EPA Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA)

Core Model Version 1.4.1 Documentation

EPA United States Environmental Protection Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

United States
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I Background

On-road vehicles are the predominant source of greenhouse gas (GHG) emissions from the transportation sector. Of all on-road vehicles, light-duty vehicles and light-duty trucks (hereafter referred to as cars and trucks) produce the majority of the GHG emissions. There are many methods for reducing GHG emissions from cars and trucks due to the myriad technology options available to improve the efficiency of vehicles. A detailed analysis of the costs and benefits of various GHG emissions reduction requires an application that accounts for all the potential technologies. Therefore, EPA's Office of Transportation and Air Quality (OTAQ) has developed the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (hereafter referred to as the "OMEGA" model) to help facilitate the analysis of the costs and benefits of reducing GHG emissions from cars and trucks.

This documentation accompanies the fifth public release of the OMEGA model. Versions 1.0.0 and 1.0.2 were respectively released with the noticed of proposed rulemaking and final rule regarding "Model Year 2012-2016 Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards." Versions 1.3.0, 1.4.0, and this version were respectively released with the first notice of intent, the proposed rulemaking, and the final rule regarding the "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and CAFE Standards." These model releases, as well as their related inputs and documentation are available at the OMEGA page on the EPA website.[1]

The model is written in the C# programming language. Inputs to and outputs from the model are provided using spreadsheet and text files. The spreadsheet output files also facilitate additional manipulation of the results. The model source code is available in the relevant rulemaking dockets.[2]

EPA has established a webpage for the OMEGA model on the EPA agency website (http://www.epa.gov/otaq/climate/models.htm). The OMEGA version 1.4.1 release includes a set of sample input files; those used to support EPA's final rulemaking on cars and light trucks for model years 2017+ are also available on the website. Input files from earlier versions of OMEGA are not compatible with this release. Periodic updates of both the model and this documentation will be available to be downloaded. Those interested in using the model are encouraged to periodically check this website for these updates.

II Model Overview

Broadly speaking, the OMEGA model evaluates the relative cost and effectiveness of available technologies and applies them to a defined vehicle fleet in order to meet a specified GHG emission target. Once the target has been met, OMEGA reports out the cost and societal benefits of doing so. This document focuses on the core model, which is the component which calculates cost of compliance. OMEGA models two GHGs; carbon dioxide (CO_2) from fuel use and refrigerant emissions from the air conditioning (A/C) system.

OMEGA is primarily an accounting model. It is not a vehicle simulation model, where basic information about a vehicle, such as its mass, aerodynamic drag, an engine map, etc. are used to

[1] http://www.epa.gov/oms/climate/models.htm
[2] EPA-HQ-OAR-2004-0075 and EPA-HQ-OAR-2010-0799

predict fuel consumption or CO_2 emissions over a defined driving cycle.[3] Such simulations may be used to inform the OMEGA inputs, but are not performed by OMEGA itself.

While OMEGA incorporates functions which generally minimize the cost of meeting a specified CO_2 target, it is not an economic simulation model which adjusts vehicle sales in response to the cost of the technology added to each vehicle. While OMEGA allows vehicle sales to change over time, the vehicle sales in OMEGA 1.4.1 do not dynamically respond to the addition of technology.[4] That being said, EPA has begun development of an economic simulation or consumer choice component to OMEGA. The model documentation and peer review documents are provided on the EPA website.[5]

OMEGA can be used to model either a single vehicle model or any number of vehicle models. Vehicles can be those of specific manufacturers or generic fleet-average vehicles. Because OMEGA is an accounting model, the vehicles can be described using only a relatively few number of terms. The most important of these terms are the vehicle's baseline emission level, the level of CO_2 reducing technology already present, and the vehicle's "type," which indicates the technology available for addition to that vehicle. Information determining the applicable CO_2 emission target for the vehicle must also be provided. This may simply be vehicle class (car or truck) or it may also include other vehicle attributes, such as footprint.[6]

Since there are a large number of technologies which reduce CO_2 emissions and a wide array of different vehicle systems to which they apply, the manufacturers' design and production processes play a major role in determining the technology cost associated with lowering fleet-wide CO_2 emissions. Vehicle manufacturers typically develop several unique models based on a limited number of shared vehicle platforms, allowing for efficient use of design and manufacturing resources. The platform typically consists of common vehicle architecture and structural components. Given the very large investment put into designing and producing each vehicle model, manufacturers typically plan on a major redesign for the models approximately every 5 years. At the redesign stage, the manufacturer will upgrade or add all of the technology and make all of the other changes needed in order that the vehicle model will meet the manufacturer's plans for the next several years. This includes meeting all of the emissions and other requirements that would apply during the years before the next major redesign of the vehicle.

This redesign often involves a package of changes, designed to work together to meet the various requirements and plans for the model for several model years after the redesign. This often involves significant engineering, development, manufacturing, and marketing resources to create a new product with multiple new features. In order to leverage this significant upfront investment, manufacturers plan vehicle redesigns with several model years' of production in mind. Vehicle models are not completely static between redesigns as limited changes are often incorporated for each model year. This interim process is called a refresh of the vehicle and generally does not allow for major technology changes although more minor ones can be done (e.g., aerodynamic improvements, valve timing improvements).

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[3] EPA has released other models that perform full vehicle simulations. See the ALPHA (http://www.epa.gov/otaq/climate/alpha.htm) and GEM models (http://www.epa.gov/oms/climate/gem.htm).
[4] OMEGA may be expanded in the future to incorporate such market responses, however, such responses may currently be addressed "outside of the model" through sequential model runs with market adjustments made between runs.
[5] http://www.epa.gov/otaq/climate/publications.htm
[6] A vehicle's footprint is the product of its track width and wheelbase, usually specified in terms of square feet.

More major technology upgrades that affect multiple systems of the vehicle thus occur at the vehicle redesign stage and not in the time period between redesigns.

There are a wide variety of emissions control technologies which involve several different vehicle systems. Many can involve major changes to the vehicle, such as changes to the engine block and heads, or redesign of the transmission and its packaging in the vehicle. This calls for tying the incorporation of the emissions control technology into the periodic redesign process. This approach reflects manufacturer capability to develop appropriate packages of technology upgrades that combine technologies in ways that work together and fit with the overall goals of the redesign. It also reflects the reality that manufacturers fit the process of upgrading emissions control technology into its multi-year planning process, and it avoids the large increase in resources and costs that would occur if technology had to be added outside of the redesign process.

Within OMEGA, GHG emission control technology can be applied individually or in groups, often called technology "packages." The user specifies the cost and effectiveness of each technology or package for a specific "vehicle type," such as midsize cars with V6 engines or minivans. The user can limit the application of a specific technology to a specified percentage of each vehicle's sales (i.e., a "cap"). The effectiveness, cost, application limits of each technology package can also vary over time.[7] A list of technologies or packages is provided for each vehicle type, providing the connection to the specific vehicles being modeled.

OMEGA is designed to apply technology in a manner similar to the way that a vehicle manufacturer might make such decisions. In general, the model considers three factors which EPA believes are important to the manufacturer: 1) the cost of the technology at the consumer level, 2) the value which the consumer is likely to place on improved fuel economy and 3) the degree to which the technology moves the manufacturer towards its CO_2 emission target.

Technology can be added to individual vehicles using one of three distinct ranking approaches. Within a vehicle type, the order of technology packages is set by the user. The model then applies technology to the vehicle with the lowest Technology Application Ranking Factor (hereafter referred to as the TARF). OMEGA offers several different options for calculating TARF values. One TARF equation considers only the cost of the technology and the value of any reduced fuel consumption considered by the vehicle purchaser. The other two TARF equations consider these two factors in addition to the mass of GHG emissions reduced over the life of the vehicle. Fuel prices by calendar year, vehicle survival rates and annual vehicle miles travelled (VMT) with age are provided by the user to facilitate these calculations.

For each manufacturer, OMEGA applies technology to vehicles until the sales-weighted GHG emission average complies with the specified GHG emission standard or until all the available technologies have been applied. The GHG emission standard can be a flat standard applicable to all vehicles within a vehicle class (e.g., cars, trucks or both cars and trucks). Alternatively the GHG standard can also be in the form of a linear or constrained logistic function, which sets each vehicle's target as a function of vehicle footprint (vehicle track width times wheelbase). When the linear form of footprint-based standard is used, the "line" can be

[7] "Learning" is the process whereby the cost of manufacturing a certain item tends to decrease with increased production volumes or over time due to experience. While OMEGA does not explicitly incorporate "learning" into the technology cost estimation procedure, the user can currently simulate learning by inputting lower technology costs in each subsequent redesign cycle based on anticipated production volumes or simply with time.

converted to a flat standard for footprints either above or below specified levels. This is referred to as a piece-wise linear standard.

The GHG emission target can vary over time, but not on an individual model year basis. One of the fundamental features of the OMEGA model is that it applies technology to a manufacturer's fleet over a specified vehicle redesign cycle. OMEGA assumes that a manufacturer has the capability to redesign any or all of its vehicles within this redesign cycle. OMEGA does not attempt to determine exactly which vehicles will be redesigned by each manufacturer in any given model year. Instead, it focuses on a GHG emission goal several model years in the future, reflecting the manufacturers' capability to plan several model years in advance when determining the technical designs of their vehicles. Any need to further restrict the application of technology can be effected through the caps on the application of technology to each vehicle type mentioned above.

GHG emission standards are specified in terms of CO_2 equivalent emissions. These CO_2 equivalent emissions can be based on any test procedure. The only requirement is that the base CO_2 emissions specified for each vehicle and the effectiveness of the specified technologies be based on the same test cycle(s). For example, these emissions can simply be those from the tailpipe as measured over the current two-cycle GHG standard test procedure or they can also include tailpipe CO_2 emissions from air conditioner use, as well as refrigerant emissions from the air conditioning system. In the case of the latter, the descriptions of vehicle emissions and technologies must include baseline refrigerant emissions and the effectiveness of each technology in reducing these emissions. GHG emissions could also be based on the 5-cycle formulae now used to calculate most vehicles' fuel economy labels. The user simply needs to take care to specify CO_2 and refrigerant emission and technology effectiveness estimates which are based on emissions over all five emission tests and as combined according to the five-cycle formulae. OMEGA bases all of its calculations on a single estimate of test cycle emissions. Compliance cannot be specified for two distinct test cycles, for example, city and highway test emissions. Only combined city alone, highway alone or city-highway emissions can be modeled.

Once technology has been added so that every manufacturer meets the specified targets (or exhausts all of the available technologies), the model produces a variety of output files. Outputs include specific information about the technology added to each vehicle and the resulting costs and emissions. Average costs and emissions per vehicle by manufacturer and industry-wide are also determined for each vehicle class.

The remainder of this document is divided into four sections. The first section describes the information which can be input to the model. The second section describes the application of technology in order to comply with the specified standards, what we define as the "core model." The third section describes the various output files produced by the model. The fourth section describes the steps necessary to operate the OMEGA model.

III Input Files

OMEGA is designed to be flexible in a number of ways. Very few numeric values are hard-coded in the model, and consequently, the model relies heavily on its input files. The model utilizes five input files: Market, Technology, Fuels, Scenario, and Reference. All of the input files are Microsoft Excel 2003 spreadsheets and should not be converted into other formats. The headings of the various types of input data are contained in Row 1 of each worksheet. It should be noted that these headings cannot be modified by the user. Each input file also contains two common types of worksheets. One is named "Validation List" and lists the types of value allowed in each column along with an allowed range of valid values. This worksheet is typically hidden and can be viewed using the Format/Sheet/Unhide command. The user can change the range of valid values as desired. The user should not change the type of data shown as OMEGA is designed to look for certain types of information in each column and changing the values entered in an input file does not affect this expectation.

The second common worksheet is named "Errors." This worksheet contains a button labeled "Validate Data" which can be selected. When "clicked" this button triggers a macro which determines if all values in the current workbook fit the expected type of data and fall within the allowed range of values. Cells that do not fit the criteria are listed and the problem described. This function can be very useful when developing new input files by reducing the number of aborted model runs. While useful, please note that the error validation routines are outdated and may falsely indicate errors, or may not indicate all errors.[8]

It is important to note that OMEGA expects all the cells below the last row of required data to be blank and, more specifically, to have never been written into. If these cells are used for temporary calculations, the user should go further below to a row which has never been written into and copy the entire row of blank cells into the row which have been used temporarily. The error identification process will then recognize these cells as actually being blank.

A The Market File: Vehicle Fleet Characterization

The market input file contains much of the required information which describes the vehicles being modeled. This file consists of three worksheets in addition to the Validation List and Errors worksheets: Vehicle, Manufacturer, and Vehicle Type. The "Manufacturer" and "Vehicle Type" tabs are lists of valid values for columns C and E in the Vehicle worksheet. The "Vehicle" worksheet, which is the substance of the market file, is discussed below.

[8] Generally, OMEGA is moving towards a dynamic where more error reporting is provided by the model itself, rather than these validation routines. The trace log, located in the same file directory as the model executable, provides useful diagnostics on the model run.

Table 1 shows the various types of data included in the "Vehicle" worksheet.

Table 1 - Input Data in Market Data Worksheet of the Market File*

Column	Name
A	Platform Index #
B	Vehicle Index #
C	Manufacturer
D	Model
E	Vehicle Type #
F	EPA Vehicle Class
G	Classic Vehicle Class
H	Baseline Sales
I-P	Annual Sales by Cycle
Q	Combined FE (mpg)
R	Tailpipe CO_2 (g/mi)
S	Footprint (ft2)
T	Curb Weight (lb)
U	No. of Cylinders

Column	Name
V	Displacement (L)
W	Horsepower
X	Max Seating
Y	Transmission Type
Z	Drive
AA	Structure
AB	Towing Capacity
AC	Primary Fuel Type
AD	Combined EC (kWh/mi)
AE	Refrigerant Type
AF	Refrigerant Lifetime Leakage (g)
AG-CD	TEB Tech Package 1-50
CE-EB	CEB Tech Package 1-50
EC-FZ	OEB Tech Package 1-50

* Columns highlighted in gray are not currently used by OMEGA

Column A contains a positive numerical identifier matching each vehicle with a specific platform type. Each platform represents a unique combination of vehicle characteristics. During input data pre-processing OMEGA automatically creates a version of the market.xls data set aggregated by manufacturer and unique platform. This process is described further in later sections.

Column B contains a unique, positive numerical identifier for each vehicle being modeled. The indices do not need to be in numerical order, just unique and positive. Column C contains the name of each manufacturer. There are no requirements with respect to the names, except that the user needs to take care that vehicles intended to be produced by the same manufacturer are given exactly the same name. Slight differences in spelling or spacing will cause the model to treat them as separate manufacturers. A list of manufacturers has been provided in the validation routine to help avoid this issue. Column D contains an alpha-numeric name for each vehicle. These names do not need to be unique, simply to be as descriptive as the user desires.

Column E contains the vehicle type number. This value provides the connection between the vehicles listed in the market data worksheet and the available technologies listed in the Technology file.

Column F contains the vehicle class designator. Currently OMEGA can model up to two vehicle classes: cars indicated with "C" and trucks indicated with "T." This code provides the connection between the vehicles listed in the market data worksheet and the standards listed in the Scenario file. If only one standard applicable to both cars and trucks is being modeled, vehicles can be labeled as either cars or trucks or both. If both vehicle labels are used, compliance will still be based on the combination of both vehicle classes, but emissions will be tracked separately in the model's outputs. This latter situation is advantageous if cars and trucks are to have distinct scrappage rates and annual travel estimates.

Column G contains the car/truck classification of vehicles under the pre-MY 2011 CAFE definition. This column is not currently used by the OMEGA model

Column H contains baseline sales. The baseline is the model year prior to the first year of the first redesign cycle being modeled. Baseline sales are not used in the core model to add technology to facilitate compliance; instead they are used in order to linearly interpolate annual vehicle sales during the interim years between the baseline year and the year of the end of the first redesign cycle. Sales must be positive and may be fractional.

Columns I through P contain sales for the last year of each of up to eight redesign cycles. Sales must be positive and may be fractional. The basic assumption made by the model related to the length of the redesign cycle is quite simple: that every vehicle sold by the manufacturer is capable of being redesigned within a redesign.

Sales must be entered for each vehicle, even if the value of sales is zero. Values need only be entered for redesign cycles actually being modeled. Thus, if only one redesign cycle is being modeled, then sales need only be entered in Column I. Columns J through P can be blank in this case. Sales can change in any manner between redesign cycles.

Column Q contains each vehicle's baseline fuel economy value in miles per gallon (mpg). It is not currently used by the model.

Column R contains each vehicle's baseline CO_2 emissions in grams per mile (g/mi) over whichever test cycle or cycles comprise the basis for compliance with the standards described in the Scenario file. This value should not include the CO_2 equivalent emissions related to refrigerant leakage emissions. Those emissions are described in later columns. The CO_2 emissions of Column R could include the CO_2 equivalent emissions of GHGs like methane and nitrous oxide, as long as the effectiveness of the technologies described in the Technology file and the standards listed in the Scenario file consider these emissions in a consistent manner.

Column S contains each vehicle's footprint value in square feet. This value is used to determine each vehicle's CO_2 emission target when the standard is either a constrained logistic curve or linear function.

Columns T through AA describe several vehicle attributes which are not currently used by the model. These are included to facilitate future versions of the model which may base compliance or evaluate model output using one or more of these attributes. Column AB contains the vehicle towing capacity in pounds.

Column AC contains a designator for each vehicle's primary fuel type. Any fuel type is allowed in the model, so long as its details appear in the Fuels input file. Plug in hybrid vehicles would be designated by their liquid fuel type, depending on which liquid fuel they used. The model will consider the electricity used by plug in vehicles based on the value of electricity consumption per mile described in Column AD, which is described below. Electric vehicles must be designated with the fuel "EL." Fuel names are case sensitive, and each vehicle fuel must appear, in exactly the same format, in the fuels file.

Column AD contains the vehicle's baseline electricity consumption in units of kilowatt-hour per mile (kw-hr/mi). This value is used in calculating the fuel savings component of the TARF equation, in which a comparison must be made between vehicles and technologies which may consume different types of energy sources, such as liquid gasoline or diesel, or electricity. Since consumers tend to make decisions on which vehicle to purchase based on how much the vehicle costs them to drive it, this column helps the model account for the any energy in the baseline vehicles which is supplied by the electrical grid. This term only applies to plug in hybrids and battery based electric vehicles. In the Fuels input file, OMEGA allows the user to input a value for the GHG emissions associated with generating a kw-hr of electricity when determining compliance with the GHG standards. Should a non-zero value be entered, the level of electricity usage per mile also affects the vehicle's baseline CO_2 emission level when the model is run.

Column AE designates the type of refrigerant used by the vehicle. This designator must match one of the types of refrigerant listed on the Refrigerant worksheet of the Reference file described further below. The primary purpose of this designation is to specify the Global Warming Potential (GWP) of the refrigerant so that mass emissions of refrigerant leakage can be converted to their CO_2 equivalent emissions. Editable refrigerant data is in the Reference file, so that the user can edit or add additional refrigerant names and GWPs.

Column AF of the market file designates the lifetime leakage of the refrigerant, which the model uses to calculate the leakage rate in CO_2 equivalents. EPA chose to input the lifetime leakage instead of the leakage rate because the lifetime leakage is easier to quantify. The yearly distribution of leakage is hard-coded, and OMEGA uses it to convert the refrigerant leakage to grams of CO_2 equivalents per mile.

Columns AG through CD are used to track technology that may be present in the baseline or reference case. This data is necessary to prevent the model from double counting technology costs and GHG improvements. Columns AG through CD represent the fraction of the technology package effectiveness for the different vehicles that is present in the reference case; for example, a value of 35% for technology package 1 means that 35% of the effectiveness of technology package 1 on that vehicle type is already present in the baseline vehicle. Similarly, columns CE through EB represent the fraction of the technology packages' cost that is reflected in the baseline. Likewise, a value of 75% in any of these columns means that 75% of the technology package's cost on the particular vehicle has been included in the reference case. A method for calculating these values is described in Appendix A.

Columns CE through FZ contain Other Effectiveness Basis (OEB) gram-per-mile credits that may be associated with each technology package. Typically these are negative numbers. While each technology package may have an associated gram-per-mile credit (specified in the Technology.xls input data set) those are only applied when calculating the TARF CO_2 value. When calculating total vehicle CO_2 for compliance purposes, the OEB values from columns CE-FZ are used instead. As documented in a later section, the use of OEBs provides vehicle level accounting for credits.

B The Technology File: Technology Package Characterization

The technology input file defines the technology packages (up to 50) which the model can add to the vehicle fleet. For each vehicle type, the user must add a separate row for each technology package in the order of how OMEGA should add them to that specific vehicle type. This approach puts considerable onus on the user to develop a reasonable sequence of technologies. However, the model also produces output information which can help the user determine if a particular technology package might be "out of order". The package approach also simplifies the model's calculations and enables synergistic effects among technology packages to be included to the fullest degree possible.

There are four tabs which contain technology packages, each tab keyed to a particular redesign cycle. Similar to the Market file, the Technology file contains an additional tab entitled "errors", which is used for validation purposes. Table **2**, below describes the data in the each redesign cycle tab.

Table 2 - Input Data in Each Worksheet of the Technology File

Column(s)	Contents
A	Vehicle type number
B	Technology package number
C	Technology package name
D	Abbreviation
E	Market penetration caps
F	Incremental tailpipe CO_2 emission control effectiveness
G	Incremental Cost
H	Primary fuel of the new technology package
I	The fuel to which the technology package applies
J	Electrical Conversion %
K	Gram/mile CO_2 credit
L	Refrigerant emission control effectiveness
M	Refrigerant type (NC = no change from previous step)

The data in this file can be categorized in four ways: 1) Information which describes the individual packages, such as name and vehicle type; 2) Parameters the model uses to calculate CO_2 improvement, such as effectiveness and market penetration cap (the latter being the cap of sales for each vehicle model of a vehicle type that can receive a technology package); 3) technology costs 4) Properties of the technology package, such as refrigerant type, fuel type, electricity usage, credit value, and applicable fuel.

Each tab in the Technology input file contains a user-defined list of technology packages for all of the different vehicle types. This list is organized in ascending order by the vehicle type to which it applied (Column A), and then by ascending technology package (Column B). The user need not use the full 20 lines for each vehicle type, but can stop after the last technology package has been listed. There cannot be any blank lines between technology packages or vehicle types. The user must record the technology packages within each vehicle type from top to bottom in the order of how the model should add them to the particular vehicle. In typical OMEGA usage, each package is replaced by the subsequent technology package, so it is critical that packages improve in aggregate CO_2 reduction. The user records a description of the technology package in Column C, and an abbreviation, if desired, in Column D. The abbreviation of the last technology package added is displayed in the output files.

Column E contains the maximum market penetration caps for the technology packages. When technology is sufficiently new, or the lead-time available prior to the end of the redesign cycle is such that it is not reasonable to project that it could be applied to all vehicle models that are of the same specific vehicle type (i.e,; all minivans), the user can limit its application to minivans through the use of a market cap of less than 100%. If subsequent technology packages can be applied to the vehicle, the user should consider whether in reality the new technology would likely be applied to those vehicles which received the previous technology or those which did not, and design the technology file accordingly. The effectiveness of adding the subsequent technology will depend on which vehicles are receiving it.

Column F contains the Average Incremental Effectiveness (AIE) of the technology package over the previous package (or over the baseline in the case of technology package 1). For example, a value of 7.0% in the AIE column would denote a 7.0% tailpipe CO_2 improvement beyond any CO_2 improvements already realized. ("Tailpipe CO_2" refers to the CO_2 emitted over the test cycle assumed to be used to determine compliance- which relates it to vehicle efficiency.) This value of 7% would include any synergistic effects that components of the technology package may have with technologies that are remaining on the vehicle type.

Column G contains the incremental technology package cost, which represents the cost beyond the cost of other technology packages that the model may have added in a previous step. In the specific case of technology package 1 on each vehicle type, this will be the package cost over the baseline, since no other technology has been added prior to technology package 1.

Column H and I respectively contain the fuel used by the vehicle after addition of the technology package, and the fuel of the vehicles to which the technology package applies. These fuel abbreviations must also appear in the Fuels input file, and are case specific.

Column J contains the electrical conversion percentage. Each technology package potentially has an "electricity conversion percentage," which refers to the increase in the grid-supplied electrical energy consumed by the electric drivetrain relative to reduction in the consumption of energy from liquid fuel. More specifically, the electricity conversion percentage is the ratio of the increase in grid-supplied electrical energy used by the vehicle (in BTU per mile) divided by the reduction in liquid fuel use (also in BTU per mile), multiplied by 100%. Electricity is a highly refined form of energy which can be used quite efficiently to create kinetic energy. Thus, electric motors are much more efficient than liquid fuel engines. Consequently, the electric consumption percentages input in the Technology File for plug-in hybrid vehicles and battery electric vehicles are generally well below 100%. It may be possible that this percentage could exceed 100% under certain circumstances, for example when one type of plug-in vehicle is being converted into another plug-in vehicle and electricity consumption per mile is increasing due to larger and heavier batteries, etc.

Column K contains a gram per mile credit that is applied to this technology step when calculating the TARF CO_2 values. As described above, the OEB, rather than this credit value, is used in calculating the compliance CO_2 for a vehicle using this technology package. However, this value is used in computing the TARF.

Column L contains the refrigerant effectiveness and is based on the fraction reduction in direct refrigerant leakage emissions and is separate from tailpipe CO_2. Based on a change in refrigerant included as part of a technology package, noted in Column V, the model will convert the refrigerant emissions to grams per mile of CO_2 equivalent emissions, and add the resultant to the tailpipe CO_2 emissions for the vehicle compliance calculation. A value of “NC” in column M denotes that there is “No Change” in refrigerant from the previous step, or in the case of technology package 1, no change from the baseline refrigerant.

C The Fuels File: Physical Properties and Prices of Fuel and Energy Sources

The Fuels input file contains data relevant to liquid fuel and electricity, including energy, mass, and carbon density, and annual price forecasts for up to 20 years. Similar to the other input files, the fuels input file is comprised of two worksheets: A worksheet containing data used by the model and an additional worksheet designed to ensure that the data is within allowable ranges. There is a third hidden worksheet which contains the range of allowable values. Table 3 describes the layout and content of the “fuel” tab in the fuels input file.

Table 3 - Input Data in Fuel Worksheet of the Fuels File

Column(s)	Contents
A	Fuel Type
B	Energy Density
C*	Mass Density*
D	Carbon Density
E	CAFE Equivalency Factor
F - Y	Fuel Price ($/gal)

*The columns highlighted in gray are not used by the model’s calculations.

Column A describes the fuel type. This value can be any descriptor desired, but EPA typically specifies gasoline as “G”, diesel fuel as “D,” etcetera. The one exception is that electricity must be designated as “EL”, in order for the model to connect inputs like the electricity conversion factor with this fuel. Please note that the fuel names in this file must match the fuels in the technology and market files at a case specific level.

Column B contains the energy density of the energy source. For the liquid fuels, this factor has the units of BTU per gallon. Electricity has the units of BTU per kilowatt-hour, which is essentially a fixed conversion factor. This factor is used when a technology package increases the ability of the vehicle to operate on grid-supplied electricity. It is used in conjunction with the electrical conversion factors listed in the technology file.

Column C contains the mass density of the liquid fuels in terms of grams per gallon, and is not used in the model.

Column D describes the carbon density of the energy source, and is used in the calculation of the fuel savings component of the TARF[9] as well as in the compliance calculations. Carbon density is specified in units of grams of carbon per gram per the unit of fuel

[9] TARF formulas are discussed on page 26.

which is associated with the fuel price. For liquid fuels, this is grams of carbon per gallon and for electricity this is grams of carbon per kWh. If a user wishes to incorporate the upstream emissions of the carbon content of CO_2 emissions in the TARF and compliance calculations, they could enter a positive value in this cell. Please note that these emission values are in terms of grams of carbon, not grams carbon dioxide.

Column E contains the CAFE equivalency factor used in the calculation of manufacturer fines. If there is a fine, and if the manufacturer fails to meet the target, then the TARF rankings would change. However, because the OMEGA model does not allows the manufacturer to choose to pay fines, this input should typically be set to 1.[10]

Columns F through Y contain the fuel price either in US Dollars per gallon or US Dollars per kWh for liquid fuel and electricity, respectively, for 20 calendar years. Fuel prices are to be input in ascending order by year and are used when calculating the fuel savings over the payback period in the TARF. The first calendar year listed should be that of the baseline year plus one.

D The Scenario File: Definition of Regulatory Scenarios and Other Economic Parameters

The Scenario input file contains data specifying the number and types of model runs. The Scenarios tab acts as a directory for different model runs, where the user can create an entry for any number of runs that the model can perform in succession. In the Scenarios tab, the user must specify the base year, type of compliance target (CO_2 or MPG), type of compliance function, the number of redesign cycles, and the names of the other input files that describe the vehicle fleet, technology packages, and fuel properties. At present, the model is limited to a CO_2 equivalent standard. The elements in the "Scenarios" tab described above are summarized in the following table:

[10] In other words, the OMEGA model's technology application algorithm only ceases to apply technology when a manufacturer comes into compliance, or when all technology options have been exhausted. There is no option to pay fines rather than comply through technology.

Table 4 - Input Data in Scenarios Worksheet of the Scenario File

Column(s)	Contents
A	Scenario ID number
B	Scenario name
C	Baseline year
D	Target Type
E	TARF Option
F	GHG Target Function Type
G	Fleet type (single or combined)
H	Number of redesign cycles
I	Fleet trading limit
J	Market input file indicator
K	Technology input file indicator
L	Fuels input file indicator
M	Reference input file indicator

*The columns highlighted in gray are not used by the model's calculations.

Column A in the Scenarios tab indicates the ID number of the model run. From a single scenario file, the model can run as many different scenarios as the user desires. In Column B, the user can give each scenario a name, which the model will use in naming the output directory and files for each scenario. Column C denotes the baseline year for each scenario. This is the year prior to the first year of the first redesign cycle. Column D indicates the type of standard or target (CO_2 or MPG) the model will use for compliance, and is not currently active in the model.

Column E is where the user designates which of the three TARF equations the model should use. The model uses the TARF equations to determine the order of technology package application on the different vehicle models. There are three TARF equations which are summarized below and are described in detail on page 32.

1. Effective Cost = [Technology package cost minus fuel savings over the payback period].
2. Cost Effectiveness-Society = [Effective Cost] divided by discounted lifetime CO_2 emissions.
3. Cost Effectiveness -Manufacturer = [Effective Cost] Divided by lifetime CO_2 emissions.

Column F indicates the user's preference for type of function for the industry-wide GHG level. There are four options for compliance targets: 1 = universal; 2 = piecewise linear; 3 = constrained logistic.

D.i Universal Target

The universal target option is a numeric designation which the manufacturers' average fleet CO_2 cannot exceed. For a universal standard (which could apply to cars, trucks or cars and trucks combined), only the value listed in the first of each set of the four coefficients is used (Labeled "A" in the header row of the Target worksheet).

D.ii **Piece-wise Linear**

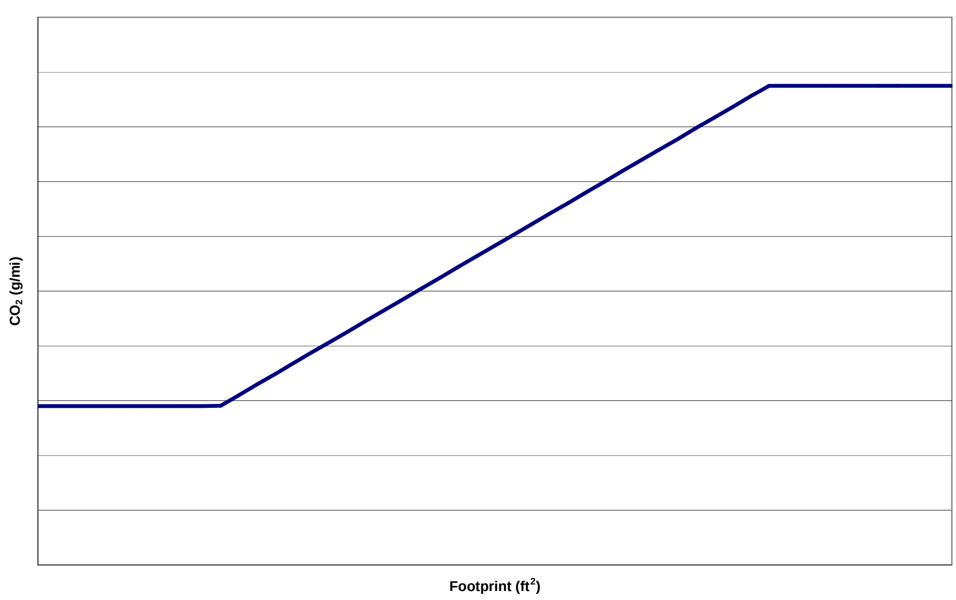
The attribute-based linear target function is described by up to four coefficients and has the following piecewise linear mathematical form:

$$y = \begin{cases} A; FP < FP_{\min} \\ [\dfrac{B - A}{FP_{\max} - FP_{\min}}] * (FP - FP_{\min}) + A; FP_{\min} \le FP < FP_{\max} \\ B; FP \ge FP_{\max} \end{cases}$$

Where
A: Minimum level of CO_2 target
B: Maximum level of CO_2 target
FP_{min}: Footprint value where CO_2 target reaches minimum value (i.e., intersection of lower asymptote with slope)
FP_{max}: Footprint value where CO_2 target reaches maximum value (i.e., intersection of upper asymptote with slope)
FP: Vehicle footprint (square feet)

When inputting a piece-wise linear target into the Target worksheet, FP_{min} and FP_{max} should be respectively entered in the C and D coefficient columns.

Example of Footprint-Based CO_2 Piecewise Linear Target Function

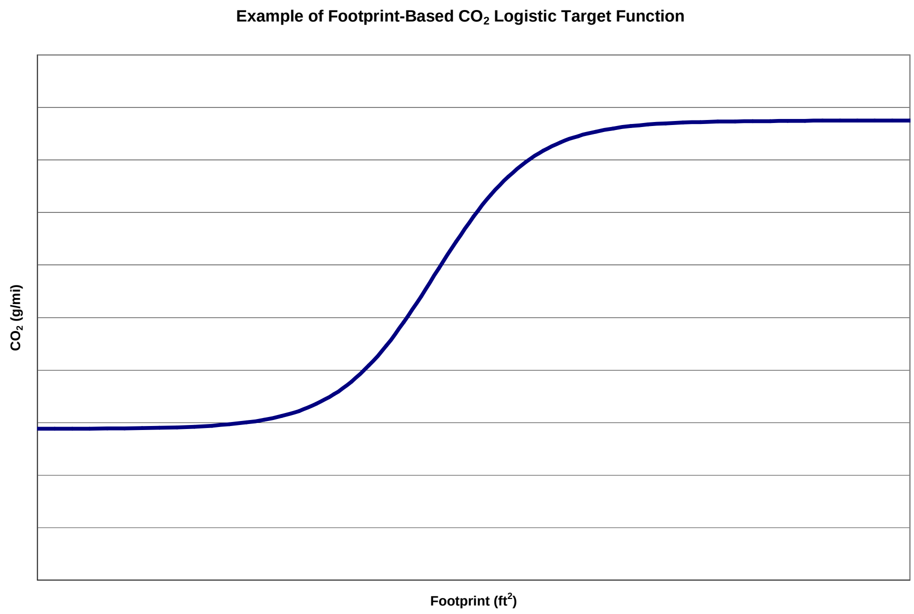


D.iii Logistic Curve Target

The footprint-based logistic curve (shown below) is described by four coefficients and has the mathematical form described below.

$$T = A + (B - A)\left(\frac{e^{\frac{FP-C}{D}}}{1 + e^{\frac{FP-C}{D}}}\right)$$

Where A, B, and FP have the same definitions as above
C: Footprint value at equation inflexion point (i.e., midpoint)
D: The term which controls the rate at which the CO_2 target moves from the minimum to maximum values. High values of D cause the curve to move slowly (in terms of footprint) from the minimum to maximum target (i.e., a sort of "inverse slope")
FP: Vehicle footprint



Column G of the Scenarios tab in the Scenario input file is entitled “fleet type.” There are two acceptable values for cells in this column: 1 = 1 fleet and 2 = 2 fleets. If 1 is chosen, the standard defined in the “Standards” tab will be taken from the “Car” standard section and applied to all of the vehicles listed in the market file, whereas if 2 is chosen, the standards will be defined by both the “Car” and “Truck” standard sections and applied to cars and trucks separately.

Column H contains the number of redesign cycles the model considers in a given run. There can be as few as one redesign cycle and as many as eight. The model allows any length to be assumed for a redesign cycle, as long as the redesign cycle length is the same for all vehicles. The inputs should be designed appropriately to reflect the user’s assumptions.

Column I contains the limit (in units of g/mi CO_2) imposed on the trading of compliance credits between cars and trucks.

Columns J-M indicate which files the model will access for the different runs. Column J contains the name of the market input file; column K contains the name of the technology input file; column L contains the name of the fuels input file; column M contains the name of the References file. All files must be in the same directory as the scenario file.

The Scenario input file also contains the economic parameters that the model uses to calculate the TARF equations. Such economic data is contained in the “Economics” tab and is organized as illustrated in the following table:

Table 5 - Input Data Contained in the Economics Worksheet of the Scenario File

Column(s)	Contents
A	Scenario ID number
B	Discount rate
C	Payback period
D	CAFE fine
E	Gap
F	Threshold cost
G	CO_2 value increase rate
H	EPA Lifetime VMT – Car
I	EPA Lifetime VMT - Truck

Column A contains the ID number for the model run, and it must be identical to that in Column A of the Scenarios tab.

Column B contains the discount rate for future dollar values. The model uses the discount rate in the TARF calculations when calculating the fuel savings over the payback period.

Column C designates the payback period over which consumers are believed to consider fuel savings when purchasing a vehicle.

Column D indicates the value of a fine for non-compliance. EPA typically records $0 into this column. Changes to this value will affect the TARF, but not allow fine payment.

Column E contains the gap, which is the percentage difference between on-road fuel economy and test cycle fuel economy. This value is important because compliance is based on test cycle CO_2, whereas the true impact on climate is based on the on-road CO_2 and consumer fuel savings are based on on-road fuel economy. The model uses this difference to convert test cycle CO_2 emissions to on-road fuel economy and calculate fuel savings in the core model's TARF equations, as described further on page 32 below.

Column F contains the value for the "threshold cost". This value determines whether the model will accept some degree of over-compliance when it determines the degree of technology addition needed for a manufacturer to meet a standard, or if it will reduce the addition of technology so that a manufacturer just barely complies. Specifically, if the per vehicle cost of the last technology added by the model in order to reach compliance exceeds the threshold value, the model reduces the percentage of that vehicle's sales which receives that technology to just the degree needed to enable compliance. If the per vehicle cost of the last technology added by the model in order to enable compliance is below the threshold value, the model leaves the percentage of vehicle sales receiving that technology at the technology penetration cap for that technology.[11]

Column G represents the rate of increase in the real value of CO_2 emission reductions over time. This value is included since some studies have predicted that the real value of CO_2 emission reductions will increase over time as the impact of global climate change increase. The units of this term are percent per annum. This value is used in the Cost Effectiveness-Society TARF described below.

Columns H and I contain the statutory lifetime miles driven by cars and trucks.   These values are used to calculate the credit trading ratio between cars and trucks. Because real VMT tends to grow over time, but the VMT used in the credit trading equation is determined by regulation, this value can differ from the VMT in the reference file (described below). For example, the lifetime VMTs per vehicle for cars and trucks provided in EPA's current GHG regulations are 195,264 and 225,865, respectively.[12]

The Target tab of the Scenario file contains the parameters describing the GHG compliance targets required by the universal, piece-wise linear and constrained logistic functions described above. The first 40 columns describe the car standards for up to eight redesign cycles, if "2" fleets are selected in column G of the Scenarios worksheet. If "1" fleet is selected, then the standards described in Columns A through AO apply to both cars and trucks. Similarly, the next 40 columns (AP through CC) describe the truck standards for up to eight redesign cycles if "1" fleet is selected. This second set of values is not used if "1" fleet is selected. This is described in Table 6.

[11] This flexibility was included in the model to reflect the different ways in which manufacturers apply various technologies. For example, when adding basic engine technology such as variable valve timing, the manufacturer would generally convert the entire production volume of a specific engine to this technology. The production of two otherwise identical engines, one with the technology and one without, would likely not be maintained. However, with more extreme technologies, such as dieselization or hybridization, the manufacturer often maintains two versions of the vehicle, one with and one without these technologies. By setting the threshold in between the costs of these two examples, the model will reflect these two approaches to technology application on the part of a manufacturer.

[12] However, while the user may choose to model different statutory and accumulated VMT, differences in this values can yield to counter-intuitive TARF values.

Table 6 - Input Data Contained in the Target Worksheet of the Scenario File

Column(s)	Contents	Vehicle Class
B – F	Coefficients describing the CO_2 Standard for Design Cycle 1	Car If "2" fleets selected Car and Truck if "1" fleet selected
G – K	Coefficients describing the CO_2 Standard for Design Cycle 2	
L – P	Coefficients describing the CO_2 Standard for Design Cycle 3	
Q – U	Coefficients describing the CO_2 Standard for Design Cycle 4	
V-Z	Coefficients describing the CO_2 Standard for Design Cycle 5	
AA – AE	Coefficients describing the CO_2 Standard for Design Cycle 6	
AF – AJ	Coefficients describing the CO_2 Standard for Design Cycle 7	
AK – AO	Coefficients describing the CO_2 Standard for Design Cycle 8	
AP – AT	Coefficients describing the CO_2 Standard for Design Cycle 1	Truck If "2" fleets selected Not used if "1" fleet selected
AU – AY	Coefficients describing the CO_2 Standard for Design Cycle 2	
AZ – BD	Coefficients describing the CO_2 Standard for Design Cycle 3	
BE – BI	Coefficients describing the CO_2 Standard for Design Cycle 4	
BJ – BN	Coefficients describing the CO_2 Standard for Design Cycle 5	
BO – BS	Coefficients describing the CO_2 Standard for Design Cycle 6	
BT – BX	Coefficients describing the CO_2 Standard for Design Cycle 7	
BY – CC	Coefficients describing the CO_2 Standard for Design Cycle 8	

As indicated, each CO_2 standard is described by up to five coefficients. For a universal standard, only the value listed in the first of each set of four columns is used (Labeled "A" in the header row of the Target worksheet). The first four columns are required to describe either the segmented linear or constrained logistic functions described above.

E The Reference File: Vehicle Survival Rates and Miles Driven

The Reference file contains car and truck annual miles driven and survival rates by year. These estimates are used in the cost effective TARF (1) and the cost effectiveness-society TARF (2) calculations when determining fuel savings over the payback period and in the cost effectiveness-manufacturer TARF (3) when determining the lifetime CO_2 reduction. TARF 3 uses the statutory VMT values in the scenario file.

The vehicle survival and VMT estimates are inputted in the tab entitled Vehicle Age. Column A in this tab contains the vehicle age in years. Columns B and C contain the percentage of cars and trucks still projected to be on the road of the specified ages, respectively. Columns D and E contain the average miles driven annually (per vehicle) for cars and trucks, respectively, for vehicles of the specified ages.

The Refrigerant tab contains data which is only used if refrigerant emissions are included in the market file. A dynamic list of acceptable refrigerants can be created, and accompanied with their respective global warming potential. Column A is the refrigerant name, while column B is the GWP.

F Non-editable Input Data

The only values "hard-coded" into the model which are potentially used in the application of technology to vehicles are the distribution of leakage rate by vehicle age.

The following table describes the refrigerant leakage rates which are currently hard-coded.

Table 7 – Refrigerant leakage rates

Refrigerant Leakage Fractions			
Year	% of Total Lifetime Leakage g/year	Year	% of Total Lifetime Leakage g/year
1	1.1%	19	3.3%
2	1.5%	20	2.7%
3	2.0%	21	2.3%
4	2.4%	22	1.8%
5	2.9%	23	1.4%
6	3.3%	24	1.1%
7	3.6%	25	0.9%
8	4.4%	26	0.7%
9	5.5%	27	0.0%
10	6.9%	28	0.0%
11	8.5%	29	0.0%
12	8.1%	30	0.0%
13	7.5%	31	0.0%
14	7.0%	32	0.0%
15	6.5%	33	0.0%
16	6.0%	34	0.0%
17	4.8%	35	0.0%
18	3.9%	36	0.0%

EPA intends to make this data editable in a future version.

G Input Files Currently Distributed with Model

The sample files bundled with the installation file contain example or "dummy" data and are only indicative of realistic values. The input files from recent rulemaking analyses are available on the EPA OMEGA webpage.

IV Model Operation

A Calculating Technology Effective Basis (TEBs) and Cost Effective Basis (CEBs)

The market data input file utilized by OMEGA, which characterizes the vehicle fleet, is designed to account for the fact that the vehicles which comprise the baseline fleet may already be equipped with one or more of the technologies available in general to reduce CO_2 emissions. As described previously, OMEGA is typically used with technologies in packages, as opposed to one at a time. However, actual vehicles are equipped with a wide range of technology combinations, many of which cut across the packages. Thus, EPA developed a method to account for the presence of the combinations of applied technologies in terms of their proportion of the technology packages. This analysis can be broken down into four steps

The first step in the process is to break down the available GHG control technologies into five groups: 1) engine-related, 2) transmission-related, 3) hybridization, 4) weight reduction and 5) other. Within each group we gave each individual technology a ranking which generally followed the degree of complexity, cost and effectiveness of the technologies within each group. More specifically, the ranking is based on the premise that a technology on a baseline vehicle with a lower ranking would be replaced by one with a higher ranking which was contained in one of the technology packages which we included in our OMEGA modeling. The corollary of this premise is that a technology on a baseline vehicle with a higher ranking would not be replaced by one with an equal or lower ranking which was contained in one of the technology packages which we chose to include in our OMEGA modeling.

In the second step of the process, we use these rankings to estimate the complete list of technologies which would be present on each baseline vehicle after the application of each technology package. We then use the EPA lumped parameter model to estimate the total percentage CO_2 emission reduction associated with the technology present on the baseline vehicle (termed package 0), as well as the total percentage reduction after application of each package, including any baseline technology still expected to remain present after the application of each package. Similarly, we use a cost estimation tool to estimate the cost of the CO_2 reducing technology present on the baseline vehicle and after the addition of each package.

The third step in this process is to convert these total levels of emission control effectiveness and cost to TEB and CEB[13] values which can be used when the OMEGA model applies technology packages on an incremental basis. This is done by comparing each technology package's incremental effectiveness and incremental cost on each specific vehicle to those of the package when applied to a vehicle with no baseline technology. The value of each vehicle's TEB for each applicable technology package is determined as follows:

[13] As described earlier, the degree to which a technology package's incremental effectiveness is reduced by technology already present on the baseline vehicle is termed the technology effectiveness basis, or TEB, in the OMEGA model. The degree to which a technology package's incremental cost is reduced by technology already present on the baseline vehicle is termed the cost effectiveness basis, or CEB, in the OMEGA model.

$$TEB_i = \frac{1-\left(\frac{TotalEffect_{v,i-1}}{1-TotalEffect_{v,i}}\right)\times\left(\frac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}{\left(1-\frac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}$$

Where

$TotalEffect_{v,i}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i
$TotalEffect_{v,i-1}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i-1
$TotalEffect_{p,i}$ = Total effectiveness of all of the technologies included in technology package i
$TotalEffect_{p,i-1}$ = Total effectiveness of all of the technologies included in technology package i-1
i = the technology package being evaluated
i-1 = the previous technology package

Equation A-1 – TEB calculation

The value of each vehicle's CEB for each applicable technology package is determined as follows:

$$CEB_i = 1 - (TotalCost_{v,i} - TotalCost_{v,i-1}) / (TotalCost_{p,i} - TotalCost_{p,i-1})$$

Where

$TotalCost_{v,i}$ = total cost of all of the technology present on the vehicle after addition of package i to baseline vehicle v
$TotalCost_{v,i-1}$ = total cost of all of the technology present on the vehicle after addition of package i-1 to baseline vehicle v
$TotalCost_{p,i}$ = total cost of all of the technology included in package i
$TotalCost_{p,i-1}$ = total cost of all of the technology included in package i-1
i = the technology package being evaluated
i-1 = the previous technology package

Equation A-2 – CEB calculation

The fourth step is to combine the TEB and CEB values for each individual vehicle models to match the vehicles being included in the Market file. The CEB for each vehicle group is simply the sales-weighted average of the CEB values for each individual vehicle model, since the cost of each package is the same for each vehicle in a vehicle type. (Only vehicles of the same vehicle type should be combined.) The TEB for each vehicle group is determined in a slightly more complex fashion. The individual TEB values are weighted by both sales and base CO_2 emission level. This appropriately weights vehicle models with either higher sales or CO_2 emissions within a vehicle type. Once again, this process prevents the model from adding technology which is already present on vehicles, and thus ensures that the model does not double count technology effectiveness and cost associated with complying with the reference standards or the CO_2 control scenarios.

B Calculating Other Effectiveness Basis (OEBs)

As noted above, the market data input file utilized by OMEGA is also designed to account for the fact vehicles may not have the exact equipment in the package after the package is applied. This is particularly relevant in the context of a regulatory incentive for specific technologies. As an example, if incentives are provided for start-stop systems, the model needs to know whether that vehicle contains a start-system in order to provide the credit. If a vehicle platform already contains start-stop before any packages are applied, the model needs to account for the baseline credit impacts of the technology. As it varies at the vehicle, rather than vehicle type, level, this accounting needs to occur at the level of the market file rather than the technology file.

However, it is important that the technology packages are ranked in the same order for all vehicles in a vehicle type. Therefore, the TARF is calculated with the credit value in the technology file, but the compliance CO_2 value is calculated using the vehicle specific value.

C Platform Aggregation

The market file includes a vehicle Platform Index (see the description of the new market.xls file layout in section 2A.) Vehicles with the same Platform Index share a common Vehicle Type and engine configuration. While every entry in the market.xls file has a unique Vehicle Index, several vehicles may share the same Platform Index. Vehicles in a single platform should share vehicle class and vehicle type.

In some analytical situations it is useful to have a market file with a single record for every unique manufacturer / platform combination.[14] This requires combining individual vehicles with matching manufacturer / platforms into single representative records. Since OMEGA already loads all of the information necessary to perform this calculation, EPA has chosen to include creation of a manufacturer / platform version of the market file as a standard feature in the model.

After loading the market file, OMEGA performs the necessary calculations and creates a Platform Aggregation version of the market file, and then uses this new market file in the subsequent OMEGA run. The new output data set is tab-delimited with a layout matching the market.xls file (the output filename is *X-Market-Platform_Mfr.log*, as shown in Table 8.)

Records in the manufacturer / platform file are created by calculating weighted average values for the vehicle records with matching manufacturer and platform codes.

The following data elements in the market file are calculated as a sales weighted average using the Annual Sales in Cycle 1:

- CO_2 (grams per mile)
- Footprint (ft^2)
- Curb Weight (pounds)
- Displacement (Liters)
- Horsepower
- Max Seating
- Towing Capacity (pounds)

[14] This is how EPA has typically run the model, although this calculation is typically done in a spreadsheet, rather than through using this model feature.

- Combined EC (kWh/mi)
- Refrigerant Lifetime Leakage (grams)
- CEB_Tech_1-CEB_Tech_50
- Combined Miles per Gallon (harmonically averaged)

The following data elements in the market file are calculated as a sales-CO_2 weighted average using CO_2 * Annual Sales in Cycle 1:

- TEB_Tech_1-TEB_Tech_50;
- OEB_Tech_1-OEB_Tech_50;[15]

Vehicle sales (baseline and annual sales) are the sum of sales in the individual vehicle records. All other data elements are set equal to the values found in the first vehicle in the manufacturer / platform set.

D Technology Application

The technology application portion of the model can be described in several steps. The first step determines the effective CO_2 emission standard for each manufacturer and vehicle class. The second step converts the baseline lifetime refrigerant emissions specified for each vehicle into its g/mi CO_2 equivalent and adds this to the baseline tailpipe CO_2 emissions for each vehicle. The third step applies technology until this standard is met or all available technology has been applied. These steps are described below.

D.i Determination of Manufacturer-Specific CO_2 Emission Standards

As described above, three types of standards can be evaluated by OMEGA: universal or flat, piecewise linear, and constrained logistic. Determining each manufacturer's effective standard under a flat standard is simple; it equals the flat standard. The other two types of standards require sales-weighting the CO_2 target applicable to each specific vehicle model produced by that manufacturer. Under these standards, the model calculates each vehicle's CO_2 target by plugging the vehicle's footprint into the formula describing the standard. Each of the vehicle-specific targets are then multiplied by the vehicle's sales in that redesign cycle and the statutory lifetime VMT for that vehicle class and summed across all vehicles. The sum is then divided by the sum of the product of vehicle sales by that manufacturer in that redesign cycle and the lifetime VMT for each vehicle. The result is a sales and lifetime VMT weighted corporate average CO_2 target for each manufacturer's relevant set of vehicles (i.e., cars, trucks, or cars and trucks combined).

If one fleet is specified, then the model only performs this calculation once and includes both cars and trucks in the calculation. If separate standards are specified for cars and trucks, then the model performs this task twice for each manufacturer for each redesign cycle being modeled: once for cars and once for trucks. If the same standard is specified for both cars and trucks and two compliance fleets are specified in the Scenario file, then two separate calculations are still performed. The result is still two distinct CO_2 emission targets, one for cars and one for trucks.

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[15] This weighting will be changed to sales-weighted only in future model versions, which is consistent with the methodology used in the MY 2017 and later light duty greenhouse gas rulemaking.

If a trading limit of “0” is specified, then this stage of the model operation is complete. If a non-zero trading limit is specified, an additional step is required to ensure that this trading limit is not exceeded, as described in the section below on credit trading algorithms. Conceptually, we assume that a manufacturer would prefer to evaluate the application of technology to both its cars and trucks at the same time in order to optimize compliance (via the TARF) over the widest set of vehicles. At the same time, the manufacturer is assumed to want to avoid generating credits from one of its two vehicle class fleets which cannot be used by the other fleet due to the limit on trading, since it would incur cost with no benefit.

D.ii Converting Lifetime Refrigerant Emissions to CO_2-Equivalent emissions per Mile

Refrigerant leakage emissions are input to the model in terms of lifetime emissions, where refrigerant leakage increases with wear and tear of the A/C system. Leakage emissions also occur during accidents, repairs and vehicle scrappage. Refrigerant emissions per year increase significantly with age. Since annual mileage decreases with age in general, refrigerant emissions per mile increase even more significantly with age than emissions per year. In contrast, CO_2 tailpipe emissions are input in terms of g/mi and are generally assumed to be constant with age. Thus, some processing is needed to ensure that the leakage rates for the two types of emissions are comparable.

OMEGA converts lifetime refrigerant emissions to their equivalent value in terms of CO_2 emissions per mile (RCO_2) considering the change in societal value of CO_2 emissions over time. The goal is to estimate a level of CO_2 emissions per mile, which, if constant over the vehicle’s life, like tailpipe CO_2 emissions are generally assumed to be, would produce the same societal value of CO_2 emissions as the distribution of refrigerant emissions over the life of the vehicle. This equality is shown in the following equation:

Equation 3 – Conversion of refrigerant emissions to equivalent lifetime emissions

Value of Equivalent Lifetime CO_2 Tailpipe Emissions =

Value of Lifetime Refrigerant Emissions

$$RCO2 * \sum_{i=1}^{L} [VMT_i * ValueofCO2_i] = GWP * \sum_{i=1}^{L} [RefLeakage_i * ValueofCO2i]$$

Where:

VMT_i = the annual miles travelled for the relevant class of vehicle at age i, (i.g., VMTi = Survival Fraction for a vehicle of age i times the annual vehicle miles driven for a vehicle of age i as input in the Reference file),
L = the lifetime of the vehicle.
$ValueofCO_{2i}$ = the societal value of CO_2 emissions in the calendar year when the vehicle is at age i,
$RefLeakage_i$ = the annual rate of refrigerant emissions when the vehicle is at age i, and
GWP is the global warming potential of the refrigerant relative to CO_2.

The value of CO_2 in a particular year can be described as its base value divided by one plus the applicable discount rate raised to the power of the age of the vehicle. In this case, the applicable discount rate is the societal discount rate less the rate of increase in the real value of CO_2 emissions. Since the normal discounting equation assumes that the relevant activity (e.g., payment) occurs at the end of the year and emissions occur throughout the year, we multiply by one plus half of the applicable annual discount rate. The resulting equation is described as follows:

$$RCO2(g/mi) * \sum_{i=1}^{L} [VMT_i * BaseValueofCO2 * \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}] =$$

$$GWP * \sum_{i=1}^{L} [RefLeakage_i * BaseValueofCO2 * \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}]$$

This equation can be rearranged to solve for the level of CO_2 equivalent emissions per mile as shown in the next equation. (Note that the societal value of CO_2 in the base year falls out of the equation.)

$$RCO2(g/mi) = \frac{\sum_{i=1}^{36} \left[LeakRate_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right] \times GWP}{\sum_{i=1}^{36} \left[VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right]}$$

There are other approaches to converting lifetime refrigerant emissions to their g/mi equivalent level. Future versions of OMEGA may provide the user with several approaches from which to select. One approach would be to simply allow the user to specify a baseline value for g/mi CO_2 equivalent refrigerant emissions in the Market file. This way, the user could use whatever approach was deemed appropriate to estimate this value. Another approach would be the same as the above, except to base the equivalency on physical emissions and remove the factors involving discounting. Therefore, if the user desires to perform this equivalency using physical emissions, they should set the rate of increase in the societal value of CO_2 emission reductions to equal the overall societal discount rate being specified. This will cause all of the discount factors in the above equation to be equal to 1.0. Then, if the user desires to use a different rate of increase in the societal value CO_2 emission reductions in the estimation of benefits, they can change this value in the benefits calculation spreadsheet.

D.iii Application of Technology - Methodology

The portion of the model which applies technology can most easily be described as the multiple application of three logical steps. The first step is to determine the vehicle in the "best" position to receive the next technological improvement to enable the manufacturer to meet the specified CO_2

emission standard. The second step is to apply this technology, reduce the vehicle's emissions accordingly and add the cost of this technology to the manufacturer's total cost for this redesign cycle. The third step is to assess the compliance situation and act accordingly. If the standard applies to cars only, trucks only, cars and trucks combined with a single standard, or cars and trucks combined with two distinct standards and a zero trading limit (i.e., no trading), the model will:

- Recalculate the manufacturer's sales and VMT-weighted emissions and compare this new corporate average emission level to the manufacturer's standard
  - If the manufacturer is now below the standard, determine if the cost of the last technology is above or below the threshold cost specified
    - if the cost is below the threshold, the evaluation of this manufacturer is over and the model moves onto the next manufacturer;
    - If the cost is above the threshold, the percentage of sales which receive the technology is decreased until the standard is just met; the evaluation of this manufacturer is over and the model moves onto the next manufacturer.
- If the manufacturer is still above the standard, the model goes back to steps 1 and 2 above and applies another technology package to further reduce emissions. If no more technology packages are available, the model moves onto the next manufacturer.

If a non-zero trading limit is specified, the model will follow largely the same procedure, but additionally will consider the credit trading algorithms.

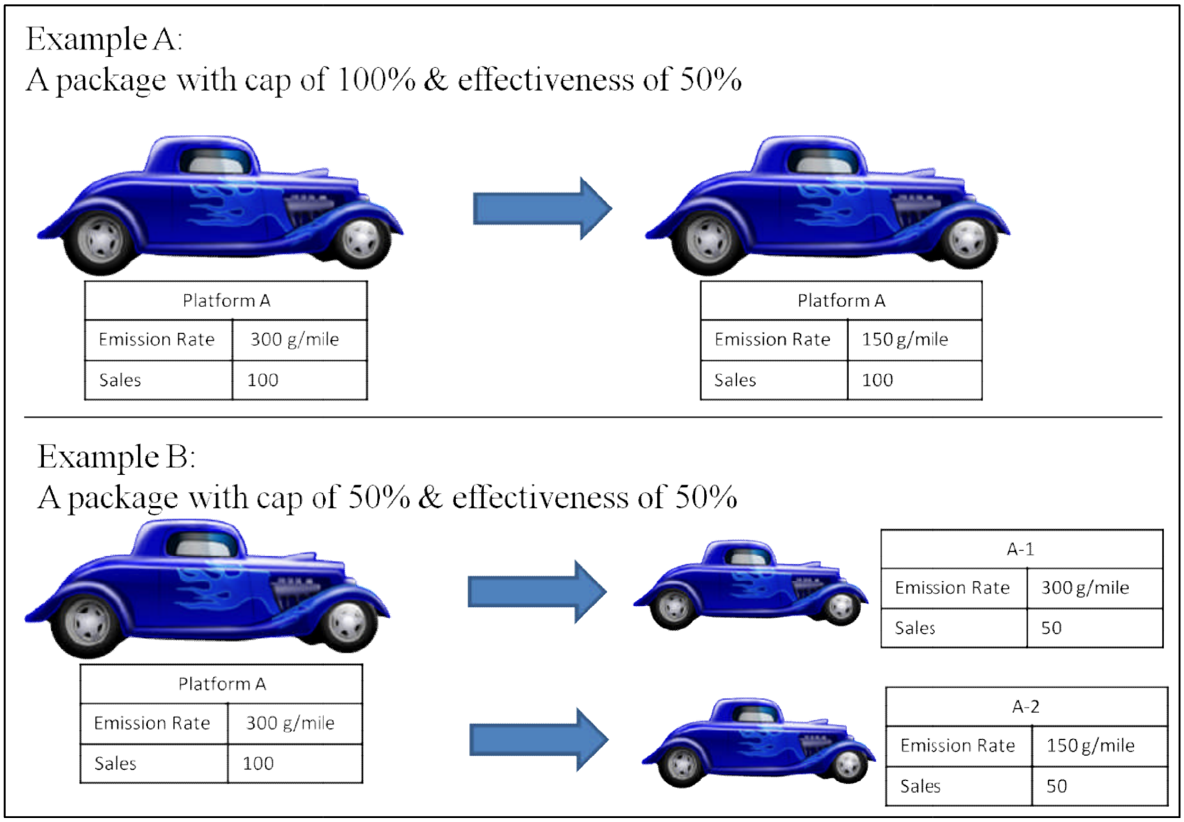
Once all manufacturers are in compliance or have exhausted the technology available for their vehicles, the model moves to the next redesign cycle and repeats the above sequence of steps. The evaluation of the second and any subsequent redesign cycles starts from scratch in that every vehicle begins with only those technologies present in the Market file. In other words, the model does not start with the technology added in previous redesign cycles. The assumption behind this aspect of the model is that manufacturers have the flexibility to reevaluate technology each time a vehicle is being redesigned. This could involve the evaluation of a technology which was not available in the prior redesign cycle or a technology which had a maximum penetration cap of less than 100%. Of course, starting the analysis over each redesign cycle could lead to situations where a manufacturer is projected to utilize several very different technologies for most of their vehicles in each of several redesign cycles. The user would have to evaluate the reasons for such an outcome and determine if the inputs were reasonable or required modification.

The application of technology, described conceptually above, is described in more detail below. In the following formulae, the subscripts (t-1) and (t) indicate vehicle conditions before and after applying technology package "t", respectively.

D.iii.a Use of Technology phase in "Caps"

OMEGA 1.4.0 tracks CO_2 emissions by fuel and at each package application step within each vehicle. Conceptually, a vehicle platform is composed of vehicles, each with its own fuel, CO_2 emission rate and energy consumption rate. When a technology is fully available (when its cap is 100%), it can be applied to all vehicles within a platform. However, when the cap is less than 100%, OMEGA applies the technology to only a portion of the vehicle platform. An example follows (Figure IV-1).

Figure IV-1 – Application of packages



This model feature simplifies the ability to apply technology packages which have caps of less than 100%. By effectively treating the cap limited packages as separate segments within a platform, we simplify the addition of subsequent technologies to the subset of vehicle sales with this technology and those without it.

Applying the caps at the vehicle platform level is consistent with our platform based approach, in that many cap limited technologies would not necessarily replace all instances of other technologies on a platform. As an example, consider a hybrid package, which is often offered in parallel to a conventional engine package.

D.iii.b Credit Trading

As the Clean Air Act allows credit trading between a manufacturer's car and truck fleets, OMEGA allows the user to utilize a full range of credit trading scenarios. This trading is controlled in OMEGA in column I of the scenarios tab of the Scenario input sheet. Entering a zero into this column prevents credit trading and requires manufacturers to comply with the relevant emission standards for their cars and its trucks separately. If the user wants to allow unlimited trading, this is accomplished by inputting a large non-zero number in Column I (e.g., 1000 g/mi CO_2). This effectively allows the model to apply technology across both cars and trucks and meet the combined standard described above. We say "effectively", because the model still checks to ensure that the trading limit is not triggered and this cannot be definitively determined until compliance is achieved at the end of the evaluation of this manufacturer.[16] Thus, in addition to requiring compliance with the fleetwide average CO_2 target, the model must also ensure that each fleet complies with its applicable target plus the trading allowance.

Should a non-zero number be entered in column I, OMEGA determines the overall sales- and VMT-weighted emissions target for the manufacturer with cars and trucks combined:[17]

$$Target_{mfr} = \frac{Sales_{cars}\ x\ Standard_{cars}\ x\ Regulatory\ VMT_{Cars} + Sales_{trucks}\ x\ Standard_{trucks}\ x\ Regulatory\ VMT_{trucks}}{Sales_{cars}\ x\ Regulatory\ VMT_{Cars} + Sales_{trucks}\ x\ Regulatory\ VMT_{trucks}}$$

The model also determines the starting point for each manufacturer using the same basic equation

$$Base\ emissions_{mfr} = \frac{Sales_{cars}\ x\ Base\ emissions_{cars}\ x\ Regulatory\ VMT_{Cars} + Sales_{trucks}\ x\ Base\ emissions_{trucks}\ x\ Regulatory\ VMT_{trucks}}{Sales_{cars}\ x\ Regulatory\ VMT_{Cars} + Sales_{trucks}\ x\ Regulatory\ VMT_{trucks}}$$

Credits are generated when a manufacturer's fleet of either cars or trucks overcomplies with the applicable standard. The amount of credits generated equals the difference between the sales weighted average emission level for that vehicle class and the applicable standard multiplied by the lifetime VMT per vehicle for that vehicle class. For either vehicle class, in aggregate, the generated credits are calculated by the equation below.

$$Credits\ Generated = (Sales\ x\ Regulatory\ VMT\ x\ CO2\ emission\ standard) - (Sales\ x\ Regulatory\ VMT\ x\ CO2\ emission\ average)$$

Where

Sales = Sales volume of each car or truck in that redesign cycle,
Regulatory VMT = Lifetime VMT per vehicle according to regulation (from the reference file).
CO_2 emission standard = The target set in the scenario file
CO_2 emission average = The achieved CO_2 level for the vehicles after the application of technology

Credit use is determined by the same formula, except for the substitution of the vehicles from the other vehicle class, as shown below.

$$Credits\ used = (Sales\ x\ Regulatory\ VMT\ x\ CO2\ emission\ standard) - (Sales\ x\ Regulatory\ VMT\ x\ CO2\ emission\ average)$$

Where

Sales = Sales volume of each car or truck in that redesign cycle,
Regulatory VMT = Lifetime VMT per vehicle according to regulation (from the reference file).

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[16] If the trading limit is greater than the emission standard, trading is effectively unlimited.
[17] VMT weighting allows the user to account for the difference in miles driven between difference classes of vehicles and provides for environmentally neutral credit trading:

CO_2 emission standard = The target set in the scenario file
CO_2 emission average = The achieved CO_2 level for the vehicles after the application of technology

OMEGA utilizes a simple set of algorithms to determine the correct distribution of technology between car and truck fleets. OMEGA calculates the level of sales and VMT weighted emissions of either car and truck emissions which will generate the maximum allowable use of credits by the other vehicle class (the "lower limit"). It then tracks sales and VMT weighted car, truck and combined emissions when adding technology. When the sales and VMT weighted average emissions for either cars or trucks reaches this lower limit, no additional technology is applied to that vehicle class. Technology is only applied to the other vehicle class, as this latter class still exceeds the level of its standard plus the allowable trading level.

For example, assume a trading limit of 10 g/mi CO_2 is input and the applicable car and truck standards for a manufacturer are 220 and 300 g/mi CO_2, respectively. The model calculates the combined sales and VMT weighted CO_2 emission target using the above equation for FleetwideCO_2Target, which can be simplified as follows:

$$\text{Fleetwide } CO_2\text{Target} = \frac{\sum_{vc=1}^{2}\left(\text{Sales}_v \times \text{LifeVMT}_v \times \text{Target}_v\right)}{\sum_{vc=1}^{2}\text{Sales}_v \times \text{LifeVMT}_v}$$

Where vc represents the two vehicle classes, cars and trucks.

Once the Fleetwide CO_2 Target is known (assumed to be 260 g/mi in this example), this same equation can be used to determine the level of average car emissions which achieves compliance when the level of average truck emissions exceeds its target by 10 g/mi CO_2 (310 g/mi in this example). For this example, assume this level is 198 g/mi CO_2. Any level of average car emissions between 198 and 220 g/mi produces credits for trading which can be effectively utilized towards compliance by trucks. Likewise, the minimum level of average truck emissions which produces useful credits for use towards compliance by cars is determined which achieves compliance when the level of average car emissions exceed its target by 10 g/mi CO_2 (230 g/mi in this example). Again, for this example, assume this level is 290 g/mi CO_2.

The model then proceeds to add technologies to cars and trucks (described in greater detail below) until one of three criteria is met:

1) combined car and truck emissions reach 260 g/mi CO_2,
2) car emissions reach 198 g/mi CO_2, or
3) truck emissions reach 290 g/mi CO_2.

If combined car and truck emissions reach 260 g/mi CO_2 before the other two criteria are met, the evaluation of this manufacturer is complete. The manufacturer complies with the sales and VMT weighted standard applicable to cars and trucks combined and any level of trading implied is less than the maximum allowed. If criterion 2 is reached first, the model continues to evaluate and apply technology, but only to trucks. In this case, the model continues to effectively add technology to trucks only until criterion 1 is met (unless insufficient technology exists to enable overall compliance). Likewise, if criterion 3 is reached first, the model continues to evaluate and apply technology to cars.

Fleetwide total tailpipe and refrigerant CO_2 equivalent emissions are determined in an analogous fashion. Compliance is achieved when fleetwide total CO_2 is equal to or less than the fleetwide CO_2 Target.

D.iv Technology Application Ranking Factors

The Technology Application Ranking Factor (TARF) is used to rank the application of available technology packages across various vehicles. As described above, the user can choose between three different TARF equations for ranking technology application: 1) Effective Cost, 2) Cost Effectiveness–Society, and 3) Cost Effectiveness–Manufacturer. The first and third TARF equations take the view of the manufacturer in determining the application of technology. This can be deemed appropriate since the manufacturer controls the decision making process. Since the manufacturer must satisfy its customers and regulatory mandates, a manufacturer's decision making processes will reflect these needs, as well. More explicitly, the technology cost is assumed to be the full cost of that technology at the consumer level, including research and development costs, amortization of capital investment, etc. This cost is generally the same cost as EPA estimates in its regulatory support analyses when estimating the cost of new standards.[18] This cost is not necessarily the increment in price that the manufacturer would charge for that technology, since price is a function of many factors which can change fairly quickly depending on market conditions. The fuel savings of interest are those assumed by a manufacturer to be valued by the customer, so they are based on fuel prices including taxes and reflect the timeframe which a customer might consider when purchasing a vehicle. The residual value of the added technology is not currently reflected in either TARF, but could be added in the future.

While the first and third TARFS take the veiew of the manufacturer, the second TARF takes the view of society in deciding which technologies should be added first. This distinction will be described further below. In all three cases, the vehicle with the TARF with the most negative value is applied first.

D.iv.a Effective Cost TARF (TARF No. 1)

The Effective Cost TARF (*EffCost*) is defined as the cost of the technology (*TechCost*) less the discounted fuel savings over a specified payback period of vehicle use. The Effective Cost TARF was included in the OMEGA model, since it is the equivalent of the technology ranking process used in NHTSA's CAFE compliance Model. It allows a user to match this aspect of the Volpe Model when modeling equivalent standards using both models, if this is desired. Quantitatively, it is defined as follows:

$$EffCost = TechCost - FS \times \frac{1}{(1 - GAP)} - CAFEFine$$

TechCost is the cost of technology t per vehicle, as input in the Technology file. Fuel consumption per mile (over the compliance test cycle used to determine compliance with the input CO_2 emission standards) before (FC_{t-1}) and after technology addition (FC_t) is calculated as follows:

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[18] See Section III.H of the Draft Regulatory Impact Analysis to the recent EPA NPRM for the control of GHG emissions from cars and light trucks for a discussion of technology costs at the manufacturer and consumer levels.

$$FC_{t-1} = \frac{CO2_{t-1}}{CD_{t-1} \times \left[\frac{44gCO2}{12gC} \right]}$$

$$FC_{t} = \frac{CO2_{TARF,t}}{CD_{t} \times \left[\frac{44gCO2}{12gC} \right]}$$

Where:

CD_{t-1} and CD_t = the carbon density of the liquid fuel (in terms of grams carbon per gallon) before and after technology application.

CO_{2t-1} = the level of tailpipe emissions prior to the application of the technology being evaluated (i.e., after the application of technology t-1), and

$CO_{2TARF,t}$ = the level of tailpipe emissions after application of technology t, without considering any cap on the level of the penetration of technology t.

44g CO_2/12 g C = the mass ratio of CO_2 to C, used in converting the carbon density of a fuel to an emitted mass of carbon dioxide.

CO_{2t-1} is the actual level of CO_2 emissions from the particular vehicle which would occur after the application of all the technologies prior to technology t, considering both the fact that: 1) some or all of these technology packages may already be present on this vehicle (i.e., the TEBs), and 2) there may be caps on the application of one or more of these technology packages which are less than 100%. This level is the appropriate "baseline" CO_2 level from which to evaluate technology t since all previous technologies must be added to the vehicle before technology t can be added.

Please note, that the TARF equations are defined on a per vehicle basis. Consequently, OMEGA does not factor in the potential cap on the level of the penetration of technology t into the TARF calculation.[19] Because the calculation of $CO_{2TARF,t}$ does not consider the impact of any cap on technology penetration, this level of CO_2 emissions will differ from the CO_2 emission level of the vehicle should this technology be selected for addition. The equation for the latter CO_2 emission level is described further below. In order to be consistent with the calculation of $CO_{2TARF,t}$, the technology cost (*TechCost*) is also determined without consideration of the presence of the technology on the vehicle (via the value of CEB) and without consideration of the cap on the penetration of the technology. Thus, TechCost is simply the incremental cost of the technology listed in the Technology file.

With these premises, the formulae describing tailpipe CO_2 emissions and refrigerant emissions after the application of this technology package are as follows:

[19] Amortized capital costs tend to be higher for technologies which are applicable to lower production volumes. However, the capital investment of many technologies can be spread across more than one vehicle model. Thus, incorporating the capital investment associated with technology into the TARF would not be a simple matter. If explicit consideration of capital costs is added to the model's operation in the future, both the cap on application of a particular technology and the sales volume of the vehicle model will likely be relevant and included in the revised TARF. The net result is that the cost of each technology should represent that for the timeframe and expected production volume for each redesign cycle.

$$CO_{2_{TARF},t} = CO_{2_{t-1}} \times (1 - AIE_t)$$

Please note that the TEB term is not included when calculating TARFS. This is to maintain consistency with the ranking process, which also does not include TEBS.

$$RCO_{2_{TARF},t} = RCO_{2_{t-1}} \times (1 - AIE_t) \times \frac{GWP_t}{GWP_{t-1}}$$

The ratio of GWPs reflects the fact that the technology might change the refrigerant used and affect the conversion of refrigerant mass emissions to CO_2 equivalent emissions.

Fuel savings without consideration of the gap between on-road and certification fuel economy (FS) is calculated as follows. Vehicles can have up to two separate energy sources, a liquid fuel (subscript "1" in the equation) and electricity (subscript "2" in the equation), as would be the case with plug in hybrids.[20]

$$FS = \sum_{i=Y}^{Y+PP} [(fuelCost_o + elecCost_o) - (fuelCost_n + elecCost_n)]$$

Y	= cycle no * 5
PP	= payback period [yrs]
$fuelCost_o$	= fuel cost with original technology
$elecCost_o$	= electricity cost with original technology
$fuelCost_n$	= fuel cost with new technology
$elecCost_n$	= electricity cost with new technology

Where energy costs are:

$$fuelCost_o = \sum_{i=Y}^{Y+PP} \left[FP_o[y + (cy - 1) \times 5] \times FC_o \times VMT_y \times \frac{\left[1 + \left(\frac{DR_y}{2}\right)\right]}{1 + DR_y} \right]$$

$$elecCost_o = \sum_{i=Y}^{Y+PP} \left[EP_o[y + (cy - 1) \times 5] \times EC_o \times VMT_y \times \frac{\left[1 + \left(\frac{DR_y}{2}\right)\right]}{1 + DR_y} \right]$$

[20] For purposes of calculating TARFS, the CO_2 credit values from the technology files are treated as both generating CO_2 reductions and fuel savings. This equivalency is required for two reasons. First, from the manufacturer's perspective, the CO_2 credit does provide real CO_2 benefit towards their CO_2 compliance goals. However, as will be seen in the next section, providing CO_2 benefit without increasing fuel savings in the TARF can provide perverse results, where the denominator is increased, but the numerator of the TARF stays constant. Having the credit generate "fuel savings" in the TARF, is a work-around for this issue.

$$fuelCost_t = \sum_{i=Y}^{Y+PP} \left[FP_n[y + (cy - 1) \times 5] \times FC_t \times VMT_y \times \frac{\left[1 + \left(\frac{DR_y}{2}\right)\right]}{1 + DR_y} \right]$$

$$elecCost_t = \sum_{i=Y}^{Y+PP} \left[EP_n[y + (cy - 1) \times 5] \times EC_n \times VMT_y \times \frac{\left[1 + \left(\frac{DR_y}{2}\right)\right]}{1 + DR_y} \right]$$

FP = fuel (liquid) price [$/gal]
FC = fuel (liquid) consumption [gpm]
EP = electricity price [$/kWh]
EC = electricity consumption [kWh/mi]
VMT_y = vehicle miles of travel in year y
DR_y = discount rate for year y
t, *n* = current technology
o = original technology from tech-apply step (or baseline)
i = year index
Annual fuel prices for both fuels (liquid & electricity) are used

CAFEFine is the fine a manufacturer pays for failing to meet the CAFE target. The equation for this is:

$$CAFEFine = FEE \times \frac{1}{SF_{cls}} \times \left[\frac{1}{CAFEFC_{avg}} - \frac{1}{CAFEFC_{avg} - SF_{cls} \times (CAFEFC_t - CAFEFC_o)} \right]$$

Where:

FEE = CAFEFee [$/mpg]
SF_{cls} = Sales fraction of vehicle in its class, for a given Manufacturer

$CAFEFC_o$ = FC_o x $CAFE\_LF_{eqv}$
(CAFE Weighted Fuel Consumption for baseline technology [gpm])

$CAFEFC_t$ = FC_t x $CAFE\_LF_{eqv}$ + EC_t x $CAFE\_EL_{eqv}$
(CAFE Weighted Fuel Consumption for current technology [gpm])

$CAFEFC_{avg}$ = $Co_{2target}$ x (12/44) / CD_{gas}
(Manufacturer's CAFE Fuel Consumption at the beginning of redesign cycle [gpm])

$Co_{2target}$ = manufacturer's CO_2 target [g/mi]
CD_{gas} = carbon density of gasoline [g/gal]
$CAFE\_LF_{eqv}$ = CAFE equivalence factor for liquid fuel [gal/gal]
$CAFE\_EL_{eqv}$ = CAFE equivalence factor for electricity [gal/kWh]

FC = fuel (liquid) consumption [gpm]
t = current technology
o = original technology from tech-apply step (or baseline)

A positive value for this TARF indicates that the consumer might view the vehicle less desirably with the technology than without. A negative value for this TARF indicates that the consumer might view the vehicle more desirably with the technology than without.[21] This TARF assumes that manufacturers will incrementally add technologies which increase this desirability to the maximum extent possible.

D.iv.b Cost Effectiveness-Society TARF (TARF No. 2)

The Cost Effectiveness-Society TARF (*CostEffSoc*) is identical to the Cost Effectiveness–Manufacturer TARF (TARF 3) with one exception. The Cost Effectiveness-Society TARF divides the Effective Cost TARF by the discounted lifetime CO_2 emission reduction instead of the lifetime CO_2 emission reduction. The discount rate used would be for the value of CO_2 emission reductions over time. The rationale for discounting is simply that society is presumed to value CO_2 reductions in this way. Also, in this case, we would recommend that the user increase the payback period for fuel savings to cover the life of the vehicle instead of the much shorter period of time often assumed to be considered by consumers when purchasing a vehicle. Society values fuel savings over the life of the vehicle and not just for the first few years of use. The user could also estimate technology costs from a societal point of view if this produced different cost estimates than those used above. The Cost Effectiveness- Society TARF can be described mathematically as follows:

$$CostEffSOC = EffCost \times \frac{(1 - Gap)}{CO_2Saving}$$

Where ***EffCost*** is defined using the equation in $TARF_1$

Where ***CO_2Saving*** is:

$$CO_2Saving = dCO_2 \times sumVMT$$

dCO_2 = delta CO_2 as calculated in $TARF_3$
sumVMT = discounted present value of lifetime VMT using the VMT schedules from the reference input file

Where ***sumVMT***:

$$sumVMT = \sum_{y=0}^{n} VMTy \times \frac{1 + \left(DR_y - \frac{IR}{2}\right)}{1 + \left(DR_y - IR\right)}$$

VMT_y = VMT in year y
n = vehicle lifetime
DR_y = discount rate [%] for year y
IR = CO_2 value increase rate [%]

D.iv.c Cost Effectiveness-Manufacturer TARF (TARF No. 3)

The Cost Effectiveness-Manufacturer TARF represents the degree to which consumer desirability might change with the technology on a per ton of CO_2 controlled basis. The Effective Cost TARF

[21] Of course, the calculated TARF values are dependent upon the assumed views of consumer valuation of fuel savings, the payback period assumed, the discounting over that payback period, and other factors.

ignores the degree to which the technology moves the manufacturer closer to compliance. Thus, a fairly expensive technology which produces a large fuel savings might have a fairly large negative Effective Cost TARF. The sequence of several less expensive technologies with smaller fuel savings might all have less negative Effective Cost TARFs and so would not be chosen over the more expensive technology. However, in total, the sequence of smaller steps might achieve the same overall emission reduction as the more expensive technology at a lower cost. The Cost Effectiveness–Manufacturer TARF would divide these less expensive technologies by smaller CO_2 emission reductions, thereby imrpoving their TARF values relative to the more expensive technology. This would allow the model to choose the sequence of less expensive technologies over the single expensive technology if their increase in effective cost per ton of CO_2 reduced was higher.

The Cost Effectiveness-Manufacturer TARF (*CostEffManuf*) incorporates all of the terms included in the effective cost TARF, but also accounts for the degree that the technology brings the manufacturer closer to its CO_2 standard. It can be described simply as the Effective Cost TARF divided by the mass of the CO_2 equivalent emission reduction over the life of the vehicle due to addition of the technology. The Cost Effectiveness-Manufacturer TARF can be described mathematically as follows:

$$CostEffManuf = EffCost \;/\; CO_2Saving$$

Where ***EffCost*** is defined using the equation in $TARF_1$

Where ***CO_2Saving*** is:

$$CO_2Saving = dCO_2 \times \; LifeVMT$$

lifeVMT = lifetime VMT for a vehicle

Where ***dCO_2*** is:

$$dCO_2 = \big((tpCO_2o - tpCO_2n) + (rfCO_2o - rfCO_2n) + (grCO_2o - grCO_2n) + (crCO_2o - crCO_2n)\big)$$

$tpCO_2$ = tailpipe CO_2
$rfCO_2$ = refrigerant CO_2
$grCO_2$ = grid CO_2
$crCO_2$ = CO_2 credit
o = original technology from tech-apply step (or baseline)
n = new Technology

Where ***$tpCO_2n$*** is:

$$tpCO_2n = tpCO_2o \;\times (1 - AIE)$$

$tpCO_2o$ = original technology from tech-apply step (or baseline)
AIE = average incremental effectiveness of the new technology

Where **rf*CO₂n*** is:

$$rfCO_2n = rfCO_2o \times refrigEff \times GWP$$

$rfCO_2o$	= original refrigerant from tech-apply step (or baseline)
refrigEff	= refrigerant effectiveness
GWP	= global warming potentials (varies by refrigerant)

Where ***grCO₂n*** is:

$$grCO_2n = kWhMi \times CD \times Cr$$

kWhMi	= kilo-watt hours per mile of travel
CD	= carbon density (gC/kWh)
Cr	= CO_2/C ratio for electricity = 44.0 / 12.0

D.v Applying Technology - Calculations

As described above, for any individual vehicle, technologies are applied in the order in which they are listed in the Technology file for the relevant vehicle type. Thus, at the beginning of the evaluation for a manufacturer, the only technology which is available to each vehicle is technology package 1 for its vehicle type. Thus, the OMEGA model compares the TARF equations for applying technology package 1 to all of the vehicles in that manufacturer's fleet and chooses the vehicle with the most negative TARF. The model then applies technology package 1 to that vehicle and reduces its GHG emission level. The formulae for calculating the new tailpipe and refrigerant CO_2 emission levels after application of the technology are shown below:

$$CO_{2_t} = \frac{CO_{2_{t-1}} \times (1 - CAP \times AIE)}{1 - AIE \times TEB}$$

$$RCO_{2_t} = \frac{RCO_{2_{t-1}} \times (1 - CAP \times AIE)}{1 - AIE \times TEB} \times \frac{GWP_t}{GWP_{t-1}}$$

Here, both the presence of the technology in the baseline configuration of this vehicle and the cap on technology application are considered. The terms shown in the denominators of both equations are included due to the definition of the incremental effectiveness of technology. When calculating the effectiveness of a technology, the user should assume that the vehicle to which this technology is being applied has all of the previous technology packages applied, but none of the additional technologies included in the technology of interest. Thus, the incremental effectiveness of hybridization over an advanced gasoline engine and transmission package might be 10%. If a specific vehicle or more likely group of vehicles already reflected half of this 10% hybrid benefit, it would not be correct to simply reduce the effectiveness of the hybrid package to half of the 10% (i.e., 5%) and multiply base emissions by 0.95. It is more accurate to remove the effect of the partial hybridization by dividing by 100% minus

5% (i.e., 0.95) and then multiplying by 100% minus 10% (i.e., 0.9). The net effect in this case is to multiply base emissions by 0.9474, which produces a slightly greater emission reduction than multiplying by 0.95. For modest technologies, the difference is small. However, for technologies which might reduce emissions by 30% or more, the difference in methodology becomes more significant. See the section discussing calculation of TEB values.

The model also adds the cost to the manufacturer's running total cost and recalculates the manufacturer's corporate average emission level. The formulae used to perform these two calculations are as follows:

Equation 4 – calculation of compliance CO_2 value

$$CO_2 = Techpack\ CO_2 + Grid\ CO_2 + Refrigerant\ CO_2 + OEB$$

Equation 5 – Total Cost Calculations

$$TotalCost_t = TotalCost_{t-1} + TechCost \times (1 - CEB) \times Sales_v$$

Equation 6 – Fleet Average CO_2 calculations

$$FleetTCO_{2\,step} = \frac{\sum_{v=1}^{V} \left(Sales_v \times LifeVMT_v \times TCO_{2_t} \right)}{\sum_{v=1}^{V} Sales_v \times LifeVMT_v}$$

Where:
v = a vehicle produced by the manufacturer,
V = the total number of vehicles (cars, trucks, or both) produced by that manufacturer,
TCO2t= the emissions of the vehicle after application of the technology
$LifeVMT_v$ = the lifetime VMT of the class of vehicle to which vehicle v belongs. Lifetime VMT is statutory VMT as given in the scenario file.

As mentioned above, compliance with the CO_2 standards is performed on a sales and VMT weighted basis, for ease in trading between cars and trucks under the provisions of the proposed CO_2 standards.

At this point, the model checks to see if the manufacturer is in compliance with its CO_2 emission standard. If so, it stops and moves on to the next manufacturer. If not, the model then evaluates the TARF for the next technology package for the vehicle which just received the last technology package. The model calculates the TARF for this package and compares it to the TARF equations for the technology packages 1 for all of the other vehicles. This sequence of adding one technology package to one vehicle, reevaluating compliance, and so on, continues until either the manufacturer complies or until all the available technologies have been applied. When either of these two endpoints is reached, the model moves to evaluating the next manufacturer or the next redesign cycle.

The model keeps track of a number of intermediate values throughout the process of adding technology. These include the order of technology application, the TARF equations for each combination of vehicle and technology, the cumulative cost per vehicle, etc. for use in producing the various output files.

V Output Files

A Summary of Outputs

The model places each scenario output in a separate subfolder. The name of each of these files includes the name of the scenario listed in Column B of the Scenarios tab of the Scenario file. Each of these output files and their purpose are summarized in the table below. The main output files are also discussed in greater detail later in this section.

Table 8 – Summary of Model Outputs

File*	Summary Description
Main Output Files	
X.log	Step by step details of the model operation including tech pack application, cost, CO_2, and electricity.
X.xls	Summary file that includes manufacturer specific details on tech pack application, cost, CO_2 and electricity.
X-Techpacksales.log	Details on the sales of vehicles by tech pack at the completion of the scenario. Useful in tracking technology application.
X-vh1.xls	Summary of final cost, emissions, and electricity consumption by vehicle
X-vh2.xls	Step by step details of cost by technology pack application, summarized by vehicle.
Diagnostic Output Files	
X-CycleResults.log	Repeats data that is contained in X.xls.
X-DetailedCycleResults.xls	Summarized Manufacturer-Fleet results by Fuel type for every cycle.
X-Market-Platform_Mfr.log	Data for a Manufacturer/Platform version of the Market.xls file
X-TARF.log	Summarizes the TARF of every technology package vehicle combination.
X-TechPackSFx.xls	Final Sales Fraction for each Tech Pack on every vehicle
X-VehicleFuelBreakDown.xls	Reports fuel-level summaries for every vehicle.
X-VehSteps.xls	Lists the sales fraction and CO_2 emissions for each fuel type without all of the extra detail in CO_2.log
Scenario Comparison Table	
SummaryOutputResults.xls	Summary table comparing manufacturer-level results across all scenarios in the scenario.xls file.

*X is substituted here for scenario name.

A.i Log of Technology Application Steps – Text Format

This file depicts the process of technology application to each manufacturer's fleet and shows the progress being made towards compliance with the specified standards. Please note that the log has several different formats which depend upon the user options selected.

The beginning of the file lists basic information about the model user, the version of OMEGA being used and the input files. It then presents the technology application information by redesign cycle and within each redesign cycle by manufacturer and within each manufacturer by vehicle class (i.e., cars first and then trucks). If a combined car-truck standard is being evaluated, then only one set of technology application steps is presented which combines both types of vehicles. At the beginning of each redesign cycle, the file describes the standard or standards being evaluated. For universal standards, this means the standard itself. For footprint-based standards, the four coefficients described in the input file are listed. The file then begins a sequence of sections which apply to a single manufacturer and single vehicle class, as shown below.

The first line lists the manufacturer, its starting CO_2 emission level, its CO_2 target or standard for this scenario and the vehicle class (C for car or combine, and T for Truck). The starting CO_2 emission level is simply the base CO_2 emission level of each vehicle weighted by vehicle sales in this redesign cycle. The CO_2 standard is either the universal standard listed in the Scenario file, or the foot-print based CO_2 standard applied to that manufacturer's vehicles.

The following lines list the step-by-step application of technology packages. Going through the columns, step is simply a numerical counter following by a hyphen. Index identifies the vehicle receiving the technology or package and refers to the vehicle number in the Market file. Type shows the vehicle type for this vehicle. The first column labeled CO_2 pipe shows the tailpipe CO_2 emissions prior to the application of technology. For the application of technology package 1, this value is the base CO_2 emission level shown in the Market file. For subsequent packages, it is the CO_2 emission level resulting from the application of the previous technology package. The first column labeled CO_2tot stands for total CO_2 equivalent emissions and is analogous to CO_2pipe. CO_2tot equals CO_2pipe plus refrigerant emissions in terms of equivalent CO_2 emissions. Again, this is either the base refrigerant emission level or the refrigerant emission level after application of the previous technology package. TP is the technology package added in this step. TARF is the value of the TARF for this package applied to this vehicle.

The second column labeled CO_2pipe shows the tailpipe CO_2 emissions after the application of the technology package. This value considers the efficiency of the technology package, the cap on the percentage of sales which can receive the package, as well as the percentage of that package already present on the vehicle (i.e., the TEB). The second column labeled CO_2tot shows this value plus the level of refrigerant emissions existing after any control which have been applied to these.

CO_2avg represents the corporate average CO_2 emission level for this manufacturer and vehicle class combination. It will generally decrease after each step of technology application and show progress towards the manufacturer's standard. Occasionally, this value will remain constant. This could be due to round off. Or, the vehicle receiving the technology may have already been completely equipped with that technology. In this case, the model simply holds both emissions and costs constant when it applies the technology.

kWhavg represents the avg kwh/mile of electricity consumed by the fleet. This includes both the baseline electricity and the additional electricity consumed by plug-in vehicles. To be clear, this is the average electricity consumed over all miles, not simply the electrically powered miles.

TotCost represents the cumulative cost in dollars per model year of the technology added up to that point. The increment in this value from step to step is the product of three terms: 1) the cost of the technology package being added, 2) the sales of the vehicle in this redesign cycle, and 3) the cap minus the percentage of that package already present in terms of cost (i.e., CEB) or zero, whichever is higher.

The very last step of technology addition for each manufacturer and vehicle class combination may be shown twice, with "OC" following the second listing. In this case, this step does not represent the addition of technology, but a backwards interpolation between the previous two steps of technology addition which eliminates the over-compliance which usually results from adding discrete technologies to specific vehicles. The presence of this interpolation step depends on the value of the threshold cost input specified in the Scenario file and the cost of the last technology package, as discussed above under Input files.

This file can be very useful both for diagnostic and analytical purposes. The presence of the TARF values in the file can be useful in identifying technology packages which have relative poor cost effectiveness followed by packages with better cost effectiveness. In general, the list of TARF values should start out negative and become more positive with continued technology application. The only exception to this should be when the same vehicle receives technology in sequential steps. In this case, the TARF may become more negative in a successive step, since the OMEGA model could not consider the more cost effective technology until it applied the previous technology to that vehicle. When the user observes a series of technologies being applied to the same vehicle in successive modeling steps, this indicates that separating these technology packages provides little practical purpose in the model run. Worse, the relatively poor cost effectiveness of the first of the series of technology packages may be causing the model to add technology to other vehicles which have worse cost effectiveness than the combination of packages for the vehicle in question. This sequence of technology package additions to the same vehicle could also be an indication that the order of technologies might not be appropriate (or there might be an error in one of the technology input values).

From an economic perspective, this file presents the increase in cumulative cost for each manufacturer as its average CO_2 level is reduced. If a sufficiently stringent CO_2 standard (e.g., 50 g/mi) is input to the model, manufacturers will not comply with the specified standard. However, the model will apply all of the technology available to each vehicle. Thus, the file represents a complete relationship between cost and emissions for each manufacturer. By reading the information contained in this file into a spreadsheet or other program capable of analysis, the user can quickly determine the cost for a wide range of CO_2 standards without rerunning OMEGA each time. Since the social costs and benefits of CO_2 standards tend to be relatively linear with CO_2 level, it is possible to represent these costs and benefits with simple linear equations. The user can then easily combine the relationship between manufacturer's emission levels and technology costs with social costs and benefits at an industry-wide level. It would then be possible to solve for the industry-wide emission levels which maximized net societal benefits, produced zero net societal benefit or met some other economic criteria.

Example:

The following table depicts a portion of the log file from an OMEGA model run.

CYCLE 1 Target Coeffs: (A=204.0, B=275.0, C=41.0, D=56.0) , (A=246.0, B=347.0, C=41.0, D=66.0)											
Industry Baseline CO_2avg = 287.35, Target CO_2avg = 223.31, Fleet Type = 'C'											
Step	Index	Type	CO_2pipe	CO_2tot	TP	TARF	CO_2pipe	CO_2tot	CO_2avg	kwhavg	TotCost
1-	19	6	405.13	405.13	1	-0.1266	375.33	375.33	286.92	0.0000	33,256,539
2-	14	6	403.17	403.17	1	-0.1264	372.63	372.63	286.61	0.0000	57,241,908
3-	29	13	446.63	446.63	1	-0.1261	412.62	412.62	286.61	0.0000	57,306,310
4-	13	10	392.46	392.46	1	-0.1255	362.57	362.57	286.44	0.0000	70,885,077
5-	18	10	389.46	389.46	1	-0.1253	359.8	359.8	286.28	0.0000	83,589,991
										0.0000	
33-	28	2	232.56	232.56	1	-0.1106	217.03	217.03	267.17	0.0000	2,117,945,615
34-	14	6	372.63	372.63	2	-0.0904	357.54	357.54	267.01	0.0000	2,158,753,183
35-	14	6	357.54	357.54	3	-0.0973	305.57	305.57	266.49	0.0000	2,238,406,536
36-	19	6	375.33	375.33	2	-0.0901	355.62	355.62	266.21	0.0000	2,297,680,885
										0.0000	
54-	7	5	325.61	325.61	2	-0.0615	300.75	300.75	244.96	0.0000	6,904,283,762
55-	7	5	300.75	300.75	3	-0.0779	250.06	250.06	243.95	0.0000	7,106,439,868
										0.0000	
92-	25	4	250.33	250.33	2	-0.0457	212.85	212.85	225.84	0.0000	11,043,478,070
93-	28	2	217.03	217.03	2	-0.0426	203.45	203.45	221.06	0.0000	12,799,723,914
93-OC	28	2	217.03	217.03	2	-0.0426	216.53	216.53	223.31	0.0000	11,973,039,155

The first five technologies added to cars in this model run were all the first technology listed for each vehicle type (TP = 1). The same is true for steps 6-32 (not shown). Step 33 also adds the first technology available to vehicle 28. Step 34 adds the second technology available to vehicle 14, while step 35 adds the third technology available to this vehicle. This sequence demonstrates how the model evaluates the next available technology for each vehicle when deciding where to add technology next. In this case, technology number 3 for vehicle 14 was preferred over any of the second technologies for all the other vehicles. Examination of the TARF values explains why this was the case.

The TARF for the technology number 2 for vehicle 14 was-0.0904, while that for technology 3 was -0.0973. Thus, if -0.0904 was the lowest TARF for step 34, an even lower TARF would have to be the lowest TARF in step 35. When it is observed that the model adds two technologies in a row to the same vehicle, the user should question whether the first technology should be modified or the two technologies should be combined. The reason for this is that, unless step 34 is the very last technology added to enable compliance, the model will never simply add technology 2 to vehicle 14. Vehicle 14 will always receive either technology 1 or 3. The primary concern is that a relatively high TARF value for technology package 2 could inappropriately inhibit the application of the combination of technology packages 2 and 3 to this vehicle relative to the application of technologies to other vehicles.

In this case, the TARFs for technologies 2 and 3 are quite close. Thus, combining them into one technology package would not produce substantively different results. The same sequence occurs with vehicle 7 later in the run (steps 54 and 55 in the above table). In this latter case, the difference between the TARFs is much greater. Combining the two steps may have resulted in the earlier application of the two technologies than applying them separately.

The final three lines of the above table illustrate the interpolation that occurs in the compliance determination if the cost of the last technology added exceeds the "threshold" input in the Scenario file. After step 93, the manufacturer's corporate average CO_2 level was 221.06 g/mi, while the standard was 223.31 g/mi. The model adjusted the manufacturer's corporate average CO_2 level to 223.31 g/mi by only applying technology 2 to a portion of the sales of vehicle 28. This reduced the overall cost of compliance from $12.8 billion to $12.0 billion. Mathematically, this is equivalent to interpolating between the average emissions (CO_2avg) and cumulative costs of steps 92 and 93.

A.ii Summary of Cost and Emissions – Excel Format

This file presents a summary of vehicle and manufacturer costs and emission levels resulting from a model run. The file contains summary information about the run, the model user, the version of OMEGA being used and the values input on the first tab of the Scenario file. The file then lists five types of information by manufacturer and vehicle class: 1) vehicle sales, 2) total costs, 3) cost per vehicle, 4) electricity consumption, and 5) emission level per vehicle.

The file continues by presenting the cost of the technology added to each vehicle and the last technology package added to each vehicle. The last section of the file presents the series of technologies added to each vehicle. For each technology, the file shows the step (for each manufacturer-vehicle class combination) in which the technology was added, the vehicle's emission levels before and after this technology and the incremental total cost of adding this technology.

A.iii Summary of Technology Pack Distribution – Text format

This file lists the final distribution of technology packs applied to each vehicle, and takes the form of a matrix of vehicles and technology packages, with the sales presented within the matrix. This is useful information when calculating technology penetrations. As an example, if 40% of vehicle 7 sales receive technology package 6, then 40% of vehicle 7 sales have the technologies in package 6.[22]

A.iv VH1 / Final summary of Vehicle Attributes– Excel Format

The "VH1" file lists each vehicle, the final technology package applied to that vehicle, the final cost, and various attributes about the vehicle. Most of these attributes are carried through from the market data file, however some such as the CO_2 emission rate and electricity consumption are modified by the model. In many senses, this file is a lower level corollary of the Excel summary file described in IV.B, and is useful for determining the average cost increase for a class of vehicles.

A.vVH2 / Stepwise listing of Vehicle Attributes—Excel Format

The VH2 file provides the cost and CO_2 emissions of each vehicle after each technology package is applied. Similar to the VH1 file, it is organized by vehicle.

[22] In rulemaking analyses, EPA typically uses a more detailed methodology to calculate technology penetrations. This method is documented in Appendix F of the Interim Join Technical Assessment Report.

VI Running the Model

Installing the model should add an "OMEGA" icon to the user's desktop. OMEGA is started by double clicking on this icon. A graphic user interface (GUI) should appear in a few seconds. The current GUI is simple and relies on the fact that all of the information needed to run the model is contained in the input files.

Once the GUI appears, the first step is for the user to select the desired scenario file. Click on "File" in the menu bar and choose "Open" from the drop down menu. A window will open which displays the files contained in the model's input directory. Double click on the desired Scenario file and the model will load the data contained in this file and that in the Market, Technology, Fuel and Reference files specified in the Scenario file. The GUI will update and display portions of the Scenario, Market and Technology input files. The GUI allows the user to partially navigate through these three files in order to confirm that the correct input files were specified in the Scenario file. When everything is loaded, the car icon will turn green.

By default, OMEGA saves output files in the Output subdirectory where the executable is installed. However, the user can specify an alternative output directory by selecting File/Output Files To… From there, browse to, and select, the desired output directory. As a reminder, the selected output directory name will display in the GUI.

In addition to the standard results, the model can generate a number of outputs which the user may select prior to running the model. Click on Log to see a drop-down list of selectable outputs. The contents of these outputs are described in Section 4. The user selections are "sticky", and will remain selected (or not) between OMEGA runs.

The user can now run the cases included in the Scenario file by clicking on the green car button.

As the model is running, the lower left hand corner of the GUI will indicate progress (e.g., processing Scenario 1 of 5, processing Scenario 2 of 5, etc.). If the Scenario file only specifies one case to be run, when the model is done with this case, the log (text) file showing the sequence of technology addition by manufacturer and by redesign cycle appears. This file, as all of the output files, is automatically named with the case name from the Scenario file, with the file type "log" added. If more than one case is run, the indicator in the lower left hand corner will simply say "Done" and no log files are displayed.