Greenhouse Gas Emissions Model (GEM) User Guide

Vehicle Simulation Tool for Compliance with the Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium and Heavy-Duty Engines and Vehicles: Phase 2

United States Environmental Protection Agency

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

United States
Environmental Protection
Agency

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I. Introduction

The Greenhouse gas Emissions Model (GEM) was first created by EPA as part of the "Heavy-Duty Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 1" rulemaking finalized in 2011. The model was developed to serve as a means for determining compliance with EPA's GHG emissions and NHTSA's fuel consumption Phase 1 vehicle standards for Class 7 and 8 combination tractors and Class 2b-8 vocational vehicles.

For the Phase 2 rulemaking, significant enhancements were made to the model. In addition to the model released with the Notice of Proposed Rulemaking (NPRM), additional refinements were made to the model based on public comments received from our NPRM and subsequent Notice of Data Availability (NODA) releases.

This User Guide describes the Phase 2 GEM release, GEM P2v3.0, published with the Phase 2 final rulemaking (FRM). The following sections include installation instructions, a general model description, and instructions for running the model, including a description of the necessary input and resulting output files. A detailed description of the model architecture and updates, including changes from our Phase 1 GEM release (GEM version 2.0.1), NPRM release (GEM P2v2.0) and NODA release (GEM P2v2.1), can be found in Chapter 4 of the Phase 2 RIA.

II. Installation

II.A. Computer Requirements

EPA developed Phase 2 GEM to be a forward-looking Matlab/Simulink-based model for heavy-duty (Class 2b-8) vehicle compliance for the Phase 2 rulemaking. The model is a free, desktop computer application provided as an executable to be operated on a single computer. Since it is provided as an executable, the user does not have to have access to the Matlab/Simulink software packages.[1] The following minimum computer specifications are required for the model to run:

- Operating System: 64-bit Windows 7 or newer
- CPU: 2 GHz processor
- Memory: 4 GB of RAM

II.B. Installation Instructions

The downloadable installation file is available on EPA's website (see Figure 1) at:

www3.epa.gov/otaq/climate/gem.htm.

A link to the most recent GEM version will be located at the top of the page. The GEM executable is bundled with this User Guide and several input file templates into a file that can be downloaded in a single step. A copy of this User Guide is also available on the website for convenience. Note that the GEM executable, sample files and documentation require about 10

[1] The Matlab and Simulink models that make up the GEM source code are available in the docket to the Phase 2 rulemaking. Please see Docket: EPA-HQ-OAR-2014-0827 available at: www.regulations.gov.

MB of free space. Users that also require the Matlab Compiler Runtime application (see Figure 7) will need about 700 MB of free space.

To request a CD of this software instead of downloading it, or to request assistance if you have trouble with accessibility of this software, please request through an email addressed to OTAQ@epa.gov.

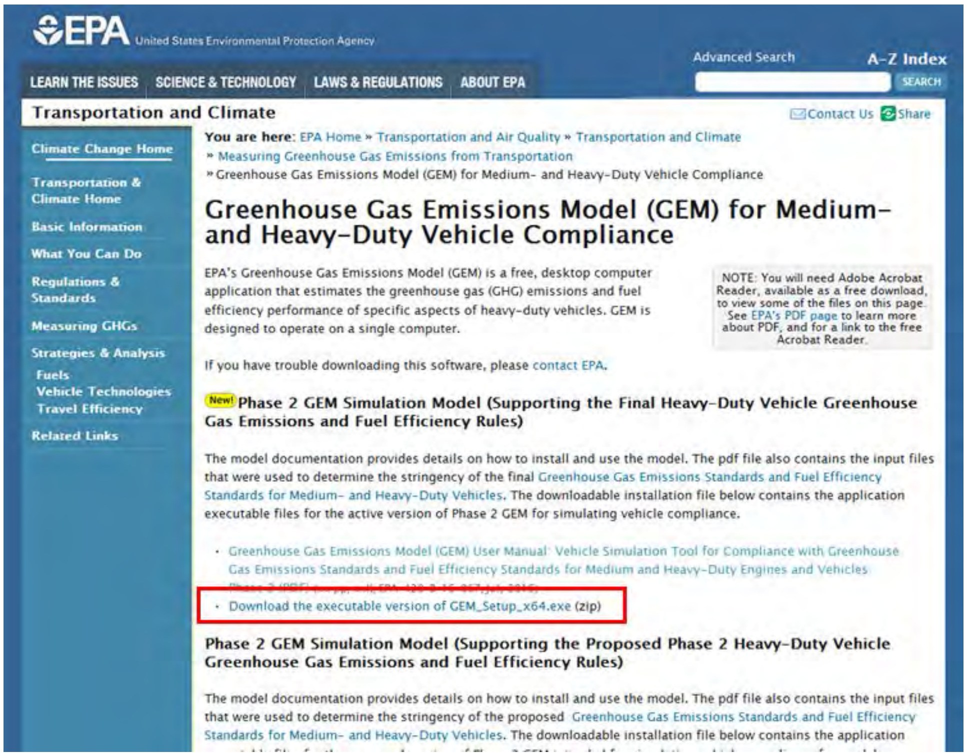

Figure 1: EPA Website to Obtain GEM Installation Package

Currently, GEM is only available to computers using 64-bit Windows operating systems (Windows 7 and newer). To check your computer's operating system, right click on "Computer" from a desktop icon or the Windows Start Menu and select the System Properties window. If your computer has a 64-bit operating system, it will be noted on the properties window, as is seen in Figure 2.

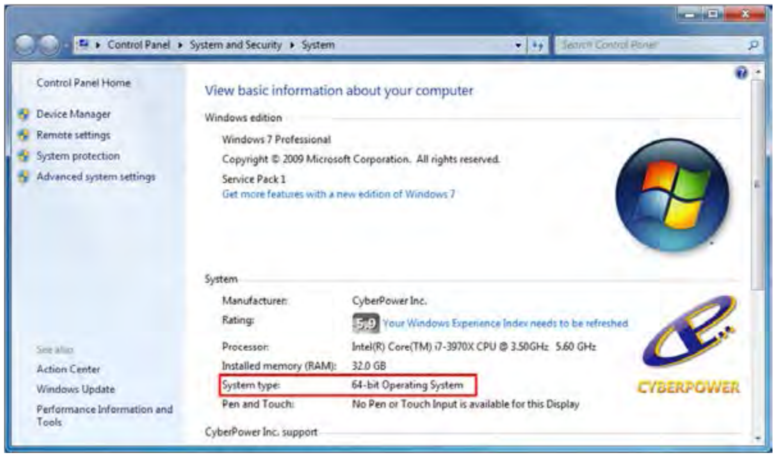

Figure 2: System Properties for a 64-bit Operating System (Newer than Windows XP)

To install GEM, download the installation file from EPA's website. Once downloaded, double-click the "GEM_P2v3.0_Setup_x64" executable to start the setup wizard that will walk you through the steps of installation.

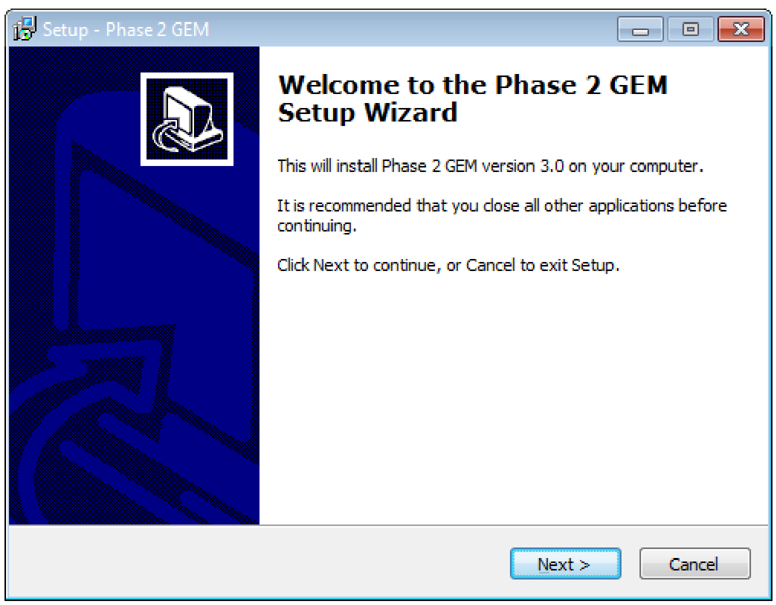

Figure 3: Welcome Window for the Setup Wizard for Phase 2 GEM

Users have the option of choosing a separate location for their Phase 2 GEM installation, but we recommend the default folders and shortcuts, as seen in Figure 4 and Figure 5. The instructions throughout this User Guide assume the user installed Phase 2 GEM in the default locations with its default folder names.

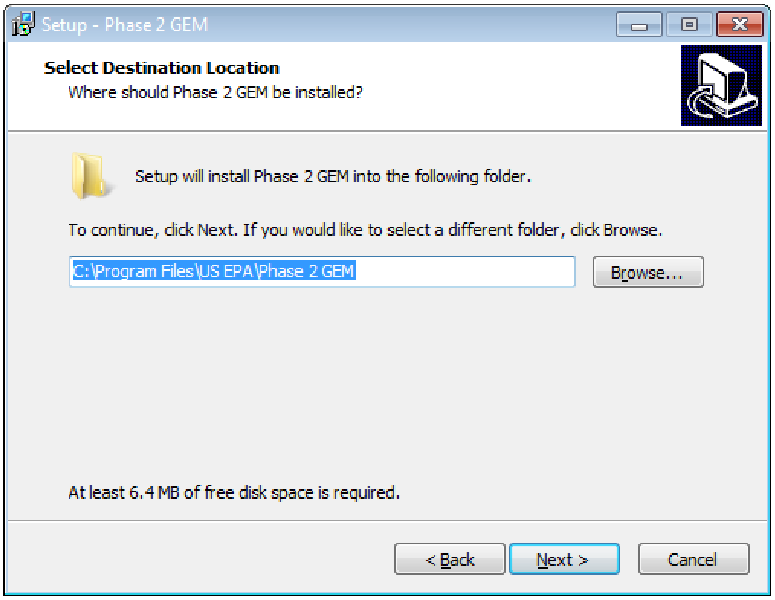

Figure 4: Destination for Phase 2 GEM Download; the Agencies Recommend the Default Location

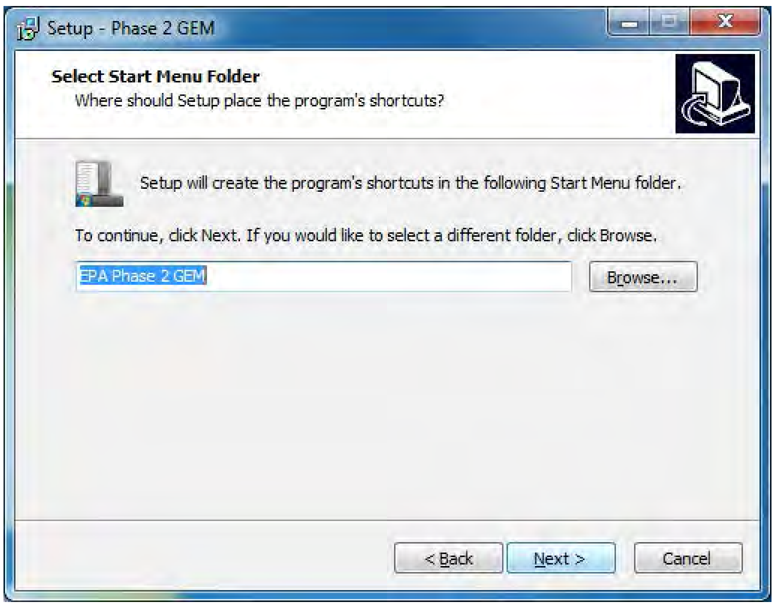

Figure 5: Start Menu Folder for Phase 2 GEM Download; the Agencies Recommend the Default Folder Name

The next screen gives users an option to create a shortcut to Phase 2 GEM on their desktop. Users that choose to install a desktop icon will see a "Phase 2 GEM" shortcut, similar to the one shown in Figure 6, on their desktop. Users can uncheck the box next to the "Create a desktop icon" if they do not wish to have a desktop shortcut.

Figure 6: Desktop Icon Shortcut to Phase 2 GEM

Phase 2 GEM requires the use of Matlab Runtime Compiler and Microsoft Visual C++ 2005 or 2008 Redistributable (x64). The setup wizard will install Matlab Runtime Compiler R2014a (version 8.3) if the box, shown in Figure 7, is checked. For computers that already have the runtime compiler (R2014a) installed, users can uncheck this box to avoid reinstallation.

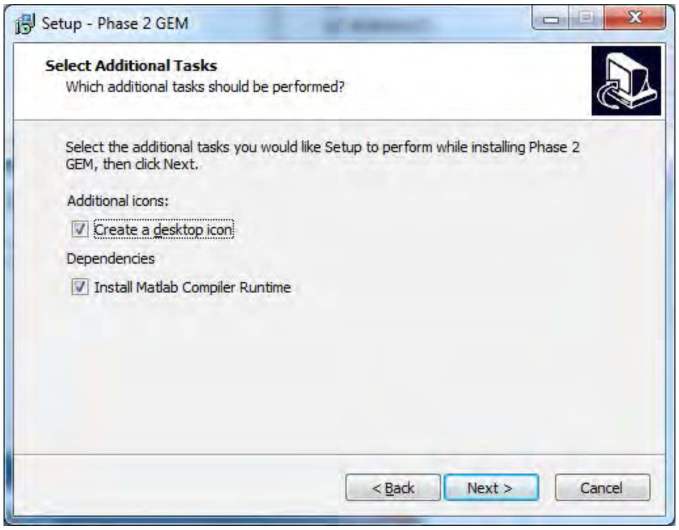

Figure 7: Additional Installation Options for Phase 2 GEM; Matlab Runtime Compiler R2014a is Required for GEM

The following windows allow users to review the installation settings and install Phase 2 GEM. The installer will warn users if their computers do not have Microsoft Visual C++ 2005 or 2008 Redistributable (x64) installed. A pop-up window will initiate installation of this software and will remain displayed until installation is complete.

A final screen (Figure 8) will show up when Phase 2 GEM has completed installing. The installation process for Matlab Runtime Compiler (if selected) will initiate shortly after this completion screen appears. The Matlab setup wizard for the runtime compiler is not described in this User Guide.

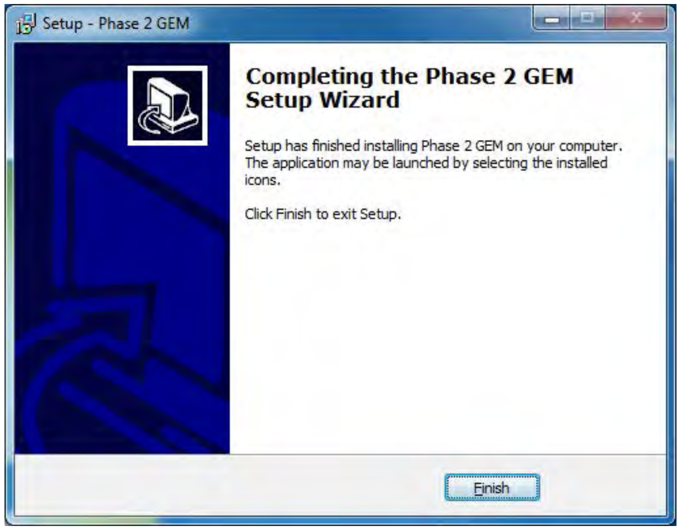

Figure 8: Installation Complete Window for Phase 2 GEM

II.C. Contents of Installation Package

Once installed, several files are stored in the installation location selected (i.e., *C:\Program Files\US EPA\Phase 2 GEM* by default). Figure 9 shows the contents of the default installation folder. Users can access the GEM User Guide (Documentation folder), the GEM executables, and sample files (Sample Input Files folder) from this directory. They can also uninstall GEM and remove all of its contents by clicking on the “unins000.exe” executable.

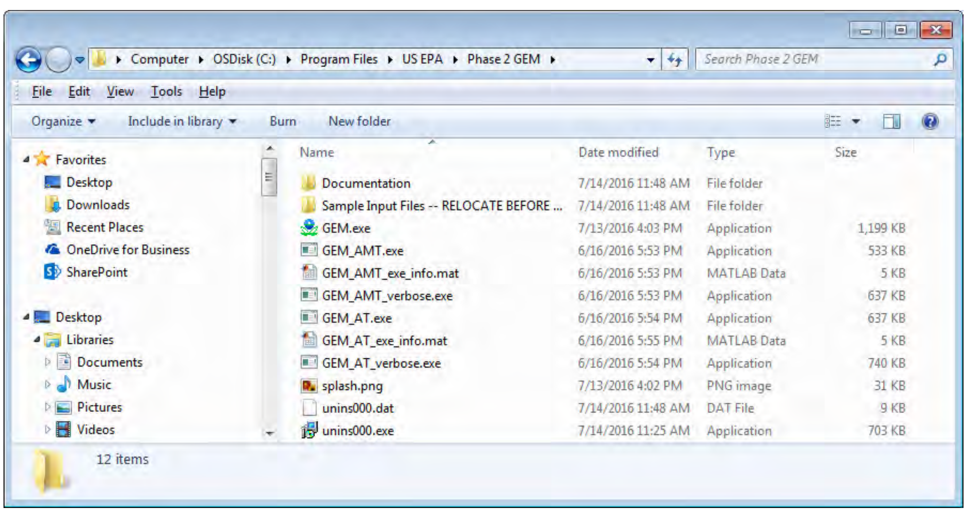

Figure 9: Contents of Installation Folder for Phase 2 GEM

GEM is also available from the Start Menu, under the folder named “EPA Phase 2 GEM”, as seen in Figure 10. Within the Start Menu folder, users have access to the executables (described in the Running GEM section of this Guide), as well as a copy of this User Guide, a link to the EPA website, additional documentation, and sample input files that can be used as templates for running GEM.

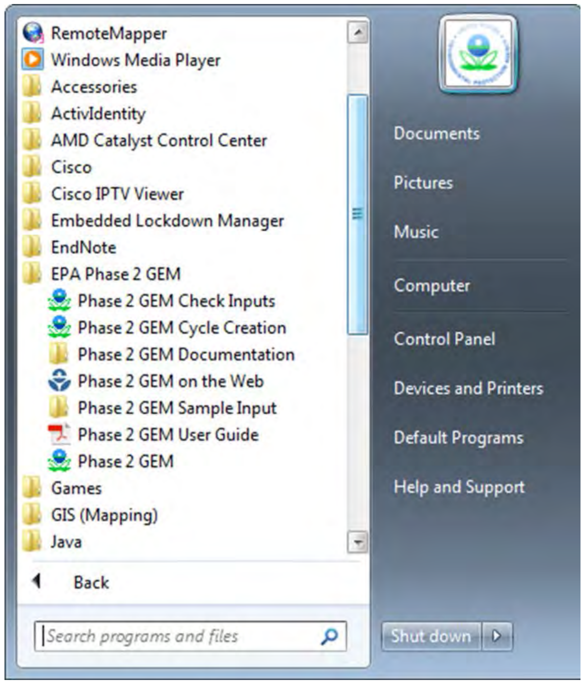

Figure 10: Start Menu Location of GEM

II.D. Sample Input Files

Sample input files are stored with the Phase 2 GEM executable. As seen in Figure 11, the "Sample Input Files – RELOCATE BEFORE USE" folder includes sample vehicle input files for each of the three vehicle regulatory subcategories, four folders with example engine, transmission, axle and powertrain input files, and two files to generate cycle averaged fuel maps. A description of each of these input files and instructions for running the model are provided in later sections.

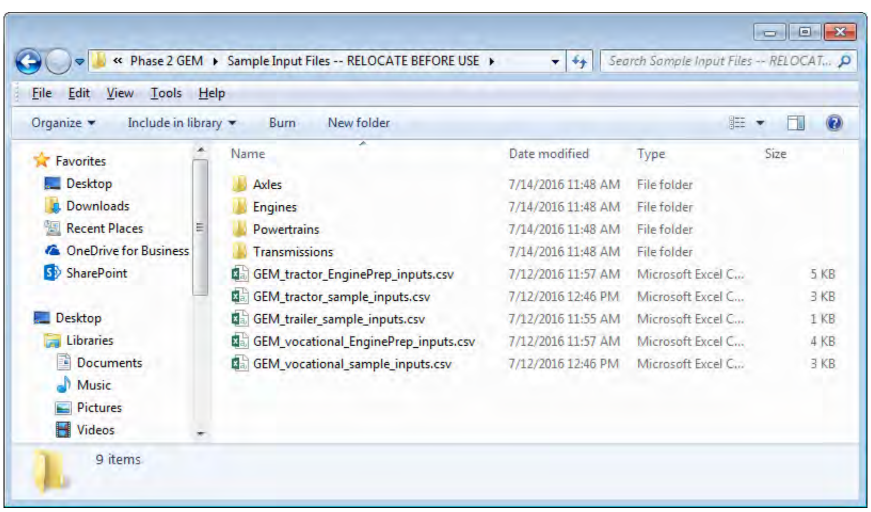

Figure 11: Sample Input Files Included with EPA Phase 2 GEM

If users select the default installation folder, C:\Program Files\US EPA\Phase 2 GEM\, it is recommended that they copy the folder "Sample Input Files – RELOCATE BEFORE USE" from this default folder to a local folder. By doing so, users can easily run GEM and write output results into the selected local folder and avoid potential administrative rights issues, since not all organizations allow users to write files to C:\Program Files folders. Users can copy the sample files folder to any convenient local folder and can rename it as needed once it is copied to its new destination.

II.E. GEM Executable

The Phase 2 GEM executable does not require the use of Matlab or Simulink software, and the agencies require tractor and vocational vehicle manufacturers to use the executable for demonstrating compliance with the CO_2 and fuel consumption standards.[2] Phase 2 GEM does not offer a graphical user interface (GUI) for users to provide their vehicle parameters. Instead, inputs are provided in a comma delimited (.csv) file. Results are available in a generated report that can be viewed using either a text editor or spreadsheet. The following sections will describe the model, its input files, and its output files in more detail.

III. Model Description

Phase 1 GEM was updated in order to meet Phase 2 rulemaking requirements. Phase 2 GEM improves the fidelity of the Phase 1 model to better match the function of the simulated vehicles and accurately reflect changes in technology for compliance purposes. Many of the modifications were the result of numerous constructive comments from both public comments and GEM peer reviews[3]. The following sections describe the model with an emphasis on the additional vehicle parameters available in the Phase 2 upgrade of the model. Users are directed to Chapter 4 of the RIA for more detailed information regarding the model architecture and validation.

III.A. GEM Architecture and Summary of Upgrades

The GEM architecture is comprised of four systems: Ambient, Driver, Powertrain, and Vehicle as seen in Figure 12. The Powertrain and Vehicle systems consist of one or more subcomponent models and a description of the subcomponent models is available in Chapter 4 of the Phase 2 RIA.

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[2] Trailer manufacturers will use a GEM-based equation and are not required to use GEM. For convenience, this User Guide provides instructions for using GEM for trailers, but manufacturers cannot use GEM for demonstrating compliance.

[3] "Peer Review of the Greenhouse gas Emissions Model (GEM) and EPA's Response to Comments," Docket # EPA-420-R-15-009, June 2015.

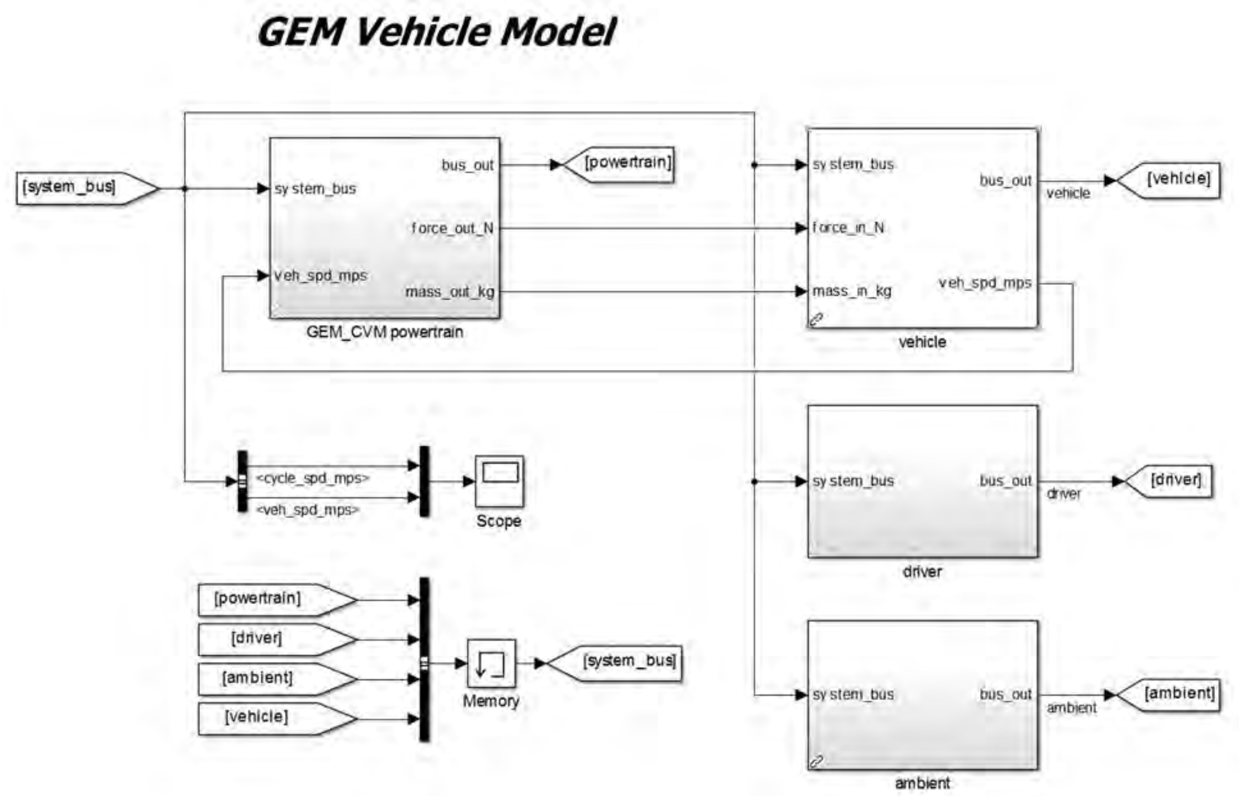

Figure 12: Simulink Structure of GEM Vehicle Model

The agencies are adopting additional regulatory subcategories to better represent the heavy-duty vehicles and these subcategories are reflected in the model with additional vehicle models. Phase 2 GEM also incorporates improvements to the duty cycles, including the addition of idle cycles for vocational vehicles, and modified cruise cycles that account for changes in road grade. Specifically, the agencies implemented the following key technical features into Phase 2 GEM:

- An upgraded engine controller, which includes engine fuel cut-off during braking and deceleration, and a cycle average method to supplement the steady state fuel map for transient simulation, and optionally apply to the cruise cycles

- An upgraded transmission model, which includes newly developed automatic and automated manual transmissions. An optional transmission power loss input is also available.

- An option to input axle power losses as a function of axle output speed and torque

- An upgraded driver model with a distance-compensated driver that will drive the certification drive trace over a prescribed distance regardless of increased drive time due to vehicle under-performance, for example

With these upgrades, the model is capable of recognizing most technologies that could be evaluated in both engine and chassis dynamometers and is better able to reflect changes in technologies for compliance purposes. See Chapter 4 of the RIA for more information about these upgrades.

III.B. Vehicle Parameters for Each Regulatory Subcategory

GEM is a flexible simulation platform that can model a wide variety of Class 2b to Class 8 vehicles. The key to this flexibility is the component description files that can be modified or adjusted to accommodate vehicle-specific information. Phase 2 GEM includes four main vehicle types, and several variations of each vehicle, to match the regulatory subcategories in the Phase 2 rulemaking. Each regulatory subcategory is associated with specific vehicle parameters and technology options.

The agencies predefined many key parameters, since those parameters are either hard to quantify due to lack of certified testing procedures or difficult to obtain due to proprietary barriers. Examples of these parameters include transmission shifting strategies and engine inertia. The values selected for these parameters are a result of substantial testing by EPA, as well as confidential discussions with engine, chassis and component manufacturers. Some default parameters have optional overrides, requiring additional testing.

Each vehicle subcategory has a set of user-defined parameters. These parameters include vehicle technologies or component attributes that impact CO_2 emissions and fuel consumption, but have the potential to vary across manufacturers. Depending on the regulatory subcategory, parameters such as aerodynamic performance, tire rolling resistance, vehicle weight, engine fuel map, transmission gear ratios, tire radius, or axle ratio can be changed as inputs by the user.

The sections to follow outline the regulatory vehicle subcategories that manufacturers may select in GEM for compliance, and summarize the user-defined and predefined model parameters applicable to each subcategory.

III.B.1. Drive Cycles and Cycle Average Engine Fuel Map

The Phase 2 rulemaking also predefines three drive cycles including a transient cycle and two cruise speed cycles. The transient mode is defined by California Air Resources Board (CARB) in their Highway Heavy-Duty Diesel Transient (HHDDT) cycle. The cruise speed cycles are represented by two nominally constant speed 65 mph and 55 mph cycles, each with varying road grade. For vocational vehicles two additional idle cycles are utilized, one simulating parked idling operation and the other idling in traffic. Each regulatory subcategory is assigned a specific set of drive cycle weightings.

The agencies recognize the limitation of the steady state engine fuel map for transient simulation, and we are requiring that a cycle average fuel map be generated to supplement the steady state fuel map for the transient cycle. Additionally, users have the option to apply the cycle average method to the 55 and 65 mph cruise cycles as well. A summary of the procedure to generate the cycle average map(s) is provided in the Supplemental Input Files section of this Guide. A detailed description and justification for the cycle average method can be found in Chapter 4 of the RIA.

III.B.2. Tractor Vehicle Parameters

The agencies are adopting a set of predefined modeling parameters to establish consistent combination tractor models from which tractor manufacturers can compare their vehicle improvements. GEM recognizes twelve variations of combination tractors. Class 8 tractors can have day or sleeper cab configurations with low, mid, or high roof heights. Class 7 tractors are only available in a day cab configuration, but also have low, mid, or high roof options. GEM also recognizes Class 8 heavy-haul tractors with a single vehicle for all cabs and roof heights, and six optional heavy Class 8 tractor subcategories to represent tractors with higher gross combined weight rating (GCWR) that are designed for heavy-haul operation in Canada. Within GEM, high roof tractors are simulated as pulling a standard box van. Mid roof tractors and low roof tractors are simulated as pulling tank and flatbed trailers, respectively. The standard box van for high roof tractor simulations also includes a skirt, which impacts the user-defined aerodynamic drag area input, CdA (described in the next section).

Table 1 through Table 6 summarize the predefined modeling parameters for default tractor subcategories. The standard Class 8 payload is 19 tons. All Class 8 heavy-haul tractors, including the optional heavy Class 8, have a payload of 43 tons. The Class 7 payload is 12.5 tons. Sleeper cab tractors are assigned drive cycle weightings that are more representative of long-haul driving with 86 percent at 65mph, 9 percent at 55 mph and 5 percent transient. Drive cycle weightings for day cab tractors are more representative of short-haul driving with 64 percent at 65 mph, 17 percent at 55 mph, 19 percent transient.

Table 1: Class 8 Combination Tractor Sleeper Cab Predefined Modeling Parameters

Regulatory Subcategory	**Class 8 Combination, Sleeper Cab**		
Roof Height	**High Roof**	**Mid Roof**	**Low Roof**
Total Weight (kg)	31978	30277	30390
Number of Axles	5		
Payload (tons)	19		
CARB HHDDT Drive Cycle Weighting	0.05		
GEM 55 mph Drive Cycle Weighting	0.09		
GEM 65 mph Drive Cycle Weighting	0.86		

Table 2: Class 8 Combination Tractor Day Cab Predefined Modeling Parameters

Regulatory Subcategory	**Class 8 Combination, Day Cab**		
Roof Height	**High Roof**	**Mid Roof**	**Low Roof**
Total Weight (kg)	31297	29529	29710
Number of Axles	5		
Payload (tons)	19		
CARB HHDDT Drive Cycle Weighting	0.19		
GEM 55 mph Drive Cycle Weighting	0.17		
GEM 65 mph Drive Cycle Weighting	0.64		

Table 3: Class 8 Heavy-Haul Combination Tractor (All Cabs) Predefined Modeling Parameters

Regulatory Subcategory	**Class 8 Combination, Day Cab**
Roof Height	**All Roof Heights**
Total Weight (kg)	53750
Number of Axles	5
Payload (tons)	43
CARB HHDDT Drive Cycle Weighting	0.19
GEM 55 mph Drive Cycle Weighting	0.17
GEM 65 mph Drive Cycle Weighting	0.64

Table 4: Class 7 Combination Tractor Predefined Modeling Parameters

Regulatory Subcategory	**Class 7 Combination, Day Cab**		
Roof Height	**High Roof**	**Mid Roof**	**Low Roof**
Total Weight (kg)	22679	20910	21091
Number of Axles	4		
Payload (tons)	12.5		
CARB HHDDT Drive Cycle Weighting	0.19		
GEM 55 mph Drive Cycle Weighting	0.17		
GEM 65 mph Drive Cycle Weighting	0.64		

Table 5: Heavy Class 8 Combination Tractor Sleeper Cab Predefined Modeling Parameters

Regulatory Subcategory	**Class 8 Combination, Sleeper Cab**		
Roof Height	**High Roof**	**Mid Roof**	**Low Roof**
Total Weight (kg)	53750	52049	52162
Number of Axles	5		
Payload (tons)	43		
CARB HHDDT Drive Cycle Weighting	0.05		
GEM 55 mph Drive Cycle Weighting	0.09		
GEM 65 mph Drive Cycle Weighting	0.86		

Table 6: Heavy Class 8 Combination Tractor Day Cab Predefined Modeling Parameters

Regulatory Subcategory	**Class 8 Combination, Day Cab**		
Roof Height	**High Roof**	**Mid Roof**	**Low Roof**
Total Weight (kg)	53069	51301	51482
Number of Axles	5		
Payload (tons)	43		
CARB HHDDT Drive Cycle Weighting	0.19		
GEM 55 mph Drive Cycle Weighting	0.17		
GEM 65 mph Drive Cycle Weighting	0.64		

Table 7 shows the predefined modeling parameters that are consistent across all tractor types. These common parameters include ambient temperature, efficiencies and accessory powers. The calculations for overall rolling resistance and the distribution of weight savings are also consistent for all simulated tractors.

Table 7: Common Predefined Modeling Parameters for All Simulated Combination Tractors

AMT Gearbox Mechanical Efficiency (9 or more gears)	96% for low gears, 98% high gears, except 100% for 1:1 gear ratio
AMT Gearbox Mechanical Efficiency (fewer than 9 gears)	100% for 1:1 gear ratio, 98% for rest of gears
AT Gearbox Mechanical Efficiency	95.5% for 1:1 gear ratio, 98% for rest of gears
Electrical Accessory Power (W)	1200
Mechanical Accessory Power (W)	2300
Environmental air temperature (°C)	25
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons, 2/3*weight reduction is subtracted from the vehicle mass during simulation
Trailer Tire Crr (kg/t)	6.0
Overall Tire Crr (kg/t)	= 0.425*Trailer Crr + 0.425*Drive Crr + 0.15*Steer Crr

The "low gears" mentioned in the AMT gearbox efficiency of Table 7 only applies when the total gear number of a transmission is greater than 9. In this type of transmission, low gear efficiency will be set to 96% when the lower gears is equal to a maximum value of either total gear number divided by 2 or the total gear number minus 6. Taking a transmission with 10 gears for example, the lower gear is defined as maximum of 10/2 or 10-6, which will be 5. This means that any gear numbers smaller than 5 will have 96% efficiency. For AMTs with less than 9 gears, such as 8 or less, all gears efficiency will be set to 98% except the 1:1 gear ratio.

GEM allows a user to modify or adjust performance information for certain components in order to model and quantify improvements the manufacturer is making to its vehicles. Table 8 lists the user-defined modeling parameters that are recognized in GEM. In addition to tire rolling resistances, Phase 2 GEM also requires axle configuration, axle ratio, and loaded size of the tires. Similar to Phase 1, Phase 2 GEM also accounts for aerodynamic drag, but manufacturers are asked to provide a wind-averaged aerodynamic drag area (CdA). Note that in MY 2027 and later, GEM will subtract 0.3 m^2 from the user's CdA input value for high roof tractors to account for improved box trailer aerodynamics. See Section III.E.2 of the preamble to this rulemaking for more information.

In Phase 1, a default engine and transmission were applied to all GEM-simulated combination tractors. For most simulated vehicles, Phase 2 GEM requires manufacturers to supply an engine fuel map and specific transmission information as separate input files to the model. Manufacturers also have the option to use engine and transmission performance data obtained from a powertrain test in their GEM runs and replace the engine and transmission files with a single powertrain file. Additionally, manufacturers can optionally include a file to account for axle losses and/or include a file to account for transmission power losses. These input files have specific requirements, as will be discussed in the Supplemental Input Files section of this Guide.

Table 8: User-Defined Modeling Parameters for Class 7 and Class 8 Combination Tractors (All Cabs and Roof Heights)

Modeling Parameter	Method of Determining Parameter
Engine data file	40 CFR 1036.510, 1036.535 and 1036.540
Transmission data file	40 CFR 1037.520(g)(1) and optionally 1037.565
Powertrain data file (Optional)	40 CFR 1037.550
Drive Axle Configuration	40 CFR 1037.520(g)(2)
Drive Axle Ratio	40 CFR 1037.520(g)(3)
Drive Axle data file (Optional)	40 CFR 1037.560
Aerodynamic Drag Area, CdA (m^2)	See 40 CFR 1037.520(b)
Steer Axle Tire Rolling Resistance (kg/t)	40 CFR 1037.520(c)
Drive Axle 1 Tire Rolling Resistance (kg/t)	
Drive Axle 2 Tire Rolling Resistance (kg/t)	
Drive Axle Loaded Tire Size (rev/mi)	See 40 CFR 1037.520(c)

Phase 2 GEM also accounts for additional technology improvements that reduce CO_2 and fuel consumption, but are not easily captured in the vehicle simulation. These reduction values vary for each technology. The vehicle speed limiter, weight reduction and neutral idle options will impact the vehicle simulation. The remaining technologies improvements are applied as post-process percent reductions to the results from the vehicle simulation. Table 9 directs users to the corresponding regulation reference to determine appropriate values to apply for each technology.

Table 9: Technology Improvement Options for Tractor Manufacturers

Technology Improvement	Regulation Reference
Vehicle Speed Limiter (MPH or NA)	40 CFR 1037.520(d)
Weight Reduction (lb)	40 CFR 1037.520(e)
Neutral Idle, AT only (Y/N)	40 CFR 1037.660
Intelligent Controls (%)	40 CFR 1037.520(j)
Accessory Load (%)	40 CFR 1037.520(j)
Extended Idle Reduction, Sleeper Cabs Only (%)	40 CFR 1037.520(j)
Tire Pressure System (%)	40 CFR 1037.520(j)
Other (%)	40 CFR 1037.520(j)

III.B.3. Vocational Vehicle Parameters

The agencies are adopting a set of predefined modeling parameters to establish consistent vocational vehicle models from which manufacturers can compare their vehicle improvements. GEM recognizes nine variations of vocational vehicles based on both vehicle weight class and duty cycle. Class 8 vocational vehicles are considered heavy heavy-duty (HHD). Classes 6 and 7 are medium heavy-duty (MHD), and Classes 2b-5 are considered light heavy-duty (LHD). As seen in Table 10, Table 11, and Table 12, the weight, number of axles, aerodynamic drag area and payload are the same for all of the vehicles within a weight class. Vehicles within each weight class are further categorized using three duty cycles (Regional, Multi-purpose and Urban) by varying the drive cycle weightings associated with each composite duty cycle.

The regulations describe the drive cycle weighting factors for each subcategory in 40 CFR 1037.510. Manufacturers should consult the regulations at 40 CFR 1037.510(c) as well as 40 CFR 1037.140(g-h) and 40 CFR 1037.150(z) for instructions on how to select the appropriate subcategory in which to certify a vocational vehicle configuration. The reasoning behind the regulations can be found in the preamble to the rule in Section V.D.1.e.

Table 10: Vocational Heavy Heavy-Duty (Class 8) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	**HHD**		
Duty Cycle	**Regional**	**Multi-Purpose**	**Urban**
Total weight (kg)	19051		
CdA (m^2)	6.86		
Payload (tons)	7.50		
ARB Transient Drive Cycle Weighting	0.20	0.54	0.90
GEM 55 mph Drive Cycle Weighting	0.24	0.23	0.10
GEM 65 mph Drive Cycle Weighting	0.56	0.23	0.00
Parked Idle Cycle Weighting	0.25	0.25	0.25
Drive Idle Cycle Weighting	0.00	0.17	0.15
Non-Idle Cycle Weighting	0.75	0.58	0.60

Table 11: Vocational Medium Heavy-Duty (Class 6-7) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	**MHD**		
Duty Cycle	**Regional**	**Multi-Purpose**	**Urban**
Total weight (kg)	11408		
CdA (m^2)	5.40		
Payload (tons)	5.60		
ARB Transient Drive Cycle Weighting	0.20	0.54	0.92
GEM 55 mph Drive Cycle Weighting	0.24	0.29	0.08
GEM 65 mph Drive Cycle Weighting	0.56	0.17	0.00
Parked Idle Cycle Weighting	0.25	0.25	0.25
Drive Idle Cycle Weighting	0.00	0.17	0.15
Non-Idle Cycle Weighting	0.75	0.58	0.60

Table 12: Vocational Light Heavy-Duty (Class 2b-5) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	**LHD**		
Duty Cycle	**Regional**	**Multi-Purpose**	**Urban**
Total weight (kg)	7257		
CdA (m^2)	3.40		
Payload (tons)	2.85		
ARB Transient Drive Cycle Weighting	0.20	0.54	0.92
GEM 55 mph Drive Cycle Weighting	0.24	0.29	0.08
GEM 65 mph Drive Cycle Weighting	0.56	0.17	0.00
Parked Idle Cycle Weighting	0.25	0.25	0.25
Drive Idle Cycle Weighting	0.00	0.17	0.15
Non-Idle Cycle Weighting	0.75	0.58	0.60

The agencies are also adopting seven custom chassis subcategories for manufacturers that know the specific end-use of their vehicles. These custom chassis are based on the nine general vocational subcategories, as shown in Table 13. In contrast to the vocational subcategories in the main program, custom chassis have several default GEM inputs as will be described in the Input File Structure section of this Guide.

Table 13: Vocational Custom Chassis Subcategories and Associated Vehicle in GEM

Custom Chassis Subcategory	GEM Simulated Vehicle
Emergency Vehicles	HHD Urban
Cement Mixers and Other Mixed Use Applications	HHD Urban
Refuse Vehicles	HHD Urban
Coach Buses	HHD Regional
Transit Bus, Other Bus and Drayage Tractors	HHD Urban
Motor Homes	MHD Regional
School Bus	MHD Urban

Table 14 shows the predefined modeling parameters that are consistent across all vocational vehicle types. These common parameters include ambient temperature, efficiencies and accessory powers. Gearbox mechanical efficiencies for AMT and AT are consistent with the tractor model (see section III.B.2 of this Guide). The calculations for overall rolling resistance and the distribution of weight savings are also consistent for all modeled vocational vehicles.

Table 14: Common Predefined Modeling Parameters for All Vocational Vehicles

AMT Gearbox Mechanical Efficiency (9 or more gears)	96% for low gears, 98% high gears, except 100% for 1:1 gear ratio
AMT Gearbox Mechanical Efficiency (less than 9 gears)	100% for 1:1 gear ratio, 98% for rest of gears
AT Gearbox Mechanical Efficiency	99.5% for 1:1 gear and 98% for all gears
Electrical Accessory Power (W)	1200 for HHD, 900 for MHD, 500 for LHD
Mechanical Accessory Power (W)	2300 for HHD, 1600 for MHD, 1000 for LHD
Environmental Air Temperature (°C degree)	25
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons, 0.5*weight reduction is subtracted from the vehicle mass during simulation
Overall Tire Crr (kg/t)	= 0.7*Drive Crr + 0.3*Steer Crr

GEM allows a user to modify or adjust performance information for certain components in order to model and quantify improvements the manufacturer is making to its vehicles. Table 15 lists the user-defined modeling parameters that are recognized in GEM for vocational vehicles. In Phase 1 GEM, vocational vehicle manufacturers were only given the option of changing the rolling resistance of their steer and drive tires. Phase 2 GEM continues to allow vocational vehicle manufacturers to model their vehicle's tire rolling resistances, but also requires axle configuration, axle ratio, and loaded size of the tires for standard vocational chassis subcategories. The model also provides these subcategories the option to account for aerodynamic drag as a wind-averaged change in aerodynamic drag area (delta CdA).

Additionally, Phase 2 GEM requires manufacturers to supply an engine fuel map and specific transmission information to for each distinct engine and transmission in the vehicles being modeled. Manufacturers also have the option to use engine and transmission performance data obtained from a powertrain test in their GEM runs and replace the engine and transmission files with a single powertrain file. Additionally, manufacturers can optionally include a file to account for axle losses and/or include a file to account for transmission power losses. Note that custom chassis manufacturers are only required to provide some of these parameters (i.e., drive axle configuration and tire rolling resistances) and the rest will be default values.

Table 15: User-Defined Modeling Parameters for Vocational Vehicles (All Weight Classes)

Modeling Parameter	Method of Determining Parameter
Engine data file	40 CFR 1036.535 and 1036.540
Transmission data file	40 CFR 1037.520(g)(1) and optionally 1037.565
Powertrain data file (Optional)	40 CFR 1037.550
Drive Axle Configuration	40 CFR 1037.520(g)(2)
Drive Axle Ratio	40 CFR 1037.520(g)(3)
Drive Axle data file (Optional)	40 CFR 1037.560
Aerodynamic Drag Area, Delta CdA (m2)	40 CFR 1037.520(m) and 40 CFR 1037.527
Steer Axle Tire Rolling Resistance (kg/t)	40 CFR 1037.520(c)
Drive Axle 1 Tire Rolling Resistance (kg/t)	
Drive Axle 2 Tire Rolling Resistance (kg/t)	
Drive Axle Loaded Tire Size (rev/mi)	See 40 CFR 1037.520(c)

Similar to the tractor model, Phase 2 GEM accounts for additional vocational vehicle technologies that reduce CO_2 and fuel consumption, but are not easily captured in the vehicle simulation. These reduction values vary for each technology. The vehicle speed limiter, weight reduction, neutral idle, and start-stop options will impact the vehicle simulation. The remaining technologies improvements are applied as post-process g/ton-mile or percent reductions to the results from the vehicle simulation. Table 16 directs users to the corresponding regulation reference to determine appropriate values to apply for each technology. These technology improvements are available to all vocational subcategories.

Table 16: Technology Improvement Options for Vocational Vehicle Manufacturers

Technology Improvement	Regulation Reference
Vehicle Speed Limiter (MPH or NA)	40 CFR 1037.520(d)
Delta Power Take Off Fuel (g/ton-mile)	40 CFR 1037.520(k) and 1037.540
Weight Reduction (lb)	40 CFR 1037.520(e)
Neutral Idle (Y/N)	40 CFR 1037.520(h)
Start-Stop (Y/N)	40 CFR 1037.520(h)
Automatic Engine Shutdown	40 CFR 1037.520(h)
Accessory Load (%)	40 CFR 1037.520(j)
Tire Pressure System (%)	40 CFR 1037.520(j)
Other (%)	40 CFR 1037.520(j)

III.B.4. Trailer Vehicle Parameters

The agencies are adopting an equation-based compliance approach for box trailer manufacturers and they are not required to certify their trailers using GEM (see 40 CFR 1037.515). However, the equations for each box trailer subcategory are based on the simulated trailers described in this section. Note that non-box trailers do not use GEM or the GEM-based equation for compliance and a discussion of non-box trailers is not included in this User Guide. The following description of the trailer model as it applies to box trailers is included for informational purposes only.

The agencies are adopting a set of predefined modeling parameters to establish consistent tractor-trailer models from which box van trailer manufacturers can compare their vehicle improvements. GEM recognizes four variations of box van based on length. Long box vans (trailers that are longer than 50-feet) are represented by either a 53-foot dry van or a 53-foot refrigerated van pulled by a Class 8 high roof sleeper cab tractor in GEM and are given the same long-haul drive cycle weightings as the Class 8 high roof sleeper cab tractors mentioned previously. GEM models all short box vans (box trailers 50-feet in length and shorter) as a single-axle, solo 28-foot dry van or refrigerated van pulled by a Class 7 high roof day cab tractor with a 4x2 drive axle configuration.

Table 17 and Table 18 summarize the predefined modeling parameters for long and short box vans, respectively. All long box vans are modeled with tandem axles and a payload of 19 tons and drive cycle weightings that are more representative of long-haul driving (i.e., 86 percent at 65-MPH, 9 percent at 55-MPH and 5 percent transient). All short box vans are modeled with a single axle, a payload of 10 tons, and drive cycle weightings more representative of short-haul driving with 64 percent at 65-MPH, 17 percent at 55-MPH, 19 percent transient. The vehicle weight varies between dry vans and refrigerated vans to account for the weight of the refrigeration unit, and weight also varies proportional to the length of the trailer. The baseline CdA values were obtained from EPA's aerodynamic testing.

Table 17: Predefined Modeling Parameters for Long Box Trailers

Regulatory Subcategory	Long Box Dry Van	Long Box Refrigerated Van
Tractor Type	C8 Sleeper Cab - High Roof	
Total weight (kg)	31978	33778
Baseline CdA Values (m^2)	6.0	6.0
Tractor Engine	15L 455 HP	
Tractor Drive Axle Configuration	6x4	
Number of Axles	5	
Payload (tons)	19	
CARB HHDDT Drive Cycle Weighting	0.05	
GEM 55 mph Drive Cycle Weighting	0.09	
GEM 65 mph Drive Cycle Weighting	0.86	

Table 18: Predefined Modeling Parameters for Short Box Trailers

Regulatory Subcategory	Short Box Dry Van	Short Box Refrigerated Van
Tractor Type	C7 Day Cab - High Roof	
Total weight (kg)	18306	20106
Baseline CdA Values (m^2)	5.6	5.6
Tractor Engine	11L 350 HP	
Tractor Drive Axle Configuration	4x2	
Number of Axles	3	
Payload (tons)	10	
ARB Transient Drive Cycle Weighting	0.19	
GEM 55 mph Drive Cycle Weighting	0.17	
GEM 65 mph Drive Cycle Weighting	0.64	

Table 19 shows the predefined modeling parameters that are consistent across all trailer types. Many of these common parameters are associated with the simulated tractor in the tractor-trailer model. The calculations for overall rolling resistance and the distribution of weight savings are consistent with the calculations for GEM-simulated tractors.

Table 19: Common Predefined Modeling Parameters for All Box Trailers

Gearbox Efficiency	100% for 1:1 gear ratio, 96% for lower gears or 98% for rest of gears
Axle Drive Ratio	3.7
Electrical Accessory Power (W)	300
Mechanical Accessory Power (W)	1000
Loaded Tire Size (rev/mi)	512
Steer Tire Crr (kg/t)	6.54
Drive Tire Crr (kg/t)	6.92
Overall Tire Crr (kg/t)	= 0.425*Trailer Crr + 0.425*Drive Crr + 0.15*Steer Crr
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons

GEM allows a user to modify or adjust performance information for certain components in order to model and quantify improvements the manufacturer is making to its vehicles. The trailer program has three user-defined parameters and one pre-defined technology improvement option that has a specified reduction value associated with its use (see Table 20). Trailer manufacturers are able to change their tire rolling resistance, aerodynamic drag and cumulative weight reduction. GEM applies an additional percent improvement value to trailers that have tire pressure systems installed on their simulated trailer. Separate percentage values apply for tire pressure monitoring systems (TPMS) and automatic tire inflation systems (ATIS).

Table 20: User-Defined Modeling Parameters and Technology Improvement Options for Trailers (All Lengths)

Modeling Parameter	Method of Determining Parameter
Trailer Tire Crr (kg/t)	40 CFR 1037.515(b)
Change in Aerodynamic Drag Area, ΔCdA (m^2)	40 CFR 1037.515(c) and 40 CFR 1037.526
Weight Reduction (lb)	40 CFR 1037.515(d)
Tire Pressure System [a]	1.2% for ATIS, 1.0% for TPMS, 0 if no system

[a] Note that 40 CFR 1037.515(a) specifies the tire pressure system values in decimal format, because trailers use a GEM-based equation for compliance. The GEM input file described in this Guide uses percent-based input values for tire pressure systems.

IV. GEM Input File Structure

As mentioned previously, Phase 2 GEM does not offer a graphical user interface (GUI) for users to provide their vehicle parameters. Instead, inputs are exclusively provided to the model in a .csv file. Phase 2 GEM executable can be initiated using the Start Menu, or a command prompt. The following subsections describe the input file structures, which are consistent for each method of running the model.

Some manufacturers may create a script to automatically generate their input files in .csv format. Others may wish to manually populate their files using a spreadsheet tool, such as Microsoft Excel, to easily view the input fields in a column format, and save the files in a .csv format. For illustration purposes, the .csv input files in this section are shown in spreadsheet format. The following section, Running GEM, describes the options for running the model.

IV.A. Note to Users Creating or Editing .csv Files Using Microsoft Excel

Users may use Microsoft Excel or any other text editor, such as Notepad, to create or edit their input files. Once a file is created, it can be saved by going to go to “Save As…” and choose *CSV (Comma delimited) (*.csv)* in the “Save as type:” pull-down menu, as shown in Figure 13. In future saves, or when editing and resaving an existing .csv formatted file, users may receive a warning similar to Figure 14. Select “Yes” to ensure the file is properly saved in .csv format.

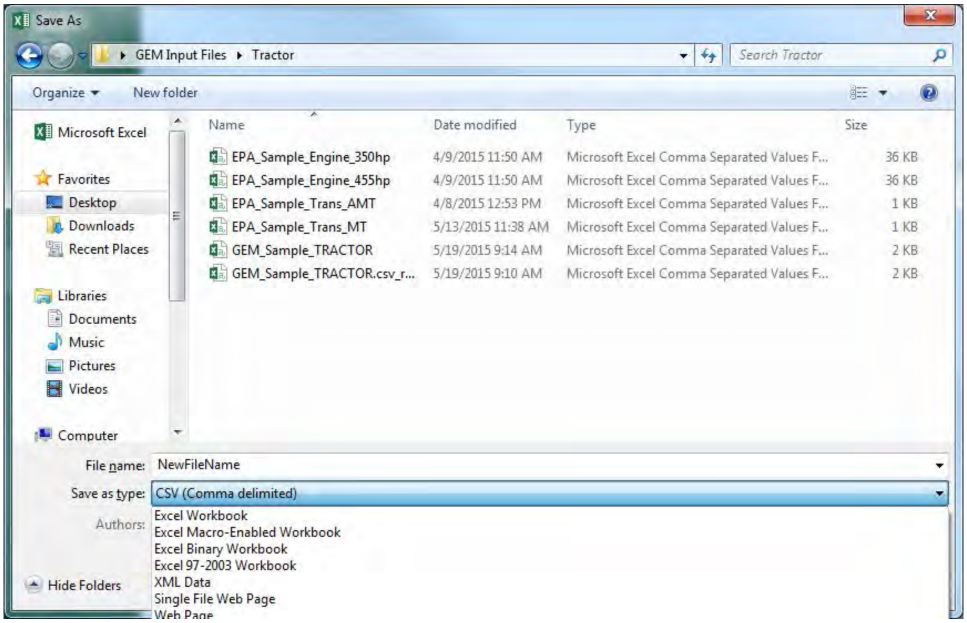

Figure 13: Example "Save As..." Window to Create a Comma Separated Value (.csv) Input File

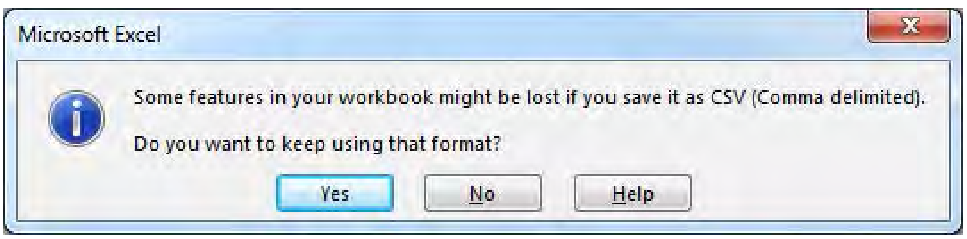

Figure 14: Warning from Microsoft Excel When Saving .csv Files Using Excel – Select "Yes"

IV.B. Tractor Input Files

The top of the tractor input file has three comma separated lines that list the regulatory category, manufacturer name and model year (see Figure 15). Users complete the second column for each line. The first line must read "Tractor" in order for GEM to run the appropriate vehicle model. Manufacturer name can be in any format, but it should be consistent with other regulatory documents from the manufacturer. Model year must be expressed as a four-digit number.

Regulatory Category	Tractor
Manufacturer Name	EPA
Model Year	2018

Figure 15: Tractor Input File Header Information

The next lines of the tractor input file contain the model inputs. In the first two columns, shown in Figure 16, the user provides a Run ID and the Regulatory Subcategory for each run.

The Run ID is a unique value that will be used to identify the run (e.g., vehicle VIN). It can be any combination of letters, numbers and separators such as dash ("-"), periods ("."), or underscores ("_"). The Regulatory Subcategory determines the vehicle that is modeled and the standard that is applied for compliance. For tractors, there are 10 standard regulatory subcategories in GEM and Table 21 shows the naming convention. In addition, GEM includes six optional heavy Class 8 tractor subcategories that represent tractors that are designed for heavy-haul operation in Canada. Manufacturers may optionally certify their tractors as heavy Class 8, using the subcategories shown in Table 22, starting in MYs 2021. See Section III.B.4.a of the preamble to this rulemaking for a discussion of these optional tractor subcategories. Note that these tractors are separate from the C8_HH subcategory that is used for U.S.-based heavy-haul tractors.

Run ID	Regulatory Subcategory
Unique Identifier	(e.g. C8_SC_HR)
Sample_1	C8_SC_HR
Sample_2	C7_DC_MR
Sample_3	C8_HH
Sample_4	HC8_SC_LR
Sample_5	HC8_DC_MR
Sample_6	C8_DC_MR
Sample_7	C8_SC_LR
Sample_8	C8_SC_HR
PT_Sample1	C8_SC_HR

Figure 16: Tractor Input File Run ID and Regulatory Subcategory Inputs

Table 21: Tractor Input File Naming Convention for Tractor Regulatory Subcategories

GEM Input Name	Regulatory Subcategory Description
C8_SC_HR	Class 8 Combination, Sleeper Cab - High Roof
C8_SC_MR	Class 8 Combination, Sleeper Cab - Mid Roof
C8_SC_LR	Class 8 Combination, Sleeper Cab - Low Roof
C8_DC_HR	Class 8 Combination, Day Cab - High Roof
C8_DC_MR	Class 8 Combination, Day Cab - Mid Roof
C8_DC_LR	Class 8 Combination, Day Cab - Low Roof
C8_HH	Class 8 Combination, Sleeper Cab - Heavy Haul
C7_DC_HR	Class 7 Combination, Day Cab - High Roof
C7_DC_MR	Class 7 Combination, Day Cab - Mid Roof
C7_DC_LR	Class 7 Combination, Day Cab - Low Roof

Table 22: Tractor Input File Naming Convention for Optional Heavy Class 8 Tractors Operating in Canada

GEM Input Name	Regulatory Subcategory Description
HC8_SC_HR	Heavy Class 8 Combination, Sleeper Cab - High Roof
HC8_SC_MR	Heavy Class 8 Combination, Sleeper Cab - Mid Roof
HC8_SC_LR	Heavy Class 8 Combination, Sleeper Cab - Low Roof
HC8_DC_HR	Heavy Class 8 Combination, Day Cab - High Roof
HC8_DC_MR	Heavy Class 8 Combination, Day Cab - Mid Roof
HC8_DC_LR	Heavy Class 8 Combination, Day Cab - Low Roof

The next columns in the input file are for the engine and transmission file names or the powertrain file name. A description of the content of these supplemental input files is located at the end of this section. The text in the fields of the input file must exactly match the file name, including the .csv extension for the code to run properly. In the Sample Input Files folder provided with GEM, the supplemental files are located in separate Axle, Engine, Powertrain and Transmission subfolders. GEM searches for the supplemental files from the same location as the vehicle input file. As a result, the subfolder name must be included in the File Name fields, as shown in Figure 17, to direct the model to the files. If users have their engine, transmission, powertrain and axle files in the same folder as the vehicle input file, only the filename is needed.

Manufacturers may choose to perform powertrain testing to obtain the engine and transmission performance for their GEM simulations. In order to indicate to GEM that powertrain data is provided, users would provide the same powertrain input file name in both the Engine and Transmission File Name fields of the tractor input file, as seen in the last row of Figure 17.

Engine Data File Name	Transmission Data File Name
Engines\EPA_2018_D_GENERIC_455_CycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_350_CycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_600_CycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_600_CycleAvg.csv	Transmissions\EPA_MT_13_C78_4543.csv
Engines\EPA_2018_D_GENERIC_455_CycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_455_CycleAvg.csv	Transmissions\EPA_AT_10_C78_8001.csv
Engines\EPA_2018_D_GENERIC_455_CycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490_power_loss.csv
Engines\EPA_2018_D_GENERIC_455_AllCycleAvg.csv	Transmissions\EPA_AMT_10_C78_4490.csv
Powertrains\EPA_Sample_Powertrain.csv	Powertrains\EPA_Sample_Powertrain.csv

Figure 17: Tractor Input File Reference to Engine, Transmission, and Powertrain Input Files

Figure 18 shows the next columns containing the tractor performance parameters and several vehicle characteristics that are user-defined in GEM. A description of these parameters was given in Table 8 and additional information is available in the preamble to the Phase 2 rulemaking. The Drive Axle Data File Name field points to the location and name of the optional axle file. Note, if users do not use an optional axle file, then input "NA". The format of this field is similar to the engine and transmission file fields shown in Figure 17. Note that for tractors (second row) that have a single rear axle (i.e., 4x2 axle configuration), the users input an "NA" into the Drive Axle 2 Tire Rolling Resistance Level field for those vehicles. Also, heavy-haul tractors (third row) have a default Aerodynamic Drag Area (CdA) of 5.0 m^2 within GEM, so users also input an "NA" into that field for heavy-haul tractors.

Drive Axle Configuration (e.g. 6x4)	Drive Axle Ratio #	Drive Axle Data File Name	Aerodynamic Aerodynamic Drag Area (CdA) m^2	Steer Axle Tire Rolling Resistance Level kg/t	Drive Axle 1 Tire Rolling Resistance Level kg/t	Drive Axle 2 Tire Rolling Resistance Level kg/t	Drive Axle Tire Loaded Tire Size rev/mi
6x4	3.08	NA	5.4	6.9	6.9	6.9	500
4x2	3.42	NA	5.1	6.9	6.9	NA	500
6x4	3.23	NA	NA	6.9	6.9	6.9	500
6x4	3.12	NA	5.07	7	6.8	6.8	512
6x4	3.45	NA	5.35	6.9	6.9	6.9	500
6x4	3.45	NA	5.18	6.9	6.9	6.9	512
6x4D	3.12	Axles\EPA_Axle.csv	4.88	6.9	6.9	6.9	500
6x4	3.08	NA	5.4	6.9	6.9	6.9	500
6x4	3.08	NA	5.4	6.9	6.9	6.9	500

Figure 18: Tractor Input File Performance Parameters and User-Defined Vehicle Characteristics

There are limits associated with each user-defined input value. Drive Axle Configuration is a text input and the allowable text is “6x4”, “4x2”, “6x4D”, or “6x2”. Vehicles with more than two drive axles are instructed to use the “6x4” configuration in the model. All tractors with “6x2” axle configurations are modeled with five axles with two steer tires, 4 non-drive tires and 4 drive tires. All tractors with “6x4” axle configurations are modeled with five axles with two steer tires and eight drive tires. The only difference in GEM between “6x2” and “6x4” axles is that there is an additional 1 percent loss for “6x4” axles to account for the inter-axle losses. All tractors with “6x4D” axle configurations are modeled as “6x2” axles on the cruise cycles and “6x4” axles on the transient cycle. All tractors with a “4x2” axle are represented by a four axle tractor with two steer tires and four drive tires. Table 23 shows the limits for the remaining six tractor inputs in the model. GEM will produce an error if any of these values are out of the acceptable range and will round any values beyond their specified decimal limits.

Table 23: Minimum and Maximum Limits for User-Defined Values in Tractor Input File

User-Defined Parameter	Units	Number of Decimals	Minimum Value	Maximum Value
Drive Axle Ratio	#	2	1.00	20.00
Aerodynamic Drag Area (CdA)	m^2	2	3.00	8.00
Steer Axle Tire, Rolling Resistance Level	kg/t	1	3.0	20.0
Drive Axle 1 Tire, Rolling Resistance Level	kg/t	1	3.0	20.0
Drive Axle 2 Tire, Rolling Resistance Level	kg/t	1	3.0	20.0 or NA
Drive Axle Loaded Tire Size	rev/mi	0	100	1000

The next columns in the tractor input file are for the optional technology improvements. These technology improvement fields cannot be blank in the input file. The first three tractor technology improvements, seen in Figure 19, will directly impact the vehicle simulation. Vehicle speed limiters reduce the maximum allowable speed of the vehicle during the simulation to the user-specified value. Weight reduction reduces the overall vehicle weight (and increases payload) as noted in Table 7. If no weight reduction is used, then input “0”. Neutral-idle reduces the fuel consumption of the engine when a simulated automatic transmission vehicle is idling. If the vehicle includes neutral-idle, then input “Y”. If it does not include neutral-idle, then input “N”. The remaining technology improvements, shown in Figure 20, have specific percent reductions that manufacturers will apply for the given technology fields. If the technology improvement(s) is not applicable to the vehicle being simulated, then input “0”. The

Other field may be used for several technologies, including results from any off-cycle testing that manufacturers may perform. See Table 9 and, generally, 40 CFR 1037.520 for the appropriate percent values. All values of “Y”, “N”, or “NA” must be in UPPERCASE LETTERS. Lowercase letters will produce an error.

Technology Improvement	Technology Improvement	Technology Improvement
Vehicle Speed Limiter	Weight Reduction	Neutral-Idle
MPH or NA	lbs	Y/N
NA	0	N
NA	100	N
NA	0	N
NA	0	N
NA	0	N
NA	0	Y
NA	0	N
NA	0	N
NA	0	N

Figure 19: Tractor Technology Improvements

Technology Improvement	Technology Improvement	Technology Improvement	Technology Improvement	Technology Improvement
Intelligent Controls	Accessory Load	Extended Idle Reduction	Tire Pressure System	Other
%	%	%	%	%
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Figure 20: Tractor Technology Improvements with Pre-Defined Percent Improvements

Similar to the user-defined parameters, these technology improvements also have limits. The format and limits for the technology improvements are shown in Table 24. Input values with additional decimal places will be rounded to the appropriate precision. Input values outside the minimum and maximum range specified will produce an error.

Table 24: Minimum and Maximum Limits for Technology Improvement Values in Tractor Input File

Modeling Parameter	Units	Number of Decimals	Minimum	Maximum
Vehicle Speed Limiter	MPH or NA	1	54.0	65.0
Weight Reduction	lb	0	0	14,000
Neutral Idle, Automatic Transmissions Only	Y/N	-	-	-
Intelligent Controls	%	1	1.0	10.0
Accessory Load	%	1	1.0	10.0
Extended Idle Reduction, Sleeper Cabs Only	%	1	1.0	10.0
Tire Pressure System	%	1	1.0	10.0
Other	%	1	1.0	50.0

IV.C. Vocational Input Files

The top of the vocational input file has three lines that list the regulatory category, manufacturer name and model year (see Figure 21). The first line must read "Vocational" in order for GEM to run the appropriate vehicle model. Manufacturer name can be in any format, but it should be consistent with other regulatory documents from the manufacturer. Model year should be expressed as a four-digit number.

Regulatory Category	Vocational
Manufacturer Name	EPA
Model Year	2018

Figure 21: Vocational Input File Header Information

The next lines of the vocational input file contain the model inputs. In the first two columns, shown in Figure 22, the user provides a Run ID and the Regulatory Subcategory for each run. The Run ID is a unique value that will be used to identify the run (e.g., vehicle VIN). It can be any combination of letters, numbers and separators such as dash ("-"), periods ("."), or underscores ("_"). The Regulatory Subcategory determines the vehicle that is modeled and the standard that is applied for compliance. For vocational, there are nine standard regulatory subcategories in GEM and Table 25 shows the naming convention. In addition, GEM includes seven optional custom chassis vocational subcategories that represent vehicles that are designed for specific operations. Manufacturers may optionally certify their vocational vehicles with these custom chassis designations, using the naming convention shown in Table 26. See Section V.B.2.b of the preamble to this rulemaking for a discussion of these optional custom chassis subcategories.

Run ID	Regulatory Subcategory
Unique Identifier	(e.g. HHD_R)
Sample_1	HHD_R
Sample_2	HHD_M
Sample_3	LHD_U
Sample_4	LHD_M
Sample_5	LHD_U
Sample_6	LHD_U
Sample_7	MHD_R
Sample_8	LHD_M
CC_Sample_1	HHD_CC_RF
CC_Sample_2	HHD_CC_EM
CC_Sample_3	HHD_CC_CM
CC_Sample_4	HHD_CC_OB
CC_Sample_5	HHD_CC_CB
CC_Sample_6	MHD_CC_MH
CC_Sample_7	MHD_CC_SB
PT_Sample1	HHD_M

Figure 22: Vocational Input File Run ID and Regulatory Subcategory Inputs

Table 25: Vocational Input File Naming Convention for Vocational Regulatory Subcategories

GEM Input Name	Regulatory Subcategory Description
HHD_R	Heavy-Heavy Duty, Regional
HHD_M	Heavy-Heavy Duty, Multipurpose
HHD_U	Heavy-Heavy Duty, Urban
MHD_R	Medium-Heavy Duty, Regional
MHD_M	Medium-Heavy Duty, Multipurpose
MHD_U	Medium-Heavy Duty, Urban
LHD_R	Light-Heavy Duty, Regional
LHD_M	Light-Heavy Duty, Multipurpose
LHD_U	Light-Heavy Duty, Urban

Table 26: Vocational Input File Naming Convention for Vocational Regulatory Subcategories

GEM Input Name	Custom Chassis Subcategory Description
HHD_CC_EM	Emergency Vehicles
HHD_CC_CM	Cement Mixers and Other Mixed Use Applications
HHD_CC_RF	Refuse Vehicles
HHD_CC_CB	Coach Buses
HHD_CC_OB	Transit Bus, Other Bus and Drayage Tractors
MHD_CC_MH	Motor Homes
MHD_CC_SB	School Bus

The next columns in the input file are for the engine and transmission file names or the powertrain file name. A description of the content of these supplemental input files is located at the end of this section. The text in the fields of the input file must exactly match the file name, including the .csv extension for the code to run properly. In the Sample Input Files folder provided with GEM, the supplemental files are located in separate Axle, Engine, Powertrain and Transmission subfolders. GEM searches for the supplemental files from the same location as the vehicle input file. As a result, the subfolder name must be included in the File Name fields, as shown in Figure 23, to direct the model to the files. If users have their engine, transmission, powertrain and axle files in the same folder as the vehicle input file, only the filename is needed. Manufacturers may choose to perform powertrain testing to obtain the engine and transmission performance for their GEM simulations. In order to indicate to GEM that powertrain data is provided, users would provide the same powertrain input file name in both the Engine and Transmission File Name fields of the tractor input file, as seen in the last row of Figure 23. Note that the custom chassis subcategories (rows 9-15 of the sample input file) use default engines and transmissions within GEM and manufacturers input “NA” in those fields.

Engine	Transmission
Data	Data
File Name	File Name
Engines\EPA_2018_D_GENERIC_350_CycleAvg.csv	Transmissions\EPA_MT_10_HHD.csv
Engines\EPA_2018_D_GENERIC_350_CycleAvg.csv	Transmissions\EPA_AT_5_HHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_CycleAvg.csv	Transmissions\EPA_AT_6_LHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_CycleAvg.csv	Transmissions\EPA_AT_6_LHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_CycleAvg.csv	Transmissions\EPA_AT_6_LHD_LU2.csv
Engines\EPA_2018_G_GENERIC_300hp_CycleAvg.csv	Transmissions\EPA_AT_6_LHD_LU2.csv
Engines\EPA_2018_D_GENERIC_270_CycleAvg.csv	Transmissions\EPA_AT_6_MHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_CycleAvg.csv	Transmissions\EPA_AT_6_LHD_LU3.csv
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
Powertrains\EPA_Sample_Powertrain.csv	Powertrains\EPA_Sample_Powertrain.csv

Figure 23: Vocational Input File Reference to Engine, Transmission, and Powertrain Input Files

The next columns of the sample input file are shown in Figure 24 and contain the vocational performance parameters and vehicle characteristics that are user-defined in GEM. A description of these parameters was given in Table 15 and additional information is available in Section V.D of the preamble to the Phase 2 rulemaking. Note that for vehicles that have a single rear axle (i.e., 4x2 axle configuration), the users input an "NA" into the Drive Axle 2 Tire Rolling Resistance Level field for those vehicles. As shown in Figure 24, custom chassis manufacturers only specify the drive axle configuration and tire rolling resistance values; all other user-defined fields are marked "NA".

Drive Axle	Drive Axle	Drive Axle	Aerodynamic Improvement (Delta)	Steer Axle Tire	Drive Axle 1 Tire	Drive Axle 2 Tire	Drive Axle Tire
Configuration	Ratio	Data	Aerodynamic Drag Area (CdA)	Rolling Resistance Level	Rolling Resistance Level	Rolling Resistance Level	Loaded Tire Size
(e.g. 6x4)	#	File Name	m^2	kg/t	kg/t	kg/t	rev/mi
6X4	3.73	NA	0	7.7	7.7	7.7	530
6X4D	4.33	Axles\EPA_Axle.csv	0	7.7	7.7	7.7	530
4x2	4.09	NA	0	6.2	6.2	NA	500
4x2	4.09	NA	0	6.2	6.2	NA	500
4x2	4.09	NA	0	6.2	6.2	NA	500
4x2	4.09	NA	0	6.2	6.2	NA	500
4x2	3.8	NA	0.2	6.2	6.2	NA	500
4x2	4.09	NA	0	6.2	6.2	NA	500
6X4	NA	NA	NA	7.7	7.4	7.4	NA
6X4	NA	NA	NA	7.3	7.1	7.1	NA
6X4	NA	NA	NA	7.7	7.7	7.7	NA
4x2	NA	NA	NA	7.7	6.9	NA	NA
6x2	NA	NA	NA	7.7	6.8	6.8	NA
4x2	NA	NA	NA	7.6	7.5	NA	NA
4x2	NA	NA	NA	7.7	7.7	NA	NA
6x4	3.54	NA	0	6.9	6.9	6.9	512

Figure 24: Vocational Input File Performance Parameters and User-Defined Vehicle Characteristics

There are limits associated with each user-defined input value. Drive Axle Configuration is a text input and the allowable text is "6x4", "4x2", "6x4D", or "6x2". Vehicles with more than two drive axles are instructed to use the "6x4" configuration in the model. All vehicles with "6x2" axle configurations are modeled with five axles with two steer tires, 4 non-drive tires and 4 drive tires. All vehicles with "6x4" axle configurations are modeled with five axles with two steer tires and eight drive tires. The only difference in GEM between "6x2" and "6x4" axles is that there is an additional 1 percent loss for "6x4" axles to account for the inter-axle losses. All vehicles with “6x4D” axle configurations are modeled as “6x2” axles on the cruise cycles and “6x4” axles on the transient cycle. All vehicles with a “4x2” axle are represented by a four axles with two steer tires and four drive tires. The Drive Axle Data File Name field points to the location and name of the optional axle file. The format of this field is similar to the engine and transmission file fields shown in Figure 23. Table 27 shows the limits for the next six vocational inputs in the model. GEM will produce an error if any of these values are out of the acceptable range and will round any values beyond their specified decimal limits. Note that the aerodynamic improvement for vocational vehicles is measured as a *delta* CdA and not the absolute CdA value used in the tractor program.

Table 27: Minimum and Maximum Limits for User-Defined Values in Vocational Input File

User-Defined Parameter	Units	Number of Decimals	Minimum Value	Maximum Value
Drive Axle Ratio	#	2	1.00	20.00
Aerodynamic Drag Area (Delta CdA)	m^2	2	0.00	4.00
Steer Axle Tire, Rolling Resistance Level	kg/t	1	3.0	20.0
Drive Axle 1 Tire, Rolling Resistance Level	kg/t	1	3.0	20.0
Drive Axle 2 Tire, Rolling Resistance Level	kg/t	1	3.0	20.0 or NA
Drive Axle Loaded Tire Size	rev/mi	0	100	1000

The next columns in the vocational input file are for the optional technology improvements. These technology improvement fields cannot be blank in the input file. Five of the next six vocational technology improvements, seen in Figure 25, will directly impact the vehicle simulation. Vehicle speed limiters reduce the maximum allowable speed of the vehicle during the simulation to the user-specified value. Weight reduction reduces the overall vehicle weight (and increases payload) as noted in Table 14. Neutral-idle reduces fueling when a simulated automatic transmission vehicle is idling, Start-Stop reduces fueling when the simulation comes to a stop in the transient drive cycle and drive idle cycle, and Automatic Engine Shutdown reduces fueling during the parked idle cycle. See preamble Section V.C.1.a.iv for a description of the three workday idle reduction options. If the vocational vehicle will be built with a hybrid power take-off (PTO) and testing was conducted according to 40 CFR 1037.540, then the Delta PTO value obtained from that test procedure may be entered. Please note that these inputs are case-sensitive. All values of “Y”, “N”, or “NA” must be in UPPERCASE LETTERS. Lowercase letters will produce an error.

Technology Improvement	Technology Improvement	Technology Improvement	Technology Improvement	Technology Improvement	Technology Improvement
Vehicle Speed Limiter	Delta PTO Fuel	Weight Reduction	Neutral-Idle	Start-Stop	Automatic Engine Shutdown
MPH or NA	g/ton-mile	lbs	Y/N	Y/N	Y/N
NA	0	0	N	N	Y
NA	0	0	N	N	Y
NA	0	0	N	N	N
NA	0	0	Y	N	N
NA	0	0	N	Y	Y
NA	0	0	Y	N	Y
NA	0	0	Y	N	N
NA	0	0	Y	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	N
NA	0	0	N	N	Y

Figure 25: Vocational Technology Improvements

The remaining three technology improvements, shown in Figure 26, have specific percent reductions that manufacturers will apply for the given technology fields. The Other field may be used for several technologies, including results from any off-cycle testing that manufacturers may perform. See Table 16 and, generally, 40 CFR 1037.520 for the appropriate percent values.

Technology Improvement	Technology Improvement	Technology Improvement
Accessory Load	Tire Pressure System	Other
%	%	%
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

Figure 26: Vocational Technology Improvements with Pre-Defined Percent Improvements

Similar to the user-defined parameters, these technology improvements also have limits. The format and limits for the technology improvements are shown in Table 28. Input values with additional decimal places will be rounded to the appropriate precision. Input values outside the minimum and maximum range specified will produce an error.

Table 28: Minimum and Maximum Limits for Technology Improvement Values in Vocational Input File

Modeling Parameter	Units	Number of Decimals	Minimum	Maximum
Vehicle Speed Limiter	MPH or NA	1	54.0	65.0
Weight Reduction	lb	0	0	10,000
Delta PTO	g/ton-mi	3	0.000	3.000
Neutral Idle, Automatic Transmissions Only	Y/N	-	-	-
Start-Stop	Y/N	-	-	-
Automatic Engine Shutdown	Y/N	-	-	-
Accessory Load	%	1	1.0	10.0
Tire Pressure System	%	1	1.0	10.0
Other	%	1	1.0	50.0

IV.D. Trailer Input Files

The top of the trailer input file has three lines that list the regulatory category, manufacturer name and model year (see Figure 27). The first line must read "Trailer" in order for GEM to run the appropriate vehicle model. Manufacturer name can be in any format, but it should be consistent with other regulatory documents from the manufacturer. Model year should be expressed as a four-digit number.

Regulatory Category	Trailer
Manufacturer Name	EPA
Model Year	2018

Figure 27: Trailer Input File Header Information

The next lines of the trailer input file contain the model inputs. In the first two columns, shown in Figure 28, the user provides a Run ID and the Regulatory Subcategory for each run. The Run ID is a unique value that will be used to identify the run. It can be any combination of letters, numbers and separators such as dash ("-"), periods ("."), or underscores ("_"). The Regulatory Subcategory determines which standard is applied for compliance. For trailers, there are four regulatory subcategories modeled in GEM and Table 29 shows the naming convention. While the trailer program does include reduced standards for some trailer types, trailer manufacturers do not use GEM for compliance and we did not configure GEM with additional subcategories for those trailers. These four vehicles are sufficient to create the GEM-based equation used in trailer compliance.

Run ID	Regulatory Subcategory
Unique Identifier	(e.g. LDV)
LDV_1	LDV
LRV_1	LRV
SDV_1	SDV
SRV_1	SRV

Figure 28: Trailer Input File Run ID and Regulatory Subcategory Inputs

Table 29: Trailer Input File Naming Convention for Trailer Regulatory Subcategory Inputs

GEM Input Name	Regulatory Subcategory Description
LDV	Long Dry Van
LRV	Long Refrigerated Van
SDV	Short Dry Van
SRV	Short Refrigerated Van

The next columns contain the trailer performance parameters and technology improvement options that are user-defined in GEM. A description of these parameters was given in Table 20 and additional information is available preamble to the Phase 2 rulemaking. Note that the aerodynamic improvement for trailers is measured as a *delta* CdA and not the absolute CdA value used in the tractor program.

Aerodynamic Improvement (Delta)	Trailer Tire	Technology Improvement	Technology Improvement
Aerodynamic Drag Area (CdA)	Rolling Resistance Level	Weight Reduction	Tire Pressure System
m^2	kg/t	lbs	%
0	6	0	0
0	6	0	0
0	6	0	0
0	6	0	0

Figure 29: Trailer Input File Performance Parameters and User-Defined Vehicle Characteristics

There are limits associated with the user-defined and technology improvement input values as shown in Table 30. GEM will produce an error if the fields are blank or if any of these values are out of the acceptable range. Users that wish to model their vehicle with weight reduction can enter the cumulative weight reduction value (0 to 5,000 lbs or "NA"). The tire pressure system is a set percent value for use of an automatic tire inflation system or a tire pressure monitoring system. See 40 CFR 1037.515, noting that the ATIS and TPMS values listed in the regulation are in decimal format, because trailers will use a GEM-based equation for compliance.

Table 30: Minimum and Maximum Limits of Technology Improvements in Trailer Input File

User-Defined Parameter	Units	Minimum Value	Maximum Value
Aerodynamic Drag Area (CdA)	m^2	0	4
Tire Rolling Resistance Level (TRRL)	kg/t	3	20
Weight Reduction	lbs	0	5000
Tire Pressure System	%	0	10

IV.E. Supplemental Input Files

As mentioned previously, the GEM installation package contains sample input files, including four folders of supplemental input files, as follows:

- Axles: one example axle definition file
- Engines: 13 example steady-state and cycle average engine definition files
- Powertrains: one an example powertrain definition file
- Transmissions: 11 example transmission definition files

IV.E.1. Engine Input File for Tractor and Vocational Vehicles

Tractor and vocational vehicle manufacturers are required to generate separate engine and transmission input files, or, optionally, a single powertrain input file for GEM. A vehicle manufacturer would generate a separate engine and transmission file for each engine and transmission used in its vehicles, or separate powertrain files for each engine and transmission combination tested. The transmission input file may optionally contain transmission power loss data. The axle input file is optional for manufacturers that would like to include more axle loss information. These files must be in .csv format to be properly read by the model. Each supplemental file consists of multiple tables that must be separated by an empty row to be processed correctly. We recommend that the manufacturers choose a consistent naming convention that provides unique file names for each of these supplemental input files. Note that trailer manufacturers do not have the option to use these supplemental input files and instead rely on default values built into the trailer model. The first row of the GEM input file for engines shows the GEM version, and the fourth row contains user-specified Manufacturer Name, Combustion Type, Fuel Type, Family Name, Calibration ID, Declared Engine Idle Speed as defined in 40 CFR 1036.510, and Displacement, as shown in Figure 30. Combustion Type and Fuel Type have specific options for a manufacturer to choose. The user can choose any name for the other header fields, but the names should be consistent with other regulatory documents from the manufacturer.

GEM P2v3.0 Engine Definition						
Manufacturer Name	Combustion Type	Fuel Type	Family Name	Calibration ID	Idle Speed at CITT	Displacement
(e.g. Cummins)	(Compression Ignition / Spark Ignition)	(Diesel / Gasoline / LNG / CNG)	(e.g. abcd12345efg)	(e.g. 123abc)	RPM	liters
EPA	Compression Ignition	Diesel	GENERIC	1	750	7

Figure 30: Sample Engine Input File Header Information

The manufacturer then specifies engine information in five separate comma-separated tables, as shown in Figure 31. The first table is the engine full-load torque curve, followed by the parent engine full load torque curve and the engine motoring torque curve. Torque curves are specified in RPM and Nm, and procedures for producing the torque curves, including the number of speed and torque points to measure, are specified in 40 CFR 1065.510. The next tables are the four-point engine idle fuel map and the steady-state engine fuel map. The speed, torque, and fuel rate in the fuel maps are specified in RPM, Nm, and g/s, respectively. Procedures for generating the idle and full engine fuel maps are specified in 40 CFR 1036.535 and 1065.510.

Engine Full Load Torque Curve		
Speed	Torque	
RPM	Nm	
750	440	
907	580	
:	:	
:	:	
Parent Engine Full Load Torque Curve		
Speed	Torque	
RPM	Nm	
750	440	
907	580	
:	:	
:	:	
Engine Motoring Torque Curve		
Speed	Torque	
RPM	Nm	
750	-129.17	
907	-129.19198	
:	:	
:	:	
Engine Idle Fuel Map		
Speed	Torque	Fuel Rate
RPM	Nm	grams / sec
750	0	0.258210373
850	0	0.261284511
750	100	0.689671498
850	100	0.726963355
Engine Fuel Map		
Speed	Torque	Fuel Rate
RPM	Nm	grams / sec
750	-188.98472	0
750	-170.2299298	0
:	:	:
:	:	:

Figure 31: Sample Engine Input File Engine Characteristics

The engine input file described so far includes all of the steady-state fuel map information needed to run GEM. However, tractor and vocational vehicle manufacturers must include a cycle average fuel map for the transient cycle, and can optionally apply cycle averaging to the 55- and 65-mph cruise cycles for compliance. Cycle average maps are added to the bottom of the engine input file, following the steady-state fuel map. Section VI.A.1 of this Guide describes the procedure to generate cycle average maps.

Figure 32 shows the information and format of the transient cycle average fuel map added to the engine input file below the steady-state engine fuel map. Similar tables can be added below the transient map for the cruise cycles using the appropriate headings (i.e., “55 MPH Cruise Cycle Average Fuel Map” or “65 MPH Cruise Cycle Average Fuel Map”). This new engine input file with cycle averaged results can now be used for compliance. Instructions for generating the information needed for the cycle average tables can be found in Section VI.A.1. Note that GEM will generate an error for tractor and vocational vehicles if the Transient Cycle Average Fuel Map information is missing in the engine input file.

Transient Cycle Average Fuel Map		
Engine Cycle Work	Simulation N/V	Fuel Mass
kWh	rev / m	grams
3.341302	2.318	914.8755
5.329391	2.5176	1355.6025

Figure 32: Cycle Average Fuel Map Table in the Engine Input File

IV.E.2. Transmission Input File for Tractor and Vocational Vehicles

The first row of the GEM input file for transmissions shows the GEM version, and manufacturers would fill in the fifth row with the transmission's Manufacturer Name, Type, and Model Name (see Figure 33). The vehicle manufacturer can choose any Manufacturer Name and Model Name for the transmission, but it should remain consistent with other regulatory documents. The transmission Type has specific options for the manufacturer to choose.

GEM P2v3.0 Transmission Definition		
Manufacturer Name	Type	Model Name
(e.g. Eaton)	(AMT / MT / AT)	(e.g. 7100)
EPA	AMT	HHD

Figure 33: Sample Transmission Input File Header Information

If the transmission is an automatic transmission that has a lockup gear other than the one programmed in the GEM shift strategy, an additional column can be added to specify the minimum lockup gear. This column is not required and GEM will use a third-gear lockup for automatic transmissions by default. Lockup does not apply for AMT and manual transmissions. The optional additional transmission header information for automatic transmissions is shown in Figure 34.

Manufacturer Name	Type	Model Name	Minimum Lockup Gear
(e.g. Eaton)	(AMT / MT / AT)	(e.g. 7100)	Number / NA
EPA	AT	HHD	3

Figure 34: Sample (Optional) Transmission Input File Header Information for Automatic Transmissions

Vehicle manufacturers provide the gear ratios for their specific transmission, as seen in the sample shown in Figure 35. If engine torque is limited when operating in a particular gear it should be entered in the appropriate column.

Transmission Gears		
Gear Number	Gear Ratio	Input Torque Limit
#	#	Nm
1	12.8	2300
2	9.25	2300
:	:	:
:	:	:

Figure 35: Sample Transmission Input File Transmission Gear Ratio Information

Manufactures can optionally include transmission power loss information in their transmission input file. Instructions for obtaining this information is found in 40 CFR 1037.565. The format of the power loss table is shown in Figure 36. When providing power loss information not all gears need to be included. Neutral is always optional. If loss information is provided for a given gear all higher gears must also be included.

Transmission Power Loss			
Gear Number	Input Speed	Input Torque	Power Loss
#	RPM	Nm	kW
0	600	0	0.5023
0	1200	0	1.3559
:	:	:	:
:	:	:	:

Figure 36: Sample Transmission Input File (Optional) Transmission Power Loss Information

IV.E.3. Optional Powertrain Input File for Tractor and Vocational Vehicles

Users may opt to use engine and transmission performance data obtained from a powertrain test in their GEM runs. Procedures for generating the data to populate a powertrain input file can be found in 40 CFR 1037.550. This section summarizes the input file format.

The first row of the GEM input file from powertrain testing show the GEM version and manufacturers would fill in the fifth, ninth, and thirteenth rows with the relevant information about the engine, transmission and powertrain, respectively. Figure 37 shows the header information required by the model.

GEM Powertrain Definition				
Engine Manufacturer Name	Combustion Type	Fuel Type	Family Name	Calibration ID
(e.g. Cummins)	(Compression Ignition / Spark Ignition)	(Diesel / Gasoline / LNG / CNG)	(e.g. abcd12345efg)	(e.g. 123abc)
Cummins	Compression Ignition	Diesel	ISX	CAL1
Transmission Manufacturer Name	Type	Gears	Model Name	
(e.g. Eaton)	(AMT / MT / AT / DCT)	Number	(e.g. 7100)	
Eaton	AMT	10	ULTRASHIFT13LAS	
Powertrain Family Name	Calibration ID	Powertrain Test Configuration		
(e.g. abcd12345efg)	(e.g. 123abc)	(1: Trans. Output, 2: Wheel Hubs)		
SmartAdvantage	CAL1	1		

Figure 37: Sample Powertrain Input File Header Information

The next rows of the powertrain input file, as seen in Figure 38, include the engine idle fuel rate and the powertrain performance information from the 55-MPH, 65-MPH, and Transient drive cycle tests. Users would supply the cycle work, output speed/vehicle speed, and fuel mass according to the procedures outlined in 40 CFR 1037.550(o).

Engine Idle Fuel Rate		
grams / sec		
0.576		
55 MPH Cruise		
Powertrain Cycle Work	N/V	Fuel Mass
kWh	rev / meter	grams
25.28	0.86	5031
25.25	0.93	5050
:	:	:
:	:	:
:	:	:
18.85	1.00	3845
65 MPH Cruise		
Powertrain Cycle Work	N/V	Fuel Mass
kWh	rev / meter	grams
29.49	0.86	5780
29.62	0.93	5865
:	:	:
:	:	:
:	:	:
21.32	1.00	4371
Transient		
Powertrain Cycle Work	N/V	Fuel Mass
kWh	rev / meter	grams
8.28	0.86	2012
8.41	0.93	2027
:	:	:
:	:	:
:	:	:
8.01	1.00	1930

Figure 38: Sample Powertrain Input File Performance Information

IV.E.4. Optional Axle Input File for Tractor and Vocational Vehicles

The first row of the GEM input file for axles shows the GEM version, and the fourth row contains user-specified Manufacturer Name, Family Name, and Type, as shown in Figure 39. The user can type any text in the first two fields, but the names should be consistent with other regulatory documents from the manufacturer. The valid options for axle type are “SINGLE”, “TANDEM” and “TANDEM WITH DISCONNECT”.

GEM P2v3.0 Axle Definition		
Manufacturer Name	Family Name	Type
(e.g. Dana)	(e.g. abcd12345efg)	
EPA	EPA	TANDEM WITH DISCONNECT

Figure 39: Sample Axle Input File Header Information

The next rows contain two comma separated tables for Axle Loss and Disconnect Axle Loss, as shown in Figure 40. Each table includes output speed in RPM, output torque in Nm, and power loss in kW. See 40 CFR 1037.560 for the test procedure to map axle efficiency and determine appropriate values for this input file's tables. The disconnect axle losses are only included by axles of type "TANDEM WITH DISCONNECT".

Axle Loss		
Output Speed	Output Torque	Power Loss
RPM	Nm	kW
100	0	1.379
100	725	1.5638
100	2900	2.1181
:	:	:
:	:	:
Disconnect Axle Loss		
Output Speed	Output Torque	Power Loss
RPM	Nm	kW
100	0	1.0835
100	725	1.2309
:	:	:
:	:	:

Figure 40: Sample Axle Loss Table in Axle Input File

V. GEM Output File Structure

An output file will be generated when the vehicle simulation completes and it is automatically saved to the same location as the input file. When users run GEM from the Start Menu or command prompt, the output file name will be given the same name as the input file with a "_result.csv" appended. During the simulation an error log file will be generated, even if there are no errors, with the same base name as the input file with an "_errors.txt" extension. Identical output files are generated for each of the methods.

V.A. Standard GEM Outputs for Compliance

Each output file is identical to the input file for the vehicle modeled, except that additional columns of the .csv file are populated with the model's results. Figure 41 shows the standard results of an example simulation. These results fields are the same for each vehicle type, but their column location in the file varies. The first result column indicates the date and time when the simulation was performed. The next two columns are the raw GEM CO_2 emissions and fuel consumption values. The next two columns are the Family Emissions Limit (FEL) values EPA and NHTSA will use for compliance. EPA's FEL CO_2 results are integer values for vocational vehicles and trailers, and reported with a single decimal place precision for tractors. NHTSA's fuel consumption results are calculated from those CO_2 values, and are reported with four decimal place precision for vocational vehicles and trailers, and five decimal place precision for tractors to ensure consistency between the agencies' results.

Date/Time of Run	GEM CO2 Emissions	GEM Consumption	FEL CO2 Emissions	FEL Consumption	Subfamily	Subfamily FEL	Subfamily Volume
YYYY_MMDD_HHMMSS	g CO2/ton-mile	gal/1000 ton-mile	g CO2/ton-mile	gal/1000 ton-mile	Name	g CO2/ton-mile	#
2016-0719 15:20:39	222.0614119	21.81349822	222	21.8075			
2016-0719 15:20:51	284.345287	27.93175708	284	27.8978			
2016-0719 15:21:00	454.7105	44.66704322	455	44.6955			
2016-0719 15:21:10	361.3490975	35.49598207	361	35.4617			

Figure 41: Example Vocational Results Columns in GEM Output File

The final three columns of the output file are left blank by the model. Manufacturers would manually add the appropriate subfamily name, target FEL for the given subfamily, and the volume of vehicles that will use the resulting FEL value prior to submitting their output file for compliance.

V.B. Optional GEM Outputs for Cycle-Specific Information

Users that run GEM using the command prompt can generate additional, cycle-specific information in their output files using the "-d" option (see Section VI.C for instructions). This option adds 10 columns to the output file for each drive cycle (i.e., Cruise 55, Cruise 65, and Transient), a column showing the final payload (which may have been adjusted if weight reduction was included), and eight columns with additional information from the idle cycle calculations.

Figure 42 shows the additional output for the 55-mph cruise cycle. The data includes crankshaft average speed (RPM), average torque (Nm), and N/V (rev/m), positive work from the crankshaft, transmission, and axle (all in kWh), fuel consumed (g) and emissions (g CO_2 and g CO_2/ton-mile), and shift count. Similar information is added in separate columns for the 65-mph cruise and transient cycles.

Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55	Cruise 55
Crankshaft Avg Speed	Crankshaft Avg Torque	Crankshaft N/V	Crankshaft Pos Work	Transmission Pos Work	Axle Pos Work	Fuel Consumed	Emissions	Emissions	Shift Count
RPM	Nm	rev/m	kWh	kWh	kWh	g	g CO2	g CO2/ton-mile	#
1263.7	948.4777	0.8598	30.75897075	28.9571046	26.71842053	5816.57	18787.79029	73.63497457	0
1264.1	970.3373	0.8598	31.46975037	29.6252395	27.33378739	5947.3	19210.03437	75.2892152	0
1265.8	905.4314	0.8598	29.36303669	27.58762017	25.38339982	5578.52	18018.87222	70.62116538	0

Figure 42: Additional Cycle-Specific Output for the Drive Cycles

Figure 43 shows the additional output for the idle cycles. The first idle data set includes payload weight (tons), and non-idle emissions (g CO_2/mile and g CO_2/ton-mile). The next idle data set includes in-gear idle crankshaft average speed (RPM) and average torque (Nm), neutral idle crankshaft average speed (RPM) and average torque (Nm), and total drive idle and parked idle emission rates (g CO_2/hr).

Payload Weight tons	Non Idle Weighted Carbon Emissions g CO2/mile	Non Idle Weighted Carbon Emissions g CO2/ton-mile		In Gear Idle Crankshaft Avg Speed RPM	In Gear Idle Crankshaft Avg Torque Nm	Neutral Idle Crankshaft Avg Speed RPM	Neutral Idle Crankshaft Avg Torque Nm	Drive Idle Carbon Emissions g CO2/hr	Parked Idle Carbon Emissions g CO2/hr
19	1668.684616	87.82550609		599.9999993	55.70423015	599.9999993	55.70423015	5162.08136	5162.08136
19	1713.681791	90.19377845		599.9999993	55.70423015	599.9999993	55.70423015	5162.08136	5162.08136
19	1595.404923	83.96868014		599.9999993	55.70423015	599.9999993	55.70423015	5162.08136	5162.08136

Figure 43: Additional Cycle-Specific Output for the Idle Cycles

VI. Running GEM

There are two options for running GEM. The first option directly accesses the program's executable file via the Start Menu folders, the Start Menu search, or a GEM icon on the computer's desktop screen. This first option initiates a GEM pop-up window to select an input file and run the model. The second option uses the command prompt, which will similarly initiate GEM, but also has several options to generate additional output information. Each of these options is described in the following sections.

VI.A. Preparing for GEM Runs

Prior to running GEM, it is important to locate all of the necessary input files. Many computers will produce warnings if the users try to make changes to files in the installation folder if it is located in the C:\Program Files directory. It is recommended that users save a copy of the input file templates from the installation folder (i.e., C:\Program Files\US EPA\Phase 2 GEM\Sample Input Files – RELOCATE BEFORE USE) to a location on their hard drive (e.g., C:\Documents and Settings\UserName\My Documents). These files can then be changed as needed to reflect the users' specific vehicles. See the previous sections for a description of the input files.

VI.A.1. Cycle Average Fuel Map for Tractor and Vocational Vehicles

Tractor and vocational vehicle manufacturers must include a cycle average fuel map for the transient cycle, and can optionally apply cycle average fuel maps to the 55 and 65 mph cruise cycles in their engine input file. The procedure to generate a cycle average map is the same for the transient and cruise cycles, except if the cycle average fuel map is used for the cruise cycles, the steady-state fuel map will not be the steady-state fuel map of the engine but will be a default fuel map with the idle portions of the fuel map from the engine. The final engine fuel map input if only the cycle average procedures is used will contain the default steady-state fuel map where the idle fuel rates are from the engine, the engine idle fuel map (for engines going into vocational vehicles) and the cycle average fuel map for each of the three vehicle duty cycles.

Included in this GEM installation package are two sample vehicle input files that serve as an example of the inputs needed to create the cycle average map:

1. "GEM_tractor_EnginePrep_inputs.csv" for tractor vehicles, and
2. "GEM_vocational_EnginePrep_inputs.csv" for vocational vehicles

These input files rely on steady-state engine input files located in the sample subfolder "Engines" and transmission input files located in the subfolder "Transmissions". Note that the sample axle file is not used when creating the cycle average map. Typing NA in the axle input column will trigger the default axle losses to be used.

Each engine is simulated in GEM with six, eight, or nine predefined vehicle configurations depending on the vehicle class(s) that may use the engine. Engines used in heavy-haul tractors are evaluated over six specific heavy-haul and sleeper cab configurations. Engines that will be installed in vocational vehicles qualifying as Light HDV or Medium HDV are evaluated over eight light- and medium-heavy duty configurations. Engines that will be installed in vocational vehicles qualifying as Heavy HDV and for tractors that are not heavy-haul tractors are evaluated over nine day cab and sleeper cab configurations. See the EnginePrep example files for the appropriate default values to apply. To generate an engine file for compliance and testing, manufacturers will supply their own steady-state engine input file except in the case where a manufacturer is using the cycle average mapping procedure for the cruise cycles and update the EnginePrep input file with the axle ratios and tire sizes that are calculated from the engine's torque curve and the equations defined in 40 CFR 1036.540. Note for engines that will be installed in vocational vehicles qualifying as Heavy HDV and for tractors the transmission and ratios and are different between the cruise cycles and the transient cycle, so separate GEM runs will have to be performed to create a cycle average fuel map for the cruise cycle.

The EnginePrep input files are used with the GEM executable (i.e., the "Phase 2 GEM Cycle Creation" executable from the Start Menu, or the "-e" option with the command prompt as described in Sections VI.B and VI.C) to generate three engine cycle files in .csv format corresponding to the transient, 55-mph, and 65-mph drive cycles. These output files are named with the text of the unique identifier of the simulation followed by the drive cycle (e.g., "EngineXYZ_cycle1_transient_cycle.csv"). The .csv files include the average vehicle speed over the drive cycle and three columns defining the engine cycle: Time (sec), Engine Speed (RPM) and Engine Torque (Nm).

The engine cycle files are then used to test the actual engine according to 40 CFR 1065 to generate the following results that will be added to the end of the steady-state fuel map file with the appropriate headers, as described previously in Section IV:

1) N/V Ratio (rev/meter) calculated from time average engine speed during engine test divided by average vehicle speed from the generated cycle. Note that the average vehicle speed is determined by GEM and is located in the GEM output file containing the engine cycle.
2) Positive cycle work (kWh) calculated from the engine test
3) Total fuel mass for the test corrected for mass-specific net energy content of the fuel, according to 40CFR 1036.540.

VI.A.2. Testing Input Files for Errors

Prior to running a GEM simulation, it is recommended that users test their input files for errors. GEM will check that data are included in the required input file fields, file headers and data are in the proper format, and supplemental input files exist with the appropriate information. Note that GEM is case-sensitive and will produce an error if inputs do not exactly match.

To test an input file, initiate the "Phase 2 GEM Check Inputs" executable from the Start Menu, or use the "-t" option with the command prompt. Sections VI.B and VI.C describe how to access the executable in the Start Menu and through the command prompt. GEM will run through each line of the input file and search for errors. Figure 44 shows the status window that appears when checking for errors. The status bar will progress as GEM checks each Run ID and indicate "FAIL!" or "Input Valid!" Users can close this window and check the output files for more information.

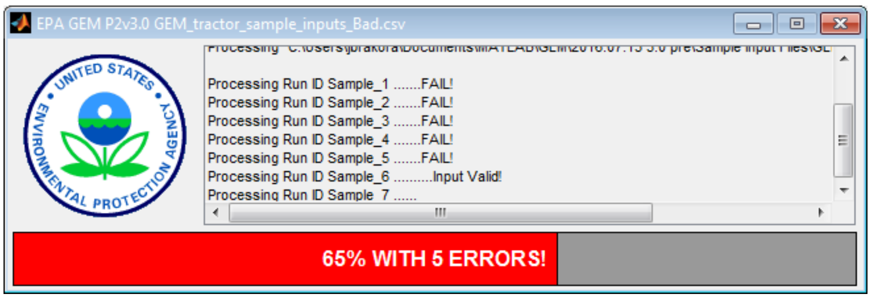

Figure 44: Status Window Checking a GEM Input File for Errors

Once an input test ends (by completing the check or after being terminated by the user), the two standard _result.csv and _errors.txt files are created. The results file will simply display if the inputs were valid or produced an error, as shown in Figure 45. Users are instructed to see the error file for details.

Regulatory Category
Manufacturer Name
Model Year
GEM Version
Run ID
Unique Identifier
Sample_1 -- ERROR: see error file for details!
Sample_2 -- ERROR: see error file for details!
Sample_3 -- ERROR: see error file for details!
Sample_4 -- ERROR: see error file for details!
Sample_5 -- ERROR: see error file for details!
Sample_6 -- Input Validated
Sample_7 -- ERROR: see error file for details!
Sample_8 -- ERROR: see error file for details!
PT_Sample1 -- Input Validated

Figure 45: Example _Results.csv Output File Generated when Testing GEM Inputs

The _error output file provides more information about each error. Figure 46 shows the errors from this example. In Sample 1 and Sample 2, the engine and transmission file names were provided, but the user did not indicate that they were located in subfolders, as noted previously in the GEM Input File Structure sections. Sample 3 attempted to provide a CdA value for a heavy-haul tractor (i.e., regulatory subcategory “C8_HH”), but this subcategory has a default value and the input should be “NA”. The remaining errors indicated that the cases were out of their allowable ranges.

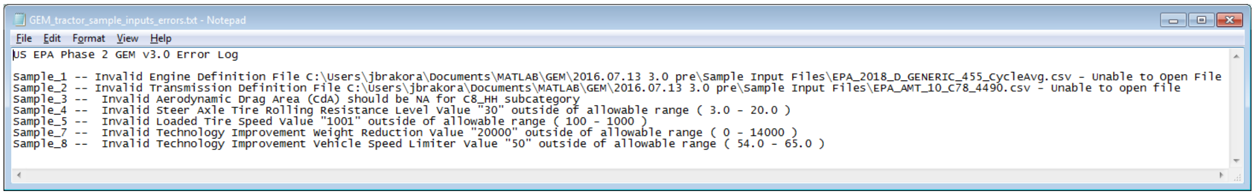

Figure 46: Example _Errors.txt Output File Generated when Testing GEM Inputs

Users should correct any errors in their files and rerun the test until they receive a confirmation that all of the inputs are valid, as seen in Figure 47. Once completed, the input files are now ready to be used in a GEM simulation.

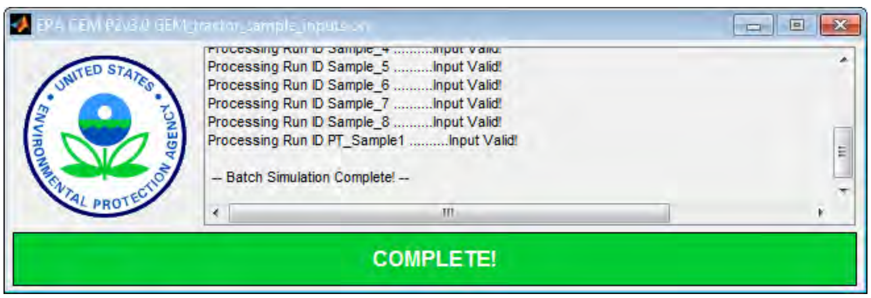

Figure 47: Status Window Indicating GEM Input Files Contain No Errors

VI.B. Running GEM Using the Start Menu and Desktop Icon

Users can access the Phase 2 GEM executable from the Start Menu. Go to All Programs > EPA Phase 2 GEM > Phase 2 GEM as shown in Figure 48. Note that this is the same location of the executables to test input files (“Phase 2 GEM Check Inputs”) and create cycle average maps (“Phase 2 GEM Cycle Creation”).

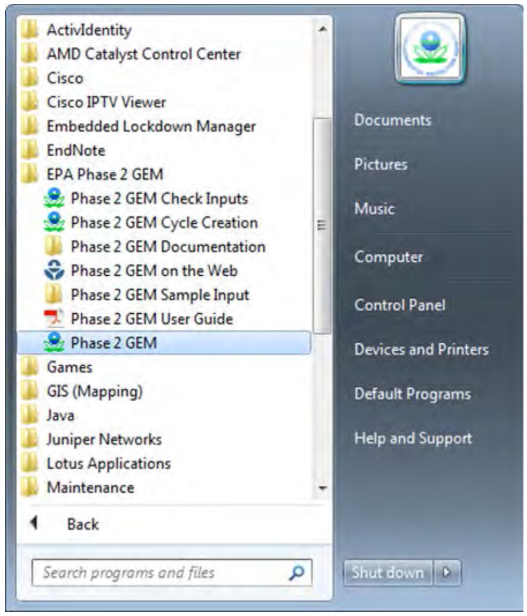

Figure 48: How to Access Phase 2 GEM from the Start Menu

Alternatively, users can access the executable by typing “Phase 2 GEM” in the *Search programs and files* box located at the bottom of the Start Menu, and hitting “Enter”. Users that selected the option to “Create Desktop Icon” during installation can double click the icon (shown previously in Figure 6) to initiate the program as well. Once the executable is selected, users will briefly see the image shown in Figure 49 as the program loads.

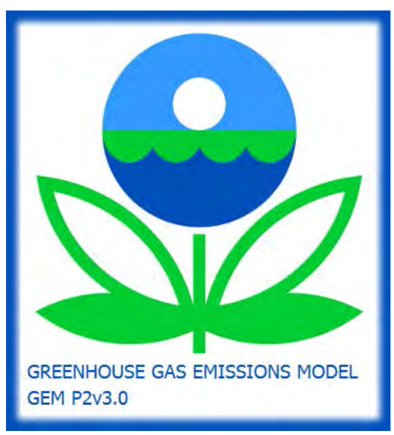

Figure 49: GEM Splash Screen as Program Loads

A pop-up window will ask the user to select an input file, as shown in Figure 50. By default, the program will first look in the installation folder. As mentioned previously, all of the input files should be moved to a separate location to avoid permissions warnings. In this example, we moved the files to the Desktop and renamed the folder GEM P2 Sample Input Files. Navigate to the input files folder, and select the appropriate input file (GEM_Sample_TRACTOR.csv in Figure 51) to begin the simulation.

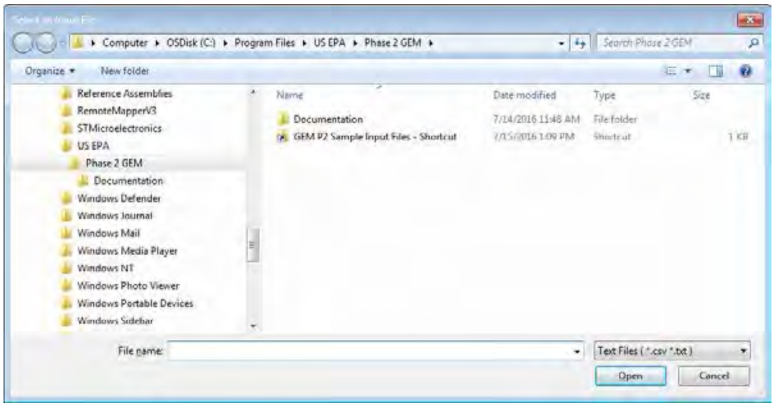

Figure 50: Pop-up Window to Select an Input File Using the Start Menu Option; Defaults to Installation Folder

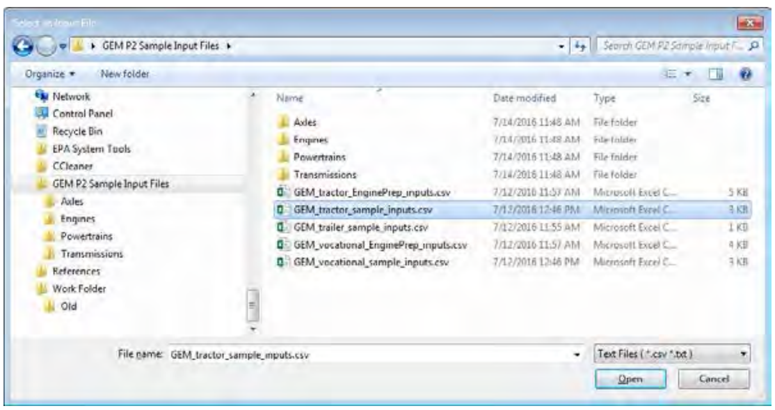

Figure 51: Input Files Folder Containing Sample Files

Once the input file is selected, the program will begin to run. A status window will step through each configuration as it runs, as shown in Figure 52. At any point in the simulation, users can stop the model by clicking the red "X" at the top right corner of the status window. A new window will appear that asks "Cancel current simulation?" If the user chooses "Yes", it will stop execution (once the current simulation has completed, which may take a few seconds) and produce an output file with only the configurations that completed.

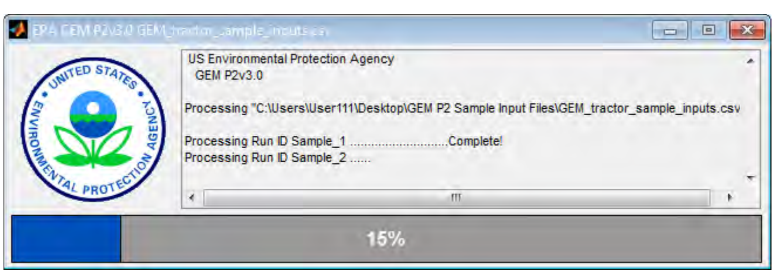

Figure 52: Sample Status Window Showing Progress of GEM Simulations

The status window will indicate when the simulations are complete with a window similar to Figure 53. The resulting output file will be saved in the same location as the input file, and will be given the same name as the input file with a "_result.csv" extension added to the end ("GEM_Sample_TRACTOR_result.csv" in this example). When the simulation is complete, users can close the status window by clicking the red "X" in the top right corner of the window.

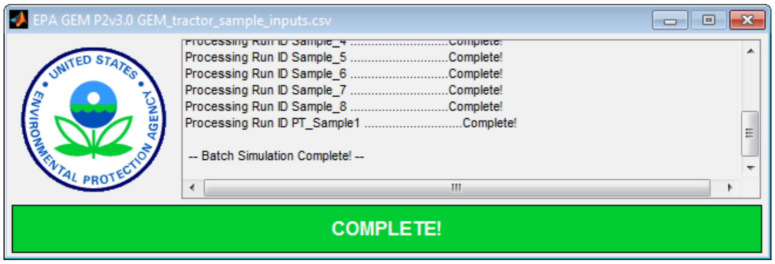

Figure 53: Sample Status Window Showing Complete GEM Simulations

This first example simulation completed without any errors. No errors were produced in the status window or the error log, shown in Figure 54, provides confirmation. If an error occurs in any simulations, the window will indicate the configurations that failed and the model will continue to the next simulation. See Section VI.A.2 of this Guide for examples of errors and a description of the _errors.txt file produced.

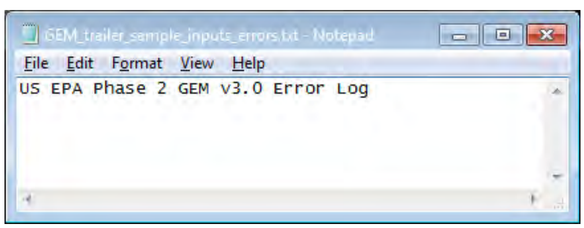

Figure 54: Sample Error Log with No Errors from Simulation

VI.C. Running GEM Using the Command Prompt

Users can also initiate GEM using the command prompt. As seen in Figure 55, the command prompt can be found using the Start Menu's *Search programs and files* feature. Once the executable cmd.exe is selected, a command window similar to the one shown in Figure 56 will display.

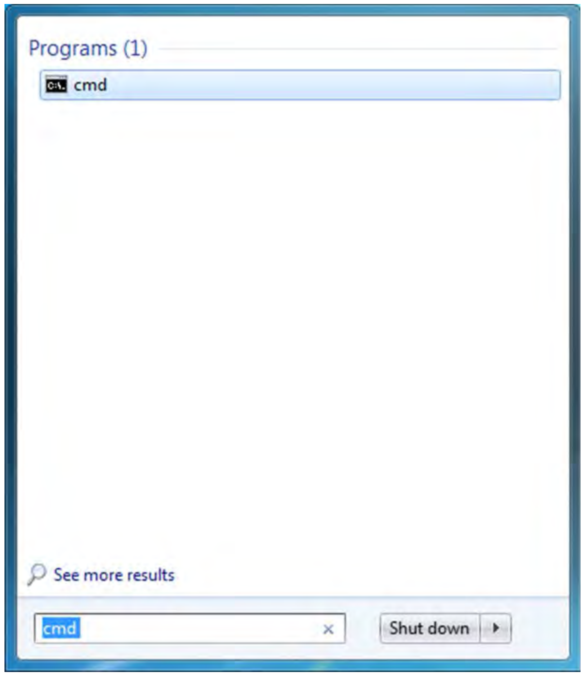

Figure 55: Initiating the Command Prompt from the Start Menu Search Bar

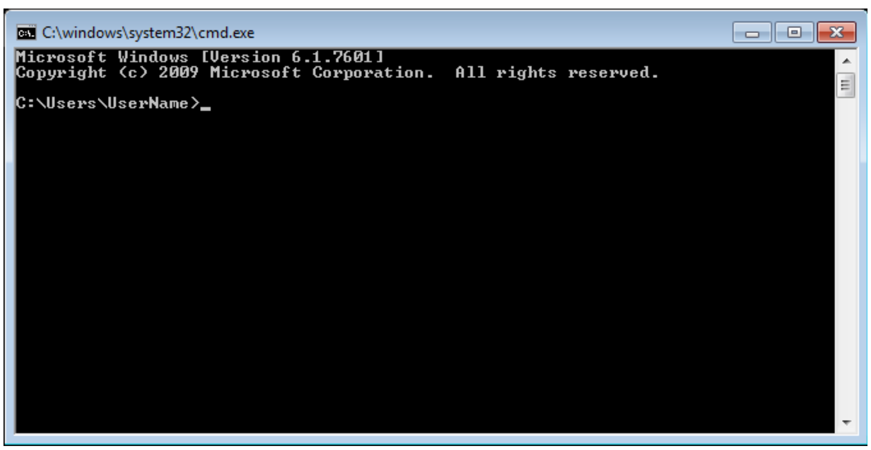

Figure 56: Windows Command Prompt Window

Users begin by navigating to the installation directory where the GEM executable is located using the command: *cd "C:\Program Files\US EPA\Phase 2 GEM*. Users can then initiate the same "Select an Input File" pop-up window shown in Figure 50 by typing the command: *GEM.exe* " ", as seen in Figure 57. Users follow the same steps to locate and select an input file as shown in the previous section and GEM will show the GEM status window similar to Figure 52.

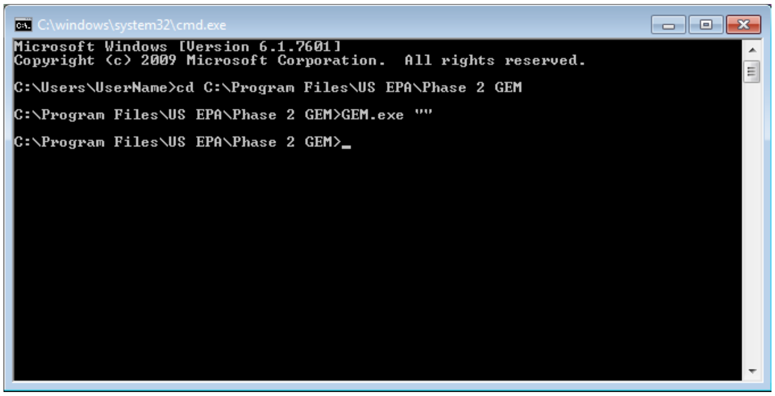

Figure 57: Command Prompt to Initiate GEM Input File Selection Pop-up Window

Alternatively, users have the option of bypassing use of the input file selection window by including the location and name of the input file (*GEM.exe "Path\Filename"*), as shown in Figure 58. In this example, the executable is stored in the default Program Files location and the input files are located in a folder on the desktop. The program will directly initiate a status window similar to Figure 52.

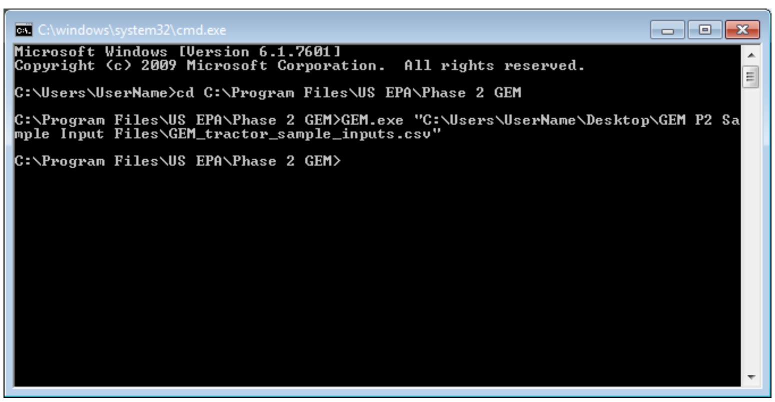

Figure 58: Command Prompt to Initiate GEM and Directly Apply Input Files (no File Selection Window)

As mentioned previously, the command prompt method of running GEM has several options that can alter the output format or generate additional data. These options are included after the main command as single-letter flags with a dash (e.g., GEM.exe "Path\Filename" -t) and users may include more than one flag in a single command. The available flags are shown in Table 31. As mentioned previously, the –e flag is used to generate the cycle average maps (Section VI.A.1) and the –t flag is used to test the input files prior to running GEM (Section VI.A.2).

Table 31: Command Line Options for GEM

Command Flag	Option Name	Description
-v N	Model output verbosity	N = 0 (default) logs only the data required for certification, N = 1 turns on the model's energy auditing N = 2 or 3 add additional signals of interest for debugging.
-d	Detailed output	Generates additional cycle-specific data columns in the _results.csv file (see Section V.B)
-p	Preserve files	Preserve the simulation raw output as a .mat file for later examination
-t	Test inputs	Disables simulation but allows the user to test the input file for errors such as out of range parameters (see Section VI.A.2)
-n	No tech improvements	Turns off all technology improvements and result modifiers
-i	Save model inputs	Exports the model parameters before simulation; useful for later running Simulink version.
-c	Console Only	Disables the status display window and runs in a console mode
-e	Engine cycle generation	Exports the engine speed and load data from each simulation of each phase to a separate file for use in cycle average testing (see Section VI.A.1)
-s	Stringency mode	Bypasses requirement of cycle average map for ARB transient cycle and rounding of input parameters is disabled.

This Guide does not provide examples of the use of each flag listed in Table 31. However, the console option may be of interest to users who wish to automate their GEM runs. As seen in Figure 59, when users apply the –c flag, the output generally shown in the GEM status window is displayed in the command window instead.

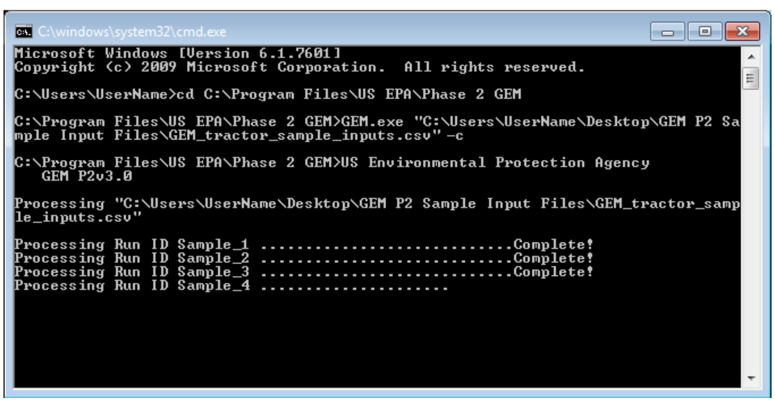

Figure 59: Command Prompt Display When Using the Console Only Option

VII. Final Notes

Users are encouraged to look through the additional information provided in the Documentation folder included with the GEM installation. For more information on the Phase 2 rule, please see Docket EPA-HQ-OAR-2014-0827 available at www.regulations.gov.