Greenhouse Gas Emissions Model (GEM) User Guide, v3.8

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 Technical Amendments Notice of Proposed Rulemaking

United States
Environmental Protection
Agency

Greenhouse Gas Emissions Model (GEM) User Guide, v3.8

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 Technical Amendments Notice of Proposed Rulemaking

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

Table of Contents

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 P2v3.7, released after the Phase 2 technical amendment (TA) NPRM. 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 more detailed description of the model architecture and updates, including changes made in each release are available in the docket associated with each release, particularly in Chapter 4 of the Phase 2 RIA.

II. Installation

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 is not required 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.A. Installation Instructions

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

https://www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty.

A link to the most recent GEM installer is located on this page. The installer includes the model executable, supporting software (MATLAB Runtime) and several sample input file templates. A copy of the GEM User Guide is also available separately on the website for convenient reference. The GEM executable, sample files and documentation require about 10 MB of free space. Users

---

[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.

that do not have the Matlab Compiler Runtime application installed will need about 700 MB of free space.

Currently, GEM is only available to computers using 64-bit Windows operating systems (Windows 7 and newer). To request a CD of this software instead of downloading, or to request assistance if having trouble with accessibility of this software, please send an email request to OTAQ@epa.gov.

Figure 1: EPA Website to Obtain GEM Installation Package

To install GEM, run the "GEM_P2v3.8_Setup_x64" executable to start the setup wizard that will walk through the installation process. Users have the option of choosing a separate location for their Phase 2 GEM installation but using the default folder as seen in Figure 2 is recommended.

The instructions throughout this User Guide assume the user has installed Phase 2 GEM in the default locations with the default folder names.

Users have the option of choosing a separate location for their Phase 2 GEM installation but using the default folder as seen in Figure 2 is recommended. The instructions throughout this User Guide assume the user has installed Phase 2 GEM in the default locations with the default folder names.
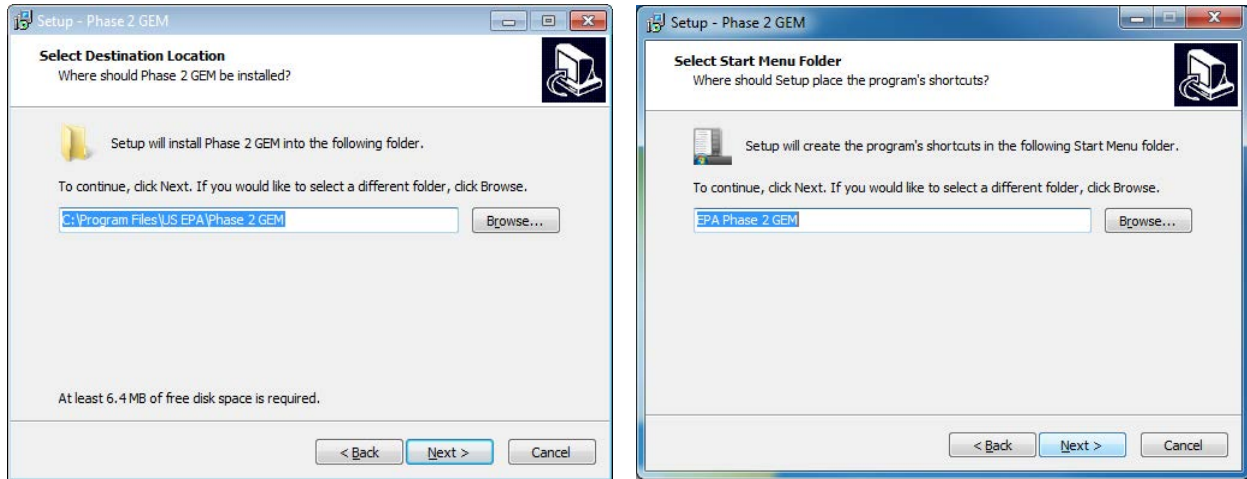
Figure 2: Destination and Start Menu Folder for Phase 2 GEM Download

Phase 2 GEM requires the use of Matlab Compiler Runtime r2014a and the Microsoft Visual C++ 2005 or 2008 Redistributable (x64). The installer will warn users if their computers do not have the necessary software installed. The setup wizard will install Matlab Runtime Compiler R2014a (version 8.3) if the box shown on the left side of Figure 3 is checked. A pop-up window will initiate installation of this software and will remain displayed until installation is complete. For computers that already have the Matlab Runtime installed, users can uncheck this box to skip this step. The final screen message as shown below on the right side of Figure 3 appears when Phase 2 GEM installation has completed.
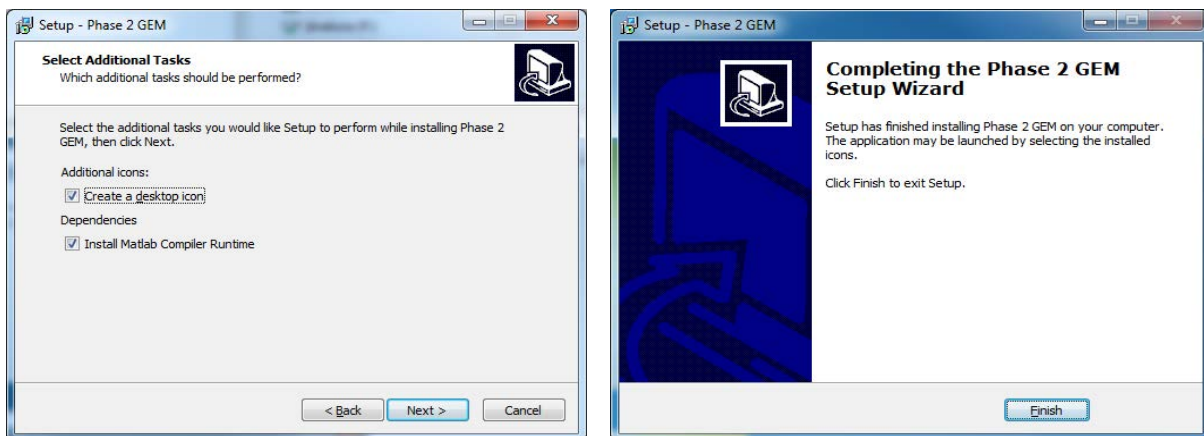
Figure 3: Installation Windows; Matlab Runtime Compiler R2014a is Required

II.B. Contents of Installation Package

Once installed, files are stored in the installation location selected (i.e., *C:\Program Files\US EPA\Phase 2 GEM* by default) and are also available from the Start Menu, under the folder named "EPA Phase 2 GEM". The start menu folder contains shortcuts to the different operating modes of GEM as well as documentation, the sample input files and an uninstaller.

II.B.1. Sample Input Files

Sample input files are stored with the Phase 2 GEM executable. 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 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 of this guide.

Due to file permissions on most installations, GEM is not permitted to use the sample input files in the location they are installed by default. The recommendation is for users to copy the contents of the sample input files folder to a location where the user has read and write permissions to minimize these issues. Users can then easily run GEM and the output results will be saved in the same folder as the input data.

II.B.2. GEM Executable

EPA and NHTSA require tractor and vocational vehicle manufacturers to use the Phase 2 GEM executable for demonstrating compliance with the CO_2 and fuel consumption standards.[2] However, 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, the input files, and the 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 the public 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.

---

[2] Trailer manufacturers will use a GEM-based equation but 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.

III.A. GEM Architecture

The GEM architecture is comprised of four systems: Ambient, Driver, Powertrain, and Vehicle as seen in Figure 4. 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 GHG RIA.
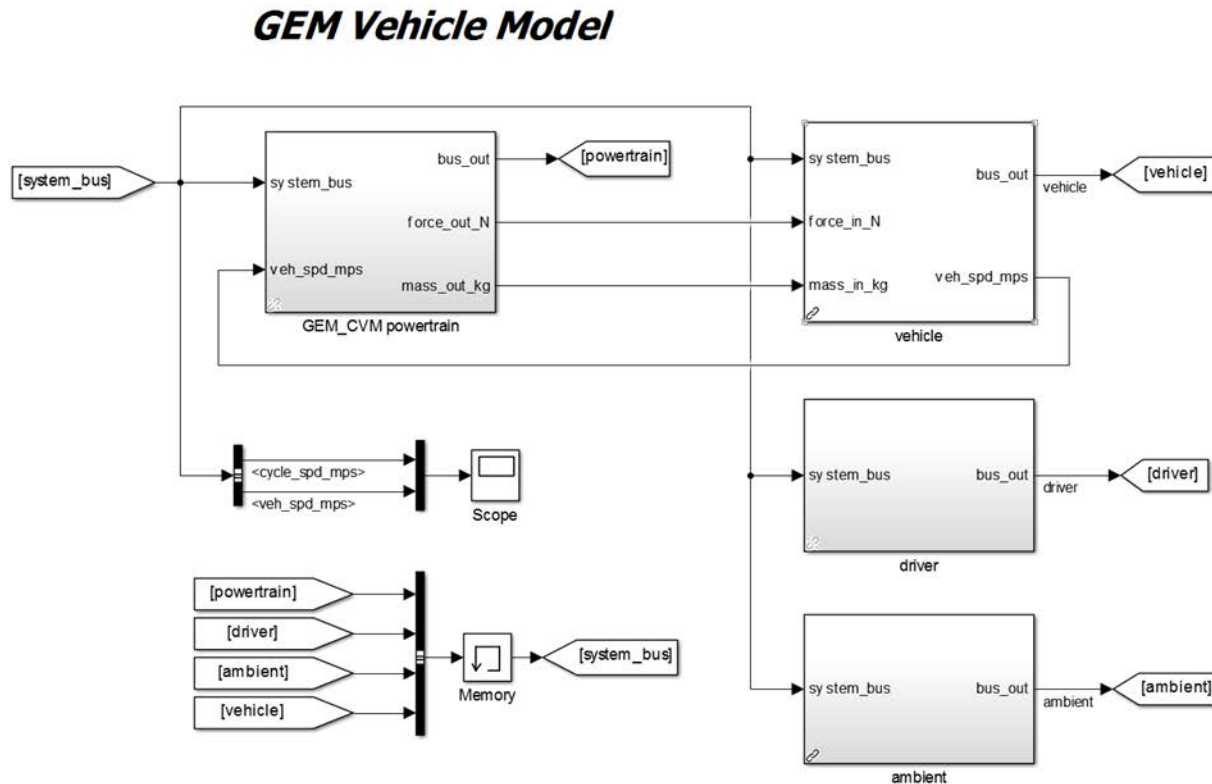
GEM Vehicle Model

Figure 4: Simulink Structure of GEM Vehicle Model

EPA and NHTSA are adopting additional regulatory subcategories to better represent the heavy-duty vehicles. These subcategories are reflected in GEM 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 along with many others:

- 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 which can optionally be applied to the cruise cycles.

- Upgraded transmission model which includes automatic and automated manual transmissions. Optional transmission power loss input and torque converter properties are also available.

- 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.

- Increased options for number of driven axles including the ability to include axle power losses measurement data.

With these upgrades, the model can recognize 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.A.1. Drive Cycles and Cycle Average Engine Fuel Map

Phase 2 GEM utilizes 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 measurements 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 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 section VI.D of this Guide. A detailed description and justification for the cycle average method can be found in Chapter 4 of the Phase 2 GHG RIA.

III.B. Vehicle Parameters for Each Regulatory Subcategory

GEM can simulate 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 a variety of vehicle-specific information. Phase 2 GEM includes several variations to match potential powertrain options and the regulatory subcategories in the Phase 2 rulemaking. Each regulatory subcategory is associated with specific vehicle parameters and technology options.

Many key parameters in GEM are predefined, 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, which require additional testing.

Each vehicle category 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 category, 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 categories that manufacturers may select in GEM for compliance and summarize the predefined and user-defined and parameters applicable to each subcategory as well as regulatory citations for associated testing procedures. Details on the file formats for entering the user defined parameters are discussed in GEM Input Files.

III.B.1. Tractor Vehicle Parameters

GEM recognizes sixteen variations (regulatory subcategories) 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 modeled aerodynamic drag area input, 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.

Table 1 through Table 3 summarize some of 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. Drive cycle weightings for day cab tractors are more representative of short-haul driving with more transient cycle operation.

Table 1: Class 8 Combination Tractor Predefined Modeling Parameters

		Sleeper Cab			Day Cab			Heavy Haul
Roof Height		High	Mid	Low	High	Mid	Low	All
Total Weight (kg)		31978	30277	30390	31297	29529	29710	53750
Number of Axles		5			5			5
Payload (tons)		19			19			43
Drive Cycle Weighting	**CARB HHDDT**	0.05			0.19			0.19
	GEM 55 mph	0.09			0.17			0.17
	GEM 65 mph	0.86			0.64			0.64

Table 2: Class 7 Combination Tractor Predefined Modeling Parameters

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

Table 3: Heavy Class 8 Combination Tractor Predefined Modeling Parameters

		Sleeper Cab			Day Cab		
Roof Height		High	Mid	Low	High	Mid	Low
Total Weight (kg)		53750	52049	52162	53069	51301	51482
Number of Axles		5			5		
Payload (tons)		43			43		
Drive Cycle Weighting	CARB HHDDT	0.05			0.19		
	GEM 55 mph	0.09			0.17		
	GEM 65 mph	0.86			0.64		

Table 4 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 4: Common Predefined Modeling Parameters for All Simulated Combination Tractors

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 mass, Subtract 2/3*weight reduction from the vehicle simulated mass
Trailer Tire Crr (kg/t)	6.0
Overall Tire Crr Calculation (kg/t)	= 0.425*Trailer Crr + 0.425*Drive Crr + 0.15*Steer Crr

GEM allows the user to modify or adjust performance information for certain components in order to quantify the reduction in tractor fuel consumption and CO_2 emissions. More information on the specific inputs and the procedures to determine them for combination tractors are listed in section IV.A.

In Phase 1, a default engine and transmission were applied to all GEM-simulated combination tractors. Phase 2 GEM requires tractor 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 data for transmission and/or axle power loss the appropriate supplemental input file. These input files have specific requirements, available in the Supplemental Input Files section of this Guide.

Table 5: Default Transmission Losses for Simulated Combination Tractors

MT or AMT Gearbox	Mechanical Efficiency	9 or more gears	96% for low gears, 98% high gears, except 100% for 1:1 gear ratio
		fewer than 9 gears	100% for 1:1 gear ratio, 98% for rest of gears
	Spin Loss		12.3 – 30.1 Nm, varies with speed
AT Gearbox	Mechanical Efficiency		99.5% for 1:1 gear ratio, 98% for rest of gears
	Spin Loss		40.5 – 65.2 Nm, varies with speed

The default transmission losses in Table 5 are used if transmission power loss information is not provided within the transmission input file. The default losses are different whether the transmission is a manual (MT), automated manual (AMT) or a planetary type automatic transmission (AT). The "low gears" mentioned in the MT or gearbox efficiency of Table 5 only applies when the total gear number of a transmission is greater than 9. In this type of transmission, the low gear efficiency of 96% will be used for gear number less than or equal to the greater of total number of gears divided by two or the total number of gears minus 6. Taking a transmission with 10 gears for example, the greater of 10/2 or 10-6, would be 5. Thus, gears 1 - 5 would have 96% efficiency.

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 effect of vehicle speed limiter, weight reduction and neutral idle technology improvement inputs will impact the vehicle simulation. The remaining technologies improvements are applied as post-process percent reductions to the results from the vehicle simulation. More detail on the available technology improvement options for tractors and how to determine the inputs is provided in section IV.A.

III.B.2. Vocational Vehicle Parameters

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 demonstrated in Table 6, Table 7 and Table 8 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 of the Phase 2 GHG Rule Section V.D.1.e.

Table 6: Vocational Heavy Heavy-Duty (Class 8) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	HHD		
Duty Cycle	Regional	Multi-Purpose	Urban
Total weight (kg)	19051		
Aerodynamic Drag Area - CdA (m²)	6.86		
Payload (tons)	7.50		
Electrical Accessory Power (W)	1200		
Mechanical Accessory Power (W)	2300		
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 7: Vocational Medium Heavy-Duty (Class 6-7) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	MHD		
Duty Cycle	Regional	Multi-Purpose	Urban
Total weight (kg)	11408		
Aerodynamic Drag Area - CdA (m²)	5.40		
Payload (tons)	5.60		
Electrical Accessory Power (W)	900		
Mechanical Accessory Power (W)	1600		
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 8: Vocational Light Heavy-Duty (Class 2b-5) Vehicle Predefined Modeling Parameters

Regulatory Subcategory	LHD		
Duty Cycle	Regional	Multi-Purpose	Urban
Total weight (kg)	7257		
Aerodynamic Drag Area - CdA (m²)	3.40		
Payload (tons)	2.85		
Electrical Accessory Power (W)	500		
Mechanical Accessory Power (W)	1000		
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

GEM also provides seven custom chassis subcategories for manufacturers that know the specific end-use of their vehicles. These custom chassis subcategories are listed in Table 9, and are based on the standard vocational subcategories. In contrast to the standard vocational subcategories, custom chassis utilize default inputs for several of the parameters, particularly the engine and transmission. Use of the custom chassis subcategories reduces the number of required inputs but also limits the ability to apply some technology improvements. Further details on how to input data for these subcategories is described in the Vocational Input Files section of this Guide.

Table 9: 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 10 provides the predefined modeling parameters that are consistent across all vocational vehicle types. These common parameters include ambient temperature, the calculations for overall rolling resistance and how weight reduction is applied. Note that some factors which were common across tractors vary with vocational weight class.

Table 10: Common Predefined Modeling Parameters for All Vocational Vehicles

Environmental Air Temperature (°C)	25
Weight Reduction (lbs)	Add 1/2*weight reduction to payload mass, Subtract 1/2*weight reduction from the simulation vehicle mass
Overall Tire Crr (kg/t)	0.7*Drive Crr + 0.3*Steer Crr

GEM allows a user to enter performance information for certain components in order to model and quantify improvements the manufacturer is making to its vehicles. Table 10 lists the user-defined modeling parameters for vocational vehicles in addition to a reference to the applicable test methods in the regulation. 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 the option to account for aerodynamic drag as a wind-averaged change in aerodynamic drag area (delta CdA).

For the non-custom chassis vocational categories Phase 2 GEM requires manufacturers to supply an engine fuel map and specific transmission information 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 data for transmission and/or axle power loss the appropriate supplemental input file. These input files have specific requirements, as will be discussed in the Supplemental Input Files section of this Guide.

The default transmission losses in Table 11 are used if transmission power loss information is not provided within the transmission input file. The default losses are different whether the transmission is a manual (MT), automated manual (AMT) or a planetary type automatic transmission (AT). The "low gears" mentioned in the MT or gearbox efficiency only applies when the total gear number of a transmission is greater than 9. In this type of transmission, the low gear efficiency of 96% will be used for gear number less than or equal to the greater of total number of gears divided by two or the total number of gears minus 6. Taking a transmission with

10 gears for example, the greater of 10/2 or 10-6, would be 5. Thus, gears 1 - 5 would have 96% efficiency.

Table 11: Default Transmission Losses for Vocational Vehicles

MT or AMT Gearbox	Mechanical Efficiency	9 or more gears	96% for low gears, 98% high gears, except 100% for 1:1 gear ratio
		fewer than 9 gears	100% for 1:1 gear ratio, 98% for rest of gears
	Spin Loss	HHD	12.3 – 30.1 Nm, varies with speed
		MHD	9.1 – 22.3 Nm, varies with speed
		LHD	5.9 – 14.5 Nm, varies with speed
AT Gearbox	Mechanical Efficiency		99.5% for 1:1 gear ratio, 98% for rest of gears
	Spin Loss	HHD	40.5 – 65.2 Nm, varies with speed
		MHD	26.2 – 42.1 Nm, varies with speed
		LHD	23.5 – 37.9 Nm, varies with speed

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 12 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 12: 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.3. 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 13 summarizes 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 13: Predefined Modeling Parameters for Box Trailers

Regulatory Subcategory	Long Box Dry Van	Long Box Refrigerated Van	Short Box Dry Van	Short Box Refrigerated Van
Tractor Type	C8 Sleeper Cab - High Roof		C7 Day Cab - High Roof	
Total weight (kg)	31978	33778	18306	20106
Baseline CdA Values (m^2)	6.0	6.0	5.6	5.6
Tractor Engine	15L 455 HP		11L 350 HP	
Tractor Drive Axle Configuration	6x4		4x2	
Number of Axles	5		3	
Payload (tons)	19		10	
CARB HHDDT Drive Cycle Weighting	0.05		0.19	
GEM 55 mph Drive Cycle Weighting	0.09		0.17	
GEM 65 mph Drive Cycle Weighting	0.86		0.64	

Table 14 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 14: 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 mass

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 15). Trailer manufacturers can 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 15: User-Defined Modeling Parameters and Technology Improvement Options for Trailers

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 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 Files

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 (comma separated value) 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. For illustration purposes, the sample input data in this document are shown in tabular spreadsheet like format. Users may use Microsoft Excel or any other text editor, to create or edit their input files. If using a spreadsheet program be sure to save the files in CSV format.

The top of the input file for each of the regulatory categories has three lines that list the regulatory category, manufacturer name and model year (see Sample 1). User entries in the second column determine the processing that will be applied to the file. The first line contains the regulatory category and must contain "Tractor", "Vocational" or "Trailer" as appropriate for the vehicles being simulated. 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.

Sample 1: Input File Header Information

Regulatory Category	Tractor
Manufacturer Name	EPA
Model Year	2018

The subsequent lines of the input file list the model inputs with one simulation listed per line. The first two columns contain 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) and can be any combination of letters, numbers and separators such as dash ("-"), periods ("."), or underscores ("_"). The Regulatory Subcategory determines the vehicle and associated predefined parameters that are to be simulated along with the standard that is applied for compliance. Additional detail is provided in the following sections regarding the columns and requirements specific to each regulatory category. Each is accompanied with snippets containing selected columns from the sample input files.

IV.A. Tractor Input Files

Tractor Sample 1 shows a sample of the first two columns for a tractor input file. Table 16 shows corresponding subcategory identifiers for use in column two. The first 10 are the standard regulatory subcategories. The final six (starting with HC8) are the optional heavy Class 8 tractor subcategories that represent tractors designed for heavy-haul operation in Canada. Manufacturers may optionally certify their tractors as heavy Class 8, using the subcategories shown 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 these tractors are separate from the C8_HH subcategory that is used for U.S.-based heavy-haul tractors.

Tractor Sample 1: Input File Run ID and Regulatory Subcategory Inputs

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_6a	C8_DC_MR
Sample_7	C8_SC_LR
Sample_8	C8_SC_HR
PT_Sample1	C8_SC_HR

Table 16: 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
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 information regarding the tractor powertrain. The primary items are 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 GEM to run properly. In the Sample Input Files folder provided with GEM, the supplemental files are 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 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.

Tractor Sample 2: Input File Reference to Engine, Transmission, and Powertrain Input Files

Engine	Engine	Transmission
Data	**Idle Speed at CITT**	**Data**
File Name	**RPM**	**File Name**
Engines\EPA_2018_D_GENERIC_455_trans_c…	600	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_350_trans_ c…	650	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_600_trans_ c…	600	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_600_trans_ c…	600	Transmissions\EPA_MT_13_C78_4543.csv
Engines\EPA_2018_D_GENERIC_455_trans_ c…	600	Transmissions\EPA_AMT_10_C78_4490.csv
Engines\EPA_2018_D_GENERIC_455_trans_ c…	600	Transmissions\EPA_AT_10_C78_8001.csv
Engines\EPA_2018_D_GENERIC_455_trans_ c…	650	Transmissions\EPA_AT_10_C78_8001.csv
Engines\EPA_2018_D_GENERIC_455_trans_ c…	600	Transmissions\EPA_AMT_10_C78_4490_power_l…
Engines\EPA_2018_D_GENERIC_455_all_cyc_…	600	Transmissions\EPA_AMT_10_C78_4490.csv
Powertrains\EPA_Sample_Powertrain1.csv	600	Powertrains\EPA_Sample_Powertrain1.csv

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 Tractor Sample 2.

Another powertrain parameter in this section is the engine idle speed. This allows calibrated idle speeds to be set at the vehicle level without the need for multiple engine input files. The idle speed in this column will be used to interpolate the idle fuel maps within the engine input file to adjust the estimated fuel consumption and emissions. For more information on the appropriate value to enter see 40 CFR 1036.510.

Tractor Sample 3 shows the next columns containing the tractor performance parameters and several vehicle characteristics that are user-defined in GEM. Procedures or guidance to determine the appropriate value for each of these parameters is available in Table 17, with further information available in the preamble to the Phase 2 rulemaking.

Tractor Sample 3: Input File Performance Parameters and User-Defined Vehicle Characteristics

Drive Axle Configuration	Drive Axle Ratio	Drive Axle Data	Aerodynamic Aerodynamic Drag Area (CdA)	Steer Axle Tire Rolling Resistance Level	Drive Axle 1 Tire Rolling Resistance Level	Drive Axle 2 Tire Rolling Resistance Level	Drive Axle Tire Loaded Tire Size
(e.g. 6x4)	#	File Name	m^2	kg/t	kg/t	kg/t	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
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

Table 17: User-Defined Modeling Parameters for Class 7 and Class 8 Combination Tractors

Modeling Parameter	Method of Determining Parameter
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)	40 CFR 1037.520(c)
Drive Axle 2 Tire Rolling Resistance (kg/t)	40 CFR 1037.520(c)
Drive Axle Loaded Tire Size (rev/mi)	See 40 CFR 1037.520(c)

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 "NA" should be entered. The format of this field is similar to the engine and transmission file fields. For tractors 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.

There are limits associated with each user-defined input value. Drive Axle Configuration is a text input and the allowable options are "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 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 18 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 18: Minimum and Maximum Limits for User-Defined Values in Tractor Input Files

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 remaining 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, shown in Tractor Sample 4, 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). 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 technology, then input "Y", otherwise enter "N".

Tractor Sample 4: Technology Improvements

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	Y
NA	0	N
NA	0	N
NA	0	N

The remaining technology improvements, shown in Tractor Sample 5, 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. Reference 40 CFR 1037.520 for general information or regarding

how to determine percent values. All values of "Y", "N", or "NA" must be in UPPERCASE LETTERS. Lowercase letters will produce an error.

Tractor Sample 5: Technology Improvements with Pre-Defined Percent Improvements

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

Table 19: 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)

Table 19 directs users to the corresponding regulation reference to determine appropriate values to apply for each technology. Similar to the user-defined parameters, these technology improvements also have limits. The format and limits for the technology improvements are shown in Table 20. 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 20: 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	40,000
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.B. Vocational Input Files

Consistent with the other regulatory categories, the first two columns, as shown in the sample in Vocational Sample 1, contain a Run ID and the Regulatory Subcategory for each run. For vocational vehicles, there are nine standard and seven custom chassis regulatory subcategories in GEM and Table 21 shows codes to use in the Regulatory Subcategory column. See Section V.B.2.b of the preamble to this rulemaking for a discussion of these optional custom chassis subcategories. For the standard regulatory subcategories, the R, M and U suffixes only alter the duty cycle weighting. GEM will calculate results for each of the possible weighting to report in the output.

Vocational Sample 1: Input File Run ID and Regulatory Subcategory Inputs

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
Sample_8	LHD
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
PT_Sample1	HHD

Table 21: 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
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 (3-5) in the input file are for the engine and transmission or the powertrain input filenames as shown in Vocational Sample 2. A description of the content of these supplemental input files is located in section IV.D. 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.

Vocational Sample 2: Input File Reference to Engine, Transmission, and Powertrain Input Files

Engine	Engine	Transmission
Data	Idle Speed at CITT	Data
File Name	RPM	File Name
Engines\EPA_2018_D_GENERIC_350_trans_c…	650	Transmissions\EPA_MT_10_HHD.csv
Engines\EPA_2018_D_GENERIC_350_trans_c…	650	Transmissions\EPA_AT_5_HHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_trans_ c…	750	Transmissions\EPA_AT_6_LHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_trans_ c…	750	Transmissions\EPA_AT_6_LHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_trans_c…	750	Transmissions\EPA_AT_6_LHD_LU2.csv
Engines\EPA_2018_G_GENERIC_300hp_trans…	600	Transmissions\EPA_AT_6_LHD_LU2.csv
Engines\EPA_2018_D_GENERIC_270_trans_ c…	750	Transmissions\EPA_AT_6_MHD_LU3.csv
Engines\EPA_2018_D_GENERIC_200_trans_c…	750	Transmissions\EPA_AT_6_LHD_LU3.csv
NA	NA	NA
NA	NA	NA
NA	NA	NA
NA	NA	NA
NA	NA	NA
NA	NA	NA
Powertrains\EPA_Sample_Powertrain1.csv	600	Powertrains\EPA_Sample_Powertrain1.csv
Powertrains\EPA_Sample_Powertrain2.csv	600	Powertrains\EPA_Sample_Powertrain2.csv

In the Sample Input Files folder provided with GEM, the supplemental files are stored 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 Vocational Sample 2, 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 Vocational Sample 2. 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.

The next columns of the sample input file are shown in Vocational Sample 3 and contain the vocational performance parameters and vehicle characteristics that are user-defined in GEM. A description of these parameters is given in Table 22 and additional information is available in Section V.D of the preamble to the Phase 2 rulemaking. 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. As shown in Vocational Sample 3, custom chassis manufacturers only specify the drive axle configuration and tire rolling resistance values; all other user-defined fields are marked "NA".

Vocational Sample 3: Input File Performance Parameters and User-Defined Vehicle Characteristics

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	530D
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
6x4	3.54	NA	0	6.9	6.9	6.9	512

Table 22: 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
Engine Idle Speed	40 CFR 1036.510
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)

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 the 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 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 Vocational Sample 2. Table 23 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. The aerodynamic improvement for vocational vehicles is measured as a *delta* CdA and not the absolute CdA value used in the tractor program.

Table 23: 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, shown in Vocational Sample 4, 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 previously in Table 10. 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.

Reference the 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, the Delta PTO value obtained from that test procedure may be entered. Please note these inputs are case-sensitive. All values of "Y", "N", or "NA" must be in UPPERCASE LETTERS. Lowercase letters will produce an error.

Vocational Sample 4: Technology Improvements

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
NA	0	0	N	N	Y

The remaining three technology improvements, shown in Vocational Sample 5, 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 perform. See Table 12 and, generally, 40 CFR 1037.520 for the appropriate percent values.

Vocational Sample 5: Technology Improvements with Pre-Defined Percent Improvements

Technology Improvement Intelligent Controls	Technology Improvement Accessory Load	Technology Improvement Tire Pressure System	Technology Improvement 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
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

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 Vocational Input File

Modeling Parameter	Units	# 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.C. Trailer Input Files

The next lines of the trailer input file contain the model inputs. In the first two columns, shown in Trailer Sample 1, the user provides a Run ID and the Regulatory Subcategory for each run. For trailers, there are four regulatory subcategories modeled in GEM and Table 25 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.

Trailer Sample 1: Input File Run ID and Regulatory Subcategory Inputs

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

Table 25: 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 few columns contain the trailer performance parameters and technology improvement options that are user-defined in GEM shown in Trailer Sample 2. A description of these parameters has been provided in prior sections and additional information is available in the preamble to the Phase 2 rulemaking. Note the aerodynamic improvement for trailers is measured as a *delta* CdA and not the absolute CdA value used in the tractor program.

Trailer Sample 2: Input File Performance Parameters and User-Defined Vehicle Characteristics

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

There are limits associated with the user-defined and technology improvement input values as shown in Table 26. 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 the ATIS and TPMS values listed in the regulation are in decimal format because trailers will use a GEM-based equation for compliance.

Table 26: 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.D. Supplemental Input Files

Supplemental input files are required to provide the necessary component data to GEM. The GEM installation package contains sample input files including four folders of supplemental input files as follows:

- Axles: 1 example axle definition file
- Engines: 30 example steady-state and cycle average engine definition files
- Powertrains: 2 example powertrain definition files
- Transmissions: 11 example transmission definition files

Tractor and vocational vehicle manufacturers are required to generate separate engine and transmission input files or 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 axle input file is optional for manufacturers that would like to include more axle loss information. As discussed in the following section, each of the different types of supplemental input files consist of various sections (tables) within each file. Examples from the sample input files are included as well. Some of these tables and columns are required while others are optional. These files must be in .csv format to be properly read by GEM. Each of the supplemental files consist of tables which must be separated by an empty row to be processed correctly. Manufacturers are recommended to choose a consistent naming convention that provides unique file names for each of these supplemental input files. The GEM trailer model does not use these supplemental input files and instead relies on default values built into the trailer model.

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

There are two basic formats for the Engine component input file for GEM. The standard format uses a complete fuel map of the engine which is interpolated during simulation. Due to the potential inaccuracy of interpolating a steady state fuel map to simulate more transient operation, as occurs during the ARB transient cycle, an additional cycle average map is required which contains results from a set of transient tests. More details on the formatting of these tables and on the cycle average method are presented below and described generally in section VI.B. The second file format uses three different cycle average fuel maps, one for each test cycle. The main

fuel map is reduced to only include the low speed points which allows adjustments to be made for differences in the idle speed of the engine tested and the vehicle being simulated.

The first line of the GEM engine input file reports the GEM version for which the input is intended. The first section consists of various engine parameters such as Manufacturer Name, Combustion Type, Fuel Type, Family Name, Calibration ID, and Displacement, as shown in Engine Sample 1. 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.

Engine Sample 1: Input File Header Information

GEM P2v3.8 Engine Definition					
Manufacturer Name	Combustion Type	Fuel Type	Family Name	Calibration ID	Displacement
(e.g. Cummins)	(Compression Ignition / Spark Ignition)	(Diesel / Gasoline / LNG / CNG)	(e.g. abc12345)	(e.g. 123abc)	liters
EPA	Compression Ignition	Diesel	GENERIC	1	7

The next three sections in the engine input file specify the operating range of the engine. An example with specific numbers removed, is provided in Engine Sample 2. The first section, titled "Engine Full Load Torque Curve", specifies the maximum torque curve for the engine, and is used to define the upper bound on engine torque in the simulation. Similarly, the third section, titles "Engine Motoring Torque Curve" defines the lower bound from the motoring torque curve. The second section provides the maximum torque curve of a parent engine, which is used to estimate the transient torque response of the engine during simulation. The test procedures for each of these inputs including the number of speed and torque points to measure can be found in 40 CFR 1065.510.

Engine Sample 2: Operating Range of the Engine

Engine Full Load Torque Curve	
Speed	Torque
RPM	Nm
###	###
###	###
⋮	⋮

Parent Engine Full Load Torque Curve	
Speed	Torque
RPM	Nm
###	###
###	###
⋮	⋮

Engine Motoring Torque Curve	
Speed	Torque
RPM	Nm
###	###

###	###
⋮	⋮

The next two sections in the engine input file contain information on the fuel consumption as shown in Engine Sample 3 and Engine Sample 4. The data is detailed in three columns including engine speed in RPM, torque in Nm and fuel consumption in grams per second.

The "Engine Idle Fuel Map" is only required for vocational vehicles and provides data on fuel consumption during extended idling, corresponding with the parked idle cycle weighting for vocational vehicles in Table 6, Table 7 and Table 8. The fuel map data should consist of the four test points specified in 40 CFR 1036.535. The table will be interpolated based on the idle speed entered for the tractor or vocational vehicle and torque estimated from the simulation.

Engine Sample 3: Engine Idle Fuel Map

Engine Idle Fuel Map		
Speed	**Torque**	**Fuel Rate**
RPM	**Nm**	**grams / sec**
###	###	###
###	###	###
⋮	⋮	⋮

The "Engine Fuel Map" can exist in two forms, either as a full engine map or a limited low speed map if cycle average data is provided for each test cycle. The procedures to select the test points and run the test can be found in 40 CFR 1036.535.

Engine Sample 4: Engine Fuel Map

Engine Fuel Map		
Speed	**Torque**	**Fuel Rate**
RPM	**Nm**	**grams / sec**
###	###	###
###	###	###
⋮	⋮	⋮

The remaining sections in the engine input file include the cycle average fuel maps titled "Transient Cycle Average Fuel Map", "55 MPH Cruise Cycle Average Fuel Map" and "65 MPH Cruise Cycle Average Fuel Map" shown in Engine Sample 5. The section for the ARB Transient cycle is required while the others are optional if a complete engine fuel map is provided. Each section consists of columns for engine cycle work in kWh, the ratio of engine speed to vehicle speed (more detail on this in Section VI.B), and fuel consumed over the cycle in grams. The section for the ARB Transient cycle contains additional columns for engine speed and load at idle. This information, along with the idle speed from the tractor of vocational input file is used to adjust the fuel consumption calculation for differing idle conditions.

Engine Sample 5: Cycle Average Fuel Maps

Transient Cycle Average Fuel Map				
Engine Cycle Work	Simulation N/V	Fuel Mass	Idle Speed	Idle Torque
kWh	rev / m	grams	RPM	Nm
###	###	###	###	###
###	###	###	###	###
⋮	⋮	⋮	⋮	⋮

55 MPH Cruise Cycle Average Fuel Map		
Engine Cycle Work	Simulation N/V	Fuel Mass
kWh	rev / m	grams
###	###	###
###	###	###
⋮	⋮	⋮

65 MPH Cruise Cycle Average Fuel Map		
Engine Cycle Work	Simulation N/V	Fuel Mass
kWh	rev / m	grams
###	###	###
###	###	###
⋮	⋮	⋮

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

The first line of the GEM transmission input file reports the GEM version number for which the file is intended. The first section, as shown in Transmission Sample 1 contains basic information on the transmission such as Manufacturer Name, Type, and Model Name. 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 field Type has specific options for the manufacturer to choose.

Transmission Sample 1: Input File Header Information

GEM P2v3.8 Transmission Definition		
Manufacturer Name	Type	Model Name
(e.g. Eaton)	(AMT / MT / AT / DCT)	(e.g. 7100)
EPA	AMT	HHD

If the transmission is an automatic transmission where the torque converter clutch lockup can occur in a gear lower than the GEM default of 3rd gear, an additional column may be added to specify the minimum lockup gear. The Minimum Lockup Gear input does not apply for AMT and manual transmissions. The optional additional transmission header information for automatic transmissions is shown in Transmission Sample 2.

Transmission Sample 2: Optional Input File Header Information for Automatic Transmissions

GEM P2v3.8 Transmission Definition			
Manufacturer Name	Type	Model Name	Minimum Lockup Gear
(e.g. Eaton)	(AMT / MT / AT / DCT)	(e.g. 7100)	Number / NA
EPA	AT	HHD	3

The next section in the GEM transmission input file contains information on the transmission gear ratios as shown in the sample shown in Transmission Sample 3. If engine torque is limited when operating in a specific gear, the limit amount should be entered in the appropriate column. This will constrain simulated engine torque when operating in the specified gear and alter the shift strategy accordingly.

Transmission Sample 3: Transmission Gear Ratio Information

Transmission Gears		
Gear Number	Gear Ratio	Input Torque Limit
#	#	Nm
1	#	#
2	#	#
⋮	⋮	⋮

The next section, titled "Transmission Power Loss" is optional and can be used to include data on transmission losses. Instructions for obtaining this information are found in 40 CFR 1037.565. The format of the power loss table is shown in Transmission Sample 4. When providing power loss information not all gears need to be included. Neutral, signified by gear number zero, is optional. If loss information is provided for a given gear, all higher gears must also be included. For example, supplying data for only 8th gear on a 10-speed transmission would not be valid, data would need to be provided for 8th, 9th and 10th gears. The data points for this section are transmission input speed and torque as well as total power loss across the transmission, in kW, at each point. If power loss data is not provided, GEM uses default loss maps which are scaled based on the regulatory subcategory of the vehicle and type of transmission.

Transmission Sample 4: Optional Transmission Power Loss Information

Transmission Power Loss			
Gear Number	Input Speed	Input Torque	Power Loss
#	RPM	Nm	kW
#	#	#	#
#	#	#	#
⋮	⋮	⋮	⋮

The final section in the transmission input file, which is also optional and only available for automatic transmissions contains data on the torque converter characteristics as shown in Transmission Sample 5. The test procedure to generate the information can be found in 40 CFR 1037.570. This section contains columns for speed ratio, torque ratio and the calculated k-factor in RPM per square root Nm. If this data is not provided, GEM generates torque converter properties based on the engine torque curve.

Transmission Sample 5: Torque Converter Characteristics

Torque Converter Properties		
Speed Ratio	**Torque Ratio**	**K Factor**
		RPM/sqrt(Nm)
#	#	#
#	#	#
⋮	⋮	⋮

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

In lieu of providing separate engine and transmission performance data, a single powertrain test input can be used for GEM simulation. 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 line of the GEM input file for powertrain contains the GEM version for which it is intended. Next are three header sections, shown in Powertrain Sample 1, each contain a single row of data summarizing the engine, transmission and combined powertrain tested. The engine parameters include engine rated power which is used to scale the default powertrain during simulation to match the engine. The powertrain test configuration contains information on whether the measurements provided in the following sections were conducted at the transmission output or at the wheel hubs.

Powertrain Sample 1: Input File Header Information

GEM P2v3.8 Powertrain Definition

Engine Manufacturer Name	Combustion Type	Fuel Type	Family Name	Calibration ID	Rated Power
(e.g. Cummins)	(Compression Ignition / Spark Ignition)	(Diesel / Gasoline / LNG / CNG)	(e.g. abc12345)	(e.g. 123abc)	kW
EPA	Compression Ignition	Diesel	abc	CAL1	340

Transmission Manufacturer Name	Type	Gears	Model Name
(e.g. Eaton)	(AMT / MT / AT / DCT)	Number	(e.g. 7100)
EPA	AMT	10	abc1

Powertrain Family Name	Calibration ID	Powertrain Test Configuration
(e.g. abcd12345efg)	(e.g. 123abc)	(1: Trans. Output, 2: Wheel Hubs
EPA	CAL1	1

The next section in the powertrain input file contains data on engine fuel consumption at idle as shown in Powertrain Sample 2. For powertrains with a singular fixed idle speed this section would contain a single row while those with a calibratable idle speed must feature multiple

entries spanning the range of options. Each entry must contain the idle speed setpoint and fuel consumption rates for idling in gear and when parked, the latter of which is only required for vocational vehicles. This data is used by GEM for vocational idle fuel consumption and to adjust for differences between tested and simulated idle speeds. The procedures for collecting the necessary data can be found in 40 CFR 1037.550(o).

Powertrain Sample 2: Engine Idle Fuel Consumption

Idle Fuel Rate		
Idle Speed	**Drive**	**Parked**
RPM	**grams / sec**	**grams / sec**
#	#	#
#	#	#

The final three sections contain the powertrain cycle fuel maps and are somewhat analogous to the cycle average fuel maps of the engine input file. Each contain columns for work, N/V and the measurement of fuel consumed. The data for work and N/V are relative to the point of measurement, which was noted as Powertrain Test Configuration in the file header. The map for the ARB transient features an additional column to report the calibrated engine idle speed used in the test. This data is used to adjust for differences in idle speed between the tested powertrain and the vehicle simulation.

Powertrain Sample 3: Additional Performance Information

Transient			
Powertrain Cycle Work	**N/V**	**Fuel Mass**	**Idle Speed**
kWh	**rev / meter**	**grams**	**RPM**
#	#	#	#
#	#	#	#
⋮	⋮	⋮	⋮

55 MPH Cruise		
Powertrain Cycle Work	**N/V**	**Fuel Mass**
kWh	**rev / meter**	**grams**
#	#	#
#	#	#
⋮	⋮	⋮

65 MPH Cruise		
Powertrain Cycle Work	**N/V**	**Fuel Mass**
kWh	**rev / meter**	**grams**
#	#	#
#	#	#
⋮	⋮	⋮

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

The first row of the GEM input file for axles provides the GEM version and the subsequent rows contain user-specified details including Manufacturer Name, Family Name, and Type, as shown in Axle Sample 1. 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".

Axle Sample 1: Input File Header Information

GEM P2v3.8 Axle Definition		
Manufacturer Name	**Family Name**	**Type**
(e.g. Dana)	**(e.g. abcd12345efg)**	
EPA	EPA	TANDEM WITH DISCONNECT

The next rows contain two comma separated tables for Axle Loss and Disconnect Axle Loss, as shown in Axle Sample 2. Each section 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 Sample 2: Axle Loss Table in Axle Input File

Axle Loss		
Output Speed	**Output Torque**	**Power Loss**
RPM	**Nm**	**kW**
#	#	#
#	#	#
⋮	⋮	⋮

Disconnect Axle Loss		
Output Speed	**Output Torque**	**Power Loss**
RPM	**Nm**	**kW**
#	#	#
#	#	#
⋮	⋮	⋮

V. GEM Output File Structure

An output file will be generated when the vehicle simulation is complete and will automatically save 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 aligned to the input file for the simulated vehicle, with additional columns if the .csv file populated with the model's results. Sample 2 shows the standard results of an example simulation. These results fields are the same for each vehicle type, but their exact 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 two columns after that contain the Family Emissions Limit (FEL) values EPA and NHTSA use for compliance. For trailers and vocational vehicles, EPA's FEL CO_2 results are reported as integer values and for tractors, the results are reported with a single decimal place precision. NHTSA's FEL fuel consumption results are calculated using the EPA's FEL 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. The vocational vehicles have additional GEM and FEL CO2 Emissions and Consumption result columns, highlighted below in yellow, for each of the duty cycles, Regional, Multipurpose and Urban.

Sample 2: Example Results Columns in GEM Output File

Date/Time of Run	GEM CO2 Emissions	GEM Consumption	FEL CO2 Emissions	FEL Consumption	Subfamily	Subfamily FEL	Subfamily Volume
YYYY-MM-DD HH:MM:SS	g CO2 / ton-mile	gal / 1000 ton-mile	g CO2 / ton-mile	gal / 1000 ton-mile	Name	g CO2 / ton-mile	#
YYYY-MM-DD HH:MM:SS	###	###	##(.#)	##(.####)			
YYYY-MM-DD HH:MM:SS	###	###	##(.#)	##(.####)			
⋮	⋮	⋮	⋮	⋮			

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.

VI. Running GEM

There are two options for running GEM. The first option directly accesses the program's executable file via one of the Start Menu entries or a GEM icon on the desktop. This 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 Simulation

Prior to running GEM, an important consideration is to locate the necessary input files. Many computers will produce errors if users try to alter files in a folder where they do not have write permissions such as the default installation folder (C:\Program Files\US EPA\Phase 2 GEM). See the previous sections for a description of the input files and their formats.

VI.B. Running GEM from the Start Menu Icons

Users can access Phase 2 GEM from a collection of Start Menu icons found within the EPA Phase 2 GEM folder. The "Phase 2 GEM" shortcut runs the certification version of GEM while "Phase 2 GEM Check Inputs" and "Phase 2 GEM Cycle Creation" provide other functionality discussed in the following sections.

A pop-up window will ask the user to select an input file. By default, the program will first look in the installation folder. As mentioned previously, all the input files should be moved to a separate location to avoid permission warnings. In this example, the files were moved to the desktop and the folder was renamed GEM P2 Sample Input Files. Navigate to the input files folder and select the appropriate input file to begin the simulation.

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 5. 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", the execution will stop once the current simulation has completed (which may take a few seconds) and produce an output file with only the configurations that completed.
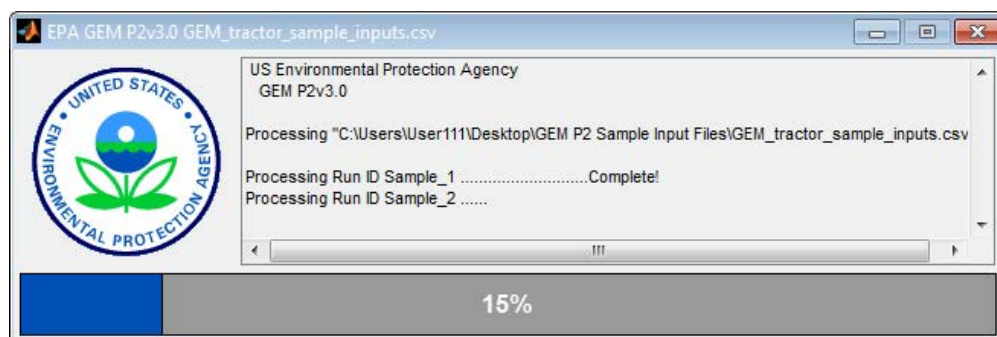
Figure 5: Sample Status Window Showing Progress of GEM Simulations

The status window will indicate when the simulations are complete with messages like those shown in Figure 6. The resulting output file will be saved in the same location as the input file and given the same name as the input file with a "_result.csv" extension added to the end. When the simulation is complete, as indicated by the green "Complete!" message, users can close the status window by clicking the red "X" in the top right corner of the window. If an error occurs during any simulation, the window will indicate which configurations failed and the model will continue to the next simulation. See Section VI.C of this Guide for examples of errors and a description of the _errors.txt file produced.
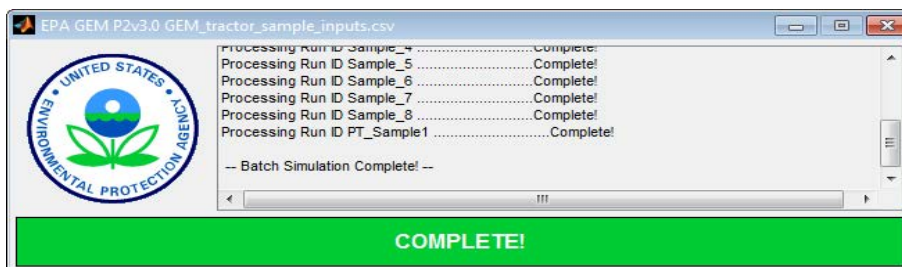

Figure 6: Sample Status Window Showing Complete GEM Simulations

VI.C. Testing Input Files for Errors

Prior to running a GEM simulation with a large number of runs, users are recommended to test their input files for errors. GEM will ensure the appropriate data is included in the required input file fields, the file headers and data are in the proper format, and supplemental input files exist with the representative information. Note that some GEM inputs are 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" shortcut and select an input file as before. GEM will run through each line of the input file and search for errors. Figure 7 shows the status window that appears when checking for errors. The status bar will progress as GEM checks each Run ID and indicates "FAIL!" or "Input Valid!" Users can close this window and check the output files for more detailed information.
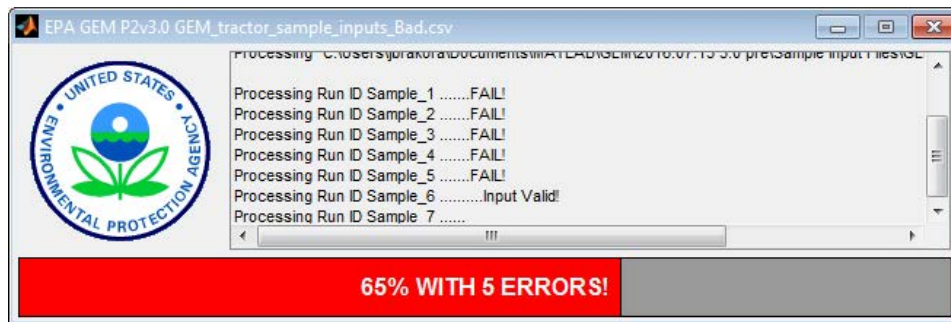
Figure 7: Status Window Checking a GEM Input File for Errors

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 Sample 3. Users are instructed to see the error file for details.

Sample 3: Example _Results.csv Output File Generated when Testing GEM Inputs

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 -- Input Validated
Sample_6 -- ERROR: see error file for details!
Sample_7 -- ERROR: see error file for details!
Sample_8 -- ERROR: see error file for details!
PT_Sample1 -- ERROR: see error file for details!

Figure 8 shows the error output file from this example which provides details about each error. Error messages describe the powertrain area with the error, file location, line item and text description.

```
US EPA Phase 2 GEM P2v3.8 Error Log

Sample_1 -- Invalid Engine Definition File EPA_2018_D_GENERIC_350_trans_cyc_avg.csv Line 2131 Incorrect Transient....
Sample_2 -- Invalid Engine Definition File EPA_2018_D_GENERIC_350_trans_cyc_avg.csv Line 2131 Incorrect Transient....
Sample_3 -- Invalid Technology Improvement Automatic Engine Shutdown Value "F" not recognized must be "Y" or "N"
Sample_3 -- Invalid Axle Definition File EPA_AxleB.csv - Unable to open file
Sample_4 -- Unknown Regulatory Sub Category "LHQ" see Documentation for Valid Options
Sample_6 -- Invalid Engine Definition File EPA_2018_G_GENERIC_300hp_trans_cyc_avg.csv Line 2 Incorrect Data Field ....
Sample_6 -- Invalid Engine Definition File EPA_2018_G_GENERIC_300hp_trans_cyc_avg.csv Line 2403 Incorrect Data....
Sample_6 -- Invalid Engine Definition File EPA_2018_G_GENERIC_300hp_trans_cyc_avg.csv Line 2403 Incorrect Data....
Sample_6 -- Invalid Engine Definition File \EPA_2018_G_GENERIC_300hp_trans_cyc_avg.csv Incorrect number of Engine....
Sample_7 -- Invalid Technology Improvement Start-Stop Value "T" not recognized must be "Y" or "N"
Sample_8 -- Invalid Drive Axle 2 Tire Rolling Resistance Level should be NA for Axle configuration 4x2
PT_Sample1 -- Invalid Powertrain Definition File EPA_Sample_Powertrain1.csv Line 22 Incorrect Transient Data Field....
```

Figure 8: 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 the inputs are valid. Once completed, the input files are now ready to be used in a GEM simulation.

VI.D. Cycle Average Engine Fuel Map for Tractor and Vocational Vehicles

Tractor and vocational vehicle manufacturers must include a cycle average fuel map for the transient cycle within the engine input file and can optionally apply cycle average fuel maps to the 55 and 65 mph cruise cycles. The cycle average method involves using GEM to generate a collection of engine dynamometer test cycles based upon a collection of vehicle simulations. These simulated vehicles are intended to span the range of potential vehicle applications for the engine. The engine is run over each of the cycles on the dynamometer and summarized in the cycle average map by work, the average speed (represented via N/V) and fuel consumed. Testing over the ARB transient also requires average speed and load at idle to be recorded. As discussed in Section IV.D.1 the cycle average map is interpolated to determine fuel consumer over the test cycle.

Included in this GEM installation package are two sample vehicle input files that serve as an example of the inputs needed to generate the dynamometer cycles 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 different engine input files located in the sample subfolder "Engines" and transmission input files located in the subfolder "Transmissions". Note the sample axle file is not used when creating the cycle average map.

To generate cycles for the cycle average map, six, eight, or nine vehicle configurations are simulated in GEM depending on the vehicle class(es) that may use the engine as defined in 40 CFR 1036.540. Engines used in heavy-haul tractors are evaluated over six specific heavy-haul

and sleeper cab configurations. Engines installed in vocational vehicles qualifying as Light HDV or Medium HDV are evaluated over eight light- and medium-heavy duty configurations. Engines installed in vocational vehicles qualifying as Heavy HDV and for tractors that are not heavy-haul tractors are evaluated over nine vehicle configurations. The example EnginePrep files show some of the default values that may be applied. The method of selecting appropriate axle ratios, tire sizes and other parameters to construct the cycle generation configurations intended to cover the expected range of potential vehicles where the engine will be used is defined in 40 CFR 1036.540. Note the configurations may vary by test cycle therefore separate simulations may be required.

As mentioned in Section IV.D.1 the engine input file exists in two formats, a full steady-state engine map and cycle average map for the ARB transient or a cycle average map for all three test cycles. The engine input file for cycle generation similarly varies depending on the expected format. If creating a final engine input using the steady-state map, the same steady-state map should also be included for cycle generation. If the final engine input uses the three-cycle average map, the steady-state map should be omitted.

The EnginePrep input files are used with the GEM executable (i.e., the "Phase 2 GEM Cycle Creation" executable from the Start Menu). Each simulation line in the input file will 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). A sample of a generated cycle file is shown in Sample 4.

Sample 4: Generated Test Cycle File

GEM P2v3.8 Engine Test Cycle			
Configuration ID:2018_Engine350_all_cyc_prep_cycle1			
Simulation Average Vehicle Speed: #.### m/sec			
Simulation Crankshaft Work: ##.### kWh			
Time	Engine Speed	Engine Torque	Vehicle Moving
sec	RPM	Nm	BOOL
#	#	#	#
#	#	#	#
⋮	⋮	⋮	⋮

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 engine input file with the appropriate headers as described previously in Section IV.D.1:

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 the average vehicle speed is determined by GEM and is stored 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.

Two additional parameters are included for the ARB transient to enable correction of fuel consumption at idle, which could vary based upon different transmissions or idle speed calibrations.

4) Average speed at idle where idle is identified by the flag in the generated cycle output file.
5) Average torque at idle where idle is identified by the flag in the generated cycle output file.

VI.E. Running GEM from the Command Prompt and Advanced Options

Users can also operate GEM using the command prompt, calling the executable directly where additional functionality is available beyond what is provided in the start menu shortcuts. The default installation directory for the GEM executable is *"C:\Program Files\US EPA\Phase 2 GEM*. Users can then initiate the same "Select an Input File" pop-up window as when using the start menu links by executing *GEM.exe* with no additional arguments.

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 the one shown in Figure 9.
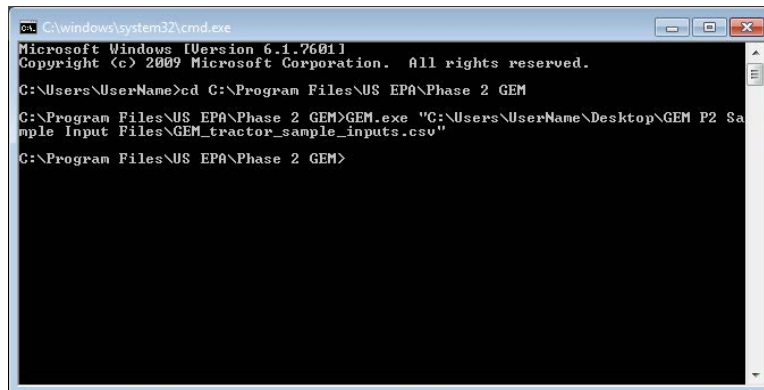
Figure 9: Command Prompt to Initiate GEM and Directly Apply Input Files (no File Selection Window)

The different GEM operating modes are accessible by specifying the mode as the first argument (e.g. *GEM.exe cycle-generation*). The modes are listed along with a summary of their operation in Table 27. The 'cycle-generation' mode is used to generate the cycle average maps (Section VI.B) and the 'check-inputs' mode is used to test the input files (Section VI.C).

Table 27: GEM Operating Modes

Mode Command	Description
certification	Simulate vehicle parameters for certification [DEFAULT]
cycle-generation	Export 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.B)
check-inputs	Test the input file for errors such as syntax and out of range parameters, but do not simulate (see Section VI.C)
simulink-parameters	Export the model parameters for later running Simulink version (see Appendix B)
hil-parameters	Export model parameters for the hardware in the loop Simulink model (see Appendix A)

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 optional mode specifier as single-letter flags with a leading dash and users may include more than one flag in a single command (e.g., *GEM.exe -d -s* or *GEM.exe cycle-generation -c*). The available flags are shown in Table 28.

Table 28: Command Line Options for GEM

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
-p	Preserve files	Preserve the simulation raw output as a .mat file for later examination
-n	No tech improvements	Turns off all technology improvements and result modifiers
-c	Console Only	Disables the status display window and runs in a console mode
-s	Stringency mode	Bypasses requirement of cycle average map for ARB transient cycle and rounding of input parameters is disabled

Figure 10: Command Prompt Display When Using the Console Only Option

To specify a GEM input file, which bypasses the file selection dialog, specify the path to the file as the last argument (e.g. *GEM.exe "path_to\input_file.csv"* or *GEM.exe -v 2 "path_to\another_file.csv"*). If the file or path contains spaces, be sure to enclose the file in quotes.

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 or the Technical Amendments, please see Docket EPA-HQ-OAR-2014-0827 available at www.regulations.gov.

Appendix A. GEM HIL Model

Included with GEM is a Simulink model which can be used in conjunction with the procedures in 1037.550 for simulation during powertrain testing. There are three powertrain testing scenarios, and their usage with GEM is summarized in Table 29 below.

Table 29: Powertrain Testing Scenarios

Components Tested	Resulting Input Format	Model Used
Engine & Transmission	Powertrain (see Section IV.D.3)	Equations in 1037.550 *or* GEM HIL Driveline & Vehicle
Engine, Transmission & Axle		
Engine with Hybrid System	Engine (see Section IV.D.1)	GEM HIL Transmission *and* Equations in 1037.550 *or* GEM HIL Driveline & Vehicle

Model Description

The GEM HIL model, shown in Figure 11 below, consists of multiple sub-models that are used to meet these different scenarios. The model as provided, targets the most complicated scenario of a hybrid engine. Testing a hybrid engine requires the use of the transmission sub-model (marked in blue) along with the driveline and vehicle sub-models (marked in green), which can be substituted with the equations found in 1037.550. The remaining sub-models can be altered or replaced as necessary to implement the testing procedures. A short explanation of the content in each sub-model is provided in Table 30.
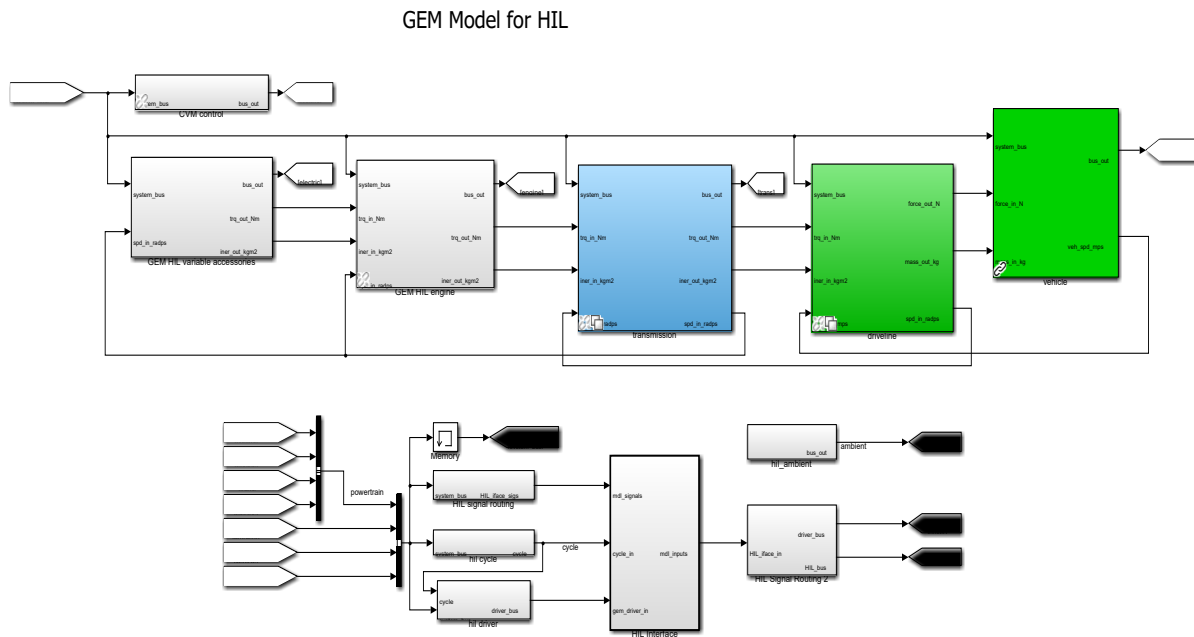

Figure 11: GEM HIL Model

Sub-model	Description
transmission	Physical model and gear selection logic for automatic and AMT transmissions. Physical model mirrors GEM certification model, but the shift routine is updated to enable an improved interface for real engine hardware versus what is simulated in GEM.
driveline	Physical model for axle(s), brakes and tires, including axle losses and rolling resistance losses. Model mirrors GEM certification model. When used for HIL testing the wheel slip model used in GEM certification is disabled.
vehicle	Physical model for vehicle mass and aerodynamic drag. Model mirrors GEM certification model. Also includes integrator for vehicle speed.
HIL engine	Interface to convert engine dynamometer measurements to transmission model inputs including calculating engine statistics used within the model. Also includes logic for handling dynamometer operating in torque mode, which drives modeled engine speed to match measured speed. The values in the `hil` data structure can be adjusted to tune this behavior.
HIL accessories	Lookup tables versus time to adjust engine load as necessary. For the default implementation these values are set to zero.
HIL ambient	Information on ambient conditions available for use by the physical models.
HIL cycle	Lookup tables to interpolate the drive cycle including current phase, grade and whether the transmission should be in gear. Also includes the distance compensation logic, which can be disabled. The definition for the drive cycle is contained in the `drive_cycle` data structure.
HIL driver	A base PID control with additional logic to drive vehicle speed to match selected cycle. Also includes logic to split output between accelerator pedal (to engine) and brake pedal (to brakes model). The calibration for the driver can be tuned via the `driver` data structure to adjust behavior as needed.
HIL signal routing & HIL signal routing 2	Translations to convert model signals to / from a more comprehensible format for interface with test cell systems. Includes conditions to enable adjustments to the load applied at idle, which can be activated via the `hil` data structure.
HIL interface	Primary point to interface a test cell system to the model. A more detailed description of the various signals is available in Tables 31 & 32.

The HIL Interface block is intended to provide a common point where signals can be sent to and received from the model. Contained in Table 31 is a list of signals provided from the model. The signals are divided into three groups, powertrain model signals (those that correspond to dynamometer commands), drive cycle signals and driver signals. The latter two correspond to functionality that can be implemented separately if desired. Table 32 contains the list of signals input to the model such as dynamometer measurements and driver inputs (which may be passed through if using the provided drive cycle and driver sub-models).

Table 31: GEM HIL Interface Model Outputs

Signal	Description
dyno_idle_load_Nm	Load to apply during idle conditions when the dynamometer is operating in a torque control mode.
dyno_tgt_speed_rpm	Dynamometer target speed during normal running operation.
trans_driveline_engaged_bool	Status flag showing whether the simulated driveline is engaged. The signal will be false when the transmission is in neutral during shifts.
trans_current_gear	Status signal showing the current transmission gear.
trans_eng_load_limit_Nm	Torque limit signal from transmission logic to engine. When running this limit may correspond to a limit on torque for the current gear. During shifts (particularly for AMTs) the limit is used to cut engine torque enabling the shift sequence to begin.
trans_eng_speed_cmd_rpm	Speed control signal from transmission logic to the engine which is used by the AMT transmission to coordinate shifts. Downshifts require the engine speed achieve this target in order to complete the shift.
trans_eng_torque_cmd_Nm	Alternate implementation of the transmission speed target which uses a PID within the model to generate a supplemental torque target to be included in the command to the engine.
vehicle_speed_mps	Status signal showing the current modeled vehicle speed.
cycle_pos_secs	Drive cycle position signal used as the input to the various interpolation blocks. When distance compensation is disabled should be equivalent to time.
cycle_key_on	Flag from drive cycle lookup for ignition to be on, included for completeness.
cycle_in_gear	Flag from drive cycle lookup to instruct transmission to be put into drive.
cycle_spd_mps	Current drive cycle target vehicle speed.
cycle_lookahead_spd_mps	Drive cycle target speed at a point a few seconds into the future used to anticipate speed changes.
cycle_lookahead_accel_mps2	Average acceleration anticipated over the next few seconds of the drive cycle, which is useful to estimate the power required for vehicle acceleration.
cycle_grade_pct	Current drive cycle interpolated grade, which can be either based on distance (integrated vehicle speed) or time.
gem_driver_accel_norm	Accelerator pedal command from driver model for command to engine.
gem_driver_brake_norm	Brake pedal command from driver model to command brakes within model.

Table 32: GEM HIL Interface Model Inputs

Signal	Description

dyno_mode	Signal of the currently commanded dyno mode:
	  0 indicates the dynamometer is being commanded to a given torque
	  1 indicates the dynamometer is being controlled to match a target speed.
	More detail on how the model operates in these different modes is in the subsequent paragraphs.

dyno_torque_Nm	Dynamometer measured torque signal.
dyno_speed_rpm	Dynamometer measured speed signal.
eng_load_est_Nm	Signal from the engine controller indicating the current engine crankshaft torque output. This is used by the AMT shift logic to delay the shift sequence until the torque has been reduced to near zero.
driver_key_on	Boolean input comparable to engine on; could use provided drive cycle lookups, external signal or always true.
driver_in_gear	Boolean input to indicate the driver is shifting the transmission into drive, could use provided drive cycle lookups or external implementation.
driver_accel_anticipate_bool	Boolean input to indicate a stopped drive cycle phase is about to end, triggering transmission gear engagement if neutral idle is active or beginning the clutch engagement process for an AMT.
driver_accel_norm	Accelerator pedal signal used to estimate driver demand within gear selection and torque converter lockup logic.
driver_brake_norm	Brake pedal signal used to command brakes within vehicle model in addition to clutch logic.
cycle_grade_pct	Grade to implement within the vehicle model, could be from provided cycle lookup or externally.

The dynamometer mode signal is important for keeping the GEM_HIL model operating properly when running at idle conditions with the dyno controlling torque. Normal model operation receives torque measurements which drive changes in vehicle speed and thus engine speed (dynamometer speed setpoint). At idle conditions this process flow needs to be altered. The model provides an output for the torque to apply, however this could result in a deviation between the dynamometer speed and the target speed generated by the model as there is no longer feedback coordinating the speeds. To correct for this, a PID is included within the HIL engine sub-model to drive the modeled speed to match the dyno measurement. The dyno_mode flag set to false activates this functionality. The calibration for the PID can be adjusted to ensure proper behavior.

Using the GEM HIL Model

The first step in making use of the GEM_HIL model for powertrain or hybrid engine testing involves integrating the provided model or selected sub-models with the test control hardware. As outlined in 1037.550 the test cell dynamometer must be configured to receive control setpoints from the simulation and the appropriate measurements and signals provided to the model. The descriptions in Table 31 and Table 32 provide information on these signals and their use. Given the variations in different testing hardware and associated systems a detailed description of such integration is outside the scope of this document.

The next step is generating the parameters for use by the model, which is done via the GEM executable in hil-parameters mode as briefly discussed in Section VI.E.. The command line syntax for hil-parameters mode with an input tractor or vocational input file named input_file.csv would be:

    gem.exe hil-parameters input_file.csv

In hil-parameters mode, each row in the input file is processed and a MATLAB mat file containing the HIL model parameters is created. The data within the mat file is similar to the parameters used for the certification GEM simulation with adjustments to match the GEM_HIL model parametrization and values altered from their GEM defaults to match the applicable test procedures. Examples of these differences would be revising the transmission losses or disabling the tire slip model. One parameter of the model not included within the generated mat file is the drive cycle. A separate mat file 'GEM_hil_drive_cycle.mat' containing a sample drive cycle structure is included with the GEM package for reference.

As noted earlier, there is room for customizing the integration of these models within the test environment. A specific example could be alternate implementations of the driver. Similarly, given the variety of test automation systems and vendors it is difficult to provide a full example of implementation.

Appendix B. GEM Simulink Model

The GEM software used for certification or cycle average test generation is built from precompiled models which simulate vehicle operation. To better document the content of these models the original Simulink source code is bundled with the GEM install package and a simulink-parameters mode is included to generate the necessary model inputs. Usage of the Simulink model requires MATLAB/Simulink and the stateflow package.

Model Description

This document is intended to provide a rough overview of the GEM model and its components. The goal is to provide documentation on where to look for certain functionality but not necessarily be a complete explanation of the model or its subsystems. The top level of the GEM model is shown in Figure 12 which illustrates the sub-models for the powertrain, vehicle (chassis), driver, ambient conditions and routing of signal buss helping the various parts of the model communicate. Within the powertrain model, as shown in Figure 13, are the component models for various powertrain elements explained in more detail later in this section. The vehicle sub-model contains items corresponding to the physical chassis of the vehicle, notably the mass of the vehicle and the aerodynamic drag losses. The driver model contains both the drive cycle to simulate and logic to operate the virtual pedals. The ambient sub-model provides information about external parameters such as temperature and grade for use during simulation.
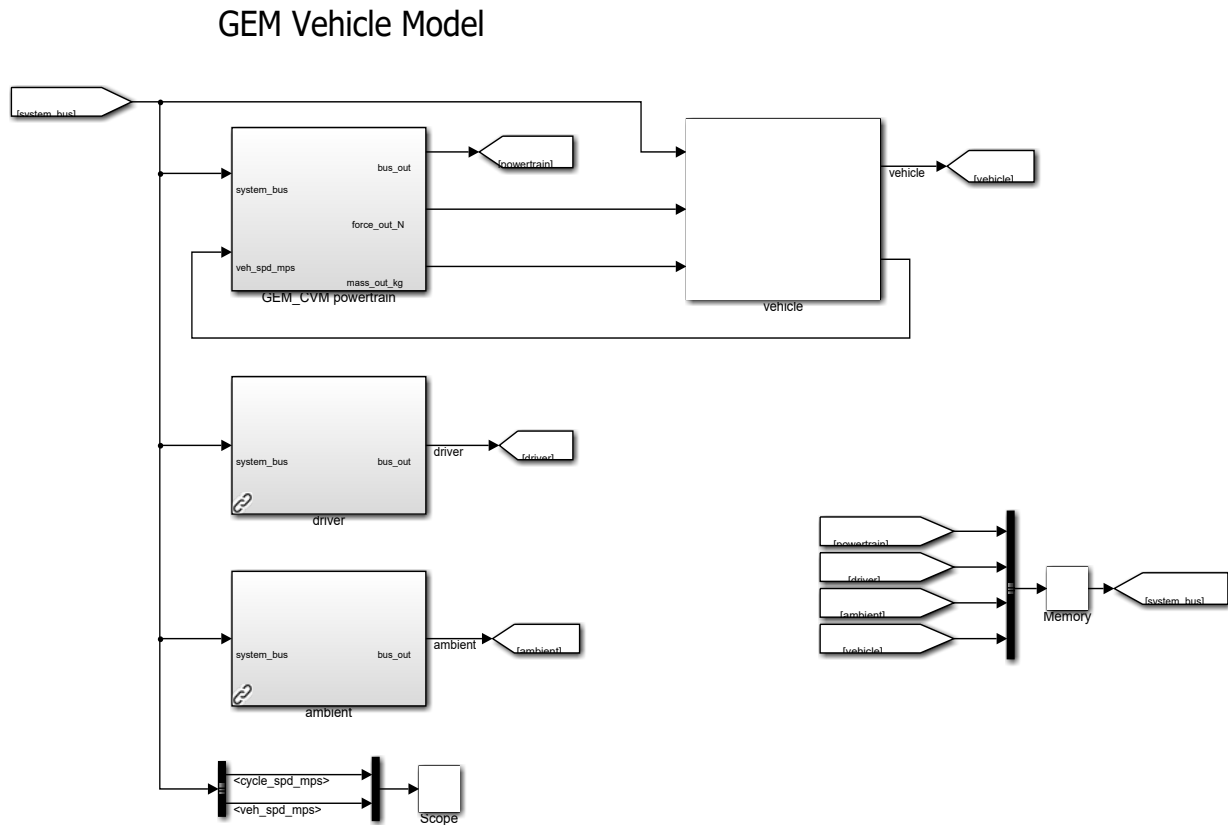

Figure 12: GEM Vehicle Model Top Level Diagram
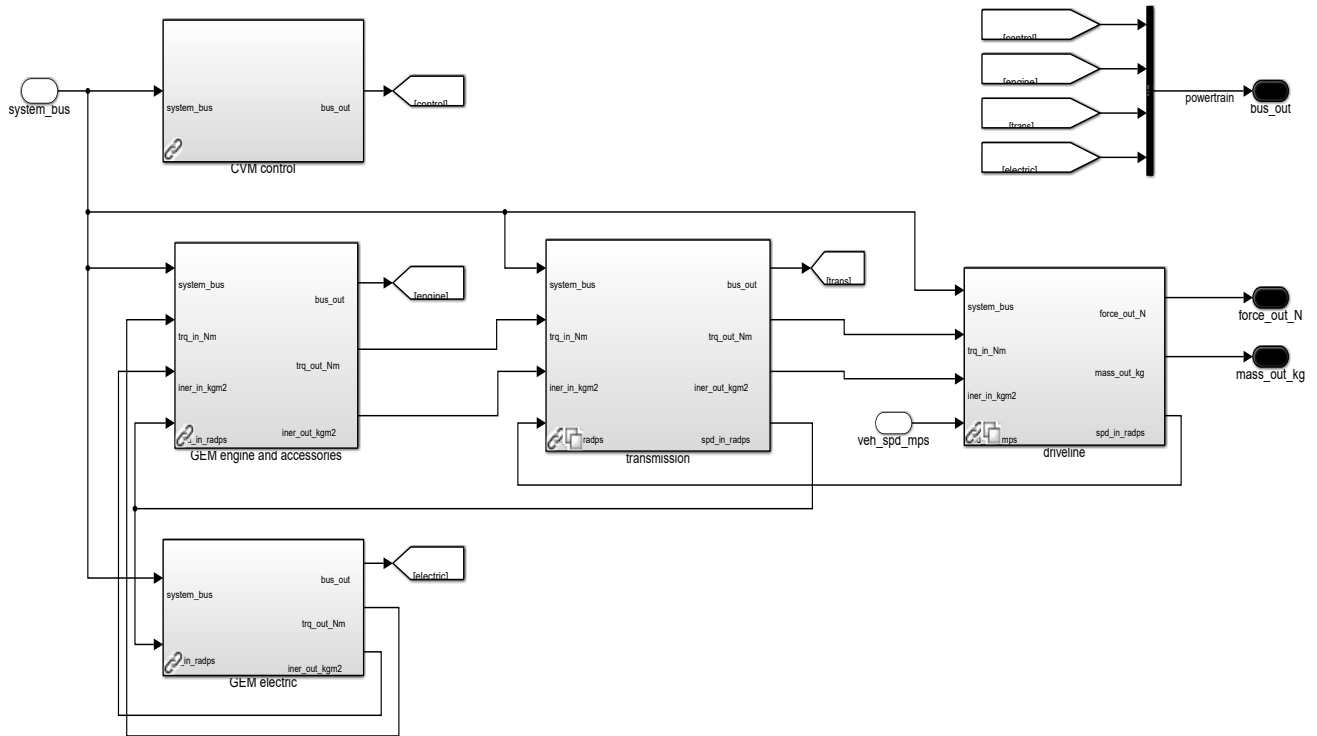
GEM_CVM Conventional Vehicle Powertrain

Figure 13: GEM Vehicle Model Powertrain Sub-Model Diagram

The powertrain sub-model provides all the functionality converting the driver request via the pedals to force output at the wheels. The CVM control block houses the start-stop logic to shut off the engine when appropriate in simulation. The GEM engine and accessories sub-models take the driver requested accelerator signals and provides an engine torque output in addition to fuel consumption. There is some modeling for transient behavior along with specific logic for idle control and coordination during transmission shifting. Some mechanical constant power accessories are also included; the load associated with these is determined by regulatory subcategory.

The electric model contains additional accessory losses intended to replicate the alternator and charging system. A starter is also present to enable simulation of start-stop operation.

The transmission model contains two sub-models, one for an automatic transmission with a torque converter and one for an AMT, which requires coordination with the engine for proper shift behavior. Within GEM, manual transmission vehicles are simulated using the AMT model but are adjusted post-process to slightly reduce their efficiency. Both transmission architectures use the same gear selection logic ALPHAshift which seeks to minimize fuel consumption by selecting an appropriate gear.

The driveline block contains the components such as the driveshaft, axles, brakes and tires, with their associated inertias and losses. To simplify simulation and improve calculation speed, the different axles and tires are lumped into one single equivalent axle.

Using GEM Simulink Mode

To generate the GEM Simulink model input parameters a GEM tractor or vocational input file is passed into the GEM executable (or MATLAB source code if preferred). The -s (stringency mode) flag is desirable to avoid the need for cycle average maps in engine input files.

    Calling from the command line:

       GEM.exe simulink-parameters -s "sample_inputs\GEM_tractor_inputs.csv"

    Calling from MATLAB with GEM source code:

       >> GEM_main('simulink-parameters', '-s', 'sample_inputs\GEM_tractor_inputs.csv');

    One of the resulting mat files can be opened in MATLAB:

       >> load sample_inputs\run_*******_inputs.mat

When in the Simulink folder provided with the GEM release, the sim_gem_phase2 script can run the simulation and postprocessing:

       >> sim_gem_phase2

This will result in a variety of variables created within the workspace such as audit, datalog, result and postproc_result which contain continuous and phase data from the simulation for analysis. Contained within the script is the loading of the drive cycle, if desiring to simulate different cycles the drive_cycle variable can be altered or replaced. Similarly, various component model or parameters can be replaced or adjusted for educational purposes. A slightly more detailed version of this information can be found in the README_RunningGEM.txt document bundled with the source code.

Appendix C. Changelog

Summary of Changes for 3.4 from 3.0

- Fixed typo in Class 7 default tractor transmission torque limits
- Revised engine idle control
    - Reduced gains for improved stability
    - Added feed forward for a smoother transition to idle
- Improved handling of larger input tables
    - Engine torque curves previously could exceed size allowed by model executable
    - Tables are now pre-interpolated to fit within allowable dimensions
- Revised engine cycle generation outputs
    - Corrected engine cycle generation torque output from model based on simulated inertia and rate limited speed target
    - Added output of simulated crankshaft work to cycle header
- Added scaling of powertrain simulation default engine & transmission maps based on new rated power input
- Recalibrated driver over-speed allowance on cruise cycles from 3 mph to 2.5 mph
- Increased weight reduction input range for tractors up to 25k lbs
- Changed fuel map interpolation to be consistent between simulation and post processing
- Moved idle speed parameter from engine file to the main (vehicle) file
- Added adjustment to cycle average fuel for differences between tested and simulated idle
    - Added inputs in transient cycle average map for speed and load when stopped
    - Regression lookup of cycle average map uses only portions with vehicle moving
    - Post process adjustment to fuel consumption based on simulated idle speed
- Fixed bug where parked fuel map was used for ARB transient idle correction
    - Parked fuel map is now only required for vocational vehicles
- Adjusted accessory work correction for powertrain inputs to exclude work that is provided by the inertia of the vehicle
- Added ability to print detailed output (-d) when using engine cycle generation (-e)
- Detailed output columns rearranged
- ARB Transient detailed output columns for engine work, average speed and load only use portions with vehicle moving only
- Added vocational output columns with result of each cycle weighting (where applicable)
- Added detailed output columns for idle speed and load for transient simulation
- Added torque converter input table featuring speed ratio, torque ratio and k-factor to transmission input file
- Added check that engine fuel map contains a sufficient number of points

Changes for 3.5

- Increased tractor weight reduction limit to 45000 lbs
- Modified stringency mode (-s) to disable input range checking
- Improved component input file parsing for better error handling

Changes for 3.6

- Fixed issue with parsing torque converter table when transmission power loss not present
- Added ability to turn off wheel slip in compiled model
- Fixed issue with default engine map for vocational vehicles using 3 cycle average maps
- Fixed incorrect cycle weighting factor for HHD vocational vehicles

Changes for 3.7

- Fixed idle fuel adjustment to properly account for time at idle
- Adjusted method for blending idle map and default engine with 3 cycle average maps
- Changed gravitational acceleration to match CFR
- Updated model and subsystems to enable HIL model operation
    - Revised command line interface with different modes
    - Revised model, cleaning up libraries to be common with HIL model
    - Added output mode where simulation input workspace is tweaked for HIL or Simulink mode and dumped to a MAT file
    - Significantly updated AMT shift routine (only HIL version of model for now)
- Added Intelligent controls as a vocational input
- Fix very old bug where so HHD, C8 & C7 AMT transmissions use clutched upshifts

Changes for 3.8

- Include GEM HIL model for release
- Revised HIL pre-process scripts to match model revisions and test procedures