are presented here as an overview of the tool to provide a preliminary understanding of the tool and analysis methods prior to the detailed descriptions.

Key Inputs

The tool allows the user to create multiple scenarios comprised of multiple energy and CO_2 emissions related impacts across the U.S. economy. But the user must distill each impact into three key variable inputs to the tool:

- Where will energy impacts take place (in what sectors of the U.S. economy)?
- What will the energy impacts be?
- When will the energy impacts take place?

Once a scenario is developed, the tool has two main outputs:

- A table that summarizes a scenario's cumulative energy, CO_2 emissions, and energy expenditures over a user defined time period (e.g., a single year, or multiple years).
- A chart that displays the scenario's energy impacts over the 2010 – 2050 forecast period.

A single scenario can be developed for a technology of interest. Additional scenarios can then serve as sensitivity cases for exploring variations to the three key variable inputs for the single technology of interest.

Underlying Data

The tool is designed to help the users derive these by providing foundational information predicated on two publicly available and widely used datasets from the U.S. Department of Energy's (U.S. DOE) Energy Information Agency (EIA):

- Annual Energy Outlook (AEO 2015 Reference Case) [6]
- Manufacturing Energy Consumption Survey (MECS 2010) [9]

The Annual Energy Outlook (AEO) provides some detail on where energy is currently being consumed across the entire U.S. economy as well as forecasts of where energy is anticipated to be consumed in the future. The Manufacturing Energy Consumption Survey (MECS) provides much greater detail on where and how specific energy resources are consumed in the manufacturing sector as of 2010. The MECS data uses North American Industry Classification System (NAICS) codes to classify manufacturing sub-sectors to varying details (e.g., reporting 3 digit NAICS code aggregates of multiple 4, 5, and 6, digit NAICS cods, alongside reporting 4, 5, and 6 digit NAICS code sub-sectors). The tool uses MECS energy mix percentages to disaggregate AEO's 2010 energy consumption data to manufacturing sub-sectors that are not present in AEO (e.g., "Secondary Smelting and Alloying of Aluminum" is a MECS sub-sector of AEO's "Aluminum Industry"). This additional detail for the manufacturing sector helps support the AMO analysts whose primary focus is on the U.S. manufacturing and industrial sector. Both of these datasets are described in greater detail in sections below.

Scenario Development

The tool is designed to aid users in developing technology specific impact scenarios using transparent calculations and datasets. A set of calculation scratch pad columns – described in the *Calculations Scratch Pad* section of this user's manual – allows the user to input scenario variables and references, and perform calculations necessary to derive the three key inputs.

Scenarios can be comprised of multiple impacts in the four main sectors of the U.S. economy (industrial, commercial, residential, and transportation) and life cycle stages. As an example, a scenario of transportation vehicle light-weighting has been developed to analyze future manufacturing and use-phase energy impacts. Energy impacts will take place in the manufacturing sector (to make light-weighted vehicle components), and in the use-phase (light-weighted vehicle efficiency improvements). These energy impacts will be proportional to component manufacturing properties and vehicle weight reductions. Translated into the three key variables, energy impacts would take place in the manufacturing and transportation sectors (where), will be a function of light-weighting (what), and adopted in new vehicles (when).

The user can use the following three scenario development options:

1. Internally developed scenario (Type-I1)
    a. Uses the full Tool functionality based on Where, What, When inputs
    b. Forecasts a linear adoption or impact
2. Internally developed scenario (Type-I2)
    a. Forecasts are programed into the tool using excel formulas
    b. Forecast adoptions or impacts can be non-linear
3. Externally developed scenario (Type-E)
    a. Impact forecasts are developed in a separate model with annual impact results input into the tool

Regardless of how a scenario is derived, the user inputs always seek to answer the three key inputs to the tool (where, what, when). Although the key inputs to the tool are few, by controlling all of the input to the tool, the user holds the ability to create scenarios that range from quick, order-of-magnitude estimates, to detailed forecasts reflecting in-depth research. The tool does not limit the number of scenarios and the user can capture the uncertainty of any of the input variables and calculations by developing multiple scenarios for a single technology of interest.

Case study examples of Type-I1 and Type-I2 and externally developed scenarios are provided at the end of this user's guide.

Internally Developed Scenarios (Type-I1)

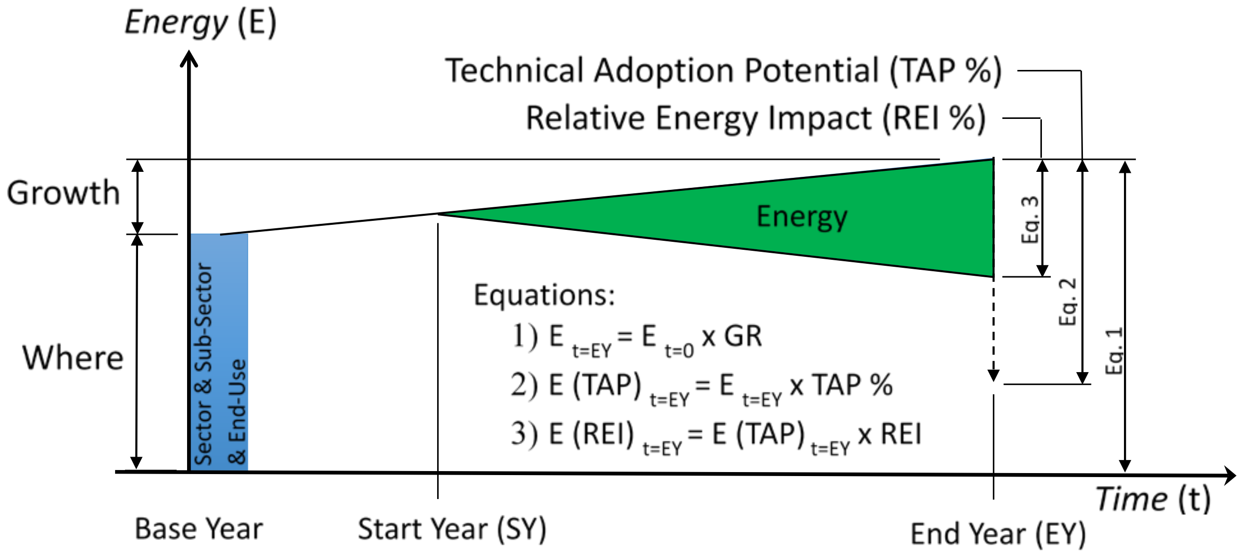
Internally developed scenarios Type-I1 (referred to herein as "type-I1") utilize the tool's full functionality. It allows the user to develop scenarios using the tool's internal datasets and the tool's core forecast method. It requires that the user select where impacts take place, and the tool provides the user with data from the datasets for the selected items. The user estimates what the impacts are (by estimating a Technical Adoption Potential percentage, and Relative Energy Impact percentage), and when impacts take place (by entering a Start Year, and End Year).

The tool's core forecast method is designed to avoid the double counting of technology impacts embedded in the AEO forecast. Scenarios start with a historic base year energy consumption (e.g., 2010), and the user selects a forecast growth driver from the AEO dataset (e.g., value of shipments, housing units, commercial square footage, vehicles, etc.) to project growth over time. The tool applies the three key variables for each impact to the base year's historic data and selected growth driver to generate a scenario's forecast. Thus, energy impacts have an implicit assumption that only the impacts modeled by the user alter the energy consumption forecast.

The tool’s core forecast method currently applies a linear assumption for technology adoption between the start and end year. Although many non-linear technology adoption curves have been presented in literature, a linear adoption is assumed at this stage of the tool development in order to minimize the users’ scenario development hurdles.

Figure 1 illustrates how the tool accounts for an impact’s adoption over time. The cumulative energy impact during the scenario’s forecast period is illustrated by the green triangle in the figure. A scenario with multiple impacts will have multiple “green triangle” results. Scenarios can have impacts that increase or decrease energy consumption and the tool will return the net energy impact sum from all of the scenario’s impacts.

Figure 1 – Internally developed (type-I1) impact forecast method



Variable	Definition	Notes
$E_{t=0}$	Energy consumption in the Base Year (e.g., 2010)	Data are either pulled from the AEO or the MECS datasets based on User Inputs on the Scenario Input tab.
$E_{t=EY}$	Energy forecasted at the End Year (EY)	Equals the Base Year energy consumption multiplied by the Growth Rate driver.
GR	Growth Rate driver	Selected in the Scenario Input tab.
TAP %	Technical Adoption Potential percentage	User Input on the Scenario Input tab.
REI %	Relative Energy Impact percentage	User Input on the Scenario Input tab.
$E(TAP)_{t=EY}$	Energy Technical Adoption Potential at End Year	Equals the energy forecasted at the End Year (EY) multiplied by the Technical Adoption Potential percentage.
$E(REI)_{t=EY}$	Relative Energy Impact at End Year	Equals the Energy Technical Adoption Potential at End Year multiplied by the Relative Energy Impact percentage.

Internally Developed Scenarios (Type-I2)

Internally developed scenarios Type-I2 (referred to herein as "type-I2") allow the user to bypass the tool's core forecast method and program impacts into the tool using Excel functions. Excel functions can extract data from the underlying datasets, perform intermediate and forecast calculations using linear or non-linear impact growth assumption, and any other method necessary to capture the mechanics of the technology scenario including infrastructure stock accounting.

Similar to Type-I1, the user must first select where impacts occur, and the tool provides the user with data from the datasets for the selected items. However, the user must select that alternate calculations will be used and then program excel formulas to develop the scenario. The user should still use the Calculation Scratch Pad to input variables (and references) and perform calculations that can be used in the excel formulas.

Externally Developed Scenarios (Type-E)

The tool also allows the user to develop scenarios externally to the tool and input annual results into the tool (referred to herein as “type-E”). This alternative scenario development approach overrides the tool’s datasets and core forecasting methods. It allows the user to develop scenarios based on any method the user chooses and tailor analyses in a way that is logical to the user, and still uses the tool to display the results. However, forecast results must be manually input to the tool. If this approach is taken, the resulting scenario’s documentation might be located in an external calculation file(s), and therefore has the potential to weaken the transparency of the scenario.

Instructions for Tool Use

LIGHTEnUP Tool Excel Worksheet Tab Schematic

The tool consists of thirteen (13) tabs depicted in Figure 2 and described in Table 1. The main user inputs and outputs are located in the tabs titled Scenario Input, Output Table, and Output Chart. Optional user inputs support tabs allow the user to modify variables that apply to all scenarios, such as business-as-usual (BAU) energy consumption and emissions, electric grid factors, and the CO_2 factors for fuels and electricity. An additional optional user input support tab titled AEO Table allows the user to select the AEO tables (and their variables) that populate dropdown menus throughout the tool. Tabs with no user inputs either contain underlying datasets, core tool calculations, or supporting excel tool programming necessary to support the tool's functionality.

Figure 2 – LIGHTEnUp Excel Worksheet Tab Schematic

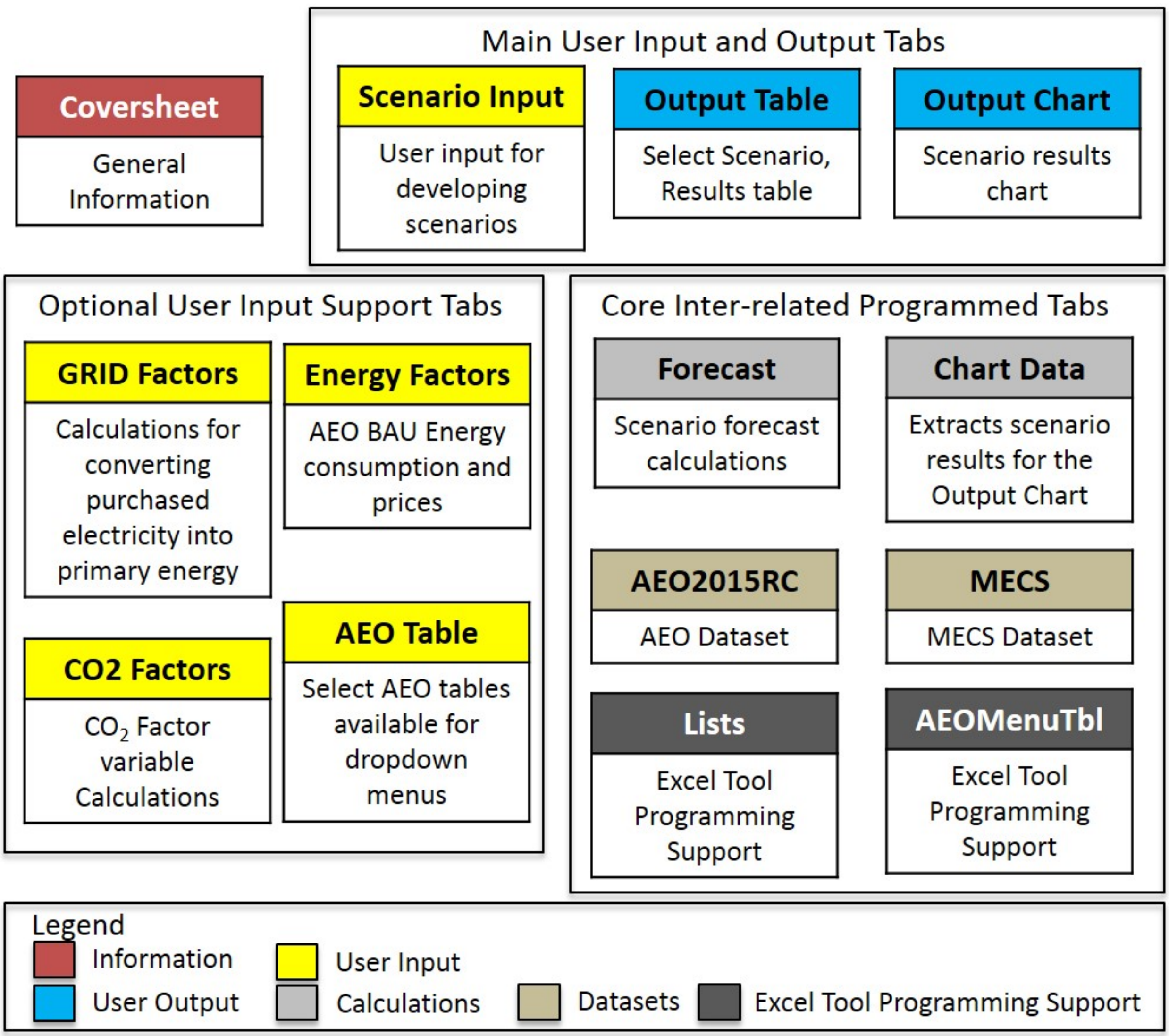


Table 1 – LIGHTEnUP Excel Tool Tabs

Tab Name / User Input?	Description
Coversheet No	Informational Contains the version of the tool, contact information, a key to the tool's color-coding scheme, and basic outline of the tool tabs.
Scenario Input Yes	Main user input and modeling Primary user input tab within the tool. It allows the user to develop scenarios for the tool's forecast. The Scenario Development and Model Input section of this user's guide provides a detailed description of this tab and user inputs.
Output Table Yes	User scenario choice for output table When a scenario is chosen, it is loaded into the Forecasting tab, and the results are shown in the output table on this tab and the graph on the Output Chart tab. The output table shows the cumulative energy impacts, net CO_2 emissions, and energy expenditures.
Output Chart Yes	Output chart Annual energy impacts chart associated with a scenario.
Forecast No	Scenario forecasting Calculation engine that translates a scenario's input to the annual impact forecasts.
Chart Data No	Scenario data for Output Chart Pulls the forecast results from the Forecast tab for display in the Output Graph tab.
Energy Factors Optional	Energy factors and Energy Price Forecasts Two table that extract data from the AEO Table Table 1 – Energy Factors: extracts aggregated energy consumption forecasts from the AEO Table for use as a business as usual forecast Table 2 – Energy Prices: extracts energy prices and total energy expenditures from the AEO Table
Grid Factors Optional	Electricity final to primary energy conversion factor Calculates the conversion factors used to translate final (end-use) electricity impacts into primary energy (i.e. energy required for electricity generation).
CO_2 Factors Optional	CO_2 emissions factors The CO_2 Factors tab contains the CO_2 emissions factors used to convert energy impacts into CO_2 emissions impacts.
AEO2015RC No	Annual Energy Outlook (AEO) dataset AEO 2015 Reference Case Dataset used in the tool.
MECS No	Manufacturing Energy Consumption Survey (MECS) fuel and end-use tables MECS data used in the tool. No User input is required on this tab.
Lists No	Lists required for dropdown menus Contains some lists necessary for the tool functionality (e.g., dropdown lists).
AEO Table Optional	Selecting AEO tables available in Scenario Input tab dropdown menus User can choose which AEO tables will be available in the Scenario Input tab.
AEOMenuTbl No	AEO lists required for AEO dropdown menus Organizes the AEO tables selected in the AEO Table tab for use in the Scenario Input tab.

LIGHTEnUP Tool Excel Cell Color Scheme

Cells within the excel tabs are color code according to the color scheme in Table 2. The color scheme is also presented in the Coversheet tab in the tool.

Table 2 – LIGHTEnUP Tool Excel Cell Color Scheme

Cell Color Scheme	Description
Table Headings and Descriptions	**No User Input** - defined excel table headings and table instructions
Light gray with red top border	**User Input** - Used exclusively in the Scenario Input tab to highlight when a new scenario begins. Scenario are developed in the rows between this color scheme
	User Input - In defined Excel Tables
Orange	**User Input Dropdown Menu** - populated with dropdown lists for user input
Green	**No User Input** - Returns information either a) extracted from datasets, or b) the result of a previous User Input
Gray	**No User Input** - Intermediate Calculations
Brown	**No User Input** - Data Sets
Dark gray	**No User Input** - Excel Tool Programming Support (lists used in dropdown menus and formulas)

Scenario Input Tab

The Scenario Input tab contains an Excel Table titled TableScenario. This table is divided into the 10 column sections listed in Table 3. The TableScenario's column sections occupy worksheet columns from left to right in the order presented in Table 3. Table 3 also indicates if the sections require user inputs, and their applicability for the three scenario development types (Type-I1, Type-I2, and Type-E).

Table 3 – Scenario Input Table Sections

Column Sections		Brief Description	User Input	Scenario Type[(1)]		
				I1	I2	E
Description		Name scenarios and impacts	X	X	X	X
Row Function[(2)]		New Scenario, Intermediate, Forecast	X	X	X	X
Where will energy impacts take place?	sector	Industrial, Commercial, Residential, Transportation	X	X	X	X
	sub-sector	Select from MECS or AEO datasets	X	X		
	end-use[(3)]	MECS dataset	X	X		

Column Sections	Brief Description	User Input	Scenario Type(1)		
			I1	I2	E
CO_2 Factor(4)	Select a CO_2 factor variable for the impact (e.g., Natural Gas)	X	X	X	X
Growth Driver	Select an AEO growth driver for the impact (e.g., value of shipments)	X	X		
Energy Price	Select an AEO energy price forecast for the impact	X	X	X	X
Dataset Values and Information	Dataset values and information displayed within the Scenario Input tab		X	X	
What Impact?	Technical Adoption Potential %, Relative Energy Impact %	X	X		
When?	Start Year, End Year	X	X		
Alternative Calculations Units must be TBtus, or TWh	input values derived from external calculations or program excel functions	X		X	X
Calculation Scratch Pad	12 sets of variables to derive calculations	X	X	X	X

Notes:

(1) I1 = Internally Developed Type-I1; I2 = Internally Developed Type-I2; E = Externally Developed Type-E
(2) New Scenario starts a new scenario, intermediate will not show on Output Chart, Forecast will show on Output Chart
(3) only for industrial impacts
(4) CO_2 Factor variables are defined in the CO_2 Factors tab and generally are in units of Million $MtCO_2$/Quad

LIGHTEnUP tool scenarios are comprised of one or more impacts. By breaking a scenario into multiple impacts, the tool is able to forecast impacts that affect varying sub-sectors, energy resources, and end-uses. Although individual impacts can be linked together through calculations, each impact must occupy a dedicated row in the Scenario Input tab.

Scenario & Impact labels and row functionality

When developing scenarios, an impact can serve as an intermediate step (i.e., one that does not appear in the forecast, but is used to support subsequent impacts), or as an impact used in the Forecast tab and summarized in the Output Table and Output Chart tabs. Thus, the first two columns in the Scenario Input tab are labeled: Description, and Row Function. Descriptions should either a) label each scenario with a unique title, or b) label each impact, or row, used in the scenario. Cells in the Row Function column are populated with a dropdown menu where the user must select if the row is: a) New Scenario, b) Intermediate (or blank), or c) Forecast. This is summarized in Table 4.

Table 4 –Scenario and impact labels and row functionality

Column Title ***[Scenario type]***	**Value**	**Description**
Description *[Type-I1, Type-I2, Type-E]*	Input Text	Name of a scenario – must be unique (no two scenarios should have the same name)
		Impact identification – any text is accepted
Row Function *[Type-I1, Type-I2, Type-E]*	New Scenario	Select New Scenario for the first line of each new scenario (the Description Column should have the Scenario's name).
	Intermediate (or blank)	Intermediate support for subsequent impacts. These will not appear on the Output Table or the Output Graph tabs.
	Forecast	Impact will be used in the Forecast tab, and will be itemized in the Output Table or the Output Graph tabs.

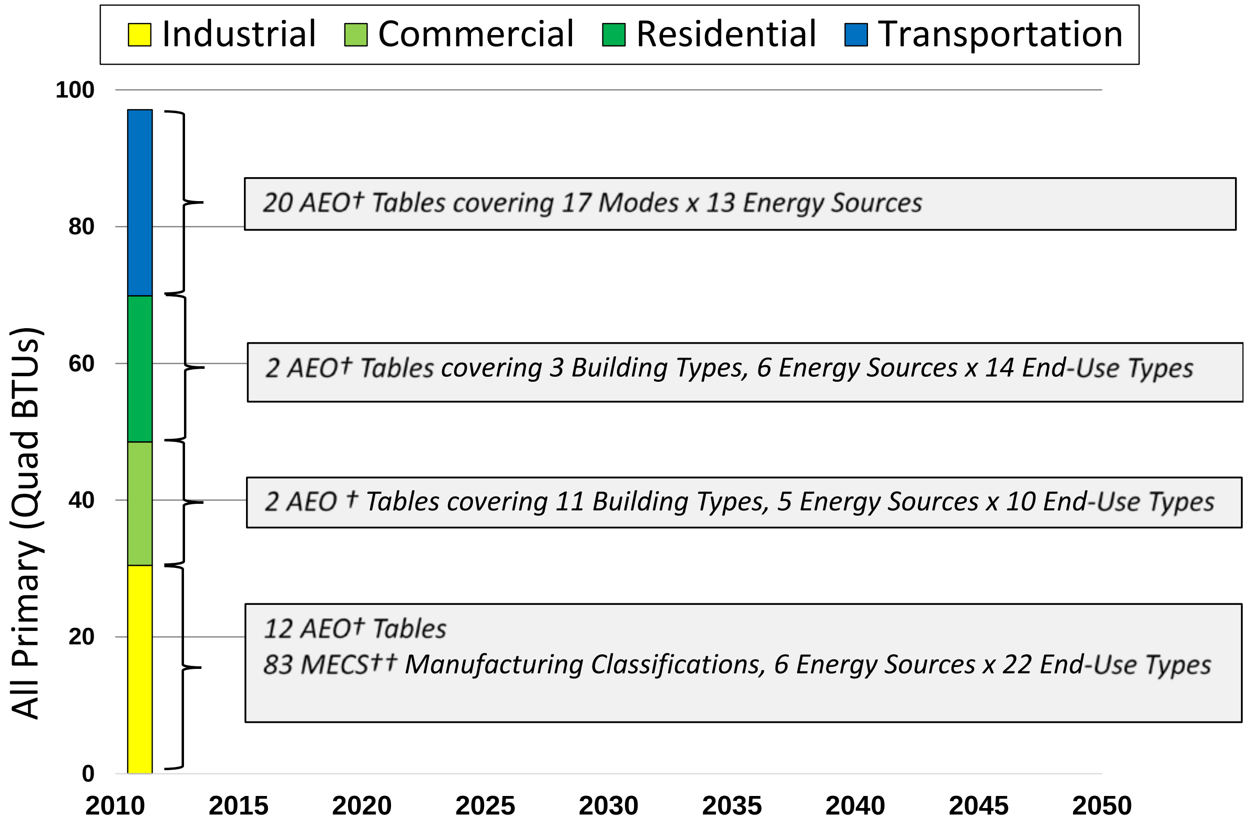
Overview – Where will energy impacts take place (In which sectors)?

The first task of the user is to determine areas of the U.S. economy affected in the scenario. The tool is designed to forecast impacts within four major sectors of the U.S. economy: Industrial, Residential, Commercial, and Transportation. For each of these sectors, the tool allows the user to leverage the AEO and MECS datasets to select where impacts will take place.

Industrial sector energy consumption in the base year (2010) is taken from AEO tables and the tool disaggregates AEO data to 109 North American Industry Classification System (NAICS)[10] classifications based on the MECS dataset. This allows the user to select specific manufacturing sub-sectors that the scenario might impact. However, a scenario that impacts the manufacturing sector's highest energy consuming industry can be developed from AEO data and bypass the MECS functionality of the tool. In addition, the total industrial sector can also be selected in cases where the user does not wish to model impacts in a specific manufacturing sub-sector. A description of the MECS dataset is provided in the Underlying Datasets, MECS 2010 section of this user's guide.

Figure 3 illustrates current base year (2010) energy consumption by each of the four energy consumption sectors in the AEO dataset.

Figure 3 – Current (2010) energy consumption by sector and disaggregation data



† Annual Energy Outlook (AEO) Tables
†† Manufacturing Energy Consumption Survey

Tool Inputs – Where will energy impacts take place (In which Sectors)?

The user selects where in the U.S. economy impacts take place through a series of sequential selections across the columns of an impact's row in the Scenario Input tab. The following tables provide a description of these columns and user inputs.

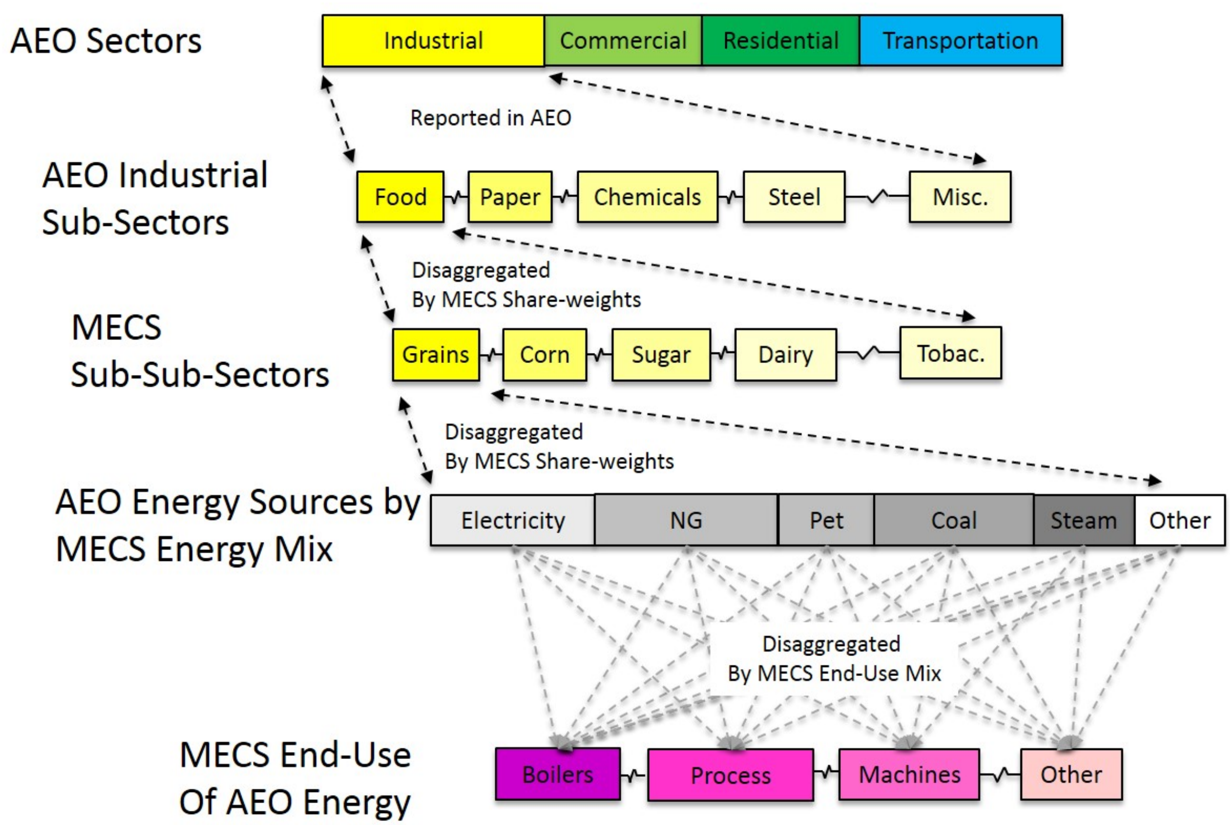
Table 5 – Input Instructions for Sector Information

Column Title ***[Scenario type]***	**Value**	**Description**
Sector *[Type-I1, Type-I2, Type-E]*	Commercial, Industrial, Residential, Transportation	Energy sector the given impact will affect. This selection is necessary for the Output Table and Output Chart to aggregate results for output.
IF Sector is Industrial, Select MECS End-Use or AEO Table? *[Type-I1, Type-I2]*	MECS, AEO	If the Sector is Industrial, choose between MECS or AEO Data that will be used to identify energy source and end-use. If MECS is selected, then follow Table 6 for subsequent columns. If AEO is selected, then follow Table 7 for subsequent columns.

For industrial impacts that pertain to a specific MECS industry and/or end-use, the MECS classification and end-use type can be selected in the Scenario Input tab as identified in Table 5. The 109 NAICS classifications can be viewed in *Appendix A – Manufacturing Energy Consumption Survey Sub-Sectors* of this guide, as well as in the MECS tab of the excel tool. The tool uses this information to disaggregate broader AEO data into the processes specifically affected in the scenario. For industrial impacts where MECS data is chosen, use the following columns according to Table 6. For all other impacts (those using AEO data), follow Table 7.

Figure 4 provides an illustrative graphical representation of how the tool disaggregates AEO data by MECS data to allow the user to closely examine and use the detailed end-use consumption that occurs in the industrial and manufacturing sector. The next three figures shows illustrative examples of AEO commercial (Figure 5) and residential (Figure 6) data mapping to energy and end uses, as well as an illustrative example of transportation sector (Figure 7) data mapping from transportation modes and vehicles to energy.

Figure 4 – AEO sectors and disaggregation examples for industrial end-uses



If the impact sector is Industrial, then the user can identify the industrial sector through an AEO table, or through MECS data. MECS data provide much greater detail on the industrial or manufacturing sector of the U.S. economy. A list of MECS based manufacturing sub-sectors by NAICS codes are listed in *Appendix A – Manufacturing Energy Consumption Survey Sub-Sectors*. Table 6 outlines the user inputs required to select an industrial or manufacturing sub-sector.

Table 6 – Input Instructions for Industrial Impacts using MECS disaggregation

Column Title *[Scenario type]*	Value	Description
IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table *[Type-I1, Type-I2]*	Drop-down Menu	Manufacturing classification the impact will affect. There are 109 options, which can be seen on the MECS tab of the tool and in *Appendix A – Manufacturing Energy Consumption Survey Sub-Sectors* of this guide.
IF using MECS, Select Energy Resource Otherwise Select AEO Table Variable *[Type-I1, Type-I2]*	Drop-down Menu	Energy source affected by the impact. There are 6 options for Electricity, Natural Gas, Petroleum, Coal, Total Fuels (NG, Petroleum, Coal), and All Non-Electricity. See *Modified MECS data used in the tool* section below for information on how these options are used in the tool.
IF Sector is Industrial, Select Energy End-Use Else leave blank *[Type-I1, Type-I2]*	Drop-down Menu	End-use type affected by the impact. There are 22 options, which can be seen on the MECS tab of the tool.

For all other (non-industrial) impacts, and for industrial impacts where MECS disaggregation is not used, the AEO Table and Table Variable related to the impact must be input to the tool. AEO data held in the tool is comprised of 82 tables, the names of which can be viewed in *Appendix B – AEO Tables*, as well as the AEO Table tab of the excel tool. Each table contains up to 250 entries (referred to as table variables). Some table variables are actual energy consumption metrics, and are sometimes broken into specific fuel source and/or end-use (e.g., Residential: Electricity: Dishwashers). Other variables, such as vehicle sales and miles traveled, building square footage, and energy intensity, can be used in the tool as intermediate steps to derive the energy impacts. The full list of all AEO Tables and Table Variables can be seen on the AEO2015RC tab of the excel tool.

Table 7 – Input Instructions for Impacts using AEO disaggregation

Column Title *[Scenario type]*	Value	Description
IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table *[Type-I1, Type-I2]*	Drop-down Menu	AEO Table to pull data from. There are 38 options, which can be seen on the AEO2015RC tab of the tool and in *Appendix B – AEO Tables* of this guide.
IF using MECS, Select Energy Resource Otherwise Select AEO Table Variable *[Type-I1, Type-I2]*	Drop-down Menu	Line item from AEO Table which is being affected. Options will vary depending on table selected, and are generally for varying energy sources, end uses, and other characteristics. All tables and variables can be seen on the AEO2015RC tab of the tool.
IF Sector is Industrial, Select Energy End-Use Else leave blank *[Type-I1, Type-I2]*	Drop-down Menu	Leave blank.

Figure 5 – AEO sectors and disaggregation examples for commercial end-uses

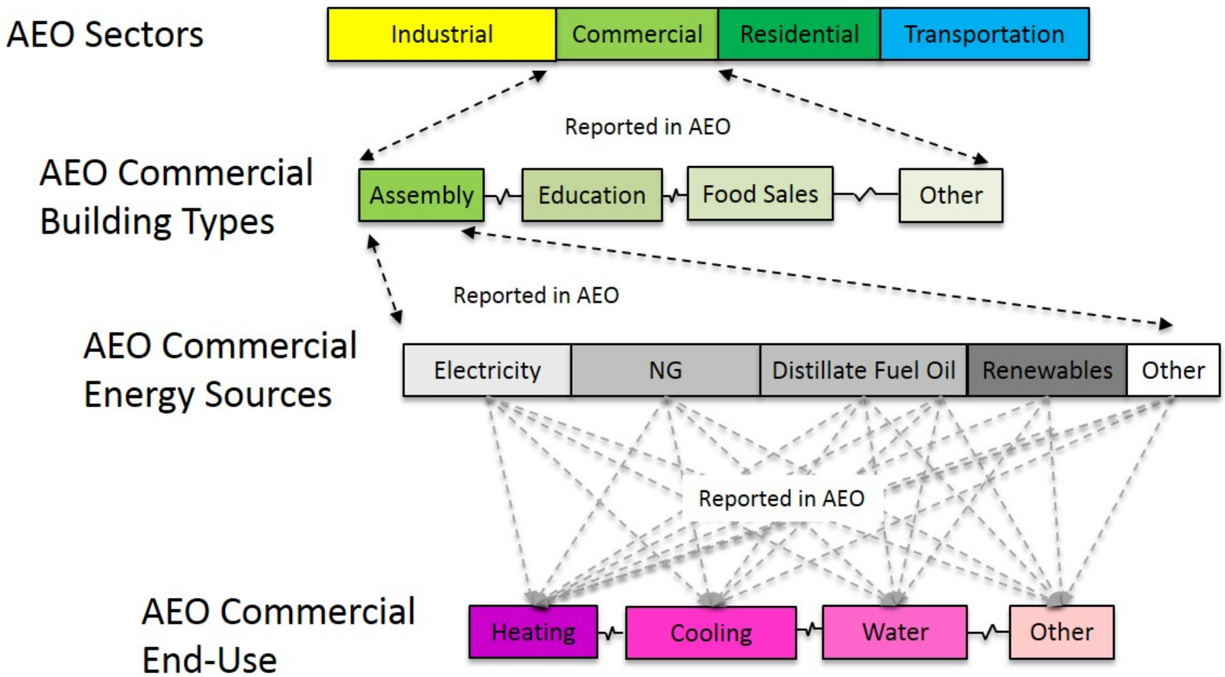


Figure 6 – AEO sectors and disaggregation examples for residential end-uses

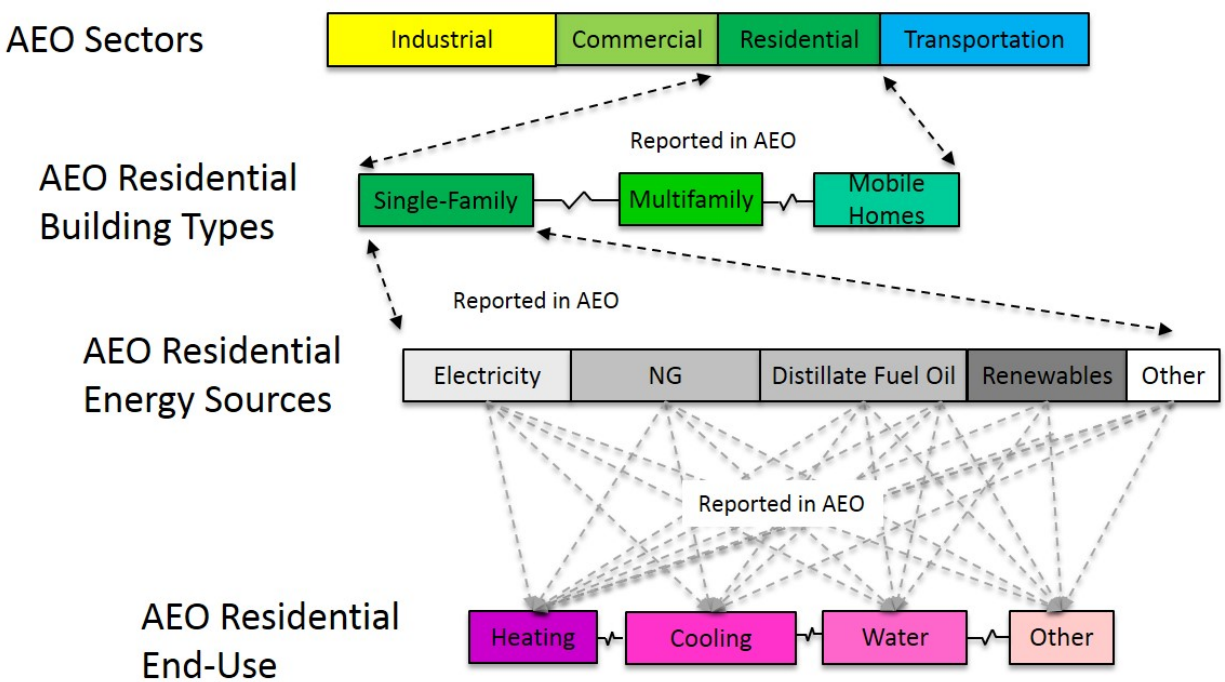
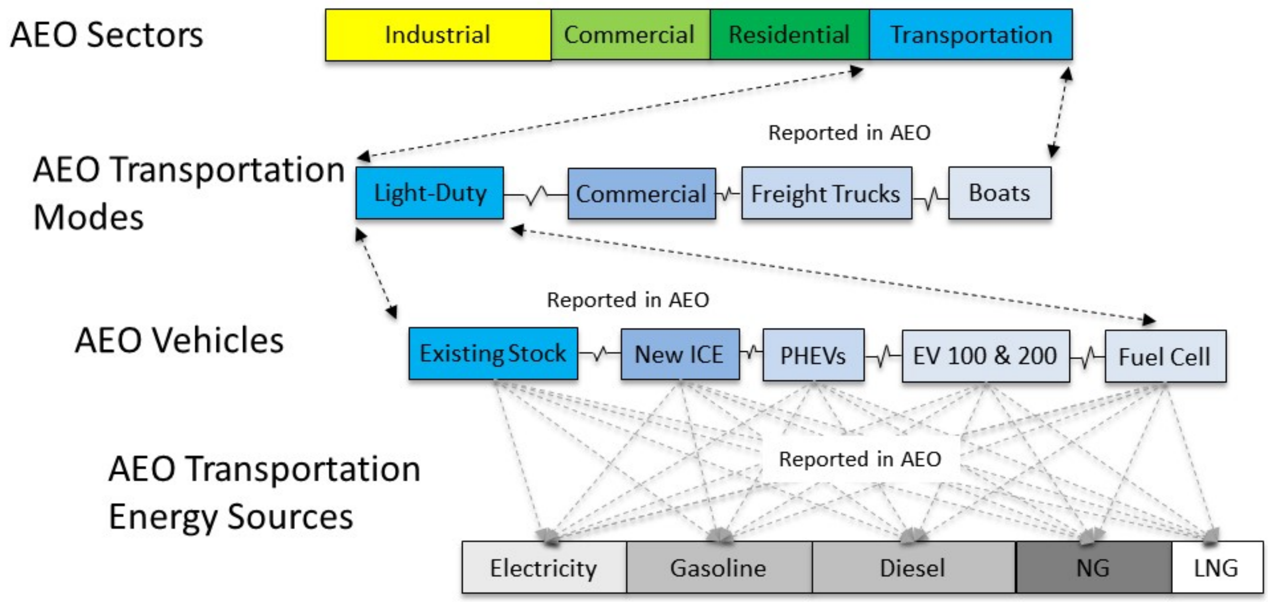


Figure 7 – AEO sectors and disaggregation examples for transportation end-uses



Tool Inputs – CO_2 factors, Forecast Growth Drivers and Energy Prices

Each impact designated as a Forecast impact in the Row Function column requires three additional selections to enable the impact's forecast: a) a CO_2 emissions factor associated with the impact, b) a forecast growth driver over the time horizon, and c) an energy price forecast. Table 8 describes these three selections.

Table 8 – CO_2 factors, forecast growth drivers and energy prices

Column Title ***[Scenario type]***	**Value**	**Description**
Energy Resource for CO_2 accounting *[Type-I1, Type-I2, Type-E]*	Drop-down Menu	Select CO_2 emissions factors for the major energy resource affected by the impact. CO_2 factors can be seen on the CO_2 Factors tab of the tool [11]. This is required for CO_2 impact forecasts.
Forecast Growth Driver (AEO Table) *[Type-I1]*	Drop-down Menu	AEO Table from which the projection curve will be pulled.
Forecast Growth Driver (AEO Table Variable) *[Type-I1]*	Drop-down Menu	Line item from AEO Table whose projection curve will be followed. This is required for impact forecasts.
Energy Prices *[Type-I1, Type-I2, Type-E]*	Drop-down Menu	Price of affected energy. There are over 400 options, which can be seen on the Lists tab of the tool. This is required for energy expenditure forecasts.

Tool Inputs – Base year energy data

Each scenario's default base year is 2010, the first year in the AEO dataset. The base year data for the selected sector, energy source, and end-use is scaled by the forecast growth driver in the Forecast tab. If it is useful to use a different year than 2010 when developing a scenario, it can be selected in the column “Year if other than 2010 (for AEO Data)” in the Scenario Input tab. If an alternative year is input in the Scenario Input tab, then the resulting year’s data will be displayed in the “Dataset Values and Information” columns for those impacts, but will not be used in the forecast – only year 2010 data are used in the forecast. The resulting year’s data displayed in the “Dataset Values and Information” columns are provided to help the user develop a scenario when calculating the Technical Adoption Potential % and Relative Energy Impact % inputs. Calculation of these inputs is described in the *What will the energy impact be?* section of this user’s guide.

If an alternative year is used in the scenario development, the results will reflect the alternative year’s data and thus reflect technology adoptions embedded in the AEO forecast. The user should carefully consider this if using an alternative year, and limit its use to instances when the impact is not likely affected by the primary technology analyzed in the scenario.

Data extraction within the Scenario Input tab.

The key data used in the scenario is extracted from the respective database of the selections for the impacts and is displayed on the Scenario Input tab. Displaying this data allows the user to view the selected data and units. It is also translated to the Forecast tab when the scenario is forecasted. Table 9 describes these columns (highlighted as green cells in the Scenario Input tab).

Table 9 – Dataset values and information displayed within the Scenario Input tab

Column Title	Description
AEO Row	Displays the AEO dataset row (located in the AEO2015RC tab) for the Select AEO Table Variable. Returns a blank if Sector is Industrial and MECS data are used.
AEO Table Variable Data	Displays the AEO value corresponding to the AEO Row and selected year (2010 is the default year)
AEO Forecast Growth Driver Row	Displays the AEO dataset row (located in the AEO2015RC tab) for the Select AEO Forecast Growth Driver Table Variable.
Energy Price Row	Displays the AEO dataset row (located in the AEO2015RC tab) for the Select AEO Energy Price Table Variable.
MECS Sector Energy	Displays the total 2010 energy consumption for the selected Manufacturing Industry, by selected Energy Resource. Returns a blank if AEO data are used.
MECS End-Use %	Displays the selected Manufacturing Industry End-Use %, by selected Energy Resource. Returns a blank if AEO data are used.
MECS End-Use Energy	Displays the selected Manufacturing Industry End-Use energy consumption by Multiplying the selected MECS Sector Energy by the selected End-Use %. Returns a blank if AEO data are used.
Data Units	Displays the units for the data selected.

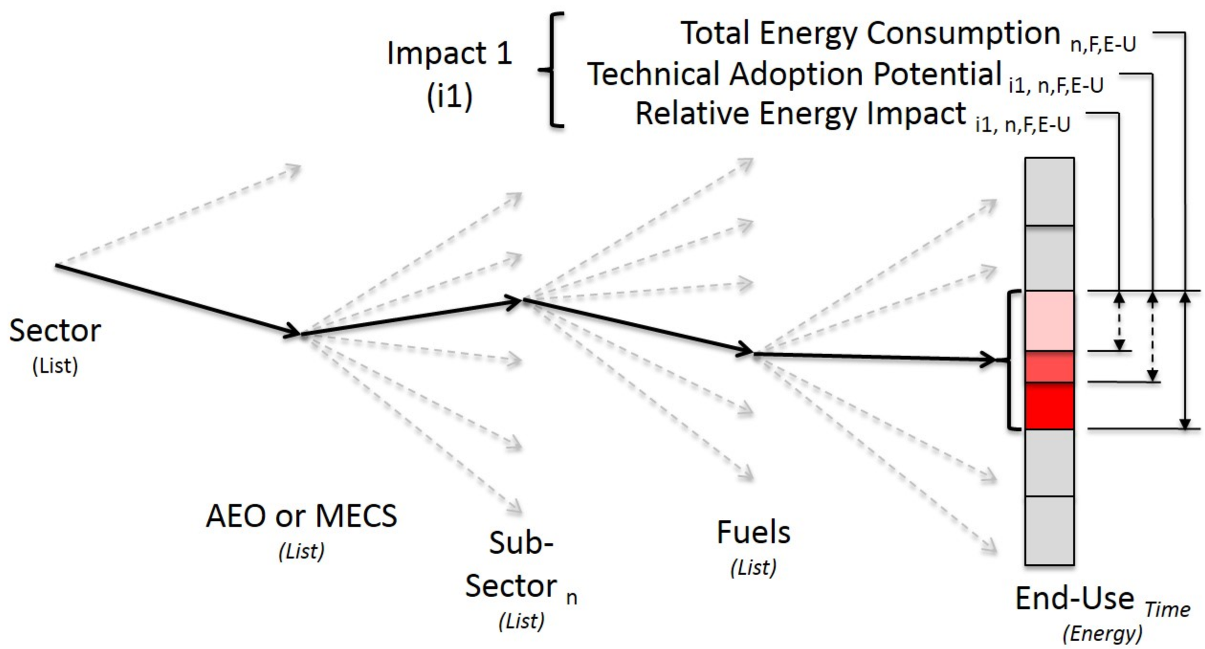
What will the energy impact be?

For Type-I1 scenarios, the second key input is to specify what impact is anticipated. Impacts are input to the tool through two variables:

- Technical Adoption Potential % - the fraction of a sub-sector's energy end-use that could be altered by the impact (e.g., proportion of consumers that will adopt the technology).
- Relative Energy Impact % - the percentage of the Technical Adoption Potential that could be altered by the impact (relative to business-as-usual (BAU)). A negative number decreases energy consumption and positive number increases energy consumption.

Figure 8 illustrates how these two variables can be estimated. Impact 1 in the figure could affect total sub-sector fuel consumption but will likely be limited by a technical adoption potential (e.g., only a portion of consumers will adopt the technology). This should be expressed as a ratio of the BAU energy consumption. Likewise, the adopted technology will have an energy impact relative to a BAU technology, or a relative energy impact. This also should be expressed as a ratio of the BAU energy consumption. For example, if technology A is identified by the user as the only technology currently deployed and therefore responsible for 100% of a sub-sector's energy end-use, the technical potential for replacement by technology B would be 100%. If technology B is anticipated to be 10% more efficient than technology A, then its relative energy impact would be -10%. In this hypothetical example, technology B should reduce the sub-sector's energy end-use consumption by 10% if fully (100%) deployed.

Figure 8 – Technical Adoption Potential and Relative Energy Impact



$$\text{Technical Adoption Potential \%} = \frac{\text{Technical Adoption Potential}_{i1,n,F,E-U}}{\text{Total Energy Consumption}_{n,F,E-U}}$$

$$\text{Relative Energy Impact \%} = \frac{\text{Relative Energy Impact}_{i1,n,F,E-U}}{\text{Technical Adoption Potential}_{i1,n,F,E-U}}$$

Variable	Definition	Notes
Sector	Industrial, Commercial, Residential, Transportation	User Selected
AEO or MECS	Sub-Sector of the selected Sector	Select between AEO or MECS datasets
Sub-Sector$_n$	Sub-Sector$_n$ of the selected Sector	Select specific AEO variable or specific MECS sub-sector
Fuels	e.g., Elec., NG, Coal, Petroleum, etc.	User Input on the Scenario Input tab.
End-Use $_{\text{Time (Energy)}}$	End-Use	User Input on the Scenario Input tab. (e.g., boilers)
TEC $_{n,F,E\text{-}U}$	Total End-Use energy consumption in Sub-Sector$_n$, by Fuel (F) and by End-Use (E-U)	Information supplied by the LIGHTEnUP based on the previously selected sector, sub-sector, and selected End-Use.
TAP $_{i1,\, n,F,E\text{-}U}$	Technical Adoption Potential – End-Use energy consumption that could potentially be changed by impact i1 in Sub-Sector$_n$, by Fuel (F) and by End-Use (E-U)	Analyst's Homework
REI $_{i1,\, n,F,E\text{-}U}$	Relative Energy Impact – Technology performance of impact i1 in Sub-Sector$_n$, by Fuel (F) and by End-Use (E-U) relative to the incumbent technology (in units of energy)	Analyst's Homework
TAP %	Technical Adoption Potential % TAP $_{i1,\, n,F,E\text{-}U}$ ÷ TEC $_{n,F,E\text{-}U}$	Analyst's Homework
REI %	Relative Energy Impact % RES $_{i1,\, n,F,E\text{-}U}$ ÷ TAP $_{i1,\, n,F,E\text{-}U}$	Analyst's Homework

The magnitude of each impact must be calculated based on the expected changes in energy usage. For most scenarios, this can be captured by a "Technical Adoption Potential %" and a "Relative Energy Impact %" which can be entered directly into the tool. However, the user can also develop scenarios from non-energy information extracted from the datasets (e.g., vehicle sales) with annual energy impact calculations placed in the Alternate Calculations section of the Scenario Input tab. Examples of both approaches are provided in the appendix as case study examples.

When will the energy impact take place?

For Type-I1 scenarios, the third key input from the user is when are impacts are anticipated to take place? The tool does not restrict the user's input except that the impact cannot end before it begins. An impact will grow between when it is first introduced (i.e., the Start Year) and when it reaches full technical adoption potential (i.e., the End Year). Annual deployment rates for each forecasted impact are derived by assuming a linear adoption between its Start Year and End Year (i.e., from 0% at the Start Year to 100% in the End Year at a constant annual growth rate).

If an impact's End Year is prior to 2050, then the deployment rate remains at 100% for each year between the End Year and 2050. If an impact's End Year is after 2050, then the deployment rate will reach the appropriate deployment rate percentage for 2050.

Alternative Calculations

The next column, titled Alternate Calculations, allow the user to override calculations in the tool's forecast method. This serves two purposes. First, it allows the user to develop a scenario using excel formulas located in the rows of these columns (Internally Developed Scenarios). Second, it allows the user to input externally developed scenarios results (Externally Developed Scenarios).

If rows in the column titled "Use Alternate Impact Values?" are selected as TRUE, then the forecast will reference the results in the columns beginning with Alt_Units for years 2010 through 2050 labeled as columns Alt_2010 through Alt_2050 located further to the right in this section. If the scenario is an externally developed scenario (Type-E), then the externally calculated result values are input to the Alt_2010 through Alt_2050 columns. If the scenario is an internally developed scenario (Type-I2), then Excel formulas are input to the Alt_2010 through Alt_2050 columns.

Designating TRUE or FALSE in the Alternate Calculations column is only required when the row is a forecast row. If the row is intermediate, then the Alternate Calculations columns can simply be used for intermediate calculations (almost the same as the calculation scratch pad).

Calculations Scratch Pad

The final set of columns in the Scenario Input tab allow the user to perform and document calculations necessary for the development of the impact inputs. The columns titled Calculation Scratch Pad provide twelve (12) sets of Description, Value, Units, and Reference. These scratch pads allow the user to perform intermediate calculations within the tool itself, and provides a central location to document references and/or assumptions required to develop the impact. These can be used for all scenario development types, although Externally Developed Scenarios tend to have key variables located within the external calculation files.

Scenario #, Forecast Sequence and Forecast Index

The final three columns in the Scenario Input tab automatically index the scenarios and impacts and require no user input. This allows the Forecast tab to calculate a single scenario at a time. When a scenario is selected in the Output Table tab (described below), a macro automatically updates these columns. If the user starts a new scenario by inserting rows in the Scenario Input tab, the macro will update these columns and the user should not have to update them manually. These columns will also be updated if the user selects the Update button on the Output Table tab, which also runs the macro.

Output Table Tab

This sheet allows users to select a scenario that has been created in the Scenario Input tab. Across the top of this tab are several user selections, which should be filled in according to Table 10.

Once selected, a macro runs to update the Scenario #, Forecast Sequence, and Forecast Index columns on the Scenario Input tab and the scenario is loaded into the Forecast tab to generate the scenario forecast. Results from the forecast are presented in the output table on this tab, and the graph on the Output Chart tab will show Fuels, Electricity, or primary energy for both fuels and electricity, depending on the selection in the “Graph” drop-down menu on this tab.

Below the user controls, aggregate results for the entire selected time period are presented for the business-as-usual AEO forecast in the top rows, with each of the scenario’s impacts and the scenario totals for each sector presented below. Results for fuels, electricity, and all primary energy are given in terms of Energy, Energy Expenditures, and CO_2 Emissions. The use of the term primary implies that electricity values are being converted to the primary fuels used to generate electricity based on the “Grid Primary to Final Energy ratio” selected. Primary energy allows for a more direct comparison between fuel and electricity impact as these are in the same units (i.e., primary energy) in this column.

Table 10 – Output tab

Column Title	Value	Description
Scenario	Drop-down Menu	Scenario to display results for.
Graph	Fuels (TBtu), Fuels (PJ), Electricity (TWh), All Primary (TBtu) All Primary (PJ)	Choice to graph results for fuel, electricity, or primary energy consumption. Table will continue to show all three.
Grid Primary to Final energy ratio	AEO RC, Nuc & Ren HR=1, or Fossil Only	Choice to convert final (end-use) electricity consumption into primary energy using: a) the AEO 2015 RC average, b) nuclear and renewable electricity generation heat rate = 1, or c) Fossil only.
Table Sum from	Drop-down Menu (Year)	Starting year of time period to be summed for table values. Minimum value is 2010.
Table Sum to	Drop-down Menu (Year)	Ending year of time period to be summed for table values. Maximum value is 2050.

The Grid Primary to Final energy ratio has these three options so that the user can choose between three scenarios for converting final electricity consumption into primary energy necessary for electricity generation. The calculations for each option are presented in the *Grid Factors Tab* section below.

NOTE: When a scenario is selected, a macro runs to update the Scenario #, Forecast Sequence, and Forecast Index columns on the Scenario Input tab. This macro ensures that the indexing necessary to load scenarios into the Forecast tab works properly. This macro can also be run by clicking on the “Update” button at the top left corner of the Output Table tab. There are no calculations that alter a scenario’s forecast within this macro.

Output Chart Tab

This sheet contains a graph that reflects the options selected in the Output Table tab. Although the output table in the Output Table tab presented the cumulative results for the years selected in the Table Sum from and Table Sum to years selected in the Output Table tab, the output graph on the Output Graph tab always shows the full time period of the tool (2010 – 2050).

Tool Functionality and Underlying Datasets

Forecast Tab

The Forecast tab contains the formulas that translate a scenario's inputs into a forecast. No user input is required on this tab. Instead, this tab provides transparency for the scenario forecast, allowing the user to trace how the scenario inputs translate to a forecast. Although the formulas can be viewed, the user should not alter these formulas as errors can result throughout the tool.

The forecast formulas are designed to only calculate the scenario selected on the Output Table tab. When a scenario is selected on the Output Table tab, this tab forecasts each impact that is designated as a forecast row in the Row Function column on the Scenario Input tab for the selected scenario. Thus, all scenario development details are maintained on the Scenario Input tab, and the Forecast tab only forecasts the selected scenario. This is designed to maintain tool computation speed.

The Forecast tab is broken into three vertical (by rows) sections: business-as-usual (BAU) AEO forecast sums, the selected scenario sums, and individual impacts; and 9 horizontals (by columns) sections: impact description, growth rate, deployment rate, impact inputs, fuels, final electricity, primary energy, energy expenditures, and CO_2 emissions.

BAU AEO Sum Rows

These rows display the AEO forecast for each of the major energy consumption sectors of the U.S. economy (Industrial, Commercial, Residential, and Transportation). These values are only relevant to the fuels, final electricity, primary energy, energy expenditures, and CO_2 emissions columns.

Scenario Sum Rows

These rows display the sum of all the scenario impacts, separated by energy consumption sectors of the U.S. economy (Industrial, Commercial, Residential, and Transportation). These values are only relevant to the fuels, final electricity, primary energy, energy expenditures, and CO_2 emissions columns.

Impact Rows

These rows contain the formulas that translate a scenario's inputs into a forecast. They are grouped together for growth rates, deployment rates, fuels impacts, electricity impacts, primary energy impacts, energy expenditure impacts, and CO_2 emissions impacts. Inputs for each forecasted impact are automatically pulled from the Scenario Input sheet and populated in the impact rows.

If alternate calculation override is chosen, then the forecasts use the alternative values from the Scenario Input tab and uses them in the final fuels, final electricity, or primary energy forecasts based on selections in the Scenario Input tab.

If scenarios are forecasted using the formulas in the Forecast tab (not overridden), then each annual impact is forecasted as the product of the forecast growth driver (%), deployment rate (%), technical adoption potential (%), relative energy impact (%), and 2010 base year energy consumption selected in the Scenario Input tab. Annual results are displayed in the final fuels, final electricity, and primary energy sections based on selections in the Scenario Input tab.

Annual deployment rates for each forecasted impact are derived by a linear adoption between its Start Year and End Year (i.e., from 0% at the Start Year to 100% in the End Year). If an impact's End Year is prior to 2050, then the deployment rate remains at 100% for each year between the End Year and 2050. If an impact's End Year is after 2050, then the deployment rate will not reach 100%.

The primary energy impacts section aggregates the results from the electricity and fuels sections. For the BAU scenario, data are pulled directly from AEO. For the technology scenario's individual impacts, either the value from Final Fuel Energy Impacts is directly pulled over, or the value from Final Electricity Energy Impacts is converted to primary energy by multiplying by the Grid Primary to Final energy ratios. Then, the scenario's overall impacts are summed for each sector as before.

Carbon dioxide impacts are the product of energy impacts and energy resource specific CO_2 emission factors contained on the CO_2 Factors sheet. The user must select the energy resource specific CO_2 emission factors in the Scenario Input tab (Energy Resource for CO_2 Accounting column) for each forecasted impact.

Adding Rows to the Forecast Table

The forecast functionality of the tool is located in an excel table (named "TableForecast") located in the Forecast Tab. To maximize excel computational speed, this table is limited to 20 forecast impacts – New Scenario and Intermediate impact rows on the Scenario Input tab are not used in the TableForecast. However, if more than 20 forecast impacts are needed to fully capture a scenario, then the user can add more rows to the TableForecast. The user can use any common ways of adding row to excel tables (e.g., copying the last row to additional rows, insert rows in the middle of the table, etc.). The excel formulas should be populated automatically into the newly created rows.

AEO Table Tab

The AEO Table tab allows the user to choose which AEO tables will be available in the Scenario Input tab dropdown menus associated with the AEO. The user toggles a particular AEO table as either TRUE or FALSE in column D titled "Include in query Engine".

Energy Factors Tab

The Energy Factors tab is used to extract data from the AEO table and consists of two tables. The first table (TableEnergyFactors) extracts aggregate energy consumption data from the AEO table for each energy resource reported in AEO for each of the four energy consuming sectors of the U.S. economy. The second table (TableEnergyPrices) extracts energy prices for fuels and electricity from the AEO table for each the four energy consuming sectors.

Data from the Energy Factors table are displayed on the Forecast Tab in the top 8 rows. The Output Table sums the total fuels and electricity for each of the four sectors from the Forecast Tab.

Data from the Energy Prices table are used in the scenarios to estimate energy expenditures (or savings) associated with each of the scenario impacts. Energy expenditures are estimated within the Forecast tab by multiplying estimated energy impacts by their respective energy prices. The

Output Table sums total expenditures from the Forecast Tab.

Grid Factors Tab

A conversion factor (Grid Primary to Final energy ratio) is necessary to translate final (i.e., end-use) electricity to primary energy required for the generation of electricity. See "*Appendix C - Grid Primary to Final energy ratio Calculations*" for tables showing the annual electricity sector base-case and modified cases.

Primary energy is the energy input to conversion technologies that produce useful energy commonly referred to as final energy. When scenarios affect final electricity consumption, final electricity impacts are converted to primary energy using an annual conversion factor that includes both a) the energy input for generating electricity (which account for the efficiency of electric generation resources), and b) the transmission and distribution losses between grid generators and end users. Conversion factors are based on AEO 2015 Reference Case for the aggregate U.S. grid, but are calculated within the tool on the Grid Factors tab. These calculations will automatically update when new AEOs are released.

The Tool allows an analyst to alter the conversion factors for the following reason. EIA's Annual Energy Review reports energy inputs for renewable electricity based on the equivalent fossil energy that would have been used to generate electricity in renewable electricity's absence [12]. AEO 2015 Reference Case (AEO RC) reports energy inputs for renewable and nuclear generation using efficiencies similar to fossil fuel power plants. For example, the U.S. average coal-fired power plant fleet produces roughly one (1) unit of electricity for every three (3) units of coal fuel input. Natural Gas power generation is more efficient requiring just over two (2.2) units of natural gas energy for each unit of electricity produced. AEO 2015 Reference Case assigns 2.7 units of renewable energy input for each unit of renewable electricity generated and 3 units of nuclear energy input for each unit of nuclear electricity generated. Nuclear fuel electricity generation is a thermoelectric process where steam generated from the nuclear reactor drives a turbine and provides shaft power to the generator – similar to thermoelectric based fossil fuel electric generation plants. Both Nuclear and fossil fuel based thermoelectric generation plants have roughly a 40% efficiency; the rest of the energy is lost as waste heat. However, unlike fossil based electricity, nuclear based electric generation does not have the combustion related emissions such as CO_2. Non-combustion based renewable electricity generation also does not have emissions, and renewable combustion based electricity generation (biomass based) could reduce carbon emissions [13, 14].

Three Grid Primary to Final energy ratio scenarios are derived on this tab and are labeled as: a) AEO RC, b) Nuc & Ren HR=1, and c) Fossil Only.

AEO RC

This scenario is derived by dividing the AEO's total electric power primary energy by the total delivered electricity to all energy consuming sectors of the U.S. economy. This includes the U.S. electric grid aggregate transmission and distribution losses. It also includes the low efficiency factors for renewable electricity (2.7 to 1) and nuclear electricity (3 to 1). The Grid Primary to Final energy ratio for this scenario starts at 3.11 in 2010, dropping to 2.91 by 2040.

Nuc & Ren HR=1

This scenario is derived by assuming that primary energy inputs to nuclear electricity generation (e.g., nuclear fuels) and renewable electricity generation (e.g., sunlight, wind, water, biomass, etc.) are equal to the output of nuclear and renewable electricity generation. Thus, 1 unit of primary energy input is required to produce 1 unit of renewable or nuclear electricity respectively. This accounting choice reduces the 2010 aggregate U.S. grid generation conversion factor from 3.11 to 2.47 and the 2040 factor from 2.91 to 2.20.

Fossil Only

This scenario is derived by dividing the total fossil fuel inputs to the electric grid by the total delivered electric to all energy consuming sectors of the U.S. economy. This scenario is not recommended for analysis because it neglects any renewable or nuclear in a particular grid mix. This scenario is only provided as a reference.

Other Grid Assumptions

There is an implied assumption that electricity impacts affect the U.S. electricity grid exclusively. Therefore, on-site generation such as combined heat and power (CHP) or solar photovoltaic (PV) is not affected by electricity impacts unless the analyst directly models on-site generation impacts. If a scenario is intended to impact primary or secondary energy associated with on-site electricity generation, then the analyst should include these impacts as affecting the appropriate MECS end-use (e.g., Indirect Uses-Boiler Fuel, Conventional Boiler Use, CHP and/or Cogeneration Process).

CO_2 Factors Tab

The CO_2 Factors tab contains the CO_2 emissions factors used to convert energy impacts into CO_2 emissions impacts. With the exception of electricity generation, CO_2 factors provided by EIA remain constant over the forecasted time period. For electricity, CO_2 factors are derived from the AEO data by dividing total electric power CO_2 emissions by the total delivered electricity to all sectors.

Underlying Datasets

MECS 2010

MECS is a quadrennial facility-level survey in which industrial actors submit detailed information on where their energy comes from (fuel source) and where it goes (end-use). The most recent MECS data used in the tool is for 2010. Data in MECS is aggregated by industry type according to the North American Industry Classification System (NAICS) codes. Within the NAICS and MECS, the code increasing levels of disaggregation as the number of code digits increase. NAICS codes are first organized by sector, with any code beginning with 31, 32, or 33 belonging to manufacturing. These sectors are then disaggregated into sub-sectors (e.g., 311 for food manufacturing; 336 for transportation equipment manufacturing), and into sub-sub-sectors (e.g., 311211 for flour milling; 33612 for heavy duty truck manufacturing). For each sector/industry code, energy consumption is given for six energy sources: electricity, natural gas, petroleum, coal, purchased steam, and byproducts and biomass. Then, use of each energy source is separated into various end-use processes such as lighting, boilers, and motors. For more information on NAICS classifications, visit https://www.census.gov/eos/www/naics/, and for more information about MECS data, visit http://www.eia.gov/consumption/manufacturing/.

Modified MECS data used in the tool

MECS 2010 end-use data was modified for use within the tool by replacing non-numeric values in the MECS data tables with numeric values approximated from simple arithmetic functions and previous year MECS reports. This procedure was described in an LBNL report (LBNL # 5993E) titled “United States Industrial Sector Energy End Use: Trends and Observations of MECS Data”.

Energy end-use tables are created for use in the tool and provide percentage allocations of end-use energy consumption within the manufacturing sector. Percentage allocations are used to disaggregate AEO industrial energy consumption by sector, energy source, and end-use. The MECS energy end-use percentage allocation tables used in the tool are for: electricity, petroleum (which combines residual fuel oil, distillate fuel oil and diesel fuels, and liquefied petroleum gas & natural gas liquids MECS data), natural gas (NG), and coal (excluding coal coke and breeze). MECS energy end-use percentage allocation tables for purchased steam, and biomass and byproducts have not been created due to the large amount of non-numeric values for these two energy sources in the MECS data. However, two additional end-use percentage allocation tables (“Total Fuels (NG, Petroleum, Coal)”, and “All Non-Electricity”) are used in the tool to disaggregate total fuels (natural gas, petroleum, and coal) to end-uses, as well as all non-electricity to end-uses. When selecting between these two energy resources in the Scenario Input tab, the “Total Fuels (NG, Petroleum, Coal)” maps to the base year AEO’s sum of these energy resources, while the “All Non-Electricity” maps to the base year AEO’s sum of all energy minus electricity (which includes purchased steam, and biomass and byproducts).

Each MECS sub-sector is mapped to AEO tables that report the energy consumption for the aggregated industrial sector tables. The mapping of the MECS sub-sectors to their respective AEO tables is also provided in *Appendix A – Manufacturing Energy Consumption Survey Sub-Sectors* of this users guide, along with a description of the AEO industrial sector tables.

AEO 2015 Reference Case

AEO projects energy supply and use across the entire U.S. economy. AEO 2015 is the most recent AEO and provides projections in one year increments between 2010 and 2040. The AEO 2015 Reference Case (AEO2015 RC) is the underlying forecast dataset in the tool and the dataset is extended out to 2050 by assuming that year 2040 data remains constant between 2040 and 2050, for simplicity. Although AEO provides detail projections of energy supplies and electricity generation, the tool focuses on manufacturing and end-use energy consumption. Therefore, the AEO data is categorized and accessed according to four energy-consuming sectors: industrial, residential, commercial, and transportation. AEO provides an extensive list of metrics respective of these four sectors ranging from economic output in the industrial sector, to housing units and floor space in the residential and commercial sectors respectively, to transportation modes (e.g., vehicles, freight, and air travel) for transportation. For the purposes of LIGHTEn-UP analysis, three types of AEO projection data are of particular use: (1) base year energy consumption for individual sectors and end-uses, (2) consumption forecast growth drivers such as economic output, buildings and floor space, and miles travelled; (3) prices for various energy sources. For more information on AEO data, visit www.eia.gov/forecasts/aeo.

Modified AEO 2015 RC data used in the tool

The Annual Energy Outlook 2015 Reference Case scenario is used extensively throughout the tool. The version of the dataset contained in the tool has not been altered except for the following:

- The AEO 2015 scenario provides projections from 2010 to 2040. The tool provides scenario forecasts out to 2050. For simplicity and to be conservative in approach, in the current version of the tool AEO 2040 values are copied out to 2050 and therefore remain constant between 2040 and 2050.
- Additional columns are added to the end of the dataset (after the year 2050 data) to enable lookup table functions and AEO table variable labels that include the variable's units.

In addition, AEO data are used to calculate the conversion factor used to convert final electricity into primary energy in the *Grid Factors Tab* section described above.

Visual Basic Macros

Five Visual Basic Macros are provided in the LIGHTEnUP tool. Some macro scopes are critical for calculations performed by the tool, while others help automate tool maintenance. Each of the macros is listed in Table 11.

Table 11 – Tool Macros

Macro Name ***(purpose)***	**Brief Description**
DeploymentRate *(Critical - Function)*	Returns a deployment rate percentage. Currently only uses a linear adoption equation.
ExtractListFromTables *(Maintenance)*	Extracts a list of unique values from a table where values are listed for multiple rows. Primarily designed to work with EIA AEO tables.
Interpolate2 *(Critical - Function)*	Find the location of the target value in the cumulative curve and returns the interpolated value for the resultArray. Returns lower value if target is below the first curve entry; Returns last point in curve if target exceeds last entries.
SheetNamesHyperlink *(Maintenance)*	Populates a table containing all of the workbook tab names and adds a hyperlink to the tab.
UpdateChartSourceData *(Critical)*	Updates a chart located on "Output(Chart)" tab by: A) modifying the source data from an Excel variable name "ChartSourceData"; and B) adds a new series to the end that is the "total" row from an Excel table.

All of the macros are available to the user and can be seen and edited. The source code for each variable is provided in *Appendix D – Excel Visual Basic Macro Code*.

Assumptions, Weaknesses, and Next Steps

Assumptions

The tool is designed to perform prospective analysis of energy impacts in the U.S. economy predicated on current U.S. DOE datasets. Thus, there is an implicit assumption that the underlying datasets are accurate. For manufacturing industry data, the tool uses MECS data, which contains a certain degree of uncertainty because it is a survey and therefore represents self-reported data. This dataset also had to be modified from its original form, which included instances where the survey table's non-numeric values indicate omitted results, or where results are not statistically significant. These designations had to be overridden and converted into useable numerical entries in order to make the data operational in the excel tool. The tool also assumes accuracy in the AEO data and forecast, which is generated using the National Energy Modeling System (NEMS). Although the base year used in the tool (2011) reflects historic data, NEMS forecasts reflect assumptions related to energy markets including economic growth, cost-effective technology adoptions, energy consumption patterns, primary fuel production, and emissions. Then the tool uses AEO forecast data (e.g., forecast growth drivers, energy prices, etc.) uncertainty in these datasets are embedded in the LIGHTEn-UP tool's calculations. NEMS assumptions can be found at: http://www.eia.gov/forecasts/aeo/assumptions/

Another important assumption in the tool appears in the creation of scenario forecasts. The tool aims to observe the effects of implementing a given technology in the economy. By nature, AEO projections represent current legislation and environmental regulations across all modules, with many modules containing endogenous assumptions for expected technological changes. To avoid double-counting technology adoptions, the LIGHTEn-UP tool projects future consumption by scaling current consumption by selected AEO's forecast growth drivers (e.g., industrial and manufacturing value of shipments, housing stocks, commercial square footage, vehicles sales, etc.). However, these drivers are not necessarily independent of technology adoptions because they can be derived endogenously in NEMS to reflect cost-effective technology adoption assumptions. Therefore, some technology adoption assumptions will be embedded in the AEO-based forecast growth drivers and energy prices. Using these drivers for the tool's scenario forecasts, instead of AEO energy consumption forecasts, is designed to minimize double-counting technology adoptions. At this stage of the tool development, no attempt has been made to seek NEMS results without embedded technology adoptions in the growth drivers, nor has any attempt been made to quantify the degree of potential double counting inherent in using AEO growth drivers. The tool is designed this way to help the user quickly derive scenarios. This does not exclude users from creating their own forecast growth drivers.

Weaknesses

Analysis goals and necessary limitations

A potential weakness of the tool is a result of the overall analysis goals: to be robust, predicated on existing publically available datasets; yet simple to use and provide transparent calculations. The tool is not an equilibrium model, as it does not attempt to solve for market equilibriums across the economy in response to the developed scenario. Therefore, the tool is not a consequential life cycle analysis tool. Similarly, it does not utilize an optimization framework, as it does not attempt to optimize technology or resource allocations to satisfy goals and constraints. This ultimately means that the tool assumes the changes made due to implementation of a given scenario only alter the factors directly modeled by the user. For example, a scenario forecasting the replacement of steel vehicle components with aluminum or titanium will not consider the effects of this displaced steel re-entering the steel market unless explicitly modeled by the user. The tool allows the user to estimate and calculate an infinite number of impacts for a given scenario, but by design, the tool itself will only reflect what the user enters. This is designed to transparently support and document scenarios focused on a technology of interest, and it does not alter any factors outside the explicitly entered technological changes.

The tool utilizes existing datasets, and therefore areas of the economy that are not specifically identified in the dataset are not accessible to the user when developing scenarios. Examples of such areas observed during the development of the tool including mining specific metals or coal, water supply and treatment (both municipal and inside industries), and regional specificity. Similarly, the tool does not have a pre-set method for developing scenarios that explore new manufacturing sub-sectors, or new energy end-uses. However, if such a scenario is undertaken, the user could represent new manufacturing sub-sectors and or new energy end-uses through estimating impacts relative to sub-sectors and or energy end-uses that are in the datasets. As a hypothetical example, energy savings from technologies that improve industrial waste water treatment efficiency can be input to the tool relative to total industrial energy consumption even though there is not an industrial waste water treatment energy end-use in the tool.

The tool is focused on energy consumption, energy expenditures, and carbon dioxide emissions. It does not currently forecast non-energy impacts (e.g., labor and capital expenditures), pollutants other than carbon dioxide, or economic or market effects. Moreover, greenhouse gases include carbon dioxide, methane, perfluorocarbons, HFCs, SF6, etc. The tool accounts for carbon dioxide emissions which represent the majority of GHG emissions in the US (about 80%). The carbon dioxide emissions that are fuel related are calculated by the tool, however, the tool does not attempt to calculate the percentage of greenhouse gas emissions which are process related such as carbon dioxide emissions from the calcination process to make cement.

Boundary limitations

The tool is limited to the U.S. economy, with results only showing impacts on U.S. energy consumption and emissions. Therefore, results may underestimate impacts of technologies that have a global affect, such as those involved in manufacturing of products that have international markets. Similarly, the manufacturing embodied energy of imported products does not appear in the tool's framework. Therefore, scenarios are best when focused on U.S. domestic manufacturing of products utilized within the U.S.

Electric Grid

The Grid Primary to Final Energy Ratio is necessary to convert end-use electricity impacts to primary energy accounting and their associated greenhouse gas emissions. The primary energy values represent the energy content of the fuels input to the power plant. From a life cycle perspective, this allows scenarios to compare the net effect of impacts involving fuel switching. An example of this is the increasing use of electricity in the transportation sector as electric vehicles displace internal combustion engines (ICEs). As an example, comparing the end-use energy requirements for ICEs versus electric vehicles would account for the thermodynamic losses associated with ICEs, but exclude the thermodynamic losses associated with electricity generation. A life cycle assessment methodology allows the user to develop scenarios that compare the primary energy between technologies that utilize electricity and technologies that utilize fuels. In life cycle assessment methodologies, the upstream energy to extract, process and transport fuels to electric power plants is added to the combustion energy to determine the total primary energy to deliver electricity to the end user. Although the AEO dataset embedded in the tool does include these upstream emissions (e.g., in the mining, and transportation sectors), to reduce complexity of the model, the tool does not attempt to add these additional upstream fuel cycle energy and emissions to electricity or fossil fuels delivered to end-uses.

The tool uses a U.S. average electric grid primary energy resources mix for converting end-use electricity to primary energy. There is significant regional variation in electric grid primary energy resources mixes. The tool's current version is not programmed to allow the user to select regional electric grid mixes. This weakness will be addressed in future revisions of the tool.

Scenario development flexibility

The tool does not automatically or inherently check user inputs. The tool will calculate what the user selects and enters into the Scenario Input tab, but the tool has no inherent method to warn the user of inputs that are unrealistic or impossible. For example, the tool will allow the user to develop a scenario where all light-duty vehicles are replaced with rail transportation mode even though that is an unrealistic scenario. The user should also be cautious when developing scenarios where technologies, or impacts, are not additive. For example, if a scenario is meant to anticipate two technologies that compete with each other for the same benefit space, then the user must carefully construct scenarios where impacts are not over estimated. The main implication of this is that users must carefully review inputs and check if results are logical.

However, many of these weaknesses are intentionally present to reflect the tool's development goals presented in the *The LIGHTEnUP Tool Overview* section at the beginning of this user's guide. Developing a tool that is substantive, resilient, transparent, and intuitive to use requires a dedication to reducing complexity. Addressing these weaknesses is possible but could require increasing the complexity of the tool with tradeoffs that compromise the development goals.

Next Steps

The LIGHTEnUP tool is in continual evolution and planned next steps are to enhance the core method functionality to help users develop scenarios. This includes developing non-linear technology deployment options, infrastructure stock functionality, and potentially adding economy-wide input/output tables, and regional electric grid mixes. However, developing intuitive procedures for analysts is a high priority that will be sustained throughout the LIGHTEnUP tool's evolution.

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Case Study Examples

Four case study examples are provided to demonstrate several scenario development methods. Table CS 1 provides an overview of the case studies and how they illustrate various approaches to scenario development within the tool.

Table CS 1 – Case Study Example Table

Case Study	Description	Scenario Development Method(Notes)				
		Type-I1	Type-I2	Type-E	Alternate Calculation	Calculation Scratch Pad
1	Replace all U.S. building lighting with LEDs	X				X
2A	Light-Duty Vehicle Light-Weighting – External Calculations			X	X	
2B	Light-Duty Vehicle Light-Weighting – External Calculations		X		X	X
3	Ultra-high molecular weight polyethylene (UHMW-PE) (instead of titanium) in seawater heat exchangers for U.S. LNG exports (with Stock Accounting)		X		X	X

Notes:
Type-I1 – Internal & uses the *Technical Adoption Potential %* and *Relative Energy Impact % method*
Type-I2 – Internal & uses the Alternate Calculation columns
Type-E – External; external calculations with results pasted in the Alternate Calculation columns
Alternate Calculations – bypasses Internal Type A method
Calculation Scratch Pad – columns containing variables used in calculating scenario inputs

These four case study examples are provided to demonstrate ways that scenarios can be developed with the LIGHTEnUP Tool. Case Study Example 1 demonstrates a scenario developed using the core architecture of the tool. For this example, the Technical Adoption Potential % and Relative Energy Impact % key inputs to the tool are estimated from variables that have been added to the Calculation Scratch Pad columns. The LIGHTEnUP Tool was designed for users to develop scenarios based on this method.

The second case study (2A) demonstrates an alternate scenario development method where the calculations are completely done in an external spreadsheet and the results are pasted into the Alternate Calculation columns. However, this method limits the flexibility of the scenario because the variables used in the scenario are not located within the tool itself. The user can add "external" spreadsheet tabs to the LIGHTEnUP tool and link the two together through excel formulas. Case study 2B uses the exact same variables as 1A with the variables located in the Calculation Scratch Pad columns rather than an external spreadsheet. Several intermediate rows are used to first extract data from the AEO2015RC dataset, and then perform calculations necessary for forecast rows. These calculations are programmed into the Alternate Calculation columns.

The third scenario is derived similarly to case study 2B – data are extracted from the

AEO2015RC dataset and intermediate rows are used to derive forecast rows. However, this scenario compares to material options to each other and demonstrates an infrastructure stock accounting method to reflect separate operational life-times for each of the material options.

Case Study Example 1 – Replace all U.S. building lighting with LEDs

Case study hypothetical question: what would be the energy impact if all U.S. building lights were converted to LEDs by 2030?

The analysis tool was used to estimate the energy implications of shifting U.S. lightbulb manufacturing away from currently produced technologies to LED lights, at a rate that supplies all U.S. building lighting demand in 20 years. This scenario represents an estimate of the full technical potential for LED lighting in buildings relative to current lighting technologies. Furthermore, this scenario assumes that all future LED manufacturing takes place within the U.S. It should be noted that this scenario is illustrative hypothetical scenario because it does not take into account competing lighting technologies. Similarly, it does not take into account imported LEDs. However, this case study scenario demonstrates the direct manufacturing and light-bulb transportation formulation.

Where will the energy impacts take place?

Areas directly impacted by this case study are summarized in Table CS 2. These impacts each become a line (i.e., an impact) in the "Scenario Inputs" tab of the tool. Some impacts have two lines in the tool as impacts on fuels and electricity are calculated separately. Table CS 2 also provides a brief description of the calculation logic used to develop the scenario. Estimated building lighting energy determines the necessary LED manufacturing scale.

Table CS 2 – Areas directly impacted by building lighting replacement

<table>
<tr><th>Activity</th><th>Sector</th><th>Phase</th><th>Impact Description</th><th>Calculation Logic</th></tr>
<tr><td rowspan="3">Building lighting energy use</td><td>Residential</td><td rowspan="3">Use</td><td rowspan="3">Reduced energy consumption for lighting</td><td rowspan="3">Estimate lighting energy.
Then LED demand.</td></tr>
<tr><td>Commercial</td></tr>
<tr><td>Industrial</td></tr>
<tr><td>Decrease traditional light-bulb production</td><td rowspan="2">Industrial</td><td rowspan="2">Manufacturing</td><td>Elimination of energy used for NAICS 335110</td><td>Estimate NAICS 335110 decreased energy.</td></tr>
<tr><td>Increasing production of LEDs</td><td>Increase in semiconductor manufacturing in NAICS 334413</td><td>Estimate NAICS 334413 increased energy.</td></tr>
<tr><td>LED Transportation</td><td>Transportation</td><td>Transportation</td><td>Increase in number and weight of LEDs being shipped</td><td>Assuming average U.S. shipping distances.</td></tr>
</table>

Scenario Inputs – Impact "where"

Starting a new scenario requires the user to define the scenario and its impacts on the Scenario Input tab. Figure CS 1, and Figure CS 2 show the inputs for the impact rows needed to calculate the scenario described above. As shown there is one impact in the residential, commercial, and transportation sectors, and five impacts in the industrial sector. Each of the industrial impacts uses MECS data, with industry selection in coordination with the NAICS codes mentioned above.

Figure CS 1– impact rows impact location inputs

Description	Row Function	Sector	IF Sector is Industrial, Select MECS End-Use or AEO Table?	IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table	IF using MECS, then Select Energy Resource Otherwise Select AEO Table Variable	IF Sector is Industrial & MECS-Based, Select Energy End-Use Else leave blank
Case Study Example 1: Replace all building lighting with LEDs						
LEDs for lighting in all Residential buildings	Forecast	Residential		Residential (AEOTbl 4)	Residential : Electricity : Lighting [quad Btu]	
LEDs for lighting in all Commercial buildings	Forecast	Commercia l		Commercial (AEOTbl 5)	Commercial : Purchased Electricity : Lighting [quad Btu]	
LEDs for lighting in all Industrial buildings	Forecast	Industrial	MECS	Total Manufacturing	Electricity	Facility Lighting
Electric lamp bulb and part Sector Fuel Impact (NAICS 335110)	Forecast	Industrial	MECS	ELEC. EQUIP., APPLIANCES, COMPONENTS	All Non-Electricity	TOTAL FUEL CONSUMPTION
Electric lamp bulb and part Sector Elec Impact (NAICS 335110)	Forecast	Industrial	MECS	ELEC. EQUIP., APPLIANCES, COMPONENTS	Electricity	TOTAL FUEL CONSUMPTION
Semiconductor Sector Fuel Impact (NAICS 334413)	Forecast	Industrial	MECS	Semiconductors and Related Devices	All Non-Electricity	TOTAL FUEL CONSUMPTION
Semiconductor Sector Elec Impact (NAICS 334413)	Forecast	Industrial	MECS	Semiconductors and Related Devices	Electricity	TOTAL FUEL CONSUMPTION
Transportation for building light bulbs	Forecast	Residential		Residential (AEOTbl 4)	Residential : Electricity : Lighting [quad Btu]	

As show in Figure CS 2, sector key indicators from AEO are used for each impact's CO_2 accounting, growth driver, and energy prices.

Figure CS 2 – Emissions, Growth Driver, and Energy Price Inputs

Description	Energy Resource for CO2 accountin g	Forecast Growth Driver (AEO Table)	Forecast Growth Driver (AEO Table Variable)	Energy Prices
Case Study Example 1: Replace all building lighting with LEDs				
LEDs for lighting in all Residential buildings	Final Electricity	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Residential : Electricity [2013 $/mill Btu]
LEDs for lighting in all Commercial buildings	Final Electricity	Commercial (AEOTbl 5)	Commercial : Total Floorspace : Total [bill sq ft]	Energy Prices : Commercial : Electricity [2013 $/mill Btu]
LEDs for lighting in all Industrial buildings	Final Electricity	Industrial (AEOTbl 6)	Industrial : Value of Shipments : Manufacturing [bill 2009 $]	Energy Prices : Industrial : Electricity [2013 $/mill Btu]
Electric lamp bulb and part Sector Fuel Impact (NAICS 335110)	NG	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]
Electric lamp bulb and part Sector Elec Impact (NAICS 335110)	Final Electricity	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Industrial : Electricity [2013 $/mill Btu]
Semiconductor Sector Fuel Impact (NAICS 334413)	NG	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]
Semiconductor Sector Elec Impact (NAICS 334413)	Final Electricity	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Industrial : Electricity [2013 $/mill Btu]
Transportation for building light bulbs	Gasoline	Residential (AEOTbl 4)	Residential : Key Indicators : Households : Total [millions]	Energy Prices : Transportation : Motor Gasoline [2013 $/mill Btu]

What will the energy impacts be?

This case study uses the tool's "Technical Adoption Potential %" and "Relative Energy Impact %" inputs to directly calculate the magnitude impacts from AEO and MECS data. The values that are entered in these inputs are calculated using a set of variable assumptions described in Table CS 3 (with their references listed in Table CS 4). The variable assumptions are input to the tool in the Calculation Scratch Pad columns.

Building operational energy savings from improved lighting efficiency of LED is applied to all residential, commercial, and industrial building stock. The relative energy savings estimated for each sector is based on 2010 average lighting efficiencies of 19, 70, 77 lm/W for residential, commercial, and industrial building types, respectively, and an assumed near-future lighting efficiency of 138 lm/W for LEDs. The 2010 penetration of LEDs in overall building stock is considered negligible at <1%.

Direct manufacturing sector energy impacts consist of: A) a reduction in conventional light bulb manufacturing, and B) an increase in LED manufacturing. As stated in the introduction, this case study assumes that all LED manufacturing is located within the U.S. Conventional light bulb manufacturing takes place within "electrical equipment, appliance, and components" (NAICS 335), while LEDs manufacturing would take place in "Semiconductors and Related

Devices" (NAICS 334413). The reduction in conventional light-bulb manufacturing is calculated by estimating the portion of this sector dedicated to electric lamp bulb and parts (NAICS 335110), specifically for building applications. Since MECS data does not provide disaggregated energy use beyond the 335 NAICS code, energy use in NAICS 335110 is estimated by scaling U.S. census data for values of shipments dedicated to building lamp bulbs and parts. This assumes energy use is proportional to value of shipments which is highly uncertain. Although this assumption has a high level of uncertainty, applying this assumption is the best approach possible given the lack of direct energy use data. NAICS 334413 is provided in the MECS dataset and can be used directly.

Table CS 3 – Variable Assumptions (Calculation Scratch Pad)

Variable	Current	LED Future	Units
Avg. residential lighting efficacy	19 [1]	138 [2]	lm/W
Residential LED penetration	0 % [1]	70 %	percent
Avg. commercial lighting efficacy	70 [1]	138 [2]	lm/W
Commercial LED penetration	2 % [1]	98 %	percent
Avg. industrial lighting efficacy	77 [1]	138 [2]	lm/W
Industrial LED penetration	0 %	100 %	percent
NAICS 335 shipments	$ 129 [5]		$ Billion
NAICS 33511 building shipments	$ 1.54 [4,5]		$ Billion
2002 U.S. commercial freight shipments	$ 10,500 [6]		$ Billion
NAICS 33511 total shipping mass (2010)	8600 [1,2,5]		MT
Shipping mass for 0.5 billion LEDs	96000 [2]		MT
Energy to produce 0.5 billion LEDs	102 [2]		TBTU

Table CS 4 – Variable Assumption References

1	2010 U.S. Lighting Market Characterization http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf
2	Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_LED_Lifecycle_Report.pdf
3	Hendrickson, 2010. Reducing Environmental Burdens of Solid-State Lighting through End-of-Life Design
4	IBISWorld Industry Report Listing, United States http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=780
5	United States Census Bureau Industry Statistics Sample http://www.census.gov/econ/industry/hierarchy/i3351.htm
6	BTS http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/freight_shipments_in_america/html/figure_01.html

Scenario Inputs – Impact "what" and "when"

Impact magnitudes are entered into the tool in the form of a Technical Adoption Potential % and Relative Energy Impact % as shown in Figure CS 3. Calculations for these inputs are done in the Calculation Scratch Pad section of the tool, using the assumptions described in Table CS 3.

Figure CS 3 – impact amount and time inputs

Description	Technical Adoption Potential %	Relative Energy Impact %	Start Year	End Year
Case Study Example 1: Replace all building lighting with LEDs				
LEDs for lighting in all Residential buildings	70%	-11%	2010	2030
LEDs for lighting in all Commercial buildings	98%	-49%	2010	2030
LEDs for lighting in all Industrial buildings	100%	-44%	2010	2030
Electric lamp bulb and part Sector Fuel Impact (NAICS 335110)	100%	-1.2%	2010	2030
Electric lamp bulb and part Sector Elec Impact (NAICS 335110)	100%	-1.2%	2010	2030
Semiconductor Sector Fuel Impact (NAICS 334413)	100%	59.6%	2010	2030
Semiconductor Sector Elec Impact (NAICS 334413)	100%	59.6%	2010	2030
Transportation for building light bulbs	100%	0.15%	2010	2030

Results

With the impact data entered into the tool's inputs, the results can be viewed in the two output tabs. Scenarios and other preferences should be selected in the "Output Table" tab; which also effect the Output Chart. The cumulative effects of each individual impact are shown in the Output Table and annual results are shown in the "Output Chart" tab.

With the graph set to "All Primary (TBtus)", and the "Grid Primary to Final Energy ratio" set to "Nuc & Ren HR=1", results for this case study example scenario are shown in Figure CS 4 and Table CS 5.

Figure CS 4 – Output Chart

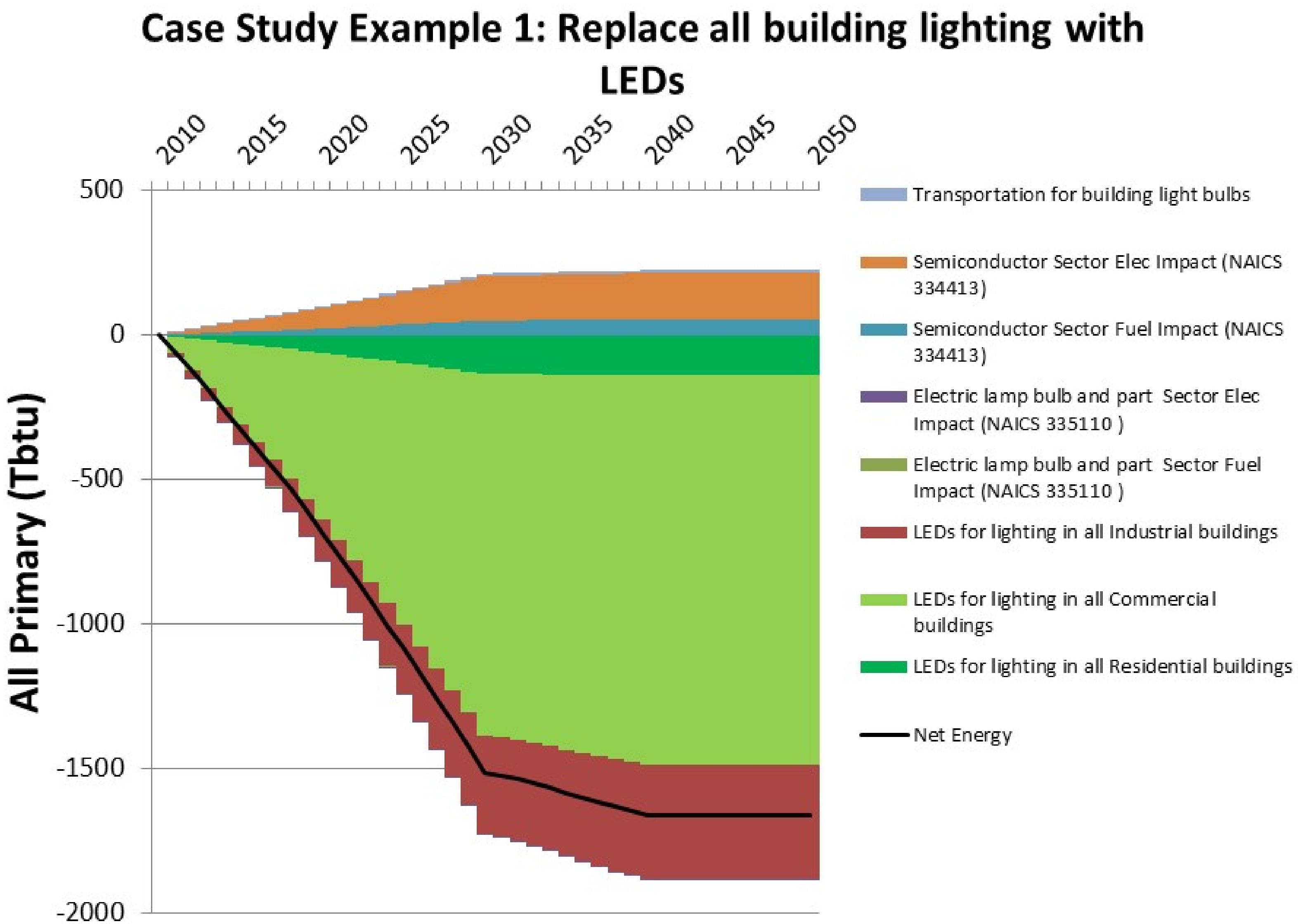

Table CS 5 – Output Table

Measure: Case Study Example 1: Replace all building lighting with LEDs for years 2010 through 2050									
	Energy			Energy Expenditures (Mil 2013 $)			CO_2 emissions (Mill Mt CO_2)		
	Fuels (TBtu)	Electricity (TWh)	Primary (TBtu)	Fuels	Electricity	Total	Fuels	Electricity	Total
BAU Industrial	795,945	46,654	1,344,120	$ 9,362,765	$ 3,636,562	$ 12,999,327	44,462	24,113	68,574
BAU Commercial	156,094	63,663	802,446	$ 2,143,422	$ 6,949,240	$ 9,092,662	9,474	32,149	41,622
BAU Residential	228,075	66,124	848,070	$ 3,094,595	$ 8,328,109	$ 11,422,703	11,637	31,735	43,372
BAU Transportation	1,088,652	523	1,093,917	$ 28,011,908	$ 60,105	$ 28,072,012	71,933	267	72,201
BAU Total	*2,268,766*	*176,964*	*4,088,554*	*$ 42,612,689*	*$ 18,974,016*	$ 61,586,705	*137,505*	*88,264*	225,769
LEDs for lighting in all Residential buildings	0	-538	-4,117	$ (75,012)	$ -	$ (75,012)	(298)	-	(298)
LEDs for lighting in all Commercial buildings	0	-5,106	-39,022	$ (580,498)	$ -	$ (580,498)	(2,822)	-	(2,822)
LEDs for lighting in all Industrial buildings	0	-1,421	-10,853	$ (113,993)	$ -	$ (113,993)	(785)	-	(785)
Electric lamp bulb and part Sector Fuel Impact (NAIC	-14	0	-14	$ (108)	$ -	$ (108)	(1)	-	(1)
Electric lamp bulb and part Sector Elec Impact (NAIC	0	-4	-33	$ (343)	$ -	$ (343)	(2)	-	(2)
Semiconductor Sector Fuel Impact (NAICS 334413)	1,558	0	1,558	$ 11,952	$ -	$ 11,952	114	-	114
Semiconductor Sector Elec Impact (NAICS 334413)	0	617	4,717	$ 49,297	$ -	$ 49,297	341	-	341
Transportation for building light bulbs	276	0	276	$ 7,946	$ -	$ 7,946	15	-	15
Industrial Measure Totals	*1,544*	*-809*	*-4,624*	*$ (53,195)*	*$ -*	$ (53,195)	*(333)*	-	(333)
Commercial Measure Totals	*0*	*-5,106*	*-39,022*	*$ (580,498)*	*$ -*	$ (580,498)	*(2,822)*	-	(2,822)
Residential Measure Totals	*0*	*-538*	*-4,117*	*$ (75,012)*	*$ -*	$ (75,012)	*(298)*	-	(298)
Transportation Measure Totals	*276*	*0*	*276*	*$ 7,946*	*$ -*	$ 7,946	*15*	-	15
Total from all sectors	*1,820*	*-6,453*	*-47,488*	*$ (700,759)*	*$ -*	$ (700,759)	*(3,438)*	-	(3,438)
Economy Wide Total	*2,270,585*	*170,512*	*4,041,067*	*$ 41,911,930*	*$ 18,974,016*	*$ 60,885,946*	*134,067*	*88,264*	*222,331*

Case Study Example 1 Conclusions

This case study provides a scenario that forecasts the direct energy impacts of replacing all U.S. building lighting with LED. This case study assumes that all residential, commercial, and industrial building lighting is replaced by 2030 and that all LEDs are manufactured within the U.S. While conventional light bulb manufacturing energy decreases, LED manufacturing energy increases. LED use reduces lighting energy consumption leading to high energy savings in the use phase. As shown in the outputs, the increase to manufacturing energy use is minimal relative to the use phase savings, particularly for commercial building applications.

Case Study 2 – Light-Duty Vehicle Light-Weighting

Case study hypothetical question: what would be the energy impact of a 5 kg weight reduction in light-duty vehicles (LDVs) within the U.S.?

This case study example answers this question by assuming that 5 kg of high-strength titanium (HST) vehicle parts (Ti6Al4V = TiH2+60Al-40V) displaces 10 kg of steel vehicle parts in future U.S. LDV sales. The use of titanium as a replacement for steel decreases vehicle weight, leading to high energy savings in the use phase, but also impacts industrial sectors in the materials and manufacturing phases due to the change in materials and vehicle part production. For simplicity, this case study does not identify what vehicle part is being light-weighted, nor does it estimate any secondary weight savings from light weighting (e.g., increased aerodynamics that could further reduce vehicle energy consumption).

The case study example demonstrates the two scenario development options presented in the user guide and are labeled as:

- Case Study Example 2A – Externally developed scenario calculations with results manually entered in the Alternate Calculations section of the Scenario Input tab.
- Case Study Example 2B – Internally developed scenario utilizing the tool's datasets and scenario forecasting method, variable assumptions entered in the Calculation Scratch Pad, and internal excel formulas entered in the Alternate Calculations. All user inputs are located in the Scenario Input tab.

Where will the energy impacts take place?

Light-weighted LDVs are the fundamental impact in this case study. Both examples of this case study account for the use-phase energy reductions from LDV use, which necessitates a forecast of producing LDVs that are light-weighted. This forecast then determines the material and manufacturing energy impacts associated with light-weighted LDVs.

Areas directly impacted by this case study (both examples) are summarized in the table below. These five impacts each become a line (i.e., an impact) in the "Scenario Inputs" tab of the tool for both case study examples.

Table CS 6 – Areas directly impacted by light-duty vehicles (LDVs) light-weighting

Activity	Sector	Phase	Impact Description	Calculation Logic
Light-weighting vehicles	Transportation	Use	Light-weighted LDVs	LDV sales forecast (AEO). Light-weighting adoption.
Reduced	Industrial	Material	Steel material embodied	Adoption reduces steel

Activity	Sector	Phase	Impact Description	Calculation Logic
production of steel parts			energy	production
		Manufacturing	Steel part manufacturing	
Increased production of titanium parts	Industrial	Material	HST material embodied energy	Adoption increases titanium production
		Manufacturing	HST part manufacturing	

Both of the case study examples use a common set of assumptions as shown in Table CS 7. These common assumptions are used in an external spreadsheet for Case Study Example 2A. And are inputs in the Calculation Scratch Pad section of the Scenario Input tab for Case Study Example 2B.

Table CS 7 – Common Assumptions

Variable	Units	Steel	HST
Raw Materials			
Final Part Mass	Kg	10	5
"Buy-to-Fly" yield†	Kg/kg	0.72	.9
Raw Material Input	Kg	14	5.2 (TiH2) 0.55 (60Al-40V)
embodied energy factor	MJ/kg	23.1	240 (TiH2) 202 (60Al-40V)
Total Raw Material Embodied Energy	MJ/Vehicle	321	1,358
Manufacturing			
Steel ingot to coil	MJ/kg	6.4	
Steel stamping	MJ/kg	5.1	
Steel assembly	MJ/kg	0.7	
TiH2 cold isostatic pressing	MJ/kg		0.04
TiH2 sintering	MJ/kg		10.3
Total manuf. energy use per vehicle	MJ/Vehicle	167	56
Vehicles (use-phase)			
Mass reduction induced change in fuel consumption	liters/(100km*100kg)	-0.38	
Average vehicle life-span	years	13	
Average vehicle miles traveled (VMT)	miles/year	12,000	
New U.S. LDV Sales	AEO 2015 RC††	Variable	
Notes: † "Buy-to-fly" ratio equals the mass of the final part divided by the mass of initial raw materials †† Annual Energy Outlook 2015 Reference Case: Light-Duty Vehicle Sales (AEOTbl 48): Light-Duty Vehicle Sales : Total Vehicles Sales [thousands]			

The assumptions that differentiate the two case study examples are the light-weighting adoption rate, and the LDV vehicle miles traveled.

Case Study Example 2A – External Calculations

Case Study Example 2A is an externally developed scenario calculations with results manually entered in the Alternate Calculations section of the Scenario Input tab.

Vehicle energy impacts

External calculations include the total materials and manufacturing energy use per vehicle (using the variables presented in the table above), an anticipated LDV light-weighting adoption forecast, and the cumulative energy savings associated with the LDV mass reductions. The anticipated LDV light-weighting adoption forecast assumes an S-shaped adoption curve beginning in the year 2018 (at 2% adoption in new vehicles sold), and reaching full adoption (100% adoption in new vehicles sold) by 2035. Vehicles are assumed to travel 250,000 km over a 13-year lifetime, with a total lifetime energy savings for the light-weighted vehicles of 1,900 MJ/vehicle. External calculations forecast the annual total materials and manufacturing energy consumption (for a reduction in steel part energy consumption and an increase in T1H2 energy consumption) and the total vehicle light-duty fleet (LDV) use-phase energy savings.

Scenario Inputs

Starting a new scenario requires the user to define the scenario and its impacts on the User Input tab. Externally developed scenarios require the user to select the Row Function, Sector, Energy Resource for CO_2 accounting, and Energy Price. These are shown by the screenshot in Figure CS 5.

Figure CS 5 – impact rows impact location inputs

Description	Row Function	Sector	Energy Resource for CO2 accounting	Energy Prices
Case Study Example 2A: 100% of 2035 LDV VMTs Light-weighted by 5 kg				
Transportation: Light-Weighted LDVs	Forecast	Transportation	Gasoline	Energy Prices : Transportation : Motor Gasoline [2013 $/mill Btu]
Steel Material Embodied Energy	Forecast	Industrial	NG	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]
Steel Part Manufacturing	Forecast	Industrial	Primary Electricity	Energy Prices : Electric Power : Natural Gas [2013 $/mill Btu]
HST Material Embodied Energy	Forecast	Industrial	NG	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]
HST Part Manufacturing	Forecast	Industrial	Primary Electricity	Energy Prices : Electric Power : Natural Gas [2013 $/mill Btu]

The results of the external calculations are total change in energy consumption, for each of the five impact rows, for each year. To enter these into the LIGHTEn-UP tool, each of the five impact row's "Use Alternate Impact Values?" column cells should be selected as "TRUE" from the dropdown menu, and annual values entered in the "Alt_Year" columns. A screenshot of the impact lines in the tool is shown in Figure CS 6, excerpting impact values for every tenth year.

Figure CS 6 – Energy Impact Values

Description	Use Alternate Impact Values?	Alt_Units	Alt_2020	Alt_2030	Alt_2040	Alt_2050

Description	Use Alternate Impact Values?	Alt_Units	Alt_2020	Alt_2030	Alt_2040	Alt_2050
Case Study Example 2A: 100% of 2035 LDV VMTs Light-weighted by 5 kg						
Transportation: Light-Weighted LDVs	TRUE	TBtu	(0)	(12)	(29)	(31)
Steel Material Embodied Energy	TRUE	TBtu	(0)	(5)	(5)	(5)
Steel Part Manufacturing	TRUE	TBtu	(0)	(2)	(3)	(3)
HST Material Embodied Energy	TRUE	TBtu	2	19	22	22
HST Part Manufacturing	TRUE	TBtu	0	1	1	1

Results

With the impact data entered into the tool's inputs, the results can be viewed in the two output tabs. Scenarios and other preferences should be selected in the "Output Table" tab. The cumulative effects of each individual impact are shown in the Output Table and annual results are shown in the "Output Chart" tab. With the graph set to "All Primary (TBtus)", and the "Grid Primary to Final Energy ratio" set to "Nuc & Ren HR=1", results for this case study example scenario are shown in Figure CS 7 and Table CS 8.

Figure CS 7 – Output Chart

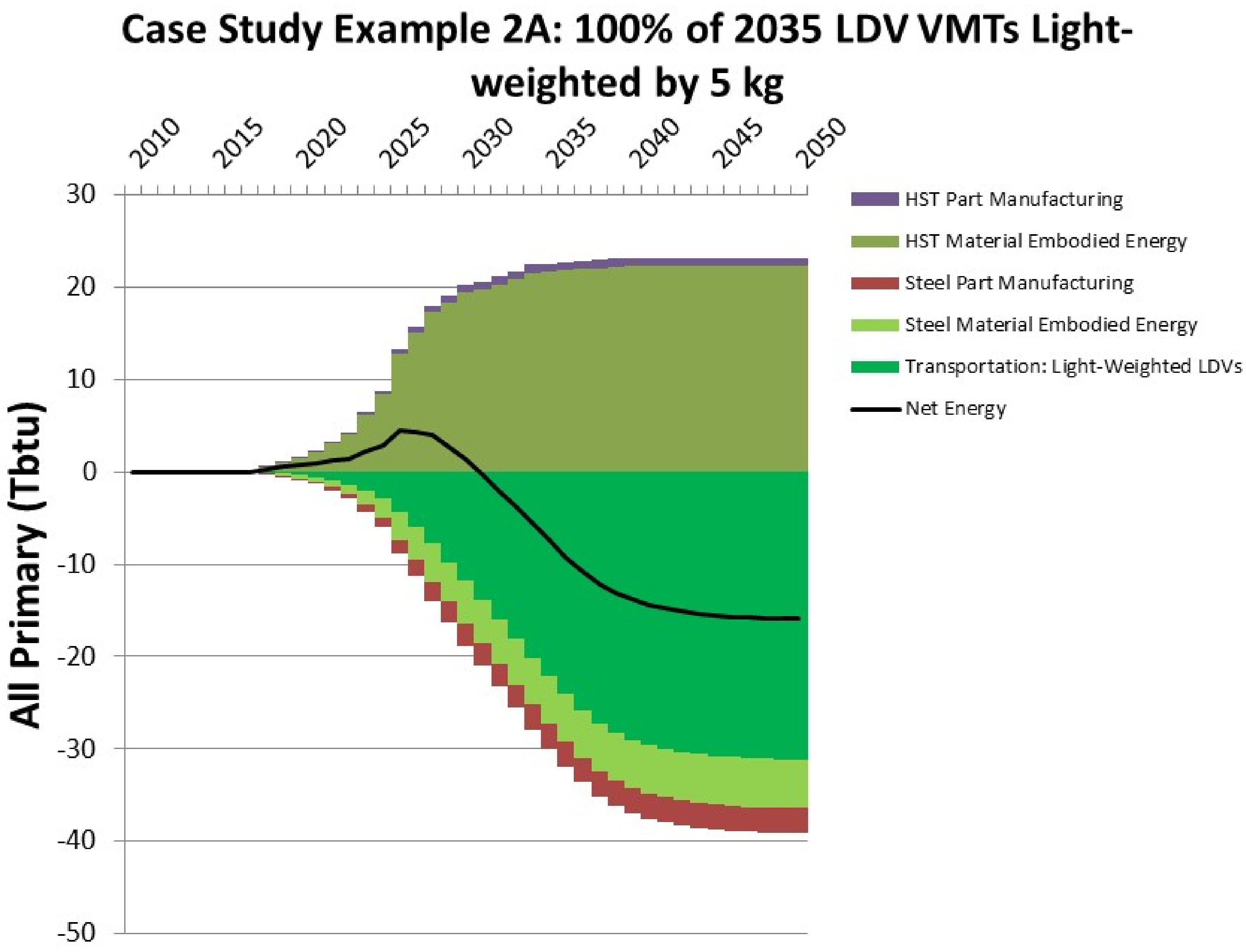

Table CS 8 – Output Table

Measure: Case Study Example 2A: 100% of 2035 LDV VMTs Light-weighted by 5 kg for years 2010 through 2050									
	Energy			Energy Expenditures (Mil 2013 $)			CO_2 emissions (Mill Mt CO_2)		
	Fuels (TBtu)	Electricity (TWh)	Primary (TBtu)	Fuels	Electricity	Total	Fuels	Electricity	Total
BAU Industrial	795,945	46,654	1,344,120	$ 9,362,765	$ 3,636,562	$ 12,999,327	44,462	24,113	68,574
BAU Commercial	156,094	63,663	802,446	$ 2,143,422	$ 6,949,240	$ 9,092,662	9,474	32,149	41,622
BAU Residential	228,075	66,124	848,070	$ 3,094,595	$ 8,328,109	$ 11,422,703	11,637	31,735	43,372
BAU Transportation	1,088,652	523	1,093,917	$ 28,011,908	$ 60,105	$ 28,072,012	71,933	267	72,201
BAU Total	*2,268,766*	*176,964*	*4,088,554*	*$ 42,612,689*	*$ 18,974,016*	$ 61,586,705	*137,505*	*88,264*	225,769
Transportation: Light-Weighted LDVs	-579	0	-579	$ (17,826)	$ -	$ (17,826)	(31)	-	(31)
Steel Material Embodied Energy	-129	0	-129	$ (1,032)	$ -	$ (1,032)	(9)	-	(9)
Steel Part Manufacturing	-67	0	-67	$ (500)	$ -	$ (500)	(4)	-	(4)
HST Material Embodied Energy	547	0	547	$ 4,363	$ -	$ 4,363	40	-	40
HST Part Manufacturing	23	0	23	$ 169	$ -	$ 169	1	-	1
Industrial Measure Totals	*373*	*0*	*373*	*$ 3,000*	*$ -*	$ 3,000	*28*	-	28
Commercial Measure Totals	*0*	*0*	*0*	*$ -*	*$ -*	$ -	-	-	-
Residential Measure Totals	*0*	*0*	*0*	*$ -*	*$ -*	$ -	-	-	-
Transportation Measure Totals	*-579*	*0*	*-579*	*$ (17,826)*	*$ -*	$ (17,826)	*(31)*	-	(31)
Total from all sectors	*-206*	*0*	*-206*	*$ (14,827)*	*$ -*	$ (14,827)	*(3)*	-	(3)
Economy Wide Total	*2,268,560*	*176,964*	*4,088,348*	*$ 42,597,863*	*$ 18,974,016*	*$ 61,571,878*	*137,502*	*88,264*	*225,766*

Case Study Example 2B – Internal Calculations

Case Study Example 2B is an internally developed scenario utilizing the tool's datasets and scenario forecasting method, variable assumptions entered in the Calculation Scratch Pad, and internal excel formulas entered in the Alternate Calculations. All user inputs are located in the Scenario Input tab.

Scenario Inputs

Although new LDV sales forecasts are provided in the AEO dataset within the tool, their energy consumption is not disaggregated from the entire U.S. LDV stock in the AEO dataset. Therefore, a bottom-up approach is used in this example to forecast the energy impacts of light-weighted LDV sales.

This scenario also has the same five impacts presented above. However, this scenario is developed from information extracted from the AEO dataset for new U.S. LDV sales, and inter-related calculations to forecast the materials and manufacturing impacts. This example also utilizes the Alternate Calculation and Calculation Scratch Pad sections in the User Input tab. Results of these calculations are total change in energy consumption, for each of the five impact rows, for each year, which are in the "Alt_Year" columns for each of the five forecast rows. The process for getting to the final results is outlined below.

Intermediate Calculation Row Inputs

The bottom-up approach for this example uses several intermediate calculation rows in the Scenario Input tab. Excel formulas are programmed into the Alternate Calculation section's "Alt_Year" for each of the intermediate calculation rows. The following table provides a description of these rows and the formula calculation programmed into the "Alt_Year" columns.

Table CS 9 –Intermediate Calculation Rows

Intermediate Calculation	Description of Excel Formula Calculations in the Alternate Calculation section's "Alt_Year" columns
LDV Sales	Extracts the new LDV sales forecast from the AEO dataset based on the input selections in the "Where will energy impacts take place?" calls.
Light-Weighted LDV Adoption Rate	Linear light-weighting adoption rate based on input in the "When?" cells.
Light-Weighted LDVs Produced	Calculates the forecasted light-weighted LDVs by multiplying the AEO annual LDV sales by the adoption rate.
Cumulative Light-Weighted LDVs	Sums together the cumulative light-weighted LDVs in the U.S. LDV stock based on a 13-year lifetime of LDVs (13-year lifetime is input in the "Calculation Scratch Pad" cells.
LDV Stock	Extracts the total LDV stock forecast from the AEO dataset based on the input selections in the "Where will energy impacts take place?" cells.
LDV VMTs	Extracts the total LDV VMTs forecast from the AEO dataset based on the input selections in the "Where will energy impacts take place?" cells.
Average VMT/LDV	Calculates the average VMTs per LDV by dividing LDV VMTs by LDV Stock

Intermediate Calculation	Description of Excel Formula Calculations in the Alternate Calculation section's "Alt_Year" columns
Light-Weighted VMTs	Calculates light-weighted VMTs by multiplying Average VMTs by Light-Weighted LDVs Produced.

The following figures are screen shots of the tool's input values for the first three intermediate calculation rows. Figure CS 8 shows that all three rows are given an "Intermediate" function label, and the LDV Sales row is given an AEO Table and AEO Table Variable. By selecting these AEO values, the tool populates the AEO Row and AEO Table Variable values (green columns). This is useful for later functions that will look up and use AEO data based on these values. AEO Table and Table Variable selection is not necessary for the second and third rows. Figure CS 9 shows the input of adoption potential for the second intermediate row. Figure CS 10 shows the resulting values (every tenth year) from these intermediate rows for use in impact calculations.

Figure CS 8 – Intermediate Row Selections

Description	Row Function	IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table	IF using MECS, then Select Energy Resource Otherwise Select AEO Table Variable	AEO Row	AEO Table Variable Data
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life					
LDV Sales	Intermediate	Light-Duty Vehicle Sales (AEOTbl 48)	Light-Duty Vehicle Sales : Total Vehicles Sales [thousands]	2129	12154.2246
Light-Weighted LDV Adoption Rate	Intermediate				
Light-Weighted LDVs Produced	Intermediate				

Figure CS 9 – Intermediate Row Adoption Inputs

Description	Technical Adoption Potential %	Relative Energy Impact %	Start Year	End Year
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life				
LDV Sales				
Light-Weighted LDV Adoption Rate	100%		2017	2035
Light-Weighted LDVs Produced				

Figure CS 10 – Rows 1-3 Annual Values

Description	Alt_2020	Alt_2030	Alt_2040	Alt_2050

Description	Alt_2020	Alt_2030	Alt_2040	Alt_2050
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life				
LDV Sales	16,231	16,720	17,310	17,310
Light-Weighted LDV Adoption Rate	0.22	0.78	1.00	1.00
Light-Weighted LDVs Produced	3,607	13,004	17,310	17,310

The additional five intermediate rows and their associated inputs are shown in Figure CS 11. As with the "LDV Sales" row previously discussed, AEO Table and Table Variables are selected for LDV Stock and LDV VMTs rows. Again, this gives the user the Row and Data numbers (green columns) to use in later functions calling the AEO data. Figure CS 12 shows the resulting values (every tenth year) from these intermediate rows for use in impact calculations.

Figure CS 11 – Additional Intermediate Row Selections

Description	Row Function	IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table	IF using MECS, then Select Energy Resource Otherwise Select AEO Table Variable	AEO Row	AEO Table Variable Data
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life					
Cumulative Light-weighted LDVs	Intermediate				
LDV Stock	Intermediate	Light-Duty Vehicle Stock (AEOTbl 49)	Light-Duty Vehicle Stock : Total Vehicle Stock [millions]	2171	223.87915
LDV VMTs	Intermediate	Light-Duty Vehicle Miles Traveled (AEOTbl 51)	Light-Duty Vehicle Miles Traveled : VMT Equation Components : Total VMT [bill miles]	2226	2550.04761
Average VMT/vehicle year	Intermediate				
Light-Weighted VMTs	Intermediate				

Figure CS 12 – Rows 4-8 Annual Values

Description	Alt_2020	Alt_2030	Alt_2040	Alt_2050
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life				
Cumulative Light-weighted LDVs	9,020	95,322	199,947	224,796
LDV Stock	242	264	277	277
LDV VMTs	2,917	3,287	3,570	3,570
Average VMT/vehicle year	12,034	12,472	12,882	12,882
Light-Weighted VMTs	109	1,189	2,576	2,896

Forecast Calculation Row Inputs

The next set of rows contains forecast rows that show up on the Output Table and Output Graph. These rows are identified as forecast rows by selecting “Forecast” in their “Row Function” column cells. Each of these rows contain excel formulas in the Alternate Calculation section’s “Alt_Year”, as well as the common assumptions variables from Table CS 3 that are input in the “Calculation Scratch Pad” section of the Scenario Input tab. Resulting values for every tenth year are shown in Figure CS 13.

Table CS 10 – Forecast Calculation Rows

Forecast Calculation	Description of Excel Formula Calculations in the Alternate Calculation section’s “Alt_Year” columns
Transportation: Light-Weighted LDVs	Calculates the energy savings associated with the light-weighted LDV VMTs by multiplying the VMTs by the savings factor calculated in the Calculation Scratch Pad section. It assumes all savings are gasoline saving for simplicity.
Steel Material Embodied Energy	Calculates the energy savings from a reduction of steel materials used in vehicle parts.
Steel Part Manufacturing	Calculates the energy savings from a reduction of steel vehicle parts manufacturing.
TiH2 Material Embodied Energy	Calculates the energy consumption associated with titanium materials used in vehicle parts.
TiH2 Part Manufacturing	Calculates the energy consumption associated with titanium vehicle parts manufacturing.

Figure CS 13 – Annual Impact Values

Description	Alt_2020	Alt_2030	Alt_2040	Alt_2050
Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life				
Transportation: Light-Weighted LDVs	(1.3)	(13.8)	(29.9)	(33.6)
Steel Material Embodied Energy	(1.1)	(4.0)	(5.3)	(5.3)
Steel Part Manufacturing	(0.6)	(2.1)	(2.7)	(2.7)
HST Material Embodied Energy	4.6	16.7	22.3	22.3
HST Part Manufacturing	0.2	0.7	0.9	0.9

Results

With the impact data entered into the tool’s inputs, the results can be viewed in the two output tabs. Scenarios and other preferences should be selected in the “Output Table” tab. The cumulative effects of each individual impact are shown in the Output Table and annual results are shown in the “Output Chart” tab. With the graph set to “All Primary (TBtus)”, and the “Grid Primary to Final Energy ratio” set to “Nuc & Ren HR=1”, results for this case study example scenario are shown in Figure CS 14 and Table CS 5.

Figure CS 14 – Output Chart

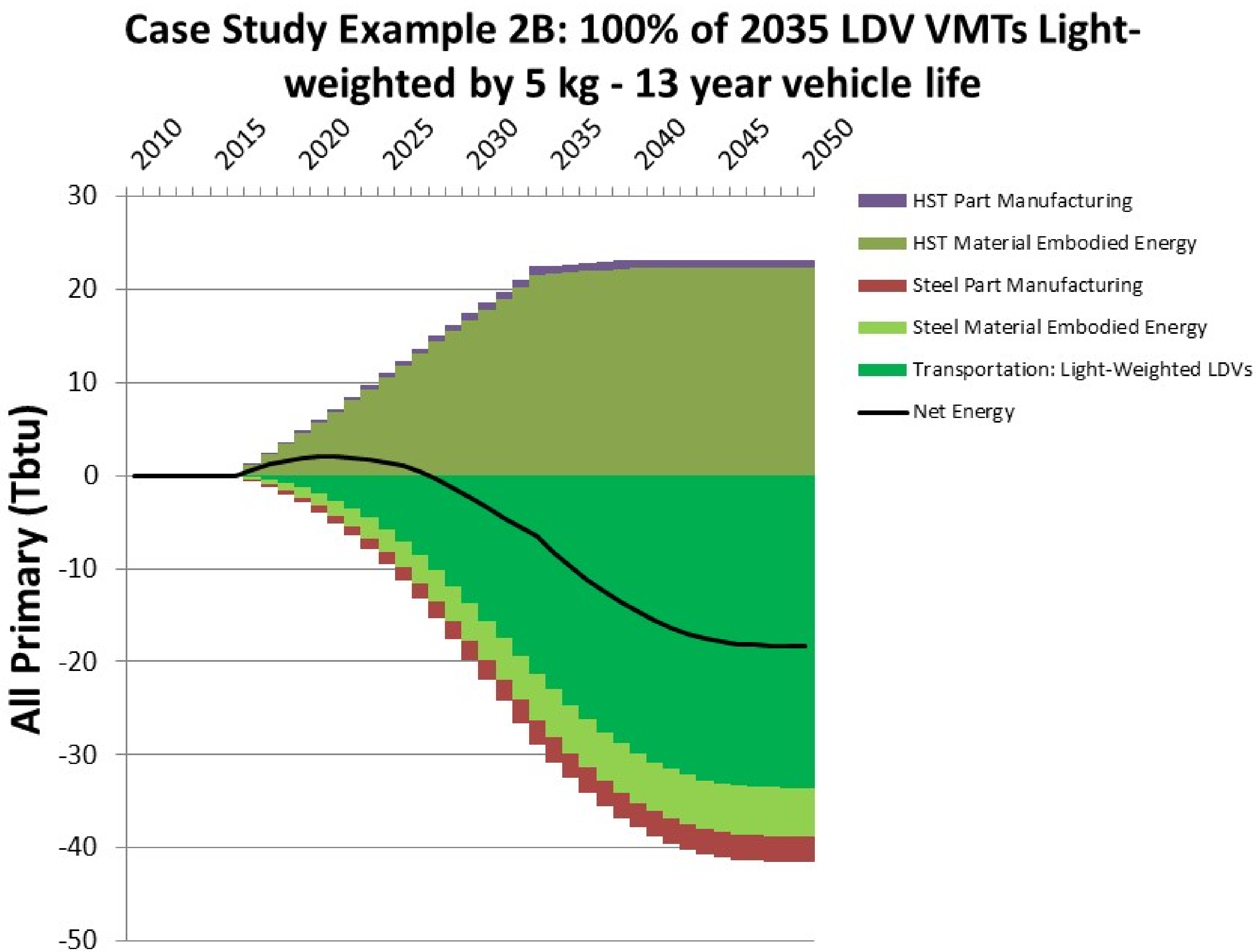

Table CS 11 – Output Table

Measure: Case Study Example 2B: 100% of 2035 LDV VMTs Light-weighted by 5 kg - 13 year vehicle life for years 2010 through 2050									
	Energy			Energy Expenditures (Mil 2013 \$)			CO_2 emissions (Mill Mt CO_2)		
	Fuels (TBtu)	Electricity (TWh)	Primary (TBtu)	Fuels	Electricity	Total	Fuels	Electricity	Total
BAU Industrial	795,945	46,654	1,344,120	\$ 9,362,765	\$ 3,636,562	\$ 12,999,327	44,462	24,113	68,574
BAU Commercial	156,094	63,663	802,446	\$ 2,143,422	\$ 6,949,240	\$ 9,092,662	9,474	32,149	41,622
BAU Residential	228,075	66,124	848,070	\$ 3,094,595	\$ 8,328,109	\$ 11,422,703	11,637	31,735	43,372
BAU Transportation	1,088,652	523	1,093,917	\$ 28,011,908	\$ 60,105	\$ 28,072,012	71,933	267	72,201
BAU Total	*2,268,766*	*176,964*	*4,088,554*	*\$ 42,612,689*	*\$ 18,974,016*	\$ 61,586,705	*137,505*	*88,264*	225,769
Transportation: Light-Weighted LDVs	-634	0	-634	\$ (19,376)	\$ -	\$ (19,376)	(34)	-	(34)
Steel Material Embodied Energy	-132	0	-132	\$ (1,044)	\$ -	\$ (1,044)	(10)	-	(10)
Steel Part Manufacturing	-68	0	-68	\$ (505)	\$ -	\$ (505)	(4)	-	(4)
HST Material Embodied Energy	557	0	557	\$ 4,416	\$ -	\$ 4,416	41	-	41
HST Part Manufacturing	23	0	23	\$ 170	\$ -	\$ 170	1	-	1
Industrial Measure Totals	*380*	*0*	*380*	*\$ 3,037*	*\$ -*	\$ 3,037	*28*	-	28
Commercial Measure Totals	*0*	*0*	*0*	*\$ -*	*\$ -*	\$ -	-	-	-
Residential Measure Totals	*0*	*0*	*0*	*\$ -*	*\$ -*	\$ -	-	-	-
Transportation Measure Totals	*-634*	*0*	*-634*	*\$ (19,376)*	*\$ -*	\$ (19,376)	*(34)*	-	(34)
Total from all sectors	*-254*	*0*	*-254*	*\$ (16,339)*	*\$ -*	\$ (16,339)	*(5)*	-	(5)
Economy Wide Total	*2,268,512*	*176,964*	*4,088,300*	*\$ 42,596,350*	*\$ 18,974,016*	*\$ 61,570,366*	*137,500*	*88,264*	*225,763*

Case Study Example 2 Conclusions

This case study provides two scenarios that forecast the direct energy impacts of a 5 kg weight reduction in light-duty vehicles (LDVs) within the U.S. This case study assumes that 5 kg of high-strength titanium (HST) vehicle parts (Ti6Al4V = TiH2+60Al-40V) displaces 10 kg of steel vehicles parts in future U.S. LDV sales. The use of titanium as a replacement for steel decreases vehicle weight, leading to high energy savings in the use phase, but also impacts industrial sectors in the materials and manufacturing phases due to the change in materials and vehicle part production.

The case study example demonstrates the two scenario development options presented in the user guide and are labeled as:

- Case Study Example 2A – Externally developed scenario calculations with results manually entered in the Alternate Calculations section of the Scenario Input tab.
- Case Study Example 2B – Internally developed scenario utilizing the tool's datasets and scenario forecasting method, variable assumptions entered in the Calculation Scratch Pad, and internal excel formulas entered in the Alternate Calculations. All user inputs are located in the Scenario Input tab.

The scenarios forecast nearly identical results primarily because the assumptions used to build up the external calculation are entered into the Calculation Scratch Pad in the Scenario Input tab and form the basis for the impacts estimated in both options. The minor differences in the two option's results reflect two modeling assumptions. First, in Case Study Example 2A, a non-linear "S-curve" adoption rate is applied, while in Case Study Example 2B, a linear adoption rate is applied. Second, in Case Study Example 2A, all vehicles are assumed to travel 250,000 km/vehicle (which translates to 11,950 vehicle miles traveled (VMT) per year for over a 13-year lifetime), while annual average VMTs are estimated from AEO forecasts in Case Study Example 2B (VMTs average 12,880 by 2050). Aggregate results summed from 2010 through 2050 show an LDV energy consumption decrease of 9%, but 2% increase in industrial energy consumption in Case Study Example 2B compared to Case Study Example 2A. This highlights that scenario development choices can produce slight variations in results even when many variables are consistent between scenarios. However, this is not a weakness of the model or method, but instead is an example of the potential variability between scenario results.

Case Study Example 3 – ultra-high molecular weight polyethylene (UHMW-PE) (instead of titanium) in seawater heat exchangers for U.S. LNG exports (with Stock Accounting)

Case study hypothetical question: what would be the total energy impact of ultra-high molecular weight polyethylene (UHMW-PE) instead of titanium (Ti) in liquefied natural gas (LNG) seawater heat exchangers?

Thermal conductivity is an important consideration in choosing materials for different manufacturing applications. Historically, heat exchangers have been manufactured from metal because metals are effective in conducting thermal energy. Plastics, although cheaper, lighter, and often less energy intensive to make than metals, are much less efficient in conducting heat than metals. This case study example considers using ultra-high molecular weight polyethylene (UHMW-PE) instead of titanium (Ti) in liquefied natural gas (LNG) seawater heat exchangers.

This case study compares the use of titanium and UHMW-PE heat exchanger designs to provide the seawater cooling necessary to accommodate a U.S. LNG export forecast. It is assumed that both titanium and UHMW-PE designed seawater heat exchangers have the same heat transfer properties, although the quantity of material required for each heat exchange design will reflect their respective heat transfer properties. In addition, their useful lives are expected to be different with titanium heat exchangers lasting 20 years while UHMW-PE heat exchangers are assumed to last only 10 years. Therefore, manufacturing the two heat exchanger options will have different material quantity requirements over time and it is necessary to account for heat exchange infrastructure stocks in order to calculate the material requirements. The resulting energy impacts are simply the embodied energy of the respective materials multiplied by the material stock requirements.

This case study example demonstrates the use of three sets of user inputs in the Scenario Input tab. First, a U.S. LNG forecast is extracted from the AEO dataset through inputs to the Where, What, and When columns. Second, variable parameters and calculations are input to the Calculation Scratch Pad columns. And lastly, excel formulas are coded in the Alternate Calculations columns to account for infrastructure stocks, material requirements, and energy impacts.

Where will the energy impacts take place?

Heat exchanger manufacturing is the fundamental impact in this case study as it is assumed that both heat exchanger designs have the same use-phase energy requirements. Several intermediate and forecast spreadsheet rows are required in the "Scenario Inputs" tab of the tool to develop the scenario. These are shown in Figure CS 15.

Figure CS 15 – Intermediate and Forecast Rows Location Inputs

Description	Row Function	Sector	IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table	IF using MECS, then Select Energy Resource Otherwise Select AEO Table Variable
Case Study Example 3: UHMW-PE (instead of titanium) in seawater heat exchangers for U.S. LNG exports				

Description	Row Function	Sector	IF Sector is Industrial, Select Manufacturing Industry Else Select AEO Table	IF using MECS, then Select Energy Resource Otherwise Select AEO Table Variable
U.S. LNG Exports (tril cu ft)			Natural Gas (AEOTbl 76)	Natural Gas : Volumes : Exports : Liquefied Natural Gas Exports [tril cu ft]
U.S. LNG Exports (Mil Tonne)				
U.S. LNG Exports Cooling X-changer energy (kW cooling)				
U.S. LNG Exports Cooling Ti HX modules (Number)				
U.S. LNG Exports Cooling Marginal Ti HX additions (Number/yr)				
U.S. LNG Exports Cooling Mass of Ti (kg/yr)				
TI manufacturing embodied energy (HX life = 20 Yr)	Forecast	Industrial		
U.S. LNG Exports Cooling UHMW-PE HX modules (Number)				
U.S. LNG Exports Cooling Marginal UHMW-PE HX additions (Number/yr)				
U.S. LNG Exports Cooling Mass of UHMW-PE (kg/yr)				
UHMW-PE manufacturing embodied energy (HX life = 10 Yr)	Forecast	Industrial		

Figure CS 16 – Emissions and Energy Price Inputs

Description	Energy Resource for CO2 accounting	Energy Prices
Case Study Example 3: Replace titanium with UHMW-PE for U.S. Export LNG seawater heat exchangers		
U.S. LNG Exports (tril cu ft)		
U.S. LNG Exports (Mil Tonne)		
U.S. LNG Exports Cooling X-changer energy (kW cooling)		
U.S. LNG Exports Cooling Ti HX modules		

Description	Energy Resource for CO2 accounting	Energy Prices
(Number)		
U.S. LNG Exports Cooling Marginal Ti HX additions (Number/yr)		
U.S. LNG Exports Cooling Mass of Ti (kg/yr)		
TI manufacturing embodied energy (HX life = 20 Yr)	NG	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]
U.S. LNG Exports Cooling UHMW-PE HX modules (Number)		
U.S. LNG Exports Cooling Marginal UHMW-PE HX additions (Number/yr)		
U.S. LNG Exports Cooling Mass of UHMW-PE (kg/yr)		
UHMW-PE manufacturing embodied energy (HX life = 10 Yr)	NG	Energy Prices : Industrial : Natural Gas [2013 $/mill Btu]

What will the energy impacts be?

The energy impacts associated with the two heat exchanger design options are predicated on the AEO LNG export forecast. However, each material's expected service life-times are different requiring an infrastructure stock method to account for the number of new heat exchangers produced annually. The energy impacts are derived by multiplying the quantity of material by the material's embodied energy. The variable assumptions necessary to estimate the energy impacts are provided in Table CS 12 and input into the tool in the Calculation Scratch pad columns in the Scenario Input tab.

Table CS 12 – Variable Assumptions (Calculation Scratch Pad)

Variable Description	Units	Ti	UHMW-PE
LNG Weight conversion	Tonne*10^6 / ft^3*10^{12}	18.99	
Methane Specific Heat	kJ/kgK	2.37	
Methane Starting Temp	C	60.00	
Methane Ending Temp	C	35.00	
Methane Temp Change	C	25.00	
HX volume (based on length, width, thickness of exchanger)	cm^3	6,000	
Heat transfer coefficient	W/kg	142.00	356.00
HX life	years	20	10
Density	g/cm^3	4.50	0.94
Embodied energy	MJ/kg	920.00	466.42

Scenario Inputs – Impact "what" and "when"

This case study example scenario does not use the tool's core "What impact?" and "When?" columns. Instead, it uses excel formulas programmed into the "Alternate Calculation" columns in conjunction with the variable assumption located in the Calculation Scratch Pad columns. Each of the excel formulas are shown in Table CS 13.

Intermediate and forecast Calculation Row Inputs

Excel formulas are programmed into the Alternate Calculation section's "Alt_Year" for each of the intermediate calculation rows. The following table provides a description of these rows and the formula calculation programmed into the "Alt_Year" columns.

Table CS 13 – Alternate Calculation Excel Formulas

Intermediate and Forecast Calculation	Description of Excel Formula Calculations in the Alternate Calculation section's "Alt_Year" columns
U.S. LNG Exports (trillion cu ft)	Extracts the LNG Export forecast from the AEO dataset based on the input selections in the "Where will energy impacts take place?" cells.
U.S. LNG Exports (Million Mt)	Converts the LNG Export from trillion cubic feet (trillion cu ft) to million metric tons of LNG.
U.S. LNG Exports Cooling X-changer energy (kW cooling)	Estimates the total annual heat exchanger energy requirement as a function of the variable assumptions for the heat exchangers.
U.S. LNG Exports Cooling Ti HX modules (Number)	Estimates the number of heat exchanger modules required to transfer the heat exchanger energy as a function of titanium heat transfer coefficient and the mass of titanium in a titanium heat exchanger.
U.S. LNG Exports Cooling Marginal Ti HX additions (Number/yr)	Infrastructure stock accounting. Returns the number of new titanium heat exchangers manufactured per year based on new LNG export capacity requirements and replacement of 20 year old heat exchangers.
U.S. LNG Exports Cooling Mass of Ti (kg/yr)	Estimates the annual titanium mass required to manufacture new heat exchangers.
TI manufacturing embodied energy (HX life = 20 Yr)	Multiplies the annual titanium mass by titanium's embodied energy variable assumption.
U.S. LNG Exports Cooling UHMW-PE HX modules (Number)	Estimates the number of heat exchanger modules required to transfer the heat exchanger energy as a function of UHMW-PE heat transfer coefficient and the mass of UHMW-PE in a UHMW-PE heat exchanger.
U.S. LNG Exports Cooling Marginal UHMW-PE HX additions (Number/yr)	Infrastructure stock accounting. Returns the number of new UHMW-PE heat exchangers manufactured per year based on new LNG export capacity requirements and replacement of 10 year old heat exchangers.
U.S. LNG Exports Cooling Mass of UHMW-PE (kg/yr)	Estimates the annual UHMW-PE mass required to manufacture new heat exchangers.
UHMW-PE manufacturing embodied energy (HX life = 10 Yr)	Multiplies the annual UHMW-PE mass by UHMW-PE's embodied energy variable assumption.

Figure CS 17 – Forecast and Intermediate Row Values

Description	Use Alternate Impact Values?	Alt_Units	Alt_2020	Alt_2030	Alt_2040	Alt_2050
Case Study Example 3: Replace titanium with UHMW-PE for U.S. Export LNG seawater heat exchangers						
U.S. LNG Exports (tril cu ft)			2.14	3.35	3.35	3.35
U.S. LNG Exports (Mil Tonne)			40.66	63.67	63.67	63.67
U.S. LNG Exports Cooling X-changer energy (kW cooling)			76,175	119,297	119,297	119,297
U.S. LNG Exports Cooling Ti HX modules (Number)			19,868	31,115	31,115	31,115
U.S. LNG Exports Cooling Marginal Ti HX additions (Number/yr)			5,178	-	5,178	-
U.S. LNG Exports Cooling Mass of Ti (kg/yr)			139,811		139,811	-
TI manufacturing embodied energy (HX life = 20 Yr)	TRUE	TBtu	(0.122)	-	(0.122)	-
U.S. LNG Exports Cooling UHMW-PE HX modules (Number)			37,939	59,415	59,415	59,415
U.S. LNG Exports Cooling Marginal UHMW-PE HX additions (Number/yr)			9,888		-	-
U.S. LNG Exports Cooling Mass of UHMW-PE (kg/yr)			55,767		-	-
UHMW-PE manufacturing embodied energy (HX life = 10 Yr)	TRUE	TBtu	0.025	-	-	-

Results

With the impact data entered into the tool’s inputs, the results can be viewed in the two output tabs. Scenarios and other preferences should be selected in the “Output Table” tab. The cumulative effects of each individual impact are shown in the Output Table and annual results are shown in the “Output Chart” tab. With the graph set to “All Primary (TBtus)”, and the “Grid Primary to Final Energy ratio” set to “Nuc & Ren HR=1”, results for this case study example scenario are shown in Figure CS 18 and Table CS 14.

Figure CS 18 – Output Chart

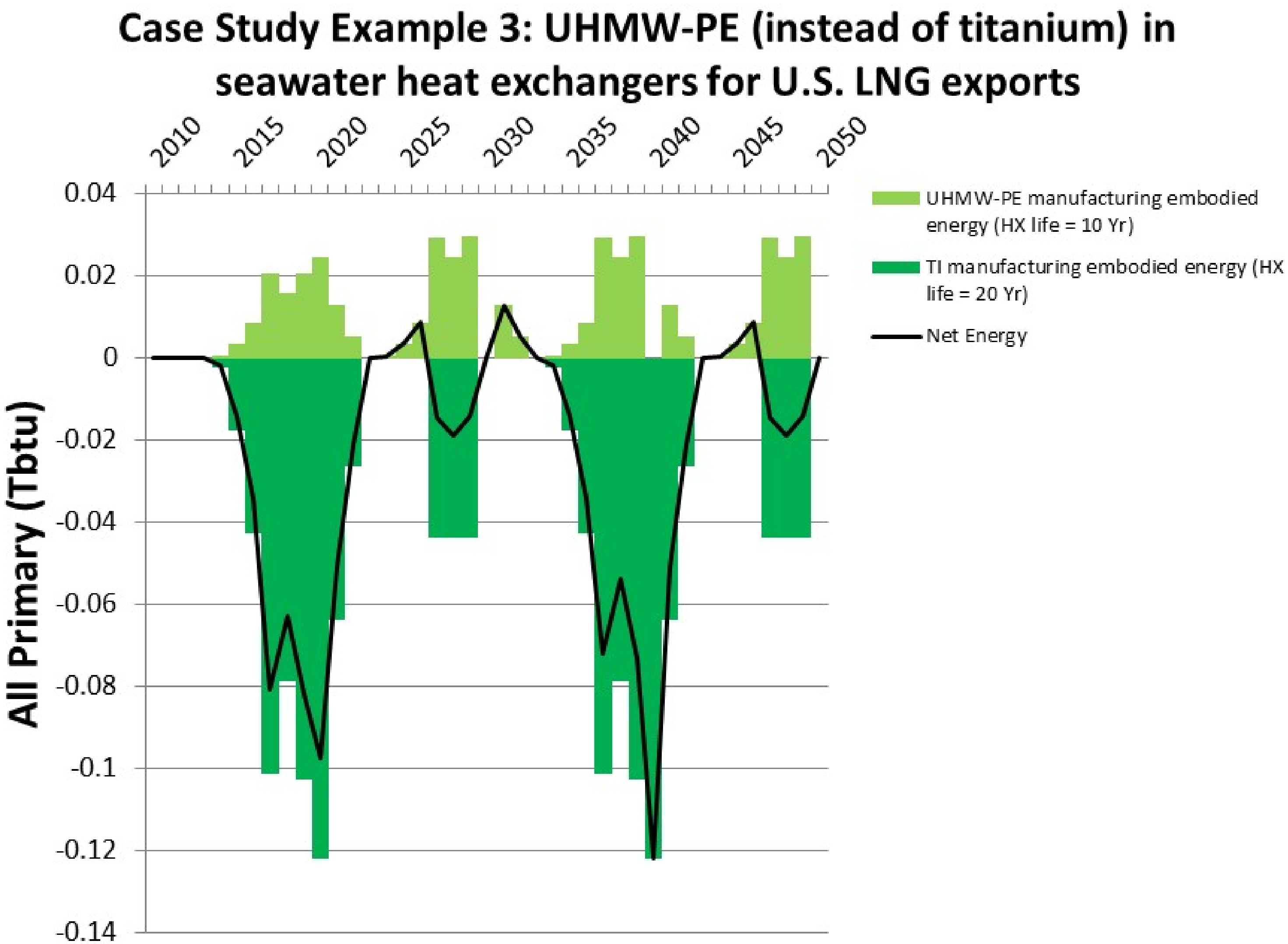

Table CS 14 – Output Table

Measure: Case Study Example 3: UHMW-PE (instead of titanium) in seawater heat exchangers for U.S. LNG exports for years 2010 through 2050									
	Energy			Energy Expenditures (Mil 2013 $)			CO_2 emissions (Mill Mt CO_2)		
	Fuels (TBtu)	Electricity (TWh)	Primary (TBtu)	Fuels	Electricity	Total	Fuels	Electricity	Total
BAU Industrial	795,945	46,654	1,344,120	$ 9,362,765	$ 3,636,562	$ 12,999,327	44,462	24,113	68,574
BAU Commercial	156,094	63,663	802,446	$ 2,143,422	$ 6,949,240	$ 9,092,662	9,474	32,149	41,622
BAU Residential	228,075	66,124	848,070	$ 3,094,595	$ 8,328,109	$ 11,422,703	11,637	31,735	43,372
BAU Transportation	1,088,652	523	1,093,917	$ 28,011,908	$ 60,105	$ 28,072,012	71,933	267	72,201
BAU Total	*2,268,766*	*176,964*	*4,088,554*	*$ 42,612,689*	*$ 18,974,016*	$ 61,586,705	*137,505*	*88,264*	225,769
TI manufacturing embodied energy (HX life = 20 Yr)	-1	0	-1	$ (10)	$ -	$ (10)	(0)	-	(0)
UHMW-PE manufacturing embodied energy (HX life =	0	0	0	$ 3	$ -	$ 3	0	-	0
Industrial Measure Totals	*-1*	*0*	*-1*	*$ (7)*	*$ -*	$ (7)	*(0)*	-	(0)
Commercial Measure Totals	*0*	*0*	*0*	*$ -*	*$ -*	$ -	-	-	-
Residential Measure Totals	*0*	*0*	*0*	*$ -*	*$ -*	$ -	-	-	-
Transportation Measure Totals	*0*	*0*	*0*	*$ -*	*$ -*	$ -	-	-	-
Total from all sectors	*-1*	*0*	*-1*	*$ (7)*	*$ -*	$ (7)	*(0)*	-	(0)
Economy Wide Total	*2,268,765*	*176,964*	*4,088,553*	*$ 42,612,683*	*$ 18,974,016*	*$ 61,586,698*	*137,505*	*88,264*	*225,769*

Case Study Example 3 Conclusions

This case study provides a scenario that forecasts the manufacturing energy impacts of two separate design options for seawater heat exchangers for U.S. LNG exports: titanium and UHMW-PE. This case study assumes that the use phase energy requirements are the same for each design option although the expected life time and embodied energy are unique to each design option. An infrastructure stock accounting method is used to estimate the annual material requirements for each design option. The energy impacts are forecasted by multiplying the quantity of material and material embodied energy for each design option. The two impacts are shown on the same output graph along with a net energy line. UHMW-PE has lower embodied energy than titanium but more material is required because of the shorter life-time of UHMW-PE heat exchangers relative to titanium heat exchangers.

Appendix A – Manufacturing Energy Consumption Survey Sub-Sectors

NAICS	Sector Name	AEO Table Mapping
311	FOOD	36
3112	Grain and Oilseed Milling	36
311221	Wet Corn Milling	36
All Other 3112	All Other Grain and Oilseed Milling	36
31131	Sugar	36
3114	Fruit and Vegetable Preserving and Specialty Foods	36
311421	Fruit and Vegetable Canning	36
3115	Dairy Products	36
3116	Animal Slaughtering and Processing	36
All Other 311	All Other FOOD	140c
312	BEVERAGE AND TOBACCO PRODUCTS	140c
3121	Beverages	140c
3122	Tobacco	140c
All Other 312	All Other BEVERAGE AND TOBACCO PRODUCTS	140c
313	TEXTILE MILLS	140c
313210	Broadwoven Fabric Mills	140c
All Other 313	All Other TEXTILE MILLS	140c
314	TEXTILE PRODUCT MILLS	140a
315	APPAREL	140a
316	LEATHER AND ALLIED PRODUCTS	140a
321	WOOD PRODUCTS	140a
321113	Sawmills	140a
321114	Wood Preservation	140a
3212	Veneer, Plywood, and Engineered Woods	37
321219	Reconstituted Wood Products	37
3219	Other Wood Products	37
All Other 321	All Other WOOD PRODUCTS	37
322	PAPER	37
322110	Pulp Mills	37
322121	Paper Mills, except Newsprint	140c
322122	Newsprint Mills	35
322130	Paperboard Mills	35
All Other 322	All Other PAPER	140c
323	PRINTING AND RELATED SUPPORT	140c
323110	Commercial Lithographic Printing	140c
All Other 323	All Other PRINTING AND RELATED SUPPORT	38
324	PETROLEUM AND COAL PRODUCTS	38
324110	Petroleum Refineries	38
324121	Asphalt Paving Mixture and Block	38
324199	Other Petroleum and Coal Products	38
All Other 324	All Other PETROLEUM AND COAL PRODUCTS	38

NAICS	Sector Name	AEO Table Mapping
325	CHEMICALS	38
325110	Petrochemicals	38
325120	Industrial Gases	38
325181	Alkalies and Chlorine	38
325182	Carbon Black	38
325188	Other Basic Inorganic Chemicals	38
325192	Cyclic Crudes and Intermediates	38
325193	Ethyl Alcohol	38
325199	Other Basic Organic Chemicals	140c
325211	Plastics Materials and Resins	140c
325212	Synthetic Rubber	140c
325222	Noncellulosic Organic Fibers	140c
325311	Nitrogenous Fertilizers	140c
325312	Phosphatic Fertilizers	140b
3254	Pharmaceuticals and Medicines	39&40
325412	Pharmaceutical Preparation	140c
All Other 3254	All Other Pharmaceuticals and Medicines	39
325992	Photographic Film, Paper, Plate, and Chemicals	39
All Other 325	All Other CHEMICALS	39
326	PLASTICS AND RUBBER PRODUCTS	39
326199	Other Plastics Products	39
All Other 326	All Other PLASTICS AND RUBBER PRODUCTS	40
327	NONMETALLIC MINERAL PRODUCTS	40
327121	Brick and Structural Clay Tile	140c
3272	Glass and Glass Products	39
327211	Flat Glass	140c
327212	Other Pressed and Blown Glass and Glassware	41&42
327213	Glass Containers	41
327215	Glass Products from Purchased Glass	41
All Other 3272	All Other Glass and Glass Products	41
327310	Cements	42
327410	Lime	42
327420	Gypsum	42
327993	Mineral Wool	42
All Other 327	All Other NONMETALLIC MINERAL PRODUCTS	42
331	PRIMARY METALS	140c
331111	Iron and Steel Mills	140c
331112	Electrometallurgical Ferroalloy Products	140c
3312	Steel Products from Purchased Steel	140c
3313	Alumina and Aluminum	140c
331312	Primary Aluminum	140c
331314	Secondary Smelting and Alloying of Aluminum	140c
331315	Aluminum Sheet, Plate and Foils	140c
331316	Aluminum Extruded Products	139a

NAICS	Sector Name	AEO Table Mapping
All Other 3313	All Other Alumina and Aluminum	139b
3314	Nonferrous Metals, except Aluminum	139c
331419	Primary Smelting and Refining of Nonferrous Metals, except Copper and Aluminum	139c
3315	Foundries	139c
331511	Iron Foundries	139d
331521	Aluminum Die-Casting Foundries	139e
331524	Aluminum Foundries, except Die-Casting	139e
All Other 3315	All Other Foundries	139e
All Other 331	All Other PRIMARY METALS	139e
332	FABRICATED METAL PRODUCTS	139e
333	MACHINERY	139e
334	COMPUTER AND ELECTRONIC PRODUCTS	140c
334413	Semiconductors and Related Devices	140c
All Other 334	All Other COMPUTER AND ELECTRONIC PRODUCTS	31-33
335	ELEC. EQUIP., APPLIANCES, COMPONENTS	36
336	TRANSPORTATION EQUIPMENT	36
336111	Automobiles	36
336112	Light Trucks and Utility Vehicles	36
3364	Aerospace Products	36
336411	Aircraft	36
All Other 336	All Other TRANSPORTATION EQUIPMENT	36
337	FURNITURE AND RELATED PRODUCTS	36
339	MISCELLANEOUS	36
31-33	Total Manufacturing	140c

AEO Mapping

AEO Table Mapping	AEO Table	Notes
6	Industrial (AEOTbl 6)	
31-33	Industrial (AEOTbl 6)	
35	Refining Industry (AEOTbl 35)	
36	Food Industry (AEOTbl 36)	
37	Paper Industry (AEOTbl 37)	
38	Bulk Chemical (AEOTbl 38)	
39&40		Adds Table 39 & 40
39	Glass Industry (AEOTbl 39)	
40	Cement Industry (AEOTbl 40)	
41&42		Adds Table 41 & 42
41	Iron and Steel (AEOTbl 41)	
42	Aluminum Industry (AEOTbl 42)	
139a	Metal Based Durables (AEOTbl 139)	Fabricated Metal Products
139b	Metal Based Durables (AEOTbl 139)	Machinery
139c	Metal Based Durables (AEOTbl 139)	Computers

AEO Table Mapping	AEO Table	Notes
139d	Metal Based Durables (AEOTbl 139)	Electrical Equipment
139e	Metal Based Durables (AEOTbl 139)	Transportation Equipment
140a	Other Manufacturing (AEOTbl 140)	Wood Products
140b	Other Manufacturing (AEOTbl 140)	Plastics
140c	Other Manufacturing (AEOTbl 140)	Balance of Manufacturing

Appendix B – AEO Tables

AEO Table #	Query Sequence	AEO Table Description
1	1	Total Energy
2	2	Energy Use
3	3	Energy Prices
4	4	Residential
5	5	Commercial
6	6	Industrial
7	7	Transportation
8	8	Electricity 1
9	9	Electricity Capacity 1
10	10	Electricity Trade
11	11	Liquid Fuels
12	12	Real Petroleum Prices
13	13	Natural Gas 1
14	14	Oil and Gas
15	15	Coal Supply 1
16	16	Renewable Energy 1
17	17	Carbon Dioxide 1
18	18	Macroeconomic Indicators 1
19	19	International Liquids
20	20	Conversion Factors
22	21	Carbon Dioxide 2
24	22	Renewable Energy 2
30	23	Residential Equipment
32	24	Commercial
34	25	Industrial Macroeconomic
35	26	Refining Industry
36	27	Food Industry
37	28	Paper Industry
38	29	Bulk Chemical
39	30	Glass Industry
40	31	Cement Industry
41	32	Iron and Steel
42	33	Aluminum Industry
43	34	Nonmanufacturing
45	35	Transportation Energy Use 1
46	36	Transportation Energy Use 2
47	37	Transportation Energy Use 3
48	38	Light-Duty Vehicle Sales
49	39	Light-Duty Vehicle Stock

AEO Table #	Query Sequence	AEO Table Description
50	40	Light-Duty Fuel Economy
51	41	Light-Duty Vehicle Miles Traveled
52	42	New Vehicle Attributes
53	43	Fleet Vehicle Energy Use
54	44	Fleet Vehicle Sales
55	45	Fleet Vehicle Stock
56	46	Fleet Vehicle Miles Traveled
57	47	Air Travel
58	48	Freight
60	49	Technology Market Penetration
62	50	Electricity 2
63	51	Electricity Generation
64	52	Electricity Capacity 2
67	53	Renewable Energy 3
70	54	Price Components
71	55	Crude Oil
72	56	Natural Gas 2
73	57	Lower 48 Reserves
76	58	Natural Gas 3
77	59	Natural Gas Use
78	60	Natural Gas Delivered
90	61	Natural Gas 4
94	62	Coal Supply 2
95	63	Coal Supply 3
96	64	World Coal 1
97	65	World Coal 2
98	66	World Total
99	67	Coal Prices
100	68	Macroeconomic Indicators 2
101	69	Imported Liquids
113	70	New Light-Duty Vehicle
114	71	New Light-Duty Vehicle Prices
115	72	New Light-Duty Vehicle Range
139	73	Metal Based Durables
140	74	Other Manufacturing
148	75	Aircraft Stock

Appendix C - Grid Primary to Final energy ratio Calculations

This table shows the electricity generation by fuel type in the AEO 2015 Reference Case (Table 8)

Total Electricity Generation by Fuel (billion kWh) - AEO Table 8					
	Petroleum	NG	Coal	Nuclear	Renewable
2010	37	987	1,847	807	428
2011	30	1,014	1,733	790	517
2012	23	1,228	1,514	769	501
2013	27	1,118	1,586	789	530
2014	28	1,133	1,616	784	542
2015	25	1,147	1,594	774	578
2016	25	1,179	1,563	781	618
2017	23	1,148	1,595	795	644
2018	23	1,165	1,614	798	663
2019	18	1,144	1,674	801	671
2020	18	1,117	1,709	804	679
2021	18	1,116	1,714	807	690
2022	18	1,132	1,720	808	698
2023	18	1,155	1,726	808	703
2024	18	1,184	1,732	808	710
2025	18	1,223	1,724	808	716
2026	18	1,252	1,723	808	723
2027	18	1,284	1,721	808	729
2028	18	1,317	1,718	808	737
2029	18	1,346	1,715	808	746
2030	18	1,371	1,713	808	756
2031	17	1,388	1,710	810	770
2032	17	1,405	1,708	810	785
2033	17	1,426	1,705	810	800
2034	17	1,449	1,704	811	814
2035	18	1,478	1,704	812	823
2036	18	1,507	1,705	813	836
2037	18	1,528	1,702	817	855
2038	18	1,543	1,704	821	876
2039	18	1,553	1,702	825	897
2040 - 2050	18	1,569	1,702	833	909

This table shows the electricity generation by fuel type converted from billion kWh/year to quads/year using a conversion factor of 1 billion kWh = 0.003412 Quads.

Total Electricity Generation by Fuel (Quads) – correlated to AEO Table 8					
	Petroleum	**NG**	**Coal**	**Nuclear**	**Renewable**
2010	0.13	3.37	6.30	2.75	1.46
2011	0.10	3.46	5.91	2.70	1.76
2012	0.08	4.19	5.17	2.63	1.71
2013	0.09	3.82	5.41	2.69	1.81
2014	0.10	3.87	5.51	2.67	1.85
2015	0.09	3.91	5.44	2.64	1.97
2016	0.09	4.02	5.33	2.67	2.11
2017	0.08	3.92	5.44	2.71	2.20
2018	0.08	3.97	5.51	2.72	2.26
2019	0.06	3.90	5.71	2.73	2.29
2020	0.06	3.81	5.83	2.74	2.32
2021	0.06	3.81	5.85	2.75	2.36
2022	0.06	3.86	5.87	2.76	2.38
2023	0.06	3.94	5.89	2.76	2.40
2024	0.06	4.04	5.91	2.76	2.42
2025	0.06	4.17	5.88	2.76	2.44
2026	0.06	4.27	5.88	2.76	2.47
2027	0.06	4.38	5.87	2.76	2.49
2028	0.06	4.49	5.86	2.76	2.52
2029	0.06	4.59	5.85	2.76	2.54
2030	0.06	4.68	5.85	2.76	2.58
2031	0.06	4.74	5.84	2.76	2.63
2032	0.06	4.79	5.83	2.76	2.68
2033	0.06	4.87	5.82	2.77	2.73
2034	0.06	4.94	5.81	2.77	2.78
2035	0.06	5.04	5.82	2.77	2.81
2036	0.06	5.14	5.82	2.78	2.85
2037	0.06	5.21	5.81	2.79	2.92
2038	0.06	5.26	5.81	2.80	2.99
2039	0.06	5.30	5.81	2.81	3.06
2040 - 2050	0.06	5.35	5.81	2.84	3.10

1 billion kWh = 0.003412 Quads

This table shows the fuel consumption for electricity generation by fuel type in the AEO 2015 Reference Case (Table 2).

Energy Use: Electric Power by Fuel (Quads) - AEO Table 2						
	Petroleum	**NG**	**Coal**	**Nuclear**	**Renewable**	**Total**
2010	0.38	7.52	19.17	8.43	3.96	39.78
2011	0.31	7.72	18.03	8.27	4.77	39.46
2012	0.22	9.31	15.82	8.06	4.53	38.34
2013	0.26	8.36	16.49	8.27	4.78	38.57
2014	0.29	8.42	16.82	8.21	4.87	38.99
2015	0.26	8.43	16.55	8.11	5.19	38.91
2016	0.25	8.64	16.18	8.19	5.55	39.18
2017	0.23	8.11	16.40	8.33	5.80	39.23
2018	0.23	8.20	16.58	8.36	5.97	39.68
2019	0.17	8.03	17.22	8.39	6.05	40.21
2020	0.17	7.80	17.59	8.42	6.13	40.45
2021	0.17	7.75	17.63	8.45	6.23	40.58
2022	0.17	7.82	17.70	8.46	6.29	40.79
2023	0.17	7.96	17.76	8.46	6.33	41.04
2024	0.18	8.14	17.82	8.46	6.38	41.32
2025	0.17	8.33	17.75	8.46	6.43	41.49
2026	0.17	8.49	17.74	8.46	6.48	41.69
2027	0.17	8.66	17.71	8.46	6.52	41.87
2028	0.17	8.79	17.68	8.46	6.58	42.02
2029	0.17	8.93	17.65	8.46	6.64	42.20
2030	0.17	9.03	17.63	8.47	6.72	42.35
2031	0.17	9.06	17.59	8.49	6.84	42.48
2032	0.17	9.10	17.57	8.49	6.96	42.62
2033	0.17	9.18	17.54	8.49	7.08	42.79
2034	0.17	9.27	17.53	8.50	7.20	42.99
2035	0.17	9.40	17.54	8.51	7.26	43.19
2036	0.17	9.52	17.54	8.52	7.37	43.44
2037	0.17	9.59	17.52	8.56	7.53	43.69
2038	0.17	9.61	17.54	8.60	7.71	43.95
2039	0.17	9.59	17.52	8.64	7.90	44.16
2040 - 2050	0.18	9.61	17.52	8.73	7.99	44.36

This table shows the implied average efficiency of the fuel-specific generation technologies. The Implied Primary/Final energy ratio is calculated by dividing the “Energy Use: Electric Power by Fuel (Quads) - AEO Table 2” values by the “Total Electricity Generation by Fuel (Quads) – correlated to AEO Table 8” values.

Implied Primary/Final energy ratio					
	Petroleum	**NG**	**Coal**	**Nuclear**	**Renewable**
2010	3.04	2.23	3.04	3.06	2.71
2011	2.99	2.23	3.05	3.07	2.71
2012	2.86	2.22	3.06	3.07	2.65
2013	2.85	2.19	3.05	3.07	2.65
2014	3.00	2.18	3.05	3.07	2.63
2015	2.94	2.16	3.04	3.07	2.63
2016	2.93	2.15	3.03	3.07	2.63
2017	2.92	2.07	3.01	3.07	2.64
2018	2.92	2.06	3.01	3.07	2.64
2019	2.86	2.06	3.01	3.07	2.64
2020	2.87	2.05	3.02	3.07	2.64
2021	2.87	2.03	3.02	3.07	2.64
2022	2.87	2.02	3.01	3.07	2.64
2023	2.87	2.02	3.02	3.07	2.64
2024	2.87	2.01	3.02	3.07	2.63
2025	2.87	2.00	3.02	3.07	2.63
2026	2.87	1.99	3.02	3.07	2.63
2027	2.86	1.98	3.02	3.07	2.62
2028	2.86	1.96	3.02	3.07	2.62
2029	2.86	1.94	3.02	3.07	2.61
2030	2.86	1.93	3.02	3.07	2.61
2031	2.86	1.91	3.02	3.07	2.60
2032	2.86	1.90	3.02	3.07	2.60
2033	2.86	1.89	3.02	3.07	2.60
2034	2.86	1.87	3.02	3.07	2.59
2035	2.86	1.86	3.02	3.07	2.59
2036	2.87	1.85	3.02	3.07	2.58
2037	2.87	1.84	3.02	3.07	2.58
2038	2.87	1.83	3.02	3.07	2.58
2039	2.88	1.81	3.02	3.07	2.58
2040 - 2050	2.88	1.80	3.02	3.07	2.57

This table shows the modified average efficiency of the fuel-specific generation technologies.

Modified Primary/Final energy ratio					
	Petroleum	**NG**	**Coal**	**Nuclear**	**Renewable**
2010	3.04	2.23	3.04	1.00	1.00
2011	2.99	2.23	3.05	1.00	1.00
2012	2.86	2.22	3.06	1.00	1.00
2013	2.85	2.19	3.05	1.00	1.00
2014	3.00	2.18	3.05	1.00	1.00
2015	2.94	2.16	3.04	1.00	1.00
2016	2.93	2.15	3.03	1.00	1.00
2017	2.92	2.07	3.01	1.00	1.00
2018	2.92	2.06	3.01	1.00	1.00
2019	2.86	2.06	3.01	1.00	1.00
2020	2.87	2.05	3.02	1.00	1.00
2021	2.87	2.03	3.02	1.00	1.00
2022	2.87	2.02	3.01	1.00	1.00
2023	2.87	2.02	3.02	1.00	1.00
2024	2.87	2.01	3.02	1.00	1.00
2025	2.87	2.00	3.02	1.00	1.00
2026	2.87	1.99	3.02	1.00	1.00
2027	2.86	1.98	3.02	1.00	1.00
2028	2.86	1.96	3.02	1.00	1.00
2029	2.86	1.94	3.02	1.00	1.00
2030	2.86	1.93	3.02	1.00	1.00
2031	2.86	1.91	3.02	1.00	1.00
2032	2.86	1.90	3.02	1.00	1.00
2033	2.86	1.89	3.02	1.00	1.00
2034	2.86	1.87	3.02	1.00	1.00
2035	2.86	1.86	3.02	1.00	1.00
2036	2.87	1.85	3.02	1.00	1.00
2037	2.87	1.84	3.02	1.00	1.00
2038	2.87	1.83	3.02	1.00	1.00
2039	2.88	1.81	3.02	1.00	1.00
2040 - 2050	2.88	1.80	3.02	1.00	1.00

This table shows the implied average efficiency of U.S. electric grid supplied electricity (column "AEO RC Scenario"), and the modified average efficiency of U.S. electric grid supplied electricity after assigning Nuclear and Renewable resources a heat rate (HR) of 1 (column "Nuc & Ren HR=1 Scenario").

Conversion Factors Primary/Final energy ratio					
	Final (Quads)	**AEO Primary (Quads)**	**AEO RC Scenario**	**Modified Primary (Quads)**	**Nuc & Ren HR=1 Scenario**
2010	12.81	39.78	3.11	31.60	2.47
2011	12.79	39.46	3.08	30.87	2.41
2012	12.61	38.34	3.04	30.08	2.39
2013	12.60	38.57	3.06	30.02	2.38
2014	12.76	38.99	3.06	30.43	2.39
2015	12.80	38.91	3.04	30.22	2.36
2016	12.95	39.18	3.02	30.21	2.33
2017	13.07	39.23	3.00	30.01	2.30
2018	13.25	39.68	2.99	30.33	2.29
2019	13.40	40.21	3.00	30.79	2.30
2020	13.45	40.45	3.01	30.96	2.30
2021	13.51	40.58	3.00	31.01	2.30
2022	13.60	40.79	3.00	31.17	2.29
2023	13.70	41.04	3.00	31.40	2.29
2024	13.82	41.32	2.99	31.66	2.29
2025	13.91	41.49	2.98	31.80	2.29
2026	14.01	41.69	2.98	31.97	2.28
2027	14.10	41.87	2.97	32.13	2.28
2028	14.18	42.02	2.96	32.25	2.27
2029	14.28	42.20	2.96	32.39	2.27
2030	14.35	42.35	2.95	32.50	2.27
2031	14.42	42.48	2.95	32.55	2.26
2032	14.48	42.62	2.94	32.62	2.25
2033	14.56	42.79	2.94	32.71	2.25
2034	14.64	42.99	2.94	32.83	2.24
2035	14.74	43.19	2.93	33.00	2.24
2036	14.85	43.44	2.93	33.17	2.23
2037	14.95	43.69	2.92	33.30	2.23
2038	15.06	43.95	2.92	33.43	2.22
2039	15.16	44.16	2.91	33.50	2.21
2040 - 2050	15.25	44.36	2.91	33.58	2.20

Appendix D – Excel Visual Basic Macro Code

Deployment Rate

```
Function DeploymentRate(Year As Double, StartYear As Double, EndYear As Double)
   If Year < StartYear Then
      DeploymentRate = 0
   ElseIf Year >= EndYear Then
      DeploymentRate = 1
   Else
      DeploymentRate = (Year - StartYear) / (EndYear - StartYear)
   End If
End Function
```

ExtractListFromTables

```
Sub ExtractListFromTables()
Dim tbl As ListObject
Dim a As Long
Dim b As Variant
Dim c As Variant
Dim d As Variant
Dim i As Long
   Sheets("AEO2015RC").Select
   Set tbl = ActiveSheet.ListObjects("AEO2015RC")
   a = tbl.Range.Rows.Count
   b = 1

   For i = 2 To a
      If Range("BJ" & i).Value <> Range("BJ" & i - 1).Value And Range("BJ" & i).Value <> "" Then
         b = b + 1
         c = Range("BJ" & i).Value
         d = Range("C" & i).Value
         Sheets("AEO Table").Cells(b, 10).Value = d
         Sheets("AEO Table").Cells(b, 11).Value = c & " (AEOTbl " & d & ")"
      End If
   Next i
   End Sub
```

Interpolate 2

```
Function Interpolate2(Target As Double, LookupArray As Variant, ResultArray As Variant)

Dim i As Integer
   Dim ArrayEnd As Integer
   Dim TempResult As Double

   ArrayEnd = LookupArray.Count
```

```
   'i notes the high end of the interval
   i = 1
   While (LookupArray(i).Value < Target And i <= ArrayEnd)
      i = i + 1
   Wend
   'If i = 1 then target is in first block
   If i = 1 Then
      If LookupArray(1) = 0 Then  'trap for div 0 and assign zero
         Interpolate2 = 0
      Else
         'Interpolate2 = ResultArray(1) * Target / LookupArray(1)
         Interpolate2 = ResultArray(1)
      End If
      Exit Function
   End If
   'If i = arrayend, then target is greater than last block
   If i > ArrayEnd Then
      'TempResult = ResultArray(i) + (ResultArray(i) - ResultArray(i - 1)) / (LookupArray(i) - LookupArray(i -
1)) * (Target - LookupArray(i))
      'Interpolate2 = TempResult
      Interpolate2 = ResultArray(i - 1)
      Exit Function
   End If
   'otherwise do a normal interpolation
   TempResult = ResultArray(i - 1) + (ResultArray(i) - ResultArray(i - 1)) / (LookupArray(i) - LookupArray(i -
1)) * (Target - LookupArray(i - 1))
   Interpolate2 = TempResult
End Function
```

SheetNamesHyperlink

```
Sub SheetNamesHyperlink()

Dim i As Integer
Dim StartRow As Integer
Dim StartColumn As Integer
Dim Name As Variant

      i = 1
      Name = Sheets(i).Name
      Sheets(Name).Select
         StartRow = Range("TabContentStartCell").row - 2
         StartColumn = Range("TabContentStartCell").Column
         Range("TabContentStartCell").Select
         Range(Selection, Selection.End(xlDown)).Select
         Selection.Clear

      For i = 2 To Sheets.Count
```

```
        Name = Sheets(i).Name
        Cells(i + StartRow, StartColumn) = Name

        If Sheets(i).Type = -4167 Then

          Cells(i + StartRow, StartColumn).Select
            ActiveSheet.Hyperlinks.Add Anchor:=Selection, Address:="", SubAddress:= _
            "'" & Name & "'!A1", TextToDisplay:=Name
        End If

    Next i

    Range("TabContentStartCell").Select
        Range(Selection, Selection.End(xlDown)).Select
        Range(Selection, Selection.End(xlToRight)).Select
        Selection.Borders(xlDiagonalDown).LineStyle = xlNone
        Selection.Borders(xlDiagonalUp).LineStyle = xlNone
        With Selection.Borders
            .LineStyle = xlContinuous
            .ColorIndex = 0
            .TintAndShade = 0
            .Weight = xlThin
        End With

End Sub
```

UpdateChartSourceData

```
Sub UpdateChartSourceData()

Dim SY As Double
Dim EY As Double
Dim tbl As ListObject
Dim tblRC As Long
Dim chartImpacts As Long
Dim x As Long

    Application.ScreenUpdating = False

' ensure measure sequencing is working & updated

    Sheets("Scenario Input").Select
    Range("TableScenario[[#Headers],[Scenario '#]]").Select
    ActiveCell.Offset(1).Select
    ActiveCell.Formula = "=IF(ROW()-ROW(TableScenario[[#Headers],[Scenario '#]])=1,1,IF([@[Row
Function]]=Lists!$O$3,DM2+1,DM2))"
    ActiveCell.Offset(0, 1).Select
    ActiveCell.Formula = "=IF([@[Scenario '#]]=DM2,IF([@[Row Function]]=Lists!$O$5,DN2+1,DN2),0)"
```

```
ActiveCell.Offset(0, 1).Select
ActiveCell.Formula = "=CONCATENATE([@[Scenario '#]],"" - "",[@[Forecast Sequence]])"

Set tbl = ActiveSheet.ListObjects("TableScenario")
tblRC = tbl.Range.Rows.Count

If tblRC > 2 Then

  Range("Variable_Scenario_Sequence").Select
  Application.CutCopyMode = False
  Selection.Copy
  Range(Selection, Selection.End(xlDown)).Select
  ActiveSheet.Paste
  Range("A3").Select

  Selection.ListObject.Range.FormatConditions.Delete
  Cells.FormatConditions.Delete
  Range("TableScenario").Select
  Selection.FormatConditions.Add Type:=xlExpression, Formula1:= _
    "=$B3=VariableNewScenario"
  Selection.FormatConditions(Selection.FormatConditions.Count).SetFirstPriority
  With Selection.FormatConditions(1).Borders(xlTop)
    .LineStyle = xlContinuous
    .Color = -16776961
    .TintAndShade = 0
    .Weight = xlThin
  End With
  With Selection.FormatConditions(1).Interior
    .PatternColorIndex = xlAutomatic
    .ThemeColor = xlThemeColorDark1
    .TintAndShade = -0.249946592608417
  End With

  Selection.FormatConditions(1).StopIfTrue = False

If Range("VariableScenario") <> 0 And Sheets("Chart Data").Range("AS2") <> 0 Then

  Sheets("Output Table").Select

  SY = Range("J2")
  EY = Range("K2")
  Range("J2") = 2011
  Range("K2") = 2050

  Sheets("Output Chart").Activate
  ActiveChart.SetSourceData Source:=Range("ChartSourceData"), PlotBy:=xlRows
  ActiveChart.SeriesCollection(1).XValues = Range("ChartXAxisData")
  ActiveChart.ChartArea.Select
```

```
        ActiveChart.PlotArea.Select
        ActiveChart.ChartType = xlColumnStacked

        chartImpacts = ActiveChart.SeriesCollection.Count
        For x = 1 To chartImpacts
            ActiveChart.SeriesCollection(x).Select
            Selection.Format.Line.Visible = msoFalse
        Next x

        With ActiveChart.SeriesCollection.NewSeries
            .Name = Range("TableChartData[[#Totals],[Impact]]")
            .ChartType = xlXYScatterLines
            .XValues = Range("ChartXAxisData")
            .Values = Range("ChartNetImpactData")
            .Select
            .Format.Line.Visible = msoCTrue
            .Format.Line.ForeColor.RGB = vbBlack
            .MarkerStyle = -4142
        End With

        ActiveChart.ChartArea.Select

        Sheets("Output Table").Select

        Range("J2") = SY
        Range("K2") = EY

        ActiveSheet.Range("$B$6:$k$37").AutoFilter Field:=1, Criteria1:="<>"

    Else: End If

    End If

    Sheets("Output Table").Select
    Application.ScreenUpdating = True

End Sub
```