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

Model Documentation 1.0

United States
Environmental Protection
Agency

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

EPA United States Environmental Protection Agency

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I. Model Overview

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 of technology options available to improve the efficiency of vehicles. A detailed analysis of the costs and benefits of various GHG emissions reduction requires a specialized application that optimizes and accounts for all the promising technologies, going beyond what can be accomplished with simple spreadsheet tools. 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..

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. Presently, OMEGA models two types of GHGs, carbon dioxide (CO2) from fuel use and refrigerant emissions from the air conditioning (A/C) system. The core model utilizes the J# programming language. However, both inputs to and outputs from the model are provided using spreadsheet files, providing accessibility to a wide range of users. The spreadsheet output files also facilitate additional manipulation of the results desired by the user.

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 predict fuel consumption or CO2 emissions over a defined driving cycle. While OMEGA incorporates functions which generally minimize the cost of meeting a specified CO2 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 vehicle sales can change over time, vehicle sales do not change in response to the addition of technology. OMEGA may be expanded in the future to incorporate such market responses. However, currently, such responses must be addressed "outside of the model" through sequential model runs with market adjustments made between runs.

OMEGA can be used to model either a single vehicle model or over a thousand vehicle models). Vehicles can be those of specific manufacturers or generic fleet-average vehicles. Because OMEGA is an accounting model, the vehicles comprising the vehicle fleet being evaluated 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 CO2 reducing technology already present, and the vehicle's "type," which indicates the technology available for addition to that vehicle. Information required to determine the applicable CO2 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.[1]

[1] A vehicle's footprint is the product of its track width and wheelbase, usually specified in terms of square feet.

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. The effectiveness and application limits of each technology package can also vary over time. Technology costs are currently held constant over time. Future versions of the model may incorporate either the ability to vary cost over time or incorporate "learning" into the technology cost estimation procedure. Learning is the process whereby the cost of manufacturing a certain item tends to decrease over time due to experience. 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 CO2 emission target.

Technology can be added to individual vehicles using three distinct ranking approaches at present. (Additional ranking approaches are planned in the future in order to provide greater flexibility to the user.) Within a vehicle type, the order of technology packages is set by the user. The model applies technology to the vehicle with the lowest Technology Application Ranking Factor (hereafter referred to as the TARF). One TARF considers only the cost of the technology and the value of any reduced fuel consumption considered by the vehicle purchaser. The other two also consider the mass of GHG emissions reduced over the life of the vehicle. Fuel costs by calendar year and annual vehicles travelled per vehicle are provided by the user to facilitate these calculations.

For each manufacturer, OMEGA applies technology to its vehicles until its 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 converted to a flat standard for footprints either above or below specified levels. This is referred to as a segmented 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 vehicle 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 capability of mid to long term planning on the part of manufacturers. 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. When calculating annual costs and benefits of a particular GHG standard or standards, OMEGA uses linear interpolation to determine standards in the interim model years. Annual standards which do not vary linearly can be modeled by the user, but must be manually input to the spreadsheet which calculates costs and benefits.

GHG emission standards are specified in terms of CO2 equivalent emissions. These CO2 equivalent emissions can be based on any test procedure. The only requirement is that the base CO2 emissions specified for each vehicle and the effectiveness of the specified technologies be based on the same test cycle. For example, these emissions can simply be those from the tailpipe as measured over the current two-cycle CAFE test procedure or they can also include tailpipe CO2 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 soon to be used to calculate a vehicle's fuel economy label. The user simply needs to take care to specify CO2 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 combined test cycle emissions. Compliance cannot be specified for two distinct test cycles, for example, city and highway test emissions. Only combined 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 wide variety of output files. Outputs include specific information about the technology added to each vehicle and the resulting costs and emissions. Average costs per vehicle by manufacturer and industry-wide are also determined for each vehicle class.

Fleet-wide average GHG emissions are also determined for each redesign cycle. As mentioned above, emissions and costs are estimated for each calendar year in between redesign cycles and are used to estimate a wide array of societal costs and benefits associated with the GHG emission control. The primary cost of GHG emission control is the cost of the added technology as compared to the baseline or reference case. The primary benefit is the value of reduced fuel consumption and is a function of the price of fuel input to the model. In addition, the value of a number of other costs and benefits are also quantified, as listed below:

1) The reduction in carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOx), particulate matter (PM), and sulfur oxides (SOx) emissions associated with reduced fuel production, as well as their monetized value,
2) Externalities associated with reduced crude oil use which are not reflected in the price of crude oil, such as price shock impacts, monopolistic
3) The value of reduced time necessary to refuel vehicles, and
4) The value of GHG emission reductions.

GHG emission control usually improves vehicle fuel economy and thus, reduces the cost of driving. Studies have shown that vehicles are often driven more if their fuel economy increases. This is commonly referred to as the rebound effect. This effect, usually specified as the percentage increase in VMT per percentage decrease in fuel consumption per mile, can be specified by the user. OMEGA output spreadsheets estimate of a number of potential costs and benefits associated with driving, as follows:

1) Increased vehicular CO, VOC, NOx, SOx, and PM emissions and their monetized value,
2) Increased vehicular noise, congestion, and accidents,
3) The value of the additional driving, and
4) The cost of fuel required by the additional driving.

This version of the OMEGA documentation is being published with the input files used to support EPA's proposed GHG emission control program for cars and light trucks. EPA has established a webpage for the OMEGA model on the EPA agency website (go to www.epa.gov/otaq/climate/models.htm). This webpage will provide additional information about OMEGA. Periodic updates of both the model and this documentation will also be available to be downloaded. Those interested in using the model for purposes other than reviewing its use in support of the above mentioned NPRM are encouraged to periodically check this website for these updates.

The remainder of this document is divided into four sections. The first section describes the information which can or must 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 run or operate the OMEGA model.

II. Input Files

OMEGA is designed to be flexible in a number of ways. Very few numerical values are hard-coded in the model, and consequently, the model relies heavily on its input files. The core model utilizes five input files: Market, Technology, Fuels, Scenario, and Reference. Many values are utilized to estimate societal costs and benefits and are included in the benefit calculation spreadsheet, which is primarily considered to be an output of the model. Thus, the user's flexibility to vary these inputs will be discussed when the benefit calculation spreadsheet is discussed in Section IV below.

All the input files are Microsoft® Excel® spreadsheets. 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 note change the type of data shown as the core model is designed to look for certain types of information in each column and changing the 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 selected or "pushed," the spreadsheet runs through the various input worksheets and determines if all values 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.

It is important to note that OMEGA expects all the cells to the right of the last column 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 to the right to a column which has never been written into and copy the entire column of blank cells into the columns which have been used temporarily. The error identification process will then recognize these cells as actually being blank. The same is true for all rows beneath the last row of actual data.

A. The Market File: Vehicle Fleet Characterization

The market input file contains essentially all the required information which describes the vehicles being modeled. This file consists of three worksheets in addition to the Validation List and Errors worksheets: Market Data, Vehicle Type, and Refrigerant. Each will be discussed in turn below.

Table II-1 shows the various types of data included in the market data worksheet.

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

Column	Name	Column	Name
A	Vehicle Index No	U	Horsepower
B	Manufacturer	V	Max Seating
C	Model	W	Transmission Type
D	Vehicle Type No	X	Drive
E	Vehicle Class	Y	Structure
F	Baseline Sales	Z	Internal Volume
G through N	Annual Sales - Cycles 1 - 8	AA	Primary Fuel Type
O	Combined FE (mpg)	AB	Combined EC (kWh/mi)
P	Tailpipe CO2 (g/mi)	AC	Refrigerant Type
Q	Footprint (ft2)	AD	Refrigerant Lifetime Leakage (g)
R	Curb Weight (lb) *	AE through AX	TEB Tech. Pkg. 1 - 20
S	No. of Cylinders	AY Through BR	CEB Tech. Pkg. 1 - 20
T	Displacement (L)		

* Columns highlighted in gray are not currently used by OMEGA

Column A 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 B 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. Column C 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 D contains the vehicle type code. OMEGA currently allows up to 20 vehicle types, numbered with integers 1-20. This code provides the connection between the vehicles listed in the market data worksheet and the available technologies listed in the Technology file.

Column E 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 F 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 simply be positive and may even be fractional.

Columns G through N contain sales for the last year of each of up to eight redesign cycles. Sales must be positive and may even be fractional. Currently, the model assumes that a redesign cycle is five years long. Future versions may allow the user to specify the length of each redesign cycle. Sales must be entered for each vehicle, even if the value of sales is zero. Values must only be entered for redesign cycles actually being modeled. Thus, if only one redesign cycle is being modeled, then sales must only be entered in Column G. Columns H through N can be blank in this case. Sales can change in any manner between redesign cycles. Costs and benefits for interim years will be based on linearly interpolated sales per year.

Column O contains each vehicle's baseline fuel economy value in miles per gallon (mpg). It is currently not used by the model. EPA intends to develop a future version of OMEGA which will evaluate compliance in terms of fuel economy in addition to GHG emissions.

Column P 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 P 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 considered these emissions in a consistent manner.

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

Columns R through Z 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 AA contains a designator for each vehicle's primary fuel type. Three types are currently allowed in the model: G for gasoline, D for diesel fuel and E for electric or battery electric vehicle. Plug in hybrid vehicles would be designated by either G or D, 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 AB, which is described below. The model does not at present allow for other fuels, such as E85, compressed or liquefied natural gas, or liquid petroleum gas. Future version of OMEGA may include these fuel types.

These vehicles can usually be included in the current model by simply designating their fuel as either G or D depending on the type of engine being utilized by the alternative fueled vehicle. For example, a dedicated E85 vehicle could be designated as a gasoline-fueled vehicle since the type of technologies applicable to both vehicles are very similar if not identical. The base emissions listed in Column P would simply be those emitted by the E85 vehicle when operating on E85. The addition of technology to facilitate compliance should be correct. The error would occur in the benefit calculation file, where the fuel savings calculated would be in terms of gasoline and not E85. The user would have to determine the percentages of pre- and post-control fuel consumption which are in terms of gasoline and E85 and apply these percentages to the model's estimates of gasoline consumption

The fuel economy of flex-fuel vehicles (FFVs) is currently determined on the basis of their fuel economy while operated on gasoline, with an adjustment factor to incentivize the production of FFVs. EPA is proposing a similar approach in its proposed GHG emission regulations for cars and light trucks. If the FFVs are already in the baseline fleet or the user does not desire to include the cost of adding flex fuel technology, this FFV factor could be included in determining the base CO_2 emissions of the FFV, as discussed above for dedicated alternative fueled vehicles. Depending on whether the user expects such vehicles to actually be operated on gasoline or E85, the fuel consumption figures in the benefits calculation file may or may not require adjustment.

However, there are usually limits on the overall credit which a manufacturer can receive from such FFV incentives. Including the FFV incentive in the baseline CO_2 emission values could exceed such limits. If a manufacturer is expected to utilize the maximum allowed FFV credit, it will likely be easier to adjust the manufacturer's standard for this credit when determining which standard to include in the Scenario file. EPA will soon publish a version of OMEGA which will allow the user to specify credits such as an FFV credit either in terms of fuel economy (mpg) or CO2 emissions (g/mi). This credit will be described in more detail below when we describe the input to the Scenario file in Section II.D. This will facilitate the modeling of multiple manufacturers' vehicles with FFV or other credits which vary by manufacturer and over time.

If the user desires to model the conversion of gasoline-fueled vehicles to FFVs, a technology which basically performs this conversion could be included in the Technology file. Its effectiveness would reflect the FFV credit granted under the particular GHG control program being modeled, plus any actual change in CO2 emissions when the vehicle is operated on gasoline. This approach requires users' careful consideration to place the FFV technology step in the appropriate place in the order of technologies for each applicable vehicle type. The fuel savings implied by the FFV credit is usually very large and the cost of the conversion technology is usually relatively small. Thus, this technology will appear to be very cost effective from the model's perspective regardless of which TARF is selected. Thus, under the typical CAFE FFV credit scenario, this technology should be placed early in the list of technologies, as discussed in more detail in the next section, if not first.

With this approach, it may be possible to restrict manufacturers' use of FFV credits to reflect real-world regulatory limits on the overall use of such credits. The overall use of the FFV technology can be limited in the Technology file, as discussed below. Its use on individual vehicles can also be limited (e.g., to reflect different manufacturers' approaches to FFV credits) by showing certain vehicles to already have such technology even if they do not. As discussed further below, if a vehicle already has a technology, the model will go through the step of adding the technology, but will not add the cost of this technology nor change the vehicle's emissions. It might take a number of model runs to get the effective level of the FFV credit for each manufacturer close to the regulatory limit.

Column AB contains the vehicle's baseline electricity consumption in units of kilowatt-hour per mile (kw-hr/mi). At present, this value is only used in calculating the Technology Application Ranking Factor (TARF), 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 grid. This term only applies to plug in hybrids and battery electric vehicles.

At present, the OMEGA model assumes that compliance with the input CO2 emission standard is based on vehicle emissions alone. Since the use of electricity produces no emissions from the vehicle, the level of electricity usage per mile is not used in the model's compliance calculation. Future versions of the model may allow the user to assign a CO2 emission rate to electricity use to represent CO2 emitted in the production of electricity. The benefits calculation file also does not track electricity use. Future versions of OMEGA will allow 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. It is possible that in a future version, users will be able to input different levels of GHG emissions varying with time into the benefits calculation file to estimate annual emission impacts associated with changing electricity use.

Column AC 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 Market 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 CO2 equivalent emissions. In version 1.0 of OMEGA, the GWPs are hard-coded, thus requiring the user to specify one of the refrigerants in the list on the refrigerants page of the market file. In the next release of OMEGA, EPA is planning to allow editable refrigerant data in the References file, such that the user can edit or add additional refrigerant names and GWPs.

Column AD of the market file designates the lifetime leakage of the refrigerant, which the model uses to calculate the leakage rate in CO2 equivalents. EPA chose to input the lifetime leakage instead of the leakage rate because the lifetime leakage is easier to quantify. The relative distribution of leakage emissions across the life the vehicle is hard-coded within the model, and OMEGA uses this to convert refrigerant leakage to grams of CO2 equivalents per mile. This process is described in section III.B below.

Columns AE through BR 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 improvement. Columns AE through AX 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 reference case. Columns AY through BQ represent the fraction of the technology packages' cost that is reflected in the reference case. 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.

The first step in determining these fractions, referred to as the TEB and CEB in the market input file, is to develop a list of individual technologies which are either contained in each technology package, or would supplant the relevant portion of each technology package (e.g., the engine, the transmission, etc.). For example, variable intake valve timing would be associated with a downsized, turbocharged, direct injection engine. Thus, the effectiveness and cost of variable intake valve timing would be considered to be already present for any technology package which included either variable intake valve timing or included an engine technology which provided greater effectiveness. The reverse case would be an example of a technology which would supplant another technology. If a vehicle already had a downsized, turbocharged, direct injection engine, the effectiveness and cost of this technology would be considered to be already fully present when evaluating the application of a technology package which included variable intake valve timing or any other engine technology up to and including a downsized, turbocharged, direct injection engine. In either case, the effectiveness and cost present on the 2008 MY vehicle would be limited to the effectiveness and cost of the engine technology. This would allow the application of non-engine related technologies also included in that package (e.g., an improved transmission) to still be applied.

A specific example would be a 2008 MY vehicle falling into EPA vehicle type 1 that is equipped with a dry DCT. A dry DCT is available as part of EPA's technology package number 3 for vehicle type 1. Thus, when package 3 is added to that vehicle, the TEB and CEB values in the market input file indicate to the model that this technology is already present, and the model will not add additional effectiveness and cost of a dry DCT when applying the effectiveness and cost of package 3 to this vehicle. If the dry DCT contributed to 50% of the total effectiveness and 40% of the cost of package 3 over package 2 and 40% of the cost of package 3 over package 2 for this vehicle, then these percentages would be included in the market data file for this vehicle. If the level of CO2 control led to the application of technology package 3 to this vehicle in a run of the OMEGA model, the model would only apply 50% of the effectiveness of package 3 to this vehicle and 60% of the cost of this package.

If two consecutive technology packages both contain a dry DCT, packages 3 and 4, for example, the model user does not need to declare it as technology already present in the baseline. Instead, the benefit of package 4 is due to engine-related technology is considered incremental to package 3 and is contained in the technology input file. When applying package 4 to this vehicle, the OMEGA model will apply its full incremental effectiveness and cost. The same would be true for packages which replace a dry DCT with a hybrid technology equipped with variable valve timing and a 6-speed automatic transmission. The cost and effectiveness of variable valve timing would be considered to be already present for any technology packages which included the addition of variable valve timing or technologies which went beyond this technology in terms of engine related CO2 control efficiency. Since vehicle models are grouped into vehicle types for technology addition, and there are relatively few vehicle types compared to the number of vehicle models analyzed, there may be special cases when the applicable technology packages are less effective than baseline technologies; EPA therefore limits the applicability of the relevant technology packages to the affected vehicle models by adjusting the cost and effectiveness reflected in the baseline by the same method described above. An example of a single technology which supplants several technologies would be a 2008 MY vehicle which was equipped with a diesel engine. The effectiveness of this technology would be considered to be present for technology packages which included small improvements to a gasoline engine, since the resultant gasoline engine would otherwise accrue technology packages which are not as effective at reducing CO2 as the baseline diesel engine. However, if these packages which included improvements also included improvements unrelated to the engine, like transmission improvements, only the engine related portion of the package already present on the vehicle would be considered. The transmission related portion of the package's cost and effectiveness would be allowed to be applied in order to comply with future CO2 emission standards.

The second step in this process is to determine the total cost and CO2 effectiveness of the technologies already present and relevant to each available package. Determining the total cost is usually as simple as adding up the costs of the individual technologies present. In order to determine the total effectiveness of the technologies already present on each vehicle, EPA uses its Lumped Parameter Model. Because the specific technologies present on each 2008 vehicle are known, the applicable synergies and dis-synergies can be fully accounted for.

The third step in this process is to divide the total cost and CO2 effectiveness values determined in step 2 by the total cost and CO2 effectiveness of the relevant technology packages. These fractions are capped at a value of 1.0 or less, since a value of 1.0 causes OMEGA to maintain both the cost and CO2 emissions of a vehicle when that technology package is added.

The fourth step is to combine the fractions of the cost and effectiveness of each technology package already present on the individual 2008 vehicles models for each vehicle type. For cost, percentages of each package already present are combined using a simple sales-weighting procedure, since the cost of each package is the same for each vehicle in a vehicle type. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO2 emission level. This appropriately weights vehicle models with either higher sales or CO2 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 2011 MY CAFE standards and the proposed CO2 standards.

Users interested in developing their own set of technologies and their related effectiveness and cost values must also develop new values of CEB and TEB for each vehicle. Section 4.2 of EPA's Draft Regulatory Impact Analysis to the Agency's proposal to establish GHG emissions standards for motor vehicles contains a detailed description of the development of CEB and TEB values for a complex set of technologies coupled with a wide range of technologies existing in the baseline fleet.

B. The Technology file: Technology Package Characterization

Since there is large number of technologies which reduce CO2 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 CO2 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). 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.

The technology input file defines the technology packages 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.

The "TechPacks" tab contains all of the data used by the model. Similar to the Market file, the Technology file contains an additional tab entitled "errors", which is used for validation purposes. Table II-2, below describes the data in the "TechPacks" tab.

Table II-2 Input Data in TechPacks Worksheet of the Technology File

Column(s)	**Contents**
A	Vehicle type number
B	Technology package number
C	Technology package description
D	Abbreviation
E-L	Market penetration caps by redesign cycle
M-T	Incremental tailpipe CO2 emission control effectiveness
U	Refrigerant emission control effectiveness
V	Refrigerant type (NC = no change from previous step)
W	Primary fuel after application of the technology package
X	Electricity consumption after application of the technology package (if applicable)
Y	Incremental technology cost

Z-AD	Placeholders for learning curve coefficients (not currently used by the model)

The data in this file can be categorized in four ways: 1) Information which describes the individual packages (name and vehicle type to which it applies, for example; 2) Parameters the model uses to calculate CO2 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) T); 3) Data the model uses to calculate technology costs, such as the package cost and cost learning coefficients 4) Properties of the technology package, such as refrigerant type and fuel type.

The "TechPacks" 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). In order to avoid the complexity of synergistic effects, 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. Since the user defines the technology packages contained in the input file, technologies are dynamic (user defined) and not "hard-coded" within the model. 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, and is useful in determining the technology penetration results via array math.

Columns E-L contain the market penetration caps for the technology packages; each column in alphabetical order represents ascending redesign cycles. When technology is sufficiently new, or the leadtime 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, for example, all minivans, the user can limit its application to minivans through the use of a market cap of less than 100% in columns D through K. This cap can vary by redesign cycle. When a technology package is applied to fewer than 100% of the sales of a vehicle model due to the market cap, the effectiveness of the technology group is simply reduced proportionately to reflect the total net effectiveness of applying that technology package to that vehicle's sales. OMEGA does not create a new vehicle with the technology package and retain the previous vehicle which did not receive the technology package, splitting sales between the old and new vehicles. 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, or a combination of the two. The effectiveness of adding the subsequent technology may depend on which vehicles are receiving it.

Values in columns M through T contain the Average Incremental Effectiveness (AIE) of the technology package over the previous package (or over the baseline in the case of technology package 1) which the user can adjust on a redesign cycle basis. For example, a value of 7.0% in the AIE column would denote a 7.0% reduction in tailpipe CO2 emissions beyond any CO2 reductions already realized. ("Tailpipe CO2" refers to the CO2 emitted over the test cycle used to determine compliance with the CO_2 emission standard being modeled.) This value of 7% would include any synergistic effects that components of the technology package may have with technologies that have already been added to the vehicle type.

The user should be aware that many CO_2 emission control technologies affect vehicle attributes, such as weight, size and performance. For example, turbocharging always increases peak engine power and thus, performance. Dieselization also tends to increase vehicle weight and depending on the size and aspiration of the engine, can also impact performance in either direction. A common way to specify a technology's CO_2 effectiveness is to do so holding other vehicle parameters, such as utility and performance, as constant as possible. It may be impossible to hold weight constant. In this case, the impact of the change in vehicle weight should be included in the specified effectiveness of the technology. However, the specification of technologies, their effectiveness and their impact on other vehicle parameters is up to the user. We simply recommend that the user indicate when the application of a given technology is expected to affect vehicle parameters which may affect consumer desirability.

Column U 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 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.

Column W describes the primary fuel or energy source utilized by the technology package. Acceptable values are G for gasoline, D for Diesel, or EL for electricity. If a vehicle model has two fuels, OMEGA assumes that the vehicle is a plug-in hybrid electric vehicle (PHEV), and electricity is the secondary fuel. Thus, for the case of PHEVs, the user must enter either "G" or "D" into the primary fuel column. If a vehicle model is run on electricity only (an EV), the primary fuel can be designated as "EL".

Column X contains the level of electricity use existing after application of the technology. While base electricity use can vary by vehicle, electricity use after the application of technology is done at the vehicle type level. The fact that the vast majority of current vehicles do not use electricity prevents us from specifying post-technology electricity use in terms of a reduction from the baseline usage. The inability to represent slight differences in electricity use between specific vehicle models is not too restrictive, given that no data are available to indicate the degree of these differences. For example given that manufacturers do not currently produce a wide range of plug in and fully electric vehicles, there is no basis to project that one manufacturer's mid-size electric cars will use 5% more electricity per mile than those produced by another manufacturer.

Column Y 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.

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

The Fuels input file contains data relevant to 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 range. There is a third hidden worksheet which contains the range values. The following table describes the layout and content of the "fuel" tab in the fuels input file.

Table II-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 - X	Fuel Price ($/gal)

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

Column A describes the fuel type. Currently, this value is limited to G for gasoline, D for Diesel, or EL for electricity. In the future, EPA plans to increase the model's capability to handle additional fuels, such as E85 and low sulfur gasoline, for example.

Column B contains the energy density of the energy source. For the liquid fuels, the units are BTU per gallon. For electricity, the units are BTU per kilowatt-hour. Column C contains the mass density of the liquid fuels in terms of grams per gallon. It has no value for electricity. Both Columns B and C are not used in the model's core algorithm.

Column D describes the carbon density of the energy source, and is used in the calculation of the Technology Application Ranking Factor (TARF), described in the section on the modeling process and algorithms. This is in units of grams of carbon per gram per the unit of fuel 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. Since manufacturers do not consider the upstream emissions of electricity when adding fuel-saving technologies to vehicles, EPA currently records the carbon density of electricity as 0. If the agency chooses in the future to incorporate the upstream emissions of carbon in the TARF calculation, EPA could enter in a generally accepted average value of 853 grams of carbon per kWh of electricity produced (or other value).

Columns E through X contain the fuel price either in US Dollars per gallon or US Dollars per kWh for liquid fuel and electricity, respectively. Fuel prices are displayed in ascending order by year and are used when calculating the fuel savings over the payback period in the TARF.

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 (CO2 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 CO2 equivalent standard. The elements in the "Scenarios" tab described above are summarized in the following table:

Table II-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

Column A in the Scenarios tab indicates the ID number of the model run. The model can run as many different scenarios as the user desires automatically in succession. In Column B, the user can give each scenario a name, which the model will use in naming the output files for each scenario.

Column C denotes the baseline year for each scenario. This is the year prior to the first year of the redesign cycle.

Column D indicates the type of standard or target the model will use for compliance. Currently, the only available option is CO2, although it is conceivable that EPA may incorporate MPG as an additional target metric in the future.

Column E is where the user designates which of the three Technology Application Ranking Factors (TARFs) the model should use. The model uses the TARF equations to determine the order of technology package application on the different vehicle types. There are three TARF equations which are summarized qualitatively below.

1. Effective Cost = [Technology package cost minus fuel savings over the payback period minus the implicit reduction in fines for non-compliance].
2. Cost Effectiveness-Society = [Effective Cost] divided by discounted lifetime CO2 emissions.

3. Cost Effectiveness-Manufacturer = [Effective Cost] Divided by lifetime CO2 emissions.

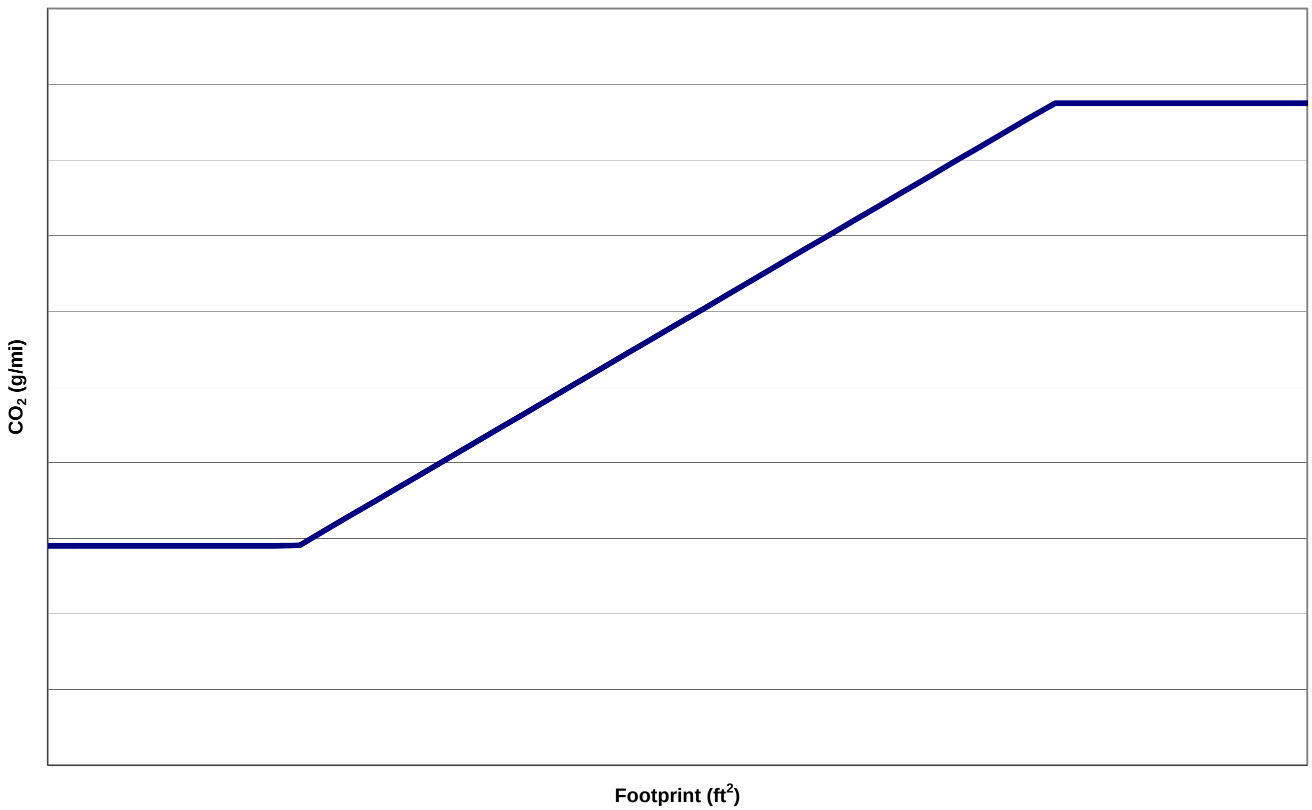
These 3 TARFs are described in detail in Section III.C below.

Column F indicates the user's preference for type of function for the industry-wide GHG level. There are three options for compliance targets: 1 = universal; 2 = piecewise linear; 3 = constrained logistic. The universal target option is simply a numerical designation which the manufacturers' average fleet CO2 cannot exceed. In contrast, the attribute-based linear target function is described by up to four coefficients and has the following piecewise linear mathematical form:

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

Where
A: Minimum level of CO2 target
B: Maximum level of CO2 target
FP_{min}: Footprint value where CO2 target reaches minimum value (i.e., intersection of lower asymptote with slope)
FP_{max}: Footprint value where CO2 target reaches maximum value (i.e., intersection of upper asymptote with slope)
FP: Vehicle footprint (square feet)

Example of Footprint-Based CO_2 Piecewise Linear Target Function



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

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

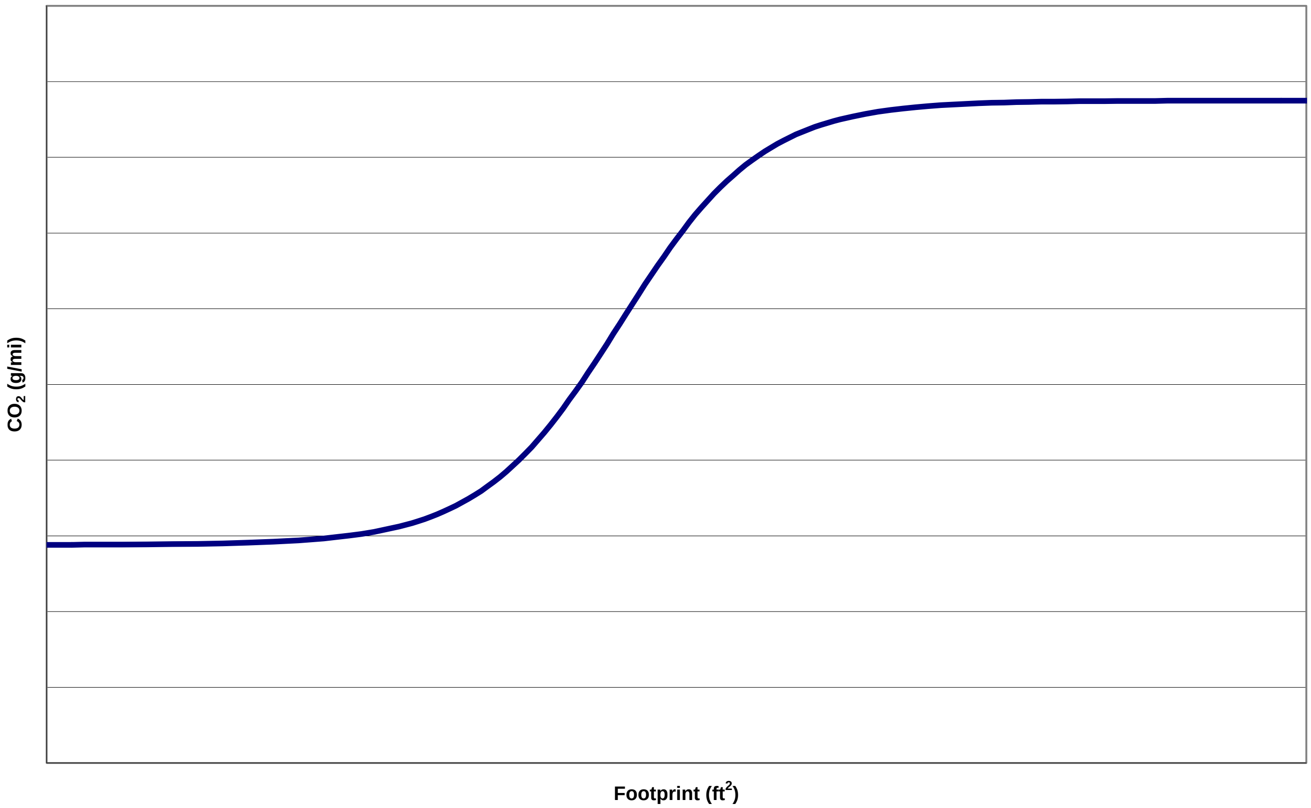
Where A, B, and FP have the same definitions as above

C: Footprint value at equation inflexion point (i.e., midpoint)

D: The term which controls the rate at which the CO2 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

Example of Footprint-Based CO_2 Logistic Target Function



Column G of the Scenarios tab in the Scenario input file is entitled “fleet type”, and EPA plans to update this title in a future version. There are two acceptable values for cells in this column: 1 = 1 fleet and 2 = 2 fleets. Originally these options were designed to indicate whether the car and truck fleets were combined or separate. However, since the user can run a combined fleet with just cars, just trucks, or cars and trucks combined, EPA plans to change the name of column G to either “Number of fleets” or “Number of standards” for clarity. If 1 is chosen, the standard defined in the “Standards” tab will be taken from the “Car” standard section, whereas if 2 is chosen, the standards will be defined by both the “Car” and “Truck” standard sections.

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 length of redesign period is currently hard coded to be 5 years, although EPA may make this an editable input in a later version. Thus, in its current state, the model can analyze standards up to 40 years into the future.

Column I contains the limit (in units of g/mi CO2) imposed on the trading of compliance credits between cars and trucks. One of the flexibilities proposed in EPA’s recent vehicle GHG rule is trading across a manufacturer’s car and truck fleets. As described in the proposed regulations, trading of credits would occur in terms of tons of CO2 emissions. Credits are generated when a manufacturer’s fleet of either cars or trucks over complies 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.

$$CreditGenerated = \frac{\sum_{v=1}^{CorT} \left(Sales_v \times LifeVMT_v \times (TCO2_v - Target_v \right)}{\sum_{v=1}^{CorT} Sales_v \times LifeVMT_v}$$

Where $Sales_v$ is the sales volume of each car or truck in that redesign cycle,
$LifeVMT_v$ is the lifetime VMT per vehicle, which is the sum (over the life of the vehicle) of the product of the vehicle survival percentage by vehicle age and the annual VMT per vehicle by vehicle age. Both sets of these values are input to the model in the Reference file. This value is the same for all cars (and all trucks) and could effectively be moved outside of the summation portion of the formula,
$TCO2_v$ is the sum of tailpipe and refrigerant emissions in terms of equivalent CO2 of each car or truck after the model has determined that compliance is achieved, and
$Target_v$ is the emission standard or target applicable to each car or truck, as defined by the type of target defined in column F and the numerical inputs described on the Target worksheet of the Scenario file (see below).

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

$$CreditUsed = \frac{\sum_{v=1}^{CorT} \left(Sales_v \times LifeVMT_v \times (Target_v - TCO2_v \right)}{\sum_{v=1}^{CorT} Sales_v \times LifeVMT_v}$$

The model implements this trading scheme by determining the standard applicable to both cars and trucks by weighting the target applicable to each car and truck by both sales and lifetime VMT, as shown below.

$$FleetwideCO2Target = \frac{\sum_{v=1}^{V} \left(Sales_v \times LifeVMT_v \times Target_v \right)}{\sum_{v=1}^{V} Sales_v \times LifeVMT_v}$$

Fleetwide total tailpipe and refrigerant CO2 equivalent emissions are determined in an analogous fashion, as shown below.

$$FleetwideTCO2 = \frac{\sum_{v=1}^{V} \left(Sales_v \times LifeVMT_v \times TCO2_v\right)}{\sum_{v=1}^{V} Sales_v \times LifeVMT_v}$$

Compliance is achieved when *FleetwideTCO2* is equal to or less than *FleetwideCO2Target.*

Inputting zero in Column I prevents such trading and requires manufacturers to comply with the relevant emission standards for their cars and its trucks separately. If the user desires to allow unlimited trading, this is accomplished by inputting a large non-zero number in Column I (e.g., 100 g/mi CO2). 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. Thus, in addition to requiring compliance with the fleetwide average CO2 target, the model must also ensure that each vehicle complies with its applicable target plus the trading allowance. The algorithms which accomplish these tasks are described below in Section III.A.

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.

The Scenario input file also contains the economic parameters that the model uses to calculate the Technology Application Ranking Factors (TARFs).Such economic data is contained in the "Economics" tab and is organized as illustrated in the following table:

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

Column(s)	Contents
A	Identification of model run
B	Discount rate
C	Payback period
D	CAFE fine
E	Gap
F	Threshold cost
G	CO2 value increase rate

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 comparing technology package and vehicle model combinations.

Column C designates the payback period, which the model uses to consider the length of time which consumers consider fuel savings when purchasing a vehicle.

Column D indicates the value of a fine for non-compliance. Since the Clean Air Act does not allow EPA to charge a monetary fine for non-compliance, EPA typically records $0 into this column. However, there are instances when EPA would like to model the impact of a fine, such as the CAFE fine. OMEGA uses this value in the TARF equations.

Column E contains the Gap, which is the difference between test cycle and real-world CO2. This value is important because manufacturers consider the test cycle CO2 when complying with a CO2 standard, whereas the true impact on climate is based on the on-road CO2. The model uses this difference to convert test cycle CO2 emissions to onroad fuel economy and calculate fuel savings in the core model's TARF equations, which are defined in Section III C, 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.

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 different engines, one with the technology and one without, would 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.

Column G represents the rate of increase in the real value of CO2 emission reductions over time. This value is included since some studies have predicted that the value of CO2 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-Manufacturer and Cost Effectiveness-Society TARFs described below.

The Target tab of the Scenario file contains the parameters describing the GHG compliance targets required by the universal, segmented linear and constrained logistic functions described above. The first 32 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 AF apply to both cars and trucks. Similarly, the next 32 columns (AG through BL) describe the truck standards for up to eight redesign cycles if “1” fleet is selected. These values are not used if “1” fleet is selected. This is described in Table II-6 below.

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

Column(s)	Contents	Vehicle Class
A - D	Coefficients describing the CO2 Standard for Design Cycle 1	Car If “2” fleets selected Car and Truck if “1” fleet selected
E – H	Coefficients describing the CO2 Standard for Design Cycle 2	
I – L	Coefficients describing the CO2 Standard for Design Cycle 3	
M – P	Coefficients describing the CO2 Standard for Design Cycle 4	
Q – T	Coefficients describing the CO2 Standard for Design Cycle 5	
U – X	Coefficients describing the CO2 Standard for Design Cycle 6	
Y - AB	Coefficients describing the CO2 Standard for Design Cycle 7	
AC - AF	Coefficients describing the CO2 Standard for Design Cycle 8	
AG – AJ	Coefficients describing the CO2 Standard for Design Cycle 1	Truck If “2” fleets selected Not used if “1” fleet selected
AK – AN	Coefficients describing the CO2 Standard for Design Cycle 2	
AO – AR	Coefficients describing the CO2 Standard for Design Cycle 3	
AS – AV	Coefficients describing the CO2 Standard for Design Cycle 4	
AW – AZ	Coefficients describing the CO2 Standard for Design Cycle 5	
BA – BD	Coefficients describing the CO2 Standard for Design Cycle 6	
BE – BH	Coefficients describing the CO2 Standard for Design Cycle 7	
BI - BL	Coefficients describing the CO2 Standard for Design Cycle 8	

As indicated, each CO2 standard is described by up to four 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). All four columns are required to describe either the segmented linear or constrained logistic functions described above. The four columns in each set of four columns describe the coefficients labeled A, B, C, and D, respectively, in the segmented linear and constrained logistic functions described above. The header row of the Target worksheet indicates these coefficient labels.

E. The Reference File: Vehicle Survival Rates and Miles Driven

The References file contains all data which refers to car and truck annual miles driven and survival rates by year. This data is used in all TARF calculations when determining fuel savings over the payback period and when determining the lifetime CO2 reduction (in TARFS 2 and 3 only). The data in this file is also used in OMEGA’s compliance calculations as it pertains to credit trading within a manufacturer’s cars and trucks.

Data which OMEGA uses in its calculations is contained in the tab entitled “Vehicle Age”. Column A in this tab contains the vehicle age in years. Columns B and C contain car and truck survival rates, respectively. This is the percent of cars and trucks which remain on the road each year. Columns D and E contain the average miles driven annually (per vehicle) for cars and trucks accordingly.

F. “Hard-coded” Input Data

The only values hard-coded into the model which are potentially used in the application of technology to vehicles are the global warming potentials and the distribution of leakage rate by vehicle age. These are only used if refrigerant emissions are included in the market file. At present, acceptable refrigerants are listed below in the following table with their respective GWPs.

Refrigerant	**GWP**
HFC-23	11700
HFC-125	2800
HFC-134a	1300
HFC-143a	3800
HFC-152a	140
HFC-227ea	2900
HFC-236fa	6300
HFC-4310mee	1300

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

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

27	0.0%
28	0.0%
29	0.0%
30	0.0%
31	0.0%
32	0.0%
33	0.0%
34	0.0%
35	0.0%
36	0.0%

EPA plans to make this data editable in a future version, such that the name and GWP of each refrigerant can be changed as new refrigerants are developed over time. Other information such as of upstream criteria pollutant emissions from fuel/energy production, storage, and distribution, regression coefficients for downstream criteria pollutant emissions, emissions damage costs, and externalities related to crude oil importation and use, externalities related to driving are automatically loaded into the benefits calculation spreadsheet, where the user can edit the values, if desired. The user can change the value of these factors in the spreadsheet if the use of alternative factors is desired.

G. Input Files Currently Being Distributed with Model

The sample files bundled with the installation file closely resemble those used by EPA in the EPA-NHTSA joint proposed rulemaking to establish greenhouse gas standards and improve fuel economy for motor vehicles. The underlying data for both sets of input files is the same; rather, it is EPA's use and presentation of the data which have evolved over time, as new versions of the model have become more capable.

The data contained in these files are from several different sources. In the Market file, the baseline vehicle models and characteristics were taken from EPA's certification database for model year 2008. Projected sales were determined using a complex mapping process between EPA's certification database and data purchased from CSM International. This process is described in detail in Chapter 1 of the EPA-NHTSA joint Draft Technical Support Document (DTSD) to the Agencies' joint rule (Document No. EPA-420-D-09-001). The only difference is that the Market file distributed with the installation file has manufacturer distinctions removed, while that used in support of the proposed rule retained the manufacturer distinctions.

The Technology file is an exact duplicate of the one used in the rulemaking proposal. EPA's methodology for creating the Technology file is described in detail in the joint DTSD, Chapter 3, and EPA's Draft Regulatory Impact Analysis (DRIA) Chapter 1 (EPA-420-D-09-003)

The source of the data in the Fuels files is the Energy Information Adminstration's Annual Energy Outlook publication for 2009, the "Stimulus" edition. This file is also a duplicate of the one used in EPA's proposed rule.

The economic data provided in the sample Scenario file is exactly the same as that used for the proposed rule. However, because the version of OMEGA used for the rule did not have a car-truck trading algorithm, EPA set the compliance target coefficients differently in the rulemaking Scenario file to determine the technology cost using an alternative approach. The sample Scenario file describes two separate scenarios using the proposed regulatory coefficients: Scenario 1 comprises the exact coefficients resulting in a 250 g/mi CO2 fleetwide average and Scenario 2 coefficients are relaxed to reflect the approximate 11 g/mi credit for air conditioning technology expected to be utilized in the 2016 model year.

The inputs in Reference file were developed by EPA and NHTSA for the rulemaking, and a detailed description of this data is contained in the DTSD, Chapter 4. The underlying data for the two files are the same, but were adjusted downward for Trucks in the rulemaking version, to accommodate the alternative car-truck trading algorithm.

III. Model Operation

The operation of the "core" model can be described in three steps. The first step determines the effective CO2 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 CO2 equivalent and adds this to the baseline tailpipe CO2 emissions for each vehicle. The third setp applies technology until this standard is met or all available technology has been applied. These steps are described below.

A. Determination of Manufacturer-Specific CO2 Emission Standards

As described above in Section II.D., three types of standards can be evaluated by OMEGA: universal or flat, segmented linear, and constrained logistic. Determining each manufacturer's effective standard under a flat standard is simple; it equals the flat standard. The second two types of standards require sales-weighting the CO2 target applicable to each specific vehicle model produced by that manufacturer. The model calculates each vehicle's CO2 target by plugging the vehicle's footprint into either the footprint-based formula describing the standard. Each of the vehicle-specific targets are then multiplied by the vehicle's sales in that redesign cycle and the 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 essentially a sales and lifetime VMT weighted corporate average CO2 target for each manufacturer.

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 CO2 emission targets, one for cars and one for trucks, which will likely differ due to difference between car and truck sales, lifetime VMT and footprint values, if applicable. However, if one fleet is specified, then the model only performs this calculation once and includes both cars and trucks in the calculation.

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. Conceptually, when trading is allowed and practically limited, a manufacturer must comply with three distinct standards, one for cars equal to its standard for cars plus the trading allowance, one for trucks equal to its standard for trucks plus the trading allowance, and the sales and VMT weighted standard for cars and trucks combined. 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 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.

OMEGA utilizes a simple set of algorithms to achieve both of these goals with a single set of technology applications. It does so by calculating 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. 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 CO2 is input and the applicable car and truck standards for a manufacturer are 220 and 300 g/mi CO2, respectively. The model calculates the combined sales and VMT weighted CO2 emission target using the above equation for FleetwideCO2Target, which can be simplified as follows:

$$FleetwideCO2Target = \frac{\sum_{vc=1}^{2}\left(Sales_v \times LifeVMT_v \times Target_v\right)}{\sum_{vc=1}^{2} Sales_v \times LifeVMT_v}$$

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

Once FleetwideCO2Target 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 exceed its target by 10 g/mi CO2 (310 g/mi in this example). For this example, assume this level is 198 g/mi CO2. 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 CO2 (230 g/mi in this example). Again, for this example, assume this level is 302 g/mi CO2.

The model then proceeds to add technologies to cars and trucks (described in greater detail below) until one of three conditions is met: 1) combined car and truck emissions reach 260 g/mi CO2, 2) car emissions reach 198 g/mi CO2, or 3) truck emissions reach 302 g/mi CO2. If combined car and truck emissions reach 260 g/mi CO2 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 1 is reached first, the model continues to evaluate and apply technology to both cars and trucks. However, if the TARF indicates that technology should be applied to a car next, the model assumes that that vehicle already has that technology present on it, retains its cumulative technology cost and emission level and moves to the next technology. In this case, the model continues to effectively add technology to trucks only until criterion 3 is met (unless insufficient technology exists to enable overall compliance). Likewise, if criterion 2 is reached first, the model continues to evaluate and apply technology to both cars and trucks. However, if the TARF indicates that technology should be applied to a truck next, the model assumes that that vehicle already has that technology present on it, retains its cumulative technology cost and emission level and moves to the next technology.

B. Converting Lifetime Refrigerant Emissions to CO2-Equivalent emissions per Mile

Refrigerant leakage emissions are input to the model in terms of lifetime emissions, while 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, CO2 tailpipe emissions are input in terms of g/mi and are generally assumed to be constant with age. Thus, some processing is needed to be the two types of emissions on a comparable basis.

OMEGA converts lifetime refrigerant emissions to their equivalent value in terms of CO2 emissions per mile (RCO2) considering the change in societal value of CO2 emissions over time. The goal is to estimate a level of CO2 emissions per mile, which, if constant over the vehicle's life, like tailpipe CO2 emissions are generally assumed to be, would produce the same societal value of CO2 emissions as the distribution of refrigerant emissions over the life of the vehicle. This equality is shown in the following equation:

Value of Equivalent Lifetime CO2 Tailpipe Emissions =
Value of Lifetime Refrigerant Emissions

$$RCO2 * \sum_{i=1}^{36} [VMT_i * ValueofCO2_i] = GWP * \sum_{i=1}^{36} [\mathrm{RefLeakage}_i * ValueofCO2_i]$$

where VMT_i is the annual miles travelled for the relevant class of vehicle at age i, (i.e., 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),

$ValueofCO2_i$ is the societal value of CO2 emissions in the calendar year when the vehicle is at age i,

$RefLeakage_i$ is 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 CO2.

The value of CO2 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 CO2 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:

$$RCO2(g/mi) * \sum_{i=1}^{36} [VMT_i * BaseValueofCO2 * \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}] =$$

$$GWP * \sum_{i=1}^{36} [\text{RefLeakage}_i * BaseValueofCO2 * \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}]$$

This equation can be rearranged to solve for the level of CO2 equivalent emissions per mile as shown in the next equation. (Note that the societal value of CO2 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 CO2 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. At the present time, the only use of the rate of increase in the societal value of CO2 emission reductions is in this calculation and as an input to the benefits calculation spreadsheet. Therefore, if the user desires to perform this equivalency using physical emissions, they should set the rate of increase in the societal value CO2 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 CO2 emission reductions in the estimation of benefits, they can change this value in the benefits calculation spreadsheet.

C. Application of Technology:

The core model 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 CO2 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:

1) recalculate the manufacturer’s sales and VMT-weighted emissions,

2) compare this new corporate average emission level to the manufacturer’s standard,

3a) if the manufacturer is now below the standard, determine if the cost of the last technology is above or below the threshold cost specified,

3.a.i) if the cost is below the threshold, the evaluation of this manufacturer is over and the model moves onto the next manufacturer,

3.a.ii) if the cost is above the threshold, the application of the technology (in terms of emissions and cost) is decreased until the standard is just met; the evaluation of this manufacturer is over and the model moves onto the next manufacturer,

3d) 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:

1) recalculate the manufacturer’s sales and VMT-weighted average emissions for cars, trucks, and both cars and trucks, combined,

2) compare these three emission levels to the three criteria described in Section III.A. above,

3.a) if the manufacturer is above all three criteria specified in Section III.A., 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.

3.b) if the manufacturer is now below the combined car and truck standard but not below either the lower limit for generating useable tradable credits for cars or trucks (i.e., meets criterion 3 specified in Section III.A , but not either criteria 1 or 2), determine if the cost of the last technology is above or below the threshold cost specified,

3.b.i) if the cost is below the threshold, the evaluation of this manufacturer is over and the model moves onto the next manufacturer, 3.b.ii) if the cost is above the threshold, the application of the technology (in terms of emissions and cost) is decreased until the standard is just met; the evaluation of this manufacturer is over and the model moves onto the next manufacturer,

3.c) if the manufacturer is now below the lower limit of either car or truck emissions which provides tradable emission credits, but not below the standard for cars and trucks combined (i.e., meets either criterion 1 or criterion 2 specified in Section III.A.), determine if the cost of the last technology is above or below the threshold cost specified,

3.c.i) if the cost is below the threshold, move to step 3.a.iii.,

3.c.ii) if the cost is above the threshold, the application of the technology (in terms of emissions and cost) is decreased until the standard is just met;

3.c.iii) Return to steps 1 and 2 above and apply another technology package to further reduce emissions, but only effectively applying these packages if they apply to the vehicle class whose lower limit criterion was not met in step 3.a.i.

3.d.) if the manufacturer is now below the combined car and truck standard and below either the lower limit for generating useable tradable credits for cars or trucks (i.e., meets either criteria 1 and 3 or 2 and 3 specified in Section III.A), determine if the cost of the last technology is above or below the threshold cost specified,

3.d.i) if the cost is below the threshold, the evaluation of this manufacturer is over and the model moves onto the next manufacturer,

3.d.ii) if the cost is above the threshold, the application of the technology (in terms of emissions and cost) is decreased until the standard is just met; the evaluation of this manufacturer is over and the model moves onto the next manufacturer.

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 technology 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 steps outlined above are 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.

Determining the best application of technology: We have defined a metric called the Technology Application Ranking Factor (TARF) to rank the application of available technology packages across various vehicles. As described above, the user can choose between three different TARFs for ranking technology application: 1) Effective Cost, 2) Cost Effectiveness–Society, and 3) Cost Effectiveness–Manufacturer. The first and third TARFs 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.[2] 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 are those assumed 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.

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. Because TARFs 1 and 3 reflect the manufacturers' perspective, they are similar conceptually. Therefore, we describe both of these TARFs before describing TARF 2 below.

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 minus the reduction in CAFE non-compliance fee (FEE). The Effective Cost TARF was included in the OMEGA model, since it is the equivalent of the technology ranking process used in NHTSA's Volpe 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:

$$EffCost = TechCost - FS \times \frac{1}{(1 - GAP)} - FEE \times \left(\frac{1}{FC_t} - \frac{1}{FC_{t-1}} \right)$$

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[2] 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.

EffCost 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 CO2 emission standards) before (FC_{t-1}) and after technology addition (FC_t) is calculated as follows:

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

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

Where CD_{t-1} and CD_t represent the carbon density of the liquid fuel (in terms of grams carbon per gallon) before and after technology application,
$CO2_{t-1}$ represents the level of tailpipe emissions prior to the application of the technology being evaluated (i.e., after the application of technology t-1), and
$CO2_{TARF,t}$ represents the level of tailpipe emissions after application of technology t, without considering any cap on the level of the penetration of technology t.

$CO2_{t-1}$ is the actual level of CO2 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" CO2 level from which to evaluate technology t since all previous technologies must be added to the vehicle before technology t can be added.

As stated above, OMEGA takes a slightly different approach to calculating the CO2 emissions after application of technology t (for the purpose here of TARF calculation) in that we do not factor in the potential cap on the level of the penetration of technology t. At the present time, the sales volume of the particular vehicle is not factored into the TARF. To factor in a percentage cap would be inconsistent. Certainly 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 TARF is essentially defined on a per vehicle basis.

Because the calculation of $CO2_{TARF,t}$ does not consider the impact of any cap on technology penetration, this level of CO2 emissions will differ from the CO2 emission level of the vehicle should this technology be selected for addition. The equation for the latter CO2 emission level is described further below.

With these premises, the formulae describing tailpipe CO2 emissions and refrigerant emissions after the application of this technology package are as follows:

$$CO2_{TARF,t} = \frac{CO2_{t-1} \times (1 - AIE_t)}{1 - AIE_t \times TEB_t}$$

$$RCO2_{TARF,t} = \frac{RCO2_{t-1} \times (1 - AIE_t)}{1 - AIE_t \times TEB_t} \times \frac{GWP_t}{GWP_{t-1}}$$

It should be noted that both equations include the term $(1\text{-}AIE_t)/((1\text{-}AIE_t{*}TEB_t)$. The effectiveness of adding the technology package (AIE) is determined relative to a vehicle which does not have that technology package. If a vehicle already has some aspect of the technology package present, its emissions are lower than they would be without this technology. The term in the denominator effectively increases the emissions of the vehicle to the level which would exist without the technology. The effectiveness of the technology package can then be applied.

Fuel savings without consideration of the gap between onroad 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.

$$FS = \sum_{i=1}^{PP} VMTi * [(FC_{1,t} - FC_{1,t-1}) * FP_{1,BY+(5*RC)+i-1} + (FC_{2,t} - FC_{2,t-1}) * FP_{2,BY+(5*RC)+i-1}]$$

Where i again represents vehicle age,

VMT_i represents annual vehicle miles travelled for a vehicle of age i,

PP represents the payback period, or the length of time the user assume that consumers value fuel savings when purchasing a new vehicle, stands

FC represents fuel consumption per mile of either fuel 1 or 2, which is independent of both vehicle age and calendar year,

FP represents fuel price of either fuel 1 or 2 in the calendar year equivalent to the vehicle age used to determine annual VMT. For i=1, this calendar year is the base year of the model run plus the redesign cycle times five years plus the vehicle age less one. For example, for a run with a base year of 2010 and the first redesign cycle, vehicles with an age of 1 are assumed to be driven in 2015, which is in fact the end of the first redesign cycle.

The GAP is the difference between real-world and test cycle fuel economy. It is defined as one minus the ratio of on-road fuel economy to real word or on-road fuel economy. In terms of CO2 emissions and fuel consumption, on-road CO2 and fuel consumption equal test cycle CO2 and fuel consumption divided by (one minus the GAP), respectively.

In order to be consistent with the calculation of $CO2_{TARF,t}$, 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.

For current uses of the model, we recommend that the CAFE fee be set to zero. CAFE fees do not apply under EPA CO2 emission controls being considered and the above methodology can produce unreasonably high values for the reduction in CAFE fees in some circumstances. In this case, the Effective Cost TARF represents the difference between what it costs the manufacturer to add the technology to the vehicle and the increase in value from the consumers perspective due to fuel savings.[3] 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. This TARF assumes that manufacturers will incrementally add technologies which increase this desirability to the maximum extent possible.

Cost Effectiveness-Manufacturer TARF (TARF No. 3): 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 CO2 standard. It can be described simply as the Effective Cost TARF divided by the mass of the CO2 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:

$$CostEffManuf_t = \frac{TechCost - FS \times \frac{1}{(1-GAP)} - FEE \times \left(\frac{1}{FC_t} - \frac{1}{FC_{t-1}}\right)}{\sum_i^{36} \left[\left[\left(RCO2_{TARF,t} - RCO2_{t-1}\right) + \left(CO2_{TARF,t} - CO2_{t-1}\right)\right] \times VMT_i\right]}$$

This equation can be rewritten more simply as follows:

$$CostEffManuf_t = \frac{EffCost}{\sum_i^{36} \left[\left[\left(RCO2_{TARF,t} - RCO2_{t-1}\right) + \left(CO2_{TARF,t} - CO2_{t-1}\right)\right] \times VMT_i\right]}$$

Where, $RCO2_{TARF.t} = RCO2_{t-1} \times \left(1 - RIE\right) \times \frac{GWP_t}{GWP_{t-1}}$

The ratio of GWPs reflects the fact that the technology might change the refrigerant used and affect the conversion of refrigerant mass emissions to CO2 equivalent emissions.
All of the terms in the above equations have already been defined. The denominator could be described simply as the reduction in gram per mile tailpipe CO2 and CO2 equivalent refrigerant emissions times the vehicle’s lifetime VMT. For vehicles of the same class, VMTi is the same, so the inclusion of VMTi in the denominator has no practical impact. However, when cars and

[3] *Ibid*.

trucks are being modeled together, the inclusion of this term has an effect. Its effect is consistent with EPA's proposed car-truck trading provisions included in its recent vehicle GHG proposal.

As described above for the Effective Cost TARF, we recommend that the CAFE fee be set to zero with this TARF. The Cost Effectiveness-Manufacturer TARF represents the degree to which consumer desirability might change with the technology on a per ton of CO2 controlled basis. The Effective Cost TARF 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 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 CO2 emission reductions, thereby increasing 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 consumer desirability per ton of CO2 reduced was higher.

Cost Effectiveness-Society TARF (TARF No. 2): The Cost Effectiveness-Society TARF (*CostEffSoc*) is identical to the Cost Effectiveness–Manufacturer TARF with one exception. The Cost Effectiveness-Society TARF divides the Effective Cost TARF by the discounted lifetime CO2 emission reduction instead of the lifetime CO2 emission reduction. The discount rate used would be that for the value of CO2 emission reductions over time. The rationale for discounting is simply that society is presumed to value CO2 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:

$$CostEffSoc_t = \frac{EffCost}{\sum_{i}^{36}\left[\left[\left(RCO2_{TARF,t} - RCO2_{t-1}\right) + \left(CO2_{TARF,t} - CO2_{t-1}\right)\right] * \left[VMT_i \times \frac{1 + \frac{DR - IR}{2}}{\left(1 + DR - IR\right)^i}\right]\right]}$$

where all the terms have already been defined.

Applying Technology: 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 TARFs for applying technology package 1 to all of the vehicles in that manufacturer's fleet and chooses the vehicle 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 CO2 emission levels after application of the technology are shown below:

If CAP is greater than AIE:

$$CO2_t = \frac{CO2_{t-1} \times (1 - CAP \times AIE)}{1 - AIE \times TEB}$$

$$RCO2_t = \frac{RCO2_{t-1} \times (1 - CAP \times AIE)}{1 - AIE \times TEB} \times \frac{GWP_t}{GWP_{t-1}}$$

If AEI is equal to or greater than the CAP:

$$CO2_t = CO2_{t-1}$$
$$RCO2_t = RCO2_{t-1}$$

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 by100% 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.

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:

$$TotalCost_t = TotalCost_{t-1} + TechCost * MIN((CAP - CEB), 0) * Sales_v$$

$$FleetTCO2_{step} = \frac{\sum_{v=1}^{V} \left(Sales_v \times LifeVMT_v \times TCO2_t \right)}{\sum_{v=1}^{V} Sales_v \times LifeVMT_v}$$

where v represents a vehicle produced by the manufacturer,

V is the total number of vehicles produced by that manufacturer,

$TCO2_t = CO2_t + RCO2_t$, which are the emissions after application of technology t, and

$LifeVMT_v$ is the lifetime VMT of the class of vehicle to which vehicle v belongs. Lifetime VMT is the sum of the product of relevant vehicle survival fractions and annual VMT by vehicle age as input in the Reference file.

As mentioned above, compliance with the CO2 standards is performed on a sales and VMT weighted basis, for ease in trading between cars and trucks under the provisions of the proposed CO2 standards.

At this point, the model checks to see if the manufacturer is in compliance with its CO2 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 (technology package 2 in this case). The model calculates the TARF for this package and compares it to the TARFs 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 TARFs for each combination of vehicle and technology, the cumulative cost per vehicle, etc. for use in producing the various output files.

IV. Output Files

The model provides the output from a run in five different formats. Four of the files are produced immediately at the end of a model run. The name of each of these files is the name of the scenario listed in Column B of the Scenarios tab of the Scenario file. The files differ according to the extension used at the end of the file name. The fifth output file is produced by the user by loading one of the other four files. Each of these output files and their purpose are described below.

A. 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. 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.

BMW Baseline Co2avg = 328.74, Target Co2avg = 252.88, Fleet Type = 'C'

Step	Index	Type	Co2pipe	Co2tot	TP	TARF	Co2pipe	Co2tot	Co2avg	TotCost
1-	5	6	426.50	426.50	1	-0.1028	388.51	388.51	-> 327.92	4,782,775

The first line lists the manufacturer, it starting CO2 emission level, its CO2 target or standard for this scenario and the vehicle class (C for car or combine, and T for Truck). The starting CO2 emission level is simply the base CO2 emission level of each vehicle weighted by vehicle sales in this redesign cycle. The CO2 standard is either the universal standard listed in the Scenario file, or the foot-print based CO2 standard applied to that manufacturer's vehicles.

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 Co2pipe shows the tailpipe CO2 emissions prior to the application of technology. For the application of technology package 1, this value is the base CO2 emission level shown in the Market file. For subsequent packages, it is the CO2 emission level resulting from the application of the previous technology package. The first column labeled Co2tot stands for total CO2 equivalent emissions and is analogous to Co2pipe. Co2tot equals Co2pipe plus refrigerant emissions in terms of equivalent CO2 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 Co2pipe shows the tailpipe CO2 emissions after the application of the technology package. This value will be consider the efficiency of the technology package, as well as the percentage of that package already present on the vehicle (i.e., the TEB). The second column labeled Co2tot shows this value plus the level of refrigerant emissions existing after any control which have been applied to these.

Co2avg represents the corporate average CO2 emission level for this manufacturer and vehicle class. 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. The OMEGA model still applies all applicable technologies to each vehicle when its TARF shows that this is the next best step. If the TEB is 100%, the model simply holds both emissions and costs constant when it applies the technology.

TotCost represents the cumulative cost in dollars 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) one minus the percentage of that package already present in terms of cost (i.e., CEB).

The very last step of technology addition for each manufacturer and vehicle class may be indicated by repeating the previous step number and adding "OC". In this case, this step does not represent the addition of technology, but a backwards interpolation between the previous two steps 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 very 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, the model is indicating that it would prefer to combine two or more of the technology packages and that separating them is providing little purpose in the model run. This is 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 analytical perspective, this file presents a series of cumulative costs as each manufacturer's average CO2 level is reduced. If a sufficiently stringent CO2 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 CO2 standards without rerunning OMEGA each time. Since the social costs and benefits of CO2 standards tend to be linear with CO2 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 using the sample input files.

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 Co2avg = 287.35, Target Co2avg = 223.31, Fleet Type = 'C'

Step	Index	Type	Co2pipe	Co2tot	TP	TARF	Co2pipe	Co2tot	Co2avg	TotCost
1-	19	6	405.13	405.13	1	-0.1266	375.33	375.33	286.92	33,256,5
2-	14	6	403.17	403.17	1	-0.1264	372.63	372.63	286.61	57,241,9
3-	29	13	446.63	446.63	1	-0.1261	412.62	412.62	286.61	57,306,3
4-	13	10	392.46	392.46	1	-0.1255	362.57	362.57	286.44	70,885,0

5-	18	10	389.46	389.46	1	-0.1253	359.8	359.8	286.28	83,589,9
33-	28	2	232.56	232.56	1	-0.1106	217.03	217.03	267.17	2,117,945,6
34-	14	6	372.63	372.63	2	-0.0904	357.54	357.54	267.01	2,158,753,1
35-	14	6	357.54	357.54	3	-0.0973	305.57	305.57	266.49	2,238,406,5
36-	19	6	375.33	375.33	2	-0.0901	355.62	355.62	266.21	2,297,680,8
54-	7	5	325.61	325.61	2	-0.0615	300.75	300.75	244.96	6,904,283,7
55-	7	5	300.75	300.75	3	-0.0779	250.06	250.06	243.95	7,106,439,8
93-	28	2	217.03	217.03	2	-0.0426	203.45	203.45	221.06	12,799,723,9
93-OC	28	2	217.03	217.03	2	-0.0426	216.53	216.53	223.31	11,973,039,1

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 2 could inappropriately inhibit the application of technologies 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 two 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.

B. Log of Technology Application Ranking Factors – Text Format

This file presents a list of all the technology packages available to each vehicle and the TARF calculated for each combination. The name of this file has the acronym TARF appended to it. The acronyms used in this file are the same as those described above. This file presents a useful summary of all the TARF values to aid the user to evaluate the appropriateness of the technology packages made available to each vehicle type.

The current file format presents the TARF values first by technology package, then by vehicle index. This provides a useful comparison of each technology package across a range of vehicles. The user may also want to read this file into a spreadsheet and sort by vehicle index and then technology package.

C. 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 starts with 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 four types of information by manufacturer and vehicle class: 1) vehicle sales, total costs, cost per vehicle and 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.

D. Summary of Cost and Emissions – XML Format

This file contains an extensive amount of data from both the input files and the other output files. It is currently used in conjunction with the benefits calculation spreadsheet. The benefit calculation spreadsheet loads the information contained in the XML file and produces estimates of the societal costs and benefits associated with the CO2 emission control. The information in the XML file can be loaded into a spreadsheet or database program. However, there are too many columns in the file for it to completely load into many spreadsheets. Therefore, use of a database program would be preferable. As the primary use of this file is associated with the benefits calculation spreadsheet, discussion of the information contained in this file will be discussed under the benefit calculation spreadsheet.

Appendix 6 contains a compilation of variable definitions used in this section.

Car-Truck Trading Algorithm

The Clean Air Act allows trading between a manufacturer's car and truck fleets to the fullest extent. Thus, EPA has designed the model such that the user can utilize a full range of trading scenarios. This section describes the additional logic required when the user enters in a non-zero value into column I of the Scenario input file, triggering a trading scenario.

1) Like the non-trading scenario, the first step of this algorithm is to determine the overall sales-weighted emissions target for the manufacturer with cars and trucks combined:

$$Target.mfr = \frac{Sales_{cars} \times Standard_{cars} + Sales_{trucks} \times Standard_{trucks}}{Sales_{cars} + Sales_{trucks}}$$

2) Then, the model determines the starting point for each manufacturer using the same basic equation

$$Target.mfr = \frac{Sales_{cars} \times BaseEmissions_{cars} + Sales_{trucks} \times BaseEmissions_{trucks}}{Sales_{cars} + Sales_{trucks}}$$

3) Because the lifetime VMT of a truck is generally higher than that of a car and in most cases will emit more GHG over its lifetime by virthe, EPA has chosen to account for lifetime VMT when trading between a manufacturer's car and truck fleet. In this step, the model determines VMT-weighted emissions targets for the manufacturers.

E. Benefits Calculation Spreadsheet – XLS Format

The benefits calculation spreadsheet provides a useful way to automatically extend the core analysis of the application of technology to reduce CO2 emissions to the estimation of national costs and benefits. The model estimates discounted costs and societal benefits on a calendar year basis. Except for technology costs, all costs and benefits are estimated on a fleetwide basis. Industry fleetwide technology costs are estimated, but they are also estimated on a disaggregated basis by manufacturer.

Unlike the other four output files, the benefits calculation spreadsheet is not automatically produced by the OMEGA model after completion of a model run. The user must open the default benefits calculation file (or a revised version created by the user), which is a Microsoft© Excel®© file. The default file opens to the load worksheet. The user clicks on the "Load" button and a window opens which shows the XML format files available for loading in the directory or subdirectory of the benefits calculation spreadsheet. The user double clicks on the appropriate XML file from the OMEGA model run to be analyzed in the benefits calculation spreadsheet and the relevant information from the XML file loads into the spreadsheet and produces estimates of various costs and societal benefits associated with CO2 emission control, as described further below.

The benefits calculation spreadsheet should be considered a framework for the estimation of costs and benefits associated with CO2 emission control from vehicles. As described below, the actual costs and benefits estimated by the spreadsheet are highly dependent on a large number of inputs. EPA provides a set of inputs in the default spreadsheet distributed with the OMEGA model. References for these inputs are provided below. However, in general, the user is responsible that the specific inputs used in any analysis are consistent with the specific analysis being performed. These may be those contained in the default spreadsheet or others chosen by the user. The spreadsheet format makes substitution of alternative input assumptions and estimates easy to perform. However, as in all spreadsheets, the user must be careful to be aware of all the consequences of specific changes to input cells. The Tools/Formula Auditing/Trace Dependents option can be very useful in this regard.

The user should note that the version of the benefits calculation spreadsheet contains one error which is described below. This error will be corrected in a revised version of the benefits calculation spreadsheet which will be posted in the near future on the OMEGA website (www.epg.gov/otaq/climate/models.htm). The reader should go to this website and download the installation file, which contains the benefits calculation spreadsheet. The user should also note that the last worksheet contained in the spreadsheet, labeled Benefits Summary, contains draft information for future versions of the spreadsheet and does not currently provide any useful information.

Overview of the Calculation of Costs and Societal Benefits

The spreadsheet can be broken down into 11 major steps:

1) Reading in of the model's estimate of 1) CO2 emissions per vehicle for each redesign cycle, 2) annual technology costs by manufacturer for each redesign cycle, and 3) other relevant factors from the various input files, such as annual VMT and vehicle scrappage rates by vehicle age, fuel prices and physical and chemical properties, the discount rate, the gap between onroad and certification fuel economy, etc.

2) Calculation of industry-wide CO2 emissions per mile and average fuel consumption per mile, both by vehicle class and redesign cycle.

3) Calculation of technology costs (per vehicle and annual) by manufacturer, and redesign cycle.

4) Interpolation of vehicle sales, CO2 emission levels, fuel consumption, and technology cost per vehicle for model years between redesign cycles.

5) Estimation of the impact of the rebound effect on per vehicle VMT per year for each model year.

6) Calculation of fleet-wide VMT, fleet-wide CO_2 emissions and fleet-wide fuel consumption by vehicle class by calendar year.

8) Calculation of the change in upstream emissions from the change in fleet-wide fuel consumption by calendar year.

9) Calculation of the change in downstream (vehicular) emissions, from the change in fleet-wide VMT by calendar year.

10) Calculation of technology costs, fuel savings, and the societal value of the changes in emissions, driving, noise, congestion, accidents, refueling time and crude oil related externalities by calendar year.

11) Adjustment of fleet-wide VMT per calendar year to be consistent with an external source.

Loading data: The procedure used to read in or load model input and output values into the benefits calculation spreadsheet are described below in Section III., Model Operation. At the most fundamental level, the model outputs which are read in include the list of vehicles which have been modeled, their manufacturer, vehicle class, sales, and starting and finishing CO_2 emission levels. This information appears in the worksheet Model Results. Technology costs are read into the Tech Costs worksheet in terms of annual costs by manufacturer for each redesign cycle. Other relevant data from the Fuels, Reference and Scenario files are loaded into the Shared Inputs worksheet.

Industry-wide CO_2 emissions per mile and average fuel consumption per mile: These values are calculated for each manufacturer, vehicle class and redesign cycle by weighting the cost per vehicle by each vehicle's sales. These calculations are performed in the Model Results worksheet. Currently, the benefits calculation spreadsheet assumes that all vehicles are gasoline-fueled when converting CO_2 emissions to fuel consumption. The user would have to adjust the fuel consumption for any diesel vehicles being modeled if their numbers were significant.

Technology costs per vehicle by manufacturer: These values are calculated in the Tech Cost worksheet by dividing annual costs by manufacturer by sales per manufacturer. Total annual costs for each redesign cycle are calculated by summing annual costs across all manufacturers.

Model years between redesign cycles: Four factors are estimated for each calendar based on values for each redesign cycle. Total annual technology costs are calculated by linearly interpolating the fleet-wide annual cost for each redesign cycle. (Technology costs are assumed to be zero in the baseline year.) For simplicity, we assume that all of the sales of a given model year's vehicles occurs in the calendar year of the same value (i.e., model year equals calendar year). This calculation is performed in the Tech Cost worksheet.

Annual vehicle sales by vehicle class are calculated similarly, except that baseline sales are those contained in the Market file and read into the Model Results worksheet. For example, if the baseline year is 2010, redesign year 1 is 2015 and redesign year 2 is 2020, the spreadsheet linearly interpolates between the 2010 and 2015 sales to estimate annual sales for years 2011-2014. Likewise, the spreadsheet linearly interpolates between the 2015 and 2020 sales to estimate annual sales for years 2016-2019.

CO2 emissions by vehicle class are calculated for each model year in columns P and R of the VMT_Rebound_Effect worksheet. (The estimates of per vehicle emissions are embedded in the formulae which calculate total CO2 emissions from all vehicles of a specific model year and age.) Fuel consumption per mile by vehicle class are calculated for each model year in columns AE and AG of the VMT_Rebound_Effect worksheet. (The estimates of per vehicle fuel consumption are embedded in the formulae which calculate total fuel consumption from all vehicles of a specific model year and age.)

Increase in VMT due to rebound effect: The rebound effect is defined as the ratio of the percentage change in VMT to the percentage change in incremental cost of driving, which is typically assumed to simply be the incremental cost of fuel consumed per mile. As mentioned above, the economic concept is that as driving becomes cheaper, people tend to drive more. Since VMT increases with a reduction in fuel consumption, the sign of the rebound effect is negative. The rebound effect (REB) is an input on the “Economics” worksheet of the “Scenario.xls” file. The percentage increase in VMT for a given change in fuel consumption per mile is calculated as follows:

$$\Delta VMT_{reb} = REB * \frac{\left(FleetFC_{new} - FleetFC_{old}\right)}{FleetFC_{old}}$$

Where REB is the rebound effect, FC is fuel consumption per mile, new is the value after CO2 emission control and old is the baseline value and ΔVMT is the percentage change in VMT per vehicle.

Since fuel consumption changes by model year, each model year’s vehicles will reflect a distinct change in VMT. This change in VMT is assumed to continue throughout the life of the vehicle, since fuel economy is assumed to be constant throughout vehicle life. Also, only new vehicles are affected by the additional technology. Thus, at any point in time, the VMT by some vehicles will be affected by the rebound effect and that by other vehicles will not be affected.

The rebound effect applicable to each model year and vehicle class is calculated in the VMT_Lookup worksheet. This effect is applied to the base estimates of annual VMT per vehicle by age (contained in the Reference file and read into the benefits calculation worksheet on the Shared Inputs worksheet) to generate annual VMT per vehicle estimates which include the rebound effect.

Fleet-wide VMT, CO2 emissions and fuel consumption by calendar year: These parameters are calculated on the Emissions_Fuel_Consv worksheet. Fleet-wide VMT is the sum of VMT from vehicles sold in the baseline model year and earlier and vehicles sold in the first year of the first redesign cycle and later. The first set of vehicles is unaffected by the CO2 emission control being modeled. Parameters related to this set of vehicles are referred to as Baseline and Earlier in the relevant column headings. Their VMT is a simple function of inputs to the model and are calculated in Column AF of the Exclusive Inputs worksheet. The VMT for each vehicle class in each calendar year is a function of sales in each model year starting with that calendar year and earlier, the VMT per vehicle by age and the percentage of vehicle sales surviving by age. Historic sales are shown in Columns Y and Z of the Exclusive Inputs worksheet. These values are only used in the Benefits Calculation spreadsheet and not in the actual running of the OMEGA model. Vehicle sales starting with the baseline year specified in the model run override the historic values in case of overlap. The estimates of historic vehicle sales contained in the default spreadsheet were taken from EPA's Motor Vehicle Emission Simulator (MOVES).

The second set of vehicles includes those affected by CO2 control (i.e., their VMT is affected by the rebound effect). Again, the VMT for each vehicle class in a given calendar year is a function of sales in each model year between that calendar year and the first year of the first redesign cycle, the VMT per vehicle by age adjusted for rebound and the percentage of vehicle sales surviving by age. Because of the rebound effect, this calculation is much more complex than that for historic vehicles. The VMT_Rebound_Effect worksheet calculates total annual VMT from each model year's vehicles in each relevant calendar year. This calculation is performed for these vehicles both before and after CO2 emission control, so that the benefit of control can be determined. The sum of the VMT from historic vehicles and controlled vehicles is performed on the Emissions_Fuel_Consv worksheet.

The calculation of fleet-wide CO2 emissions and fuel consumption by calendar year is performed analogously to that of VMT. For historic vehicles, the level of CO2 emissions by model year is added to the combination of vehicle sales, VMT per vehicle, and survival percentages. This calculation is performed in Columns AB, AC and AD of the Exclusive Inputs worksheet. The estimates of CO2 emissions from historic vehicle contained in the default spreadsheet were taken from MOVES.

With respect to controlled vehicles, total CO2 emissions from each model year's vehicles in each relevant calendar year are calculated on the VMT_Rebound_Effect worksheet. This involves simply multiplying the VMT for that vehicle cohort by its average CO2 emission level. This is done for these vehicles both before and after control. Fuel consumption is currently estimated from CO2 emissions assuming that all fuel consumed is gasoline.

Upstream emissions: Changes in upstream emissions occur due to the reduction in fuel production and distribution resulting from less vehicle fuel consumption. The benefits calculation worksheet currently tracks six upstream pollutants: CO2, CO, VOC, NOx, SOx, and PM. The model only calculates the change in these upstream emissions, not their absolute values before and after control. The change in each pollutant's emissions in each calendar year is simply the product of the total reduction in fuel consumption (after accounting for the rebound effect), conversion of this fuel volume to energy content (Btu), the estimate of the reduction in upstream emissions in grams per Btu of fuel produced and distributed per reduction in fuel production, and conversion to metric tons of emissions. The change in fuel consumption is simply the difference in fuel consumption from the application of CO2 control as described in the previous section. The other factors are simply inputs on the Exclusive_Inputs worksheet and are only used in the Benefits Calculation spreadsheet. In general, the values for the levels of upstream emissions per Btu of fuel produced should apply to the expected change in upstream emissions for an incremental change in fuel production from otherwise expected levels. These values may be different from the average upstream emissions per unit of fuel production. Use of the incremental emissions is most appropriate, since the Benefits Calculation spreadsheet only calculates the change in these emissions and not total emissions before and after vehicle CO2 control. The change in upstream emissions are calculated in Columns S through W of the Emissions_Fuel_Consv worksheet. Positive values indicate reductions in emissions.

Downstream emissions: Changes in downstream emissions (i.e., emissions from vehicles other than CO2) occur due to increased VMT related to the rebound effect. Other than CO2, emissions from vehicles per mile are assumed currently to be unaffected by CO2 emission controls. Emissions from vehicles produced prior to control are not affected. As with upstream emissions, the benefits calculation worksheet currently tracks six upstream pollutants: CO, VOC, NOx, PM, and Sox and only changes in these emissions are calculated.

Emissions of these pollutants from vehicles usually vary with vehicle age. The g/mi emission levels of each pollutant are input to the model on the Exclusive_Inputs worksheet in the form of linear or quadratic equations as a function of vehicle age. These equations were derived from emission factors taken from EPA's MOBILE6 model and used in it EPA's ANPRM for the control of vehicle GHG emissions.[4] Vehicles of all model years are assumed to have the same emissions. This is reasonable since emissions from only CO2 controlled vehicles are being evaluated. Thus, currently, the emission levels in the Benefits Calculation spreadsheet assume that all vehicles were designed to comply with the EPA Tier 2 emission standards. The change in the total emissions of each pollutant from vehicles of a specific model year and age are calculated on the VMT_Rebound_Effect worksheet based on the increase in VMT of that model year's vehicles in a particular calendar year multiplied by the emission factor of that pollutant for vehicles of that age. Negative values indicate increases in emissions.

Fuel savings and societal benefits: The value of reduced fuel consumption is calculated on the Externalities worksheet. The value of reduced fuel consumption in each calendar year is simply the product of the reduction in fuel consumption and the price of fuel. The price of fuel is specified in the Fuels file and input to the Benefits Calculation spreadsheet on the Shared_Inputs worksheet. The fuel prices used by the core model to rank and apply technology should include excise taxes, since this is the fuel price perceived by consumers. However, since the benefits calculation spreadsheet focuses on societal benefits, excise taxes should be removed when calculating the value of reduced fuel consumption. Currently, the benefits calculation spreadsheet uses the fuel prices directly from the Fuels file, so taxes are included. This will be corrected in the future.

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[4] Vehicle Technical Support Document: Evaluating Potential GHG Reduction Programs for Light Vehicles, U.S. EPA, June 16, 2008, EPA-HQ-OAR-2008-0318-0084., http://www.regulations.gov/search/Regs/home.html#documentDetail?R=09000064806692a5

The Benefits Calculation spreadsheet allows for the estimation of additional values related to reductions in crude oil based fuel consumption. These externalities vary from study to study, but can include monopsony effects, oil security effects, price shock effect, etc. Values for such externalities can be input on the Exclusive inputs worksheet in terms of dollars per gallon of fuel consumed. The total societal benefit related to the reductions in these externalities is simply the product of the total reduction in fuel consumed in each calendar year and the total value of the externalities. This calculation is performed on the Externalities worksheet. The current total value of these externalities contained in the default spreadsheet is $0.285 per gallon. EPA used an estimate of $0.34 per gallon in its ANPRM for the control of vehicle GHG emissions. EPA used an estimate of $0.467 per gallon in its recent NPRM for the control of vehicle GHG emissions.

The Benefits Calculation spreadsheet also allows for the estimation of several driving related externalities, namely noise, congestion, accidents, refueling time and the value of additional driving itself. All of these, except for refueling time, are related to the additional driving associated with the rebound effect. Their value in each case is simply the product of the increase in VMT in a calendar year times the value of that externality per mile. The values of the externalities related to noise, congestion, and accidents are input on the Exclusive_Inputs worksheet and are those used in EPA's recent NPRM for the control of vehicle GHG emissions.

The value of the reduction in refueling time assumes that manufacturers maintain fuel tank size with CO2 control and that people typically refuel when their tank reaches a certain level. The reduction in the number of refuelings in a specific calendar year is a function of the average fuel tank size of the vehicle (in gallons), an average amount of fuel added during refueling (in percent of tank volume), and the reduction in total fuel consumption in that calendar year. The value of the time saved in based on an average amount of time spent refueling a vehicle (in minutes), the value of time for the driver (in dollars per hour) and other vehicle occupants and the number of total occupants in the vehicle when refueling occurs. All of these values, except for the total reduction in fuel consumption are input on the Exclusive_Inputs worksheet. These values are consistent with those used in EPA's ANPRM for the control of vehicle GHG emissions referenced above. The current Benefits Calculation does not consider the time to recharge batteries for plug-in or battery electric vehicles.

The value of increased driving associated with the rebound effect is the sum of two components. The first component is the incremental cost of driving per mile. This is based on the assumption that the value of increased travel must exceed its direct cost or the driver will not take the additional trip. The second component is the consumer surplus generated by this driving.

The direct incremental driving is assumed to be cost of fuel consumed plus that of the additional congestion caused. The additional noise and accidents are not considered to be direct costs. Noise is primarily experienced by non-drivers and therefore not considered by drivers in their decision to take an additional trip. While accidents tend to be proportional to mileage, especially for a given driver, we assume that most of the cost of accidents is borne by insurance, where there is only a weak association with mileage driven. Congestion, on the other hand, is totally experienced by drivers and experienced fully each trip. However, it should be noted that

EPA did not include the incremental cost of congestion in its recent NRPM for the control of GHG emissions from vehicles. There, we assumed that most of the congestion experienced by additional driving was experienced by other drivers, so they would not be considered by the driver contemplating an additional trip.

The change in the consumer surplus is estimated to be one half of the change in VMT times the change in the cost of driving, which here is the reduction in fuel cost per mile. All of these terms have already been estimated for other purposes within the Benefits Calculation spreadsheet. The reader should note that the version of the Benefits Calculation spreadsheet included with the model installation package incorrectly calculates the cost of fuel needed to drive the additional VMT. This will be corrected in a revised version of the benefits calculation spreadsheet which will be posted in the near future on EPA's OMEGA website at (www.epg.gov/otaq/climate/models.htm).

The value of the changes in CO2 and other pollutant emissions are simply the product of the changes in these emissions by calendar times their value in dollars per metric ton. The societal benefits associated with upstream emission changes are calculated on the UpstreamCosts ($) worksheet, while those for downstream emission changes are calculated on the DownstreamCosts ($) worksheet. The societal values for the reduction in CO, VOC, NOx, PM, and SOx emissions are input in cells A15:B23 of the Exclusive_Inputs worksheet. These values are assumed to be constant in real dollars over the timeframe of the analysis. The values contained in the default spreadsheet are consistent with those used in EPA's ANPRM for the control of vehicle GHG emissions referenced above.

The value of CO2 emission reductions is input to the model through the Scenario file. This value is specified in terms of real dollars and can vary over time (e.g., increase at a fixed percentage rate per year in real dollars relative to a specified value in a specified base year). The societal benefits associated with upstream CO2 emission changes are calculated on the UpstreamCosts ($) worksheet, while those for downstream CO2 emission changes are calculated on the DownstreamCosts ($) worksheet. The value for CO2 emission reductions is $7.50 per ton in 2007 dollars and increases at 2.4% per year. EPA's recent NPRM for controlling GHG emissions from light vehicles evaluates a range of values for CO2 emission reductions from $5 per metric ton to $56 per metric ton. Given this wide range of values, the user should consider it her or his responsibility to justify the use of a specific value for CO2 emission control in any specific analysis using this modeling tool.

Summary of costs and societal benefits: The societal costs and benefits other than technology costs are summarized on the Non-Tech Costs worksheet. The convention assumes that costs are positive and benefits are negative. As mentioned above, total technology costs per year are calculated on the Tech Costs worksheet. These two sets of values are both shown on the All Costs worksheet, again with costs being positive and benefits being negative.

Normalization to an external source of fleet-wide VMT per year: The spreadsheet allows the user to adjust the total VMT estimated for the fleet in each calendar year to that from an external source. The calculation of fleet-wide VMT described above can be described as a "bottom up" estimate. Vehicle sales are estimated for each model year, vehicles are scrapped at a specified rate, and vehicles of a specified age drive a specified number of miles over the course of a year. Such bottom-up estimates usually do not match top-down estimates of total VMT which are produced from measurements of actual driving (e.g., from pressure or magnetic strips placed across roadways or from other traffic counts). The default benefits calculation spreadsheet includes estimates of fleet-wide VMT per calendar year from the Published 2009 Annual Energy Outlook produced by the Energy Information Administration.[5]

These fleet-wide VMT estimates are input in Column O of the AEO Adjustment Calculations worksheet. The ratio of these VMT estimates to those of the bottom up process for each calendar year is calculated in Column N. The estimates of all costs and benefits presented on the All Cost worksheet are multiplied by these ratios, except for the technology costs, which are just a function of vehicle sales and not VMT. The results are shown on the VMTAdjCosts worksheet.

Running the Model

Model Operation

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 very simple and relies on the fact that all of the information needed to run the model is contained in the input files. (Future versions of the OMEGA model may provide the user with the ability to modify the inputs through the interface.)   The user should then 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. The user should double click on the desired Scenario file and the model will loads 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 current 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. 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.). The model normally takes less than a minute to run through a fairly extensive scenario. If the Scenario file only specifies one case to be run, when the model is done with this case, a text file showing the sequence of technology addition by manufacturer and by redesign cycle appears. This file is automatically named with the case name from the Scenario file. If more than one case is run, the indicator in the lower left hand corner will simply say "Done."

There is an additional saved output file entitled "Tarf = "date-time", which includes the results of the TARF calculations for each vehicle type-technology package combination for each redesign cycle. Go back to the file menu in the GUI, and click on "Save," which is necessary to enable

[5] Annual Energy Outlook 2009 with Projections to 2030, Energy Information Administration, U.S. Dept. of Energy, DOE/EIA-0383(2009), March 2009.

the “visualization” function. In the file menu, now click on “visualization” to examine the results of the technology application process for each vehicle model in the market data file. In the near future, the information in the visualization will be generated directly in an output spreadsheet, but at present it is only available in the visualization, and if desired, the user can copy and paste the results manually. Economic costs and benefits can be loaded in a spreadsheet file entitled “Benefits Calculations,” located in the “Output” folder. Open the “Benefits Calculations” Excel® file, go to the “Load” worksheet (if the spreadsheet did not open to this worksheet), and press the “Load” button. A list of XML files available to load will appear. The user should double click on the XML file from the model run of interest. This loads the results of model run and updates the cost and benefit estimates.