

Greenhouse Gas Emissions Model (GEM) User Guide

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

The Greenhouse gas Emissions Model was created by EPA as a means for determining compliance with EPA's GHG emissions and NHTSA's fuel consumption vehicle standards, for Class 7 and 8 combination tractors and Class 2b-8 vocational vehicles. The GEM v2.0 model itself is a part of the final regulation.¹ It is a free, desktop computer application.

The GEM is designed to operate on a single computer. The downloadable installation file contains the application executable file and other supporting files, available at <http://www.epa.gov/otaq/climate/gem.htm>, and described in this guide. To request a CD of this software instead of downloading it, or to request assistance if you have trouble with accessibility of this software, please request through an email addressed to OTAQPUBLICWEB@epa.gov.

After the GEM version 1.0 was released to the public in October 2010 as a part of the proposed rules, the agencies received many constructive comments and useful suggestions from the public. Prior to promulgation of the final rules, the agencies continued validations against additional test data and benchmarking against other commonly used industrial standard vehicle models. The most noticeable improvements to the GEM version 2.0 are a new driver model, the simplified electric model in conjunction, and many other refinements including the graphical user interface.

Chapter 4 of the RIA details model validations against testing data and comprehensive model benchmark against commonly used vehicle model in industry. This user guide contains the model documentation with details on the model's input and output files. It also includes instructions on how to use the GEM. Some of the information provided here can also be found in Chapter 4 of the RIA.

1. GEM Documentation

This section describes the GEM vehicle model architecture, the list of pre-defined input parameters, output calculations, and the installation of executable GEM code into the user's computer.

1.1. Vehicle Model Architecture

The Class 2b-8 vehicle compliance model architecture is comprised of six systems: Ambient, Driver, Electric, Engine, Transmission, and Vehicle. With the exception of "Ambient," "Electric," and "Driver," each system consists of one more component models. Details on the function of each system and their respective component models can be found in Chapter 4 of the RIA.

¹ See Sections II.B and II.D of the preamble and Chapter 4 of the RIA (Regulatory Impact Analysis), available at <http://www.epa.gov/otaq/climate/regulations.htm>.

1.2. List of Predefined Input Parameters for Class 7/8 Combination Tractor Models

Although many technologies can potentially achieve GHG emission and fuel consumption reductions, EPA and NHTSA believe that for the rule's timeframe, some may be too complex to model for compliance purposes (e.g., hybrid control) while others require standardization such as the calculation of GHG and fuel consumption benefits due to aerodynamic improvements. EPA and NHTSA decided to pre-define the tractor frontal area, tractor-trailer combined and payload weight, gear box and its efficiency, final drive ratio, engine/transmission/wheel inertia, accessory load, axle base, tire radius, trailer tire coefficient of rolling resistance (C_{rr} , trailer tires), and engine fuel map. The agencies use these pre-defined input parameters in the simulation model for all subcategories of combination tractors. Table 1 lists the specific values of these parameters for Class 8 combination tractors, and Table 2 lists the similar values for Class 7 combination tractors.

Table 1: Class 8 Combination Tractor Modeling Parameters

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof
Fuel Map	15L - 455 HP					
Gearbox	10-speed Manual	10-speed Manual	10-speed Manual	10-speed Manual	10-speed Manual	10-speed Manual
Gearbox Ratio	14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1					
Gearbox Efficiency	0.96, 0.96, 0.96, 0.96, 0.98, 0.98, 0.98, 0.98, 0.98, 0.98					
Engine Inertia (kg-m ²)	4.17	4.17	4.17	4.17	4.17	4.17
Transmission Inertia (kg-m ²)	5	5	5	5	5	5
All Axle Inertia (kg-m ²)	360	360	360	360	360	360
Loaded Tire Radius (m)	0.489	0.489	0.489	0.489	0.489	0.489
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,100	17,000
Trailer Weight (lbs)	13,500	10,000	10,500	13,500	10,000	10,500
Payload (lbs)	38,000	38,000	38,000	38,000	38,000	38,000
Total weight (lbs)	70500	66750	67000	69000	65100	65500
Total weight (kg)	31978	30277	30391	31298	29529	29710
Frontal Area (m ²)	10.4	7.7	6.9	10.4	7.7	6.9
Coefficient of Aerodynamic Drag	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Axle Base	5	5	5	5	5	5
Electrical Accessory Power (W)	350	350	350	350	350	350
Mechanical Accessory Power (W)	1,000	1,000	1,000	1,000	1,000	1,000
Final Drive Ratio	2.64	2.64	2.64	2.64	2.64	2.64
Tire CRR (kg/metric ton)	$= 0.425 \times \text{Trailer CRR} + 0.425 \times \text{Drive CRR} + 0.15 \times \text{Steer CRR}$					
Trailer Tire CRR (kg/metric ton)	6	6	6	6	6	6
Steer Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Drive Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Vehicle Speed Limiter (mph)	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input

Table 2: Class 7 Combination Tractor Modeling Parameters

MODEL TYPE	CLASS 7	CLASS 7	CLASS 7
Regulatory Subcategory	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof
Fuel Map	11L - 350 HP		
Gearbox	10-speed Manual	10-speed Manual	10-speed Manual
Gearbox Ratio	11.06, 8.19, 6.05, 4.46, 3.34, 2.48, 1.83, 1.36, 1, 0.75		
Gearbox Efficiency	0.96, 0.96, 0.96, 0.96, 0.98, 0.98, 0.98, 0.98, 0.98, 0.98		
Engine Inertia (kg-m ²)	3.36	3.36	3.36
Transmission Inertia (kg-m ²)	5	5	5
All Axle Inertia (kg-m ²)	233.4	233.4	233.4
Loaded Tire Radius (m)	0.489	0.489	0.489
Tractor Tare Weight (lbs)	11,500	11,100	11,000
Trailer Weight (lbs)	13,500	10,000	10,500
Payload (lbs)	25,000	25,000	25,000
Total weight (lbs)	50000	46100	46500
Total weight (kg)	22680	20910	21092
Frontal Area (m ²)	10.4	7.7	6.9
Coefficient of Aerodynamic Drag	OEM Input	OEM Input	OEM Input
Axle Base	4	4	4
Electrical Accessory Power (W)	350	350	350
Mechanical Accessory Power (W)	1000	1000	1000
Final Drive Ratio	3.73	3.73	3.73
Tire CRR (kg/metric ton)	= 0.425 × Trailer CRR + 0.425 × Drive CRR + 0.15 × Steer CRR		
Trailer Tire CRR (kg/metric ton)	6	6	6
Steer Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input
Drive Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input
Vehicle Speed Limiter (mph)	OEM Input	OEM Input	OEM Input

1.3. List of Predefined Input Parameters for Class 2b-8 Vocational Vehicle Models

Likewise, EPA and NHTSA standardized a set of parameters for the three Class 2b-8 vocational vehicle types, which the agencies refer to as Vocational Light Heavy-Duty (VLHD), Vocational Medium Heavy-Duty (VMHD), and Vocational Heavy Heavy-Duty (VHHD). These predefined parameters include the coefficient of aerodynamic drag, truck frontal area, truck total and payload weight, the gear box and its efficiency, final drive ratio, engine/transmission/wheel inertia, accessory load, axle base, tire radius, and the engine fuel map. The specific values of these parameters are listed in Table 3.

Table 3: Vocational Vehicle Modeling Parameters

Model Type	Heavy Heavy-Duty	Medium Heavy-Duty	Light Heavy-Duty
Regulatory Subcategory	Vocational Truck (Class 8)	Vocational Truck (Class 6-7)	Vocational Truck (Class 2b-5)
Fuel Map	15L - 455 HP	7L - 270 HP	7L - 200 HP
Gearbox	10-speed Manual	6-speed Manual	6-speed Manual
Gearbox Ratio	14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1	9.01, 5.27, 3.22, 2.04, 1.36, 1	9.01, 5.27, 3.22, 2.04, 1.36, 1
Gearbox Efficiency	0.96, 0.96, 0.96, 0.96, 0.98, 0.98, 0.98, 0.98, 0.98	0.92, 0.92, 0.93, 0.95, 0.95, 0.95	0.92, 0.92, 0.93, 0.95, 0.95, 0.95
Engine Inertia (kg-m ²)	4.17	2.79	2.79
Transmission Inertia (kg-m ²)	5	0.5	0.5
All Axle Inertia (kg-m ²)	200	60	60
Loaded Tire Radius (m)	0.489	0.389	0.378
Payload (lbs)	15,000	11,200	5,700
Total weight (lbs)	42,000	25,150	16,000
Total weight (kg)	19,051	11,408	7,257
Frontal Area (m ²)	9.8	9.0	9.0
Coefficient of Aerodynamic Drag	0.7	0.6	0.6
Axle Base	3	2	2
Electrical Accessory Power (W)	350	300	300
Mechanical Accessory Power (W)	1,000	1,000	1,000
Final Drive Ratio	2.64	3.36	2.85
Tire CRR (kg/ton)	= 0.5 × Drive CRR + 0.5 × Steer CRR		
Trailer Tire CRR (kg/metric ton)	Not applicable	Not applicable	Not applicable
Steer Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input
Drive Tire CRR (kg/metric ton)	OEM Input	OEM Input	OEM Input

1.4. Output Processes

The outputs produced by the GEM include post processes to calculate the final weighted results.

The GEM produces a cycle-weighted grams CO₂/ton-mile and gallons/1,000 ton-mile result which incorporates the drive cycle weightings of the ARB transient cycle, 55 mph steady state cruise, and 65 mph steady state cruise cycle, as shown in Table 4.

Table 4: Drive Cycle Weighting

CATEGORY	CLASS 8 SLEEPER CAB TRACTORS	CLASS 7/8 DAY CAB TRACTORS	CLASS 2b-8 VOCATIONAL VEHICLES
ARB Transient	5%	19%	42%
55 mph Cruise	9%	17%	21%
65 mph Cruise	86%	64%	37%

The GEM converts the mile per gallon result into ton-mile space by using the payload for each regulatory class – 19 tons for Class 8 tractors, 12.5 tons for Class 7 tractors, 7.5 tons for HHD vocational vehicles, 5.6 tons for MHD vocational vehicles, and 2.85 tons for LHD vocational vehicles.

GEM calculates the gallons/1,000 ton-mile weighted result by converting the weighted grams CO₂/ton-mile result. The gram CO₂/ton-mile result is multiplied by 1,000 and divided by 10,180 grams CO₂ per gallon of diesel fuel.

2. GEM Installation Instructions

Certain minimum computer requirements must be met before installation. The system required to run GEM needs a minimum RAM of 1 GB (4 GB is highly recommended), and approximately 900 MB of disk storage. Window XP or Window 7 operating system is required. The validation has not been tested in other computer operating systems. The 2007 Microsoft Excel or later version is required.

The executable form of GEM named “GEM_Setup.exe” can be downloaded from the EPA website, at <http://www.epa.gov/otaq/climate/gem.htm>. Before installation, please close all other programs. Follow the procedure below to perform installation.

- Down load GEM_Setup into a temporary directory.
- Click GEM_Setup.exe to install the package and GEM Installation window will be displayed.
- Click Next; a “Choose Install Location” window will appear. The user has the option to select the folder location or just use default folder on screen. Click Next.
- A “Select Shortcuts” window will be displayed. A default checkbox for Create a Desktop Icon is already selected. Click Next.
- A Window “Ready to Install” will be displayed. Click Install.

In the next few steps, it will install 2008 Microsoft Visual C++ Redistributable Setup and the MATLAB® Runtime 7.15 if you have not installed those previously. If these two were installed previously, click Cancel once Choose Setup Language window displays. The installation is finished.

For Microsoft Visual C++ Redistributable Setup, just follow on-screen instruction to install. If Visual C++ Redistributable Setup has been installed previously, the installation will not prompt you to install, and you just go to the next step for MATLAB® Runtime 7.15 installation.

For MATLAB® Runtime 7.15 installation, follow the steps below.

- Installation of MATLAB® Runtime 7.15 will be automatically initiated either right after installation of Visual C++ Redistributable Setup or click OK once Choose Setup Language window displays.
- An InstallShield Wizard window will be displayed, prompting the user to install the MATLAB® Runtime 7.15. Click Next.
- Click Install, and then follow the steps below to complete the installation
 - a. Enter the names of user and organization, and then click Next.
 - b. A window “Destination Folder” will be displayed. Click Next if a default folder is selected.
 - c. Click Install to complete MATLAB® Compiler Runtime. It will take a while to complete the installation.
 - d. Click Finish, and entire installation is completed.

The GEM folder contains these visible files:

- GEM.exe shortcut
- GEM_input.xlsx

It should be pointed out that the GEM is compatible with MATLAB® Runtime 7.15. Different versions of MATLAB® Runtime may result in compatibility issues.

To uninstall, the user may manually delete the GEM by following the steps below:

- Delete the GEM folder entirely
- Delete the short cut on your desktop screen.

3. GEM Running Instructions

To run GEM, double click the GEM.exe on the desktop icon. A graphic user interface GUI will pop as shown in Figure 1.

Greenhouse Gas Emissions Model (GEM)

Identification

Manufacturer Name: Vehicle Configuration: Date:

Vehicle Family: Vehicle Model Year:

Regulatory Subcategory

- Class 8 Combination - Sleeper Cab - High Roof
- Class 8 Combination - Sleeper Cab - Mid Roof
- Class 8 Combination - Sleeper Cab - Low Roof
- Class 8 Combination - Day Cab - High Roof
- Class 8 Combination - Day Cab - Mid Roof
- Class 8 Combination - Day Cab - Low Roof
- Class 7 Combination - Day Cab - High Roof
- Class 7 Combination - Day Cab - Mid Roof
- Class 7 Combination - Day Cab - Low Roof
- Heavy Heavy-Duty - Vocational Truck (Class 8)
- Medium Heavy-Duty - Vocational Truck (Class 6-7)
- Light Heavy-Duty - Vocational Truck (Class 2b-5)

Simulation Inputs

Coefficient of Aerodynamic Drag:

Steer Tire Rolling Resistance [kg/metric ton]:

Drive Tire Rolling Resistance [kg/metric ton]:

Vehicle Speed Limiter [mph]:

Vehicle Weight Reduction [lbs]:

Extended Idle Reduction:

Simulation Type

- Single Configuration
- Plot Output
- Multiple Configurations

RUN

Figure 1 – GEM Input GUI for Single Configuration Run

With the GEM GUI launched, the user has two options to run the GEM. The first option is to run single configuration, and the second option is to allow the user to run multiple configurations or a batch job under the same regulatory subcategory and vehicle model year.

For the single configuration, use the following instruction:

Figure 1 allows the user to enter the required parameters into the model. There are essentially two types of input parameters. The first set of parameters is required to provide information to EPA and NHTSA. These include the following:

- Manufacturer Name
- Date
- Vehicle Family
- Vehicle Configuration

- Vehicle Model Year

The second set of parameters affects how GEM calculates the final results. The list below describes each input and how it is used within GEM.

- Vehicle Model Year: The pull-down allows the user to select five model years: “2013”, “2014”, “2015”, “2016”, and “2017 and later”. The Vehicle Model Year selects the appropriate engine fuel map in the model. The 2013 to 2016 model years all use one set of heavy-duty vehicle’s engine fuel maps which meets the 2014 through 2016 model year engine standards, while a selection of 2017 and later uses another set of the engine fuel maps which meet the 2017 MY engine standards.
- Regulatory Subcategory: The user must select one of the twelve designated regulatory subcategories in the radio button menu. The selection directs the model to use the appropriate predefined inputs and post processing parameters, as outlined in Sections 1.2 and 1.3 of this Guidance.
- Coefficient of Drag: The Cd value is input by the user based on the aerodynamic bins, as discussed in the preamble, RIA, and regulations. This input is only required for combination tractors. No input is required for vocational vehicles.
- Steer Tire Rolling Resistance: The coefficient of rolling resistance for the steer tires should be input by the user in the units of kg/metric ton where the typical value is greater than 5.5 kg/metric ton. The units are not in kg/kg or lb/lb (the other industry norm) where the values are typically greater than 0.0055 kg/kg or lb/lb.
- Drive Tire Rolling Resistance: The coefficient of rolling resistance for the drive tires (i.e. all tires used in non-steer positions) should be input by the user in the unit of kg/metric ton where the typical value is greater than 5.5 kg/metric ton. The units are not in kg/kg or lb/lb (the other industry norm) where the values are typically greater than 0.0055 kg/kg or lb/lb.
- Vehicle Speed Limiter: If the vehicle contains a vehicle speed limiter, then input the speed limit to the nearest single decimal place. Otherwise, use 65 mile/hour. The GEM will limit the maximum speed of the vehicle to the value selected. If the user is opting to allow an expiration of the VSL before the full useful life of the vehicle or include soft top features, then calculate the Effective Speed Limit as described in 40 CFR 1037.640(d). This input is only available for combination tractors. No input is allowed for vocational vehicles as indicated by a “grayed-out” feature.
- Vehicle Weight Reduction: If a combination tractor contains lighter weight wheels or tires, or other lighter components described in the preamble, RIA, and the regulations, then the user would input the sum of the weight reductions prescribed by the weight bins. This input is only available for combination tractors. No input is allowed for vocational vehicles as indicated by a “grayed-out” feature.
- Extended Idle Reduction: If a sleeper cab combination tractor contains an extended idle reduction technology and a 5 minute automatic engine shut-off, then the user would select the 5 g/ton-mile reduction. If not, then “0” should be selected. If the user is opting to allow an expiration of the automatic engine shut-off before the full life of the vehicle, then calculate the Extended Idle Reduction Credit as described in 40 CFR 1037.660(c) This input

is only available for sleeper cab combination tractors. No input is allowed for day cab combination tractors and vocational vehicles as indicated by a “grayed-out” feature.

- A check button for “Plot Output” can be selected if the user chooses to output all three cycle plots for vehicle speed traces as a function of time.
- Click RUN (Figure 1), the GEM will run.

After the simulation is completed, a window will open, prompting the user where the file is to be saved. The output file will open once clicking OK to save the file. The following output file will be created with the following naming structure:

GEM_Results_Date_Time.xlsx

The data are in the format of date-month-year, and Time is hour-minute-second-am/pm. For example, the full name is

GEM_Results_01-Jun-2011_02-25-39-pm.xlsx

The output file has the same structure as the input file, which includes all data used in the input file plus additional columns for output results. Those additional data are CO₂ in g/ton-mile and fuel consumption in gallon/1,000-ton-mile, which will be used for certification.

If the user wants to close the GEM, click  on the GUI window.

For single configuration run, input error checking features have been built in. If the user forgets entering a value to a required field, a message window will open and the field that requires entering the values will be in red, asking the user to enter a valid value.

For multiple configurations, use the following instruction

The user must set up the input file in Excel format before initiating “Multiple Configuration” run. A template input file is provided during installation.

It should be pointed out that there are a few restrictions in using the EPA provided input template Excel file (GEM_Input.xlsx) during editing before running the multiple configuration.

- Only one regulatory subcategory and one vehicle model year can be selected for the batch process.
- Do not change any format used in the template provided.
- It is the user’s responsibility to enter the appropriate, valid numerical value for each mandatory input, which should not be left blank.
- For all vocational vehicles selected in the “GEM_Input.xlsx”, those input parameters for “Cd (Bin)”, “Idle Reduction”, and “Weight Reduction” will take pre-defined default values irrespective of the values entered by the user. Those default values can be seen through “Single Configuration” run when the vocational trucks are selected in their respective grayed-out areas.

- For all day cab tractors including Class 7 and 8, the input parameter for “Idle Reduction” will use the pre-defined values irrespective of the values entered by the user. The pre-defined value can be seen through “Single Configuration” run when the vocational vehicles are selected in their respective grayed-out area.

One example of the input file can be seen in Figure 2. Note that the values in this figure and other similar figures in the following section are for illustrative purposes only. The template provided by the agency is called “GEM_Input.xlsx”. Following the steps below, one can create the input file.

Configuration	Brand/Model Name	Bin	CdA (Test)	Cd (Bin)	CRR	CRR	Idle Reduction	Weight Reduction	VSL
1	Western Star 1	Bin I	6	0.56	6	6	5	400	0
2	Western Star 2	Bin I	6	0.60	6	6	5	400	0
3	Western Star 3	Bin I	6	0.65	6	6	5	400	0

Figure 2 Example of Input file for Multiple Configuration Run

- Enter Manufacturer and Vehicle Family Names.
- Select the Model Year in row 2 and column B through a pull-down menu.
- Select one of twelve regulatory subcategories in row 4 and column B through a pull-down menu.
- Enter an input file name.
- Fill out the input parameters required by the GEM, such as Cd(Bin), CRR, Idle Reduction, Weight Reduction, and VSL. The instructions on how to enter these values is the same as those illustrated in the Single Configuration set up in the previous section.
- It is the user’s responsibility to input “configuration”, “Brand/Model Name”, “Bin”, and “CdA (Test)” for each case. These values are not used by the GEM during simulation, and they are only used for reference during certification.
- Save the file.
- Go back to GEM GUI (Figure 1).

- Click “Multiple Configurations” in Figure 1. A window that says “Select the xlsx input file for Multiple Configurations” will display as follows (Figure 3).

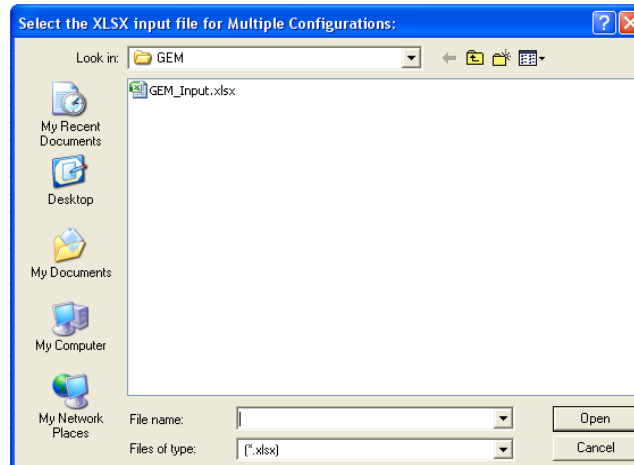
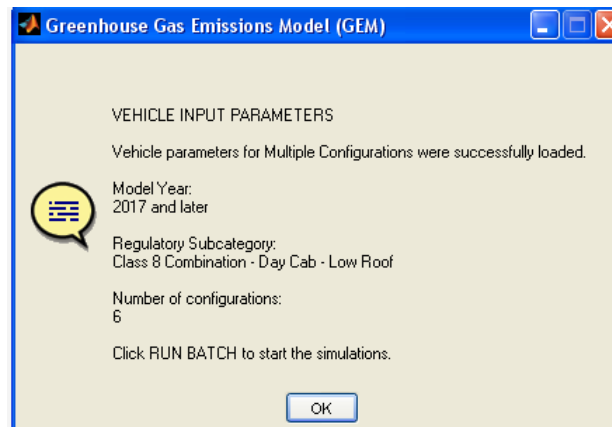
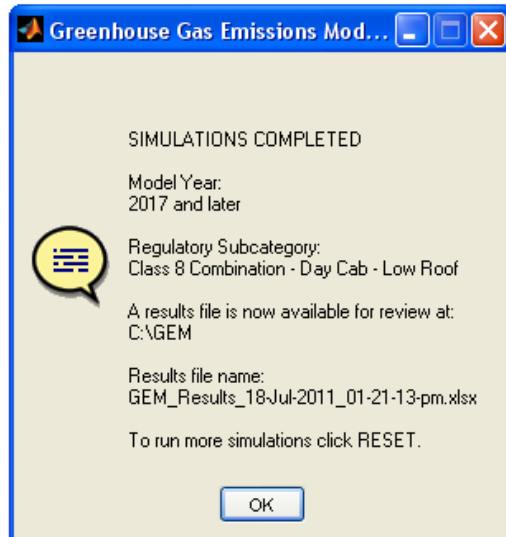


Figure 3 GEM Input File Selection

- Select the folder where the input file is located. Click the file, and then click open.
- The following window will appear. Click OK. The input file setup is completed.



- The RUN button in Figure 1 will be changed to RUN BATCH. Click RUN BATCH. Multiple Configurations will then run. A progress bar window will be displayed.
- Once simulation is completed, a window will open, prompting the user where the file is to be saved. Click OK to save the output file in your desired folder.
- After a few seconds, a window indicating completion of simulation will appear as follows. Click Ok. In the mean time, the Excel output file will open.



The same output file structure as the single configuration run is used, but with more results depending on the total number of cases running.

If the user wants to close the GEM program, click  on the GUI window.