CMAQ EMISSIONS CALCULATOR TOOLKIT

The purpose of the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) is to provide users a standardized approach to estimating emission reductions from the implementation of a CMAQ-funded project. The CMAQ Toolkit uses emission rates for highway vehicles based on a national-scale run of the Motor Vehicle Emission Simulator (MOVES) as well as other data sources. For each tool in the toolkit, the inputs and methodology are described in user guides along with some example cases. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses. Information regarding the development of default emission rates and guidance on incorporating user-supplied emission rates can be found in the accompanying documentation of the emissions data.

Transit Bus Upgrades & System Improvements Tool

The Transit Bus Upgrades and System Improvements Tool contains three modules: 1) retrofits of diesel transit buses with new emission reduction technologies, 2) replacements of diesel and compressed natural gas (CNG) transit buses (or engines) with either newer diesel, CNG, or alternative fuel (non-electric) buses, and 3) replacements of diesel and compressed natural gas (CNG) transit buses (or engines) with electric transit buses. Both of the replacement modules (2 & 3) allow for a restricted access infrastructure component, which may be selected in conjunction with or separate from a bus replacement project component.

This tool allows modeling of transit buses only. Emission benefits of other vehicle source types may be modeled using other CMAQ calculators for Diesel Retrofits, Diesel Repower/Replacements, Alternative Fuel Vehicle Fleet Purchase, or Electric Vehicle Fleet Purchase modules.[1]

The most current version is dated April 2022. To verify the version, check the date on the Introduction page of the tool. Release notes are included in the Change Log tab, which can be viewed by right-clicking on any tab in the tool, selecting “Unhide”, and revealing the tab.

This tool uses emission rates from the US Environmental Protection Agency’s (EPA) latest Motor Vehicle Emission Simulator (MOVES3)[2] and emission rate adjustment factors from the US Department of Energy’s Alternative Fuel Lifecycle Environmental and Economic Transportation (AFLEET 2020) Tool[3] for alternative fuel transit buses not included in MOVES. This tool considers only operating emissions[4] of transit buses and does not evaluate upstream (well-to-pump) emissions associated with production and transmission of fuel or manufacturing of transit buses. The specific setup of MOVES for generating the

[1] Other CMAQ tools can be found on the CMAQ website: https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/

[2] US Environmental Protection Agency, Office of Transportation and Air Quality, https://www.epa.gov/moves

[3] US Department of Energy, Argonne National Laboratory, https://greet.es.anl.gov/afleet_tool

[4] Emissions from running and start exhaust as well as brake and tire wear. This tool assumes the MOVES national average annual number of starts per bus. Analysis does not include evaporative emissions.

tool's national emission rates and instructions on importing local emission rates have been detailed in the Documentation of Emissions Data for the Transit Bus Upgrades and System Improvements Tool.[5] Appendix A provides information about the different alternative fuels included in this tool.

Non-EV Transit Bus Replacement Module

This module estimates changes in emissions from replacements of diesel and compressed natural gas (CNG) transit buses (or engines) with either newer diesel, CNG, or alternative fuel (non-electric) buses with or without the change in emissions resulting in changes in vehicle miles traveled to and from new restricted access infrastructure.

This document is organized into three sections for Non-EV Transit Bus Replacement – User Guide, Tool Methodology, and Examples – to aid the user in understanding and interpreting results from the calculator. The User Guide gives direction for the user to properly input values into the tool and provides definitions of both user inputs and tool outputs. The Tool Methodology outlines the steps taken to calculate emission reductions, and includes all equations used within the tool. The Examples section provides some examples of how to properly input information into the tool for different types of analysis.

Contents

USER GUIDE 3
User Inputs 3
Tool Outputs 6
Error Messages 7
TOOL METHODOLOGY 10
Replacement Project Methodology 10
Restricted Access Infrastructure Methodology 11
EXAMPLES 13
Example 1: Replacing diesel-fueled transit buses with Biodiesel (B100) (Population Known, VMT Unknown), No restricted access infrastructure component 13
Example 2: Replacing old diesel-fueled transit buses with newer diesel-fueled transit buses (Population and VMT Known), No restricted access infrastructure component 15
Example 3: Replacing CNG-fueled transit buses with Hybrid Electric (HEV) (Population and VMT Known) with the addition of new restricted access infrastructure 17
Example 4: Building Restricted Infrastructure for a Hydrogen Fuel Cell Transit Bus Fleet 19

[5] The Documentation of Emissions Data is available on the CMAQ website: https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/

Appendix A: Alternative Fuels and Advanced Engine Technologies 21

USER GUIDE

This section lists the input units and descriptions for each user input and tool output. A description of emission reductions reporting and error messages as well as other assumptions in the tool are also provided.

User Inputs

The interface of the Non-EV Transit Bus Replacement module functions as a wizarding tool, with questions intending to help the user input proper information for emission reduction calculations in a step-by-step process. The inputs for this tool should be specific to the conventional fuel transit buses that will be replaced by alternative fuel transit buses. The user-defined inputs are described in Table 1.

Table 1 User Inputs

Item	User Input	Units	Description
(1)	Project evaluation year	-----	Use the drop-down menu to choose a year from 2018 to 2040.
(2)	Project component: Non-EV Transit Bus Replacement	-----	Click on the box if your project incorporates a replacement component.
(2)	Project component: Restricted Access Infrastructure		Click on the box if your project incorporates new restricted access infrastructure.
REPLACEMENT			
(3)	Model year of current transit buses (buses to be replaced)	-----	Input the model year of the buses to be replaced. If you have a range of years, you may either input the individual years of transit buses separately or input a representative[6] year for all buses to be replaced. The model year cannot be later than the project year or more than 30 years prior to it. Please refer to CMAQ program guidance regarding appropriate model years eligible for funding. [7]
(4)	Fuel type of transit buses to be replaced	-----	Use the drop-down menu to select either diesel or CNG for the fuel type of the buses that will be replaced.

[6] "A representative year" indicates the model year of the majority of the transit buses to be replaced. A more accurate representative year can be estimated by taking a weighted average of the model years and number of buses of each model year, then round the result to an integer. For example, the weighted average model year for five 2010 buses and ten 2014 buses can be calculated by: (5*2010+10*2014) / (5+10) = 2012.7, users can take 2013 as the representative year in this case.

[7] US Department of Transportation, Federal Highway Administration, http://www.fhwa.dot.gov/environment/air_quality/cmaq/

Item	User Input	Units	Description
(5a)	Activity data: vehicle miles traveled to be replaced (check box)	-----	Click on the box if you know the annual vehicle miles traveled for the vehicles to be replaced. This option may be checked concurrently with the transit bus population option.
(5a)	Activity data: transit bus population to be replaced (check box)	-----	Click on the box if you know the number of buses to be replaced. This option may be checked concurrently with the vehicle miles traveled option.
(5b)	Annual total vehicle miles traveled to be replaced (input value)	miles	Input the total value of annual vehicle miles traveled for the entire fleet of transit buses to be replaced (i.e., 60,000 miles each for 10 buses would result in an input of 600,000 miles).
(5b)	Transit bus population to be replaced (input value)	vehicles	Input the number of buses to be replaced. The default value is one bus.
(6)	Model year of replacement transit buses	-----	Input the model year of the replacement transit buses. If you have a range of years, you may either input the individual years of buses separately or input a representative year for all replacement (i.e., newer) buses. The model year cannot be later than the project year or more than 30 years prior to it. Please refer to CMAQ program guidance regarding appropriate model years eligible for funding.
(7)	Fuel type of replacement transit buses	-----	Use the drop-down menu to select the alternative fuel type of the replacement buses. Not all vehicle type-fuel type combinations are allowable and some combinations will produce an error (see more information on error messages in Table 4 below).
INFRASTRUCTURE			
(8)	Model year of current transit buses (transit buses to be replaced)	-----	Input the model year of the buses to be replaced. If you have a range of years, you may either input the individual years of transit buses separately or input a representative[8] year for all buses to be replaced. The model year cannot be later than the project year or more than 30 years prior to it. Please refer to CMAQ program guidance regarding appropriate model years eligible for funding. [9]

[8] "A representative year" indicates the model year of the majority of the transit buses to be replaced. A more accurate representative year can be estimated by taking a weighted average of the model years and number of buses of each model year, then round the result to an integer. For example, the weighted average model year for five 2010 buses and ten 2014 buses can be calculated by: (5*2010+10*2014) / (5+10) = 2012.7, users can take 2013 as the representative year in this case.

[9] US Department of Transportation, Federal Highway Administration, http://www.fhwa.dot.gov/environment/air_quality/cmaq/

Item	User Input	Units	Description
(9)	Fuel type of transit buses to be replaced	-----	Use the drop-down menu to select either diesel or CNG for the fuel type of the buses that will be replaced. Note: Questions 8 and 9 are only applicable if the user chooses only the restricted access infrastructure component in question 2. These questions are grayed out if the user chooses the replacement component as this information is covered by questions 6 and 7.
(10)	Change in fueling distance	-----	In order to calculate any impact on emissions, users must select whether the restricted-access alternative fuel infrastructure will increase, decrease. Note that this tool only provides results with a change in fueling distance.
(11)	Distance changed for fueling	miles	Enter in the expected change in annual vehicle miles traveled for fueling of the alternative fuel fleet after construction of the restricted-access infrastructure.

Once the parameters are input, click on the 'Calculate Output' button to calculate results. Emission results will not automatically update, so anytime changes are made to the input parameters, this button must be pushed to calculate the updated emission reductions. If you would like to return to default settings, please click on the 'Reset to Default Values' button.

Activity Information

Users must provide some information on their fleet activity to estimate benefits. The Non-EV Transit Bus Replacement module prompts users to enter the total vehicle miles traveled for the fleet, the bus population, or both. If a user enters only one piece of activity information, the tool utilizes MOVES3 national activity rates to obtain the other piece of activity information. Providing both activities for this tool will likely provide the best estimation of emission reductions from a transit bus replacement project.

The module assumes one-to-one replacement of vehicle miles traveled and population from the conventional fuel fleet to the alternative fuel fleet. That is, new alternative fuel vehicles are expected to be operated in the same way as the conventional fuel vehicles they are replacing. Any vehicles or activity by the alternative fuel fleet or conventional fuel fleet not directly displaced will need to be accounted for outside of the tool.

Vehicle Type

This module applies to one vehicle type: Transit Bus. MOVES uses the National Transit Database's motor bus (MB) definition[10], a transit mode comprised of rubber-tired passenger vehicles operating on fixed routes and schedules over roadways. This tool pertains to standard 40-foot low floor transit buses, as

[10] US Federal Transit Administration, National Transit Database (NTD) glossary, https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary

described in procurement guidelines from the American Public Transportation Association (APTA).[11] Transit buses are regulated under separate emission standards.[12] The emission rates, activity, and population assumptions are all based on MOVES sourceTypeID 42. Information on the default transit bus weights can be found in the MOVES3 technical report on fleet composition.[13] Other transit vehicles, such as shuttles and smaller buses, may be modeled through other tools in the CMAQ Toolkit.[1]

Fuel Type

Transit buses in this module can be powered by diesel, CNG, and alternative fuel engines. Diesel and CNG emission rates are from MOVES. The AFLEET Tool provides adjustment factors to adjust MOVES emission rates for a variety of alternative fuels and advanced engine technologies. This tool uses AFLEET adjustment factors, which provides emission estimates for different hybrids, renewable fuels, natural gas, propane, and hydrogen (fuel cell). Some basic definitions of these alternative fuels and technologies have been included in Appendix A. The methodology for creating the AFLEET adjustment factors can be found in documentation of the AFLEET tool.[14]

Tool Outputs

Fleet Performance

The fleet performance (non-emission) outputs for replacement projects are detailed below in Table 2. These outputs are particularly useful when relying on national default estimates for annual miles traveled per bus. Note that this output will only calculate if the user selects the Non-EV Transit Bus Replacement as a project component, either with the Restricted Access Infrastructure component or on its own.

Table 2 Transit Bus Performance Output

Output	Units	Description
Annual Total Vehicle Miles Traveled	miles	The total vehicle miles traveled annually by the replaced transit buses, either input by the user or calculated based on transit bus population using national activity rates from MOVES.
Annual Transit Bus Population	vehicles	The number of transit buses to be replaced, either input by the user or calculated based on annual total replaced vehicle miles traveled using national activity rates from MOVES.

[11] American Public Transportation Association, "Standard Bus Procurement Guidelines – Low Floor Diesel," http://www.apta.com/resources/reportsandpublications/Documents/lfdiesel.pdf.
[12] See 40 CFR 86.091-2, Legal Information Institute, Cornell University Law School, https://www.law.cornell.edu/cfr/text/40/86.091-2
[13] Population and Activity of On-road Vehicles in MOVES3 https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=541815
[14] DOE, https://greet.es.anl.gov/files/afleet-tool-2016-user-guide

Output	Units	Description
Annual Miles Traveled per Vehicle	miles	The average annual vehicle miles traveled by each replaced transit bus. It is calculated by the annual total vehicles miles traveled divided by the bus population. Note, if population is not provided as an input, this output is based on MOVES national estimates, assumes a minimum population of one bus, and calculates VMT based on non-integer population values.

Emission Reductions

The Transit Bus Replacement module assumes that the user is replacing diesel or CNG fueled buses with newer diesel, CNG, or alternative fuel buses. The benefits are derived from the difference in exhaust emission rates between the two fuels and/or vehicle model years. Certain pollutants, vehicle types, and model years may lead to specific dis-benefits, such that the new fleet of vehicles are emitting more than the existing fleet of vehicles. Dis-benefits are displayed as negative values in tool outputs.

Emission reductions are calculated for five pollutants – Carbon Monoxide (CO), Particulate Matter 2.5 micrometers or smaller ($PM_{2.5}$), Particulate Matter 10 micrometers or smaller (PM_{10}), Nitrogen Oxides (NOx), and Volatile Organic Compounds (VOC) – in kilograms/year, and then are divided by 365 for the CMAQ daily emission reductions reporting in kilograms/day. In the event a different annualized reporting rate is desired, users can multiply their daily results by 365 and then divide by their chosen number of days annually (e.g., 250 working days). Reductions in greenhouse gases are also calculated in terms of carbon dioxide (CO_2) and carbon dioxide equivalent (CO_2e) – in kilograms per day, and total energy consumed (TEC) in million BTU.

Error Messages

Table 3 below summarizes any error and warning messages associated with this module, the reasons for those errors, and possible solutions. More information to guide solutions to errors are provided below the table. Note that once the error is corrected, please press 'Calculate Output' again to estimate emissions.

Table 3 Error Messages

Error Message	Reason for Error	Solution
ERROR: Please enter an appropriate project evaluation year.	Invalid input for project evaluation year	Input a year between 2018 and 2040
Project Component Error: Choose at least one project component.	No project component in question (1) is selected	Select either the Non-EV Transit Bus Replacement option, the Restricted Access Infrastructure option, or both

ERROR: This tool includes model years going back to a maximum of 30 years for the given evaluation year. Please choose an appropriate model year within this range.	Invalid input for model year of the transit buses in questions (3) and/or (6) for replacement project selection (checkbox in question (2)) or question (8) for restricted access infrastructure project selection.	Input an appropriate model year between the evaluation year and 30 years prior to that evaluation year
Activity Data Error: Choose at least one activity type.	No activity type in question (5a) is selected.	Select at least one activity type
Activity Data Error: Vehicle activity cannot be less than one.	Invalid input for vehicle activity in question (5b).	Input a number for annual transit bus population that is greater than one
Activity Data Error: Vehicle population cannot be less than one.	Invalid input for vehicle population in question (5b).	Input a number for annual total vehicle miles traveled that is greater than one
Please completely fill out inputs before calculating output.	Replacement project selection in question (2): No input for any of the following questions (1), (3) - (7) or no activity type in question (5a) is selected.	Either make selections or input values. Note that you need to select at least one activity type
Please completely fill out inputs before calculating output.	Restricted access infrastructure selection only in question (2): No input for any of the following questions (1), (8), (9), (10), or (11).	Either make selections or input values.
Change in Distance Error: Change in distance must be greater than zero.	Invalid input for change in vehicle miles traveled in question (11).	Input a number for change in vehicle miles traveled that is greater than zero
WARNING: There is not test data available to estimate the emissions or the national default activity from buses with these model years and fuel types, the tool will report zero emission reductions and/or activities.	Invalid input for model year or fuel type of transit buses.	Input an appropriate model year between the evaluation year and 30 years prior to that evaluation year, or change the fuel type

Data Insufficiency: Not every model year or fuel type will produce results in this CMAQ tool. Some AFLEET alternative fuels have factors for every MOVES source type and other fuels do not. Table 4 below shows which fuels have MOVES emission rates or non-zero AFLEET factors. For more information on the AFLEET factors, please consult the Greenhouse Gases, Regulated Emissions, and Energy use in

Transportation Model (GREET) documentation on analyzing heavy-duty vehicle emission rates[15] and updating GREET emission factors with MOVES data[16] accordingly.

MOVES data have some minor gaps in transit bus emission rates as well, namely for CNG buses before their phase-in period, where results will appear as zero.[17] Please consult the most recent MOVES technical report on vehicle populations and activity[18] and the latest default MOVES database[19] for identifying data gaps. As noted above, for combinations without data, warnings will pop up and any subsequent emission reductions will appear as zero.

Table 4 Alternative fuels available in this tool for transit bus replacement[20]

Replacement Fuel	Data Source
Diesel Fuel	M
Compressed Natural Gas (CNG)	M
Biodiesel (B100)	A
Biodiesel (B20)	A
Hybrid Electric (HEV)	A
Hydraulic Hybrid (HHV)	A
Liquefied Natural Gas (LNG)	A
Dual Fuel (Natural Gas/Diesel, LNG/D)	A
Hydrogen Fuel Cell (FCV)	A
M = MOVES emission rates, **A =** AFLEET factors combined with conventional fuel emission rates	

For reference, the AFLEET factors are based on diesel for heavy-duty vehicles (HDVs). By default, transit buses are considered as HDVs, therefore, this tool uses diesel-based AFLEET factors and MOVES rates for transit buses to calculate the alternative fuel rates.

Lack of AFLEET Factors for CO_2, CO_2e and TEC: Another source of data insufficiency is AFLEET's lack of alternative fuel factors for carbon dioxide (CO_2), carbon dioxide equivalent emissions (CO_2e) or total energy consumption (TEC). Because AFLEET does not contain factors for these pollutant metrics, the Replacement module of this tool will not output emissions reduction results if the replacement vehicles are of a fuel type that uses AFLEET factors to compute emissions rates for the replacement vehicles. Therefore, CO_2, CO_2e, and TEC are only output by the tool if the replacement fuel type is Diesel Fuel or Compressed Natural Gas. If the replacement fuel type is any of the other available fuel types, the

[15] DOE, https://greet.es.anl.gov/publication-heavy-duty
[16] DOE, https://greet.es.anl.gov/publication-vehicles-13
[17] For example, there are no CNG fueled transit buses before model year 1990 in MOVES2014a.
[18] EPA, *Population and Activity of On-road Vehicles in MOVES2014*, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100O7VJ.pdf
[19] EPA, https://www.epa.gov/moves/moves2014a-latest-version-motor-vehicle-emission-simulator-moves
[20] There is not sufficient test data to estimate emissions of propane (LPG) or ethanol (E85) transit buses, so these fuel types were not included in this tool.

outputs for these two metrics will be "N/A", and the interface will display a warning note adjacent to the output cells.

Evaluation years: Evaluation year and model year information: Evaluation years range from 2018 to 2040 and model years can range from the evaluation year to 30 years prior to that evaluation year. MOVES only generates results for model years in that 30-year window. The tool will generate error messages if a user selects a disallowed fuel type or an erroneous year.

TOOL METHODOLOGY

Replacement Project Methodology

This tool allows the users to calculate emission reductions of replacing a diesel or CNG fuel transit bus with a newer bus (diesel, CNG, or alternative fuel). The equation below describes the tool's calculation for emission reductions when transit buses are replaced by diesel, CNG, or alternative fuel buses. The emissions of a given pollutant reduced by replacing a diesel or CNG transit bus are reported in kilograms/day for the total number of buses replaced as followed:

$$\begin{aligned} &reduced\ emissions \\ &= \left[\left(e_{running\ \ to\ be\ replaced} - e_{running\ \ replacement}\right) \cdot VMT_{fleet}\right. \\ &\left. + \left(e_{starts\ \ to\ be\ replaced} - e_{starts\ \ replacement}\right) \cdot POP_{fleet}\right]/365 \end{aligned} \quad (1)$$

where for diesel bus replacement,

$$e_{(running\ \ or\ starts)\ replacement} = e_{MOVES_{diesel}} \quad (2)$$

where for CNG bus replacement,

$$e_{(running\ \ or\ starts)\ replacement} = e_{MOVES_{CNG}} \quad (3)$$

where for other alternative fuel bus replacement,

$$e_{(running\ \ or\ starts)\ replacement} = e_{MOVES_{diesel}} \cdot A_{alt} \quad (4)$$

where:

$e_{running\ to\ be\ replaced}$ = running emission rate for to be replaced transit bus of a specified fuel type (diesel or CNG) and model year of the transit bus to be replaced (kilogram/mile),

$e_{starts\ to\ be\ replaced}$ = start emission rate for to be replaced transit bus of a specified fuel type (diesel or CNG) and model year of the transit bus to be replaced (kilogram/vehicle),

VMT_{fleet} = total annual vehicle miles traveled by the transit bus to be replaced (miles),

POP_{fleet} = total number of alternative fuel transit buses to be replaced,

$e_{running\ replacement}$ = emission rate for replacement transit bus of specified fuel type and model year (kilogram/mile),

$e_{starts\ replacement}$ = emission rate for replacement transit bus of specified fuel type and model year (kilogram/mile),
A_{alt} = AFLEET factor for a specified alternative fuel, determined by pollutant,
$e_{MOVES_{diesel}}$ = MOVES diesel transit bus emission rate for a given model year (kilogram/mile), and
$e_{MOVES_{CNG}}$ = MOVES CNG transit bus emission rate for a given model year (kilogram/mile).

Either vehicle miles traveled or population is required for proper calculation of emission reductions. If only one of these inputs is provided by the user, the other parameter is calculated using the relationship below, such that the parameter not defined by the user is reliant on the national default ratio of VMT to Bus Population:

$$VMT_{fleet} = POP_{fleet}\left(\frac{VMT_{national}}{POP_{national}}\right) \quad (5)$$

where:
$VMT_{national}$ = national vehicle miles traveled from MOVES defaults for transit buses to be replaced by the specified model year and fuel type in the given project year, and
$POP_{national}$ = national vehicle populations from MOVES defaults for transit buses to be replaced by the specified model year and fuel type in the given project year.

Restricted Access Infrastructure Methodology

Emission reductions, reported in kilograms/day for the construction of alternative fuel infrastructure with restricted access, are calculated for a given pollutant as followed:

$$reduced\ emissions = \frac{e_{alt} \cdot \Delta VMT_{fleet}}{365} \quad (1)$$

where for E85 and fuel cell LDVs,

$$e_{alt} = e_{alt\ MOVES} \quad (2)$$

and where for all other alternative fuel vehicles,

$$e_{alt} = e_{conv\ purc\ hase} \cdot A_{alt} \quad (3)$$

such that,
e_{conv} = annual conventional fuel (diesel or gasoline) emission rate for the model year of the transit buses to be purchased (kilogram/mile) in the selected evaluation year,
e_{alt} = annual alternative fuel emission rate for the model year of the vehicles to be purchased (kilogram/mile),

$e_{alt_{MOVES}}$ = alternative fuel emission rate pulled directly from MOVES (kilogram/mile),

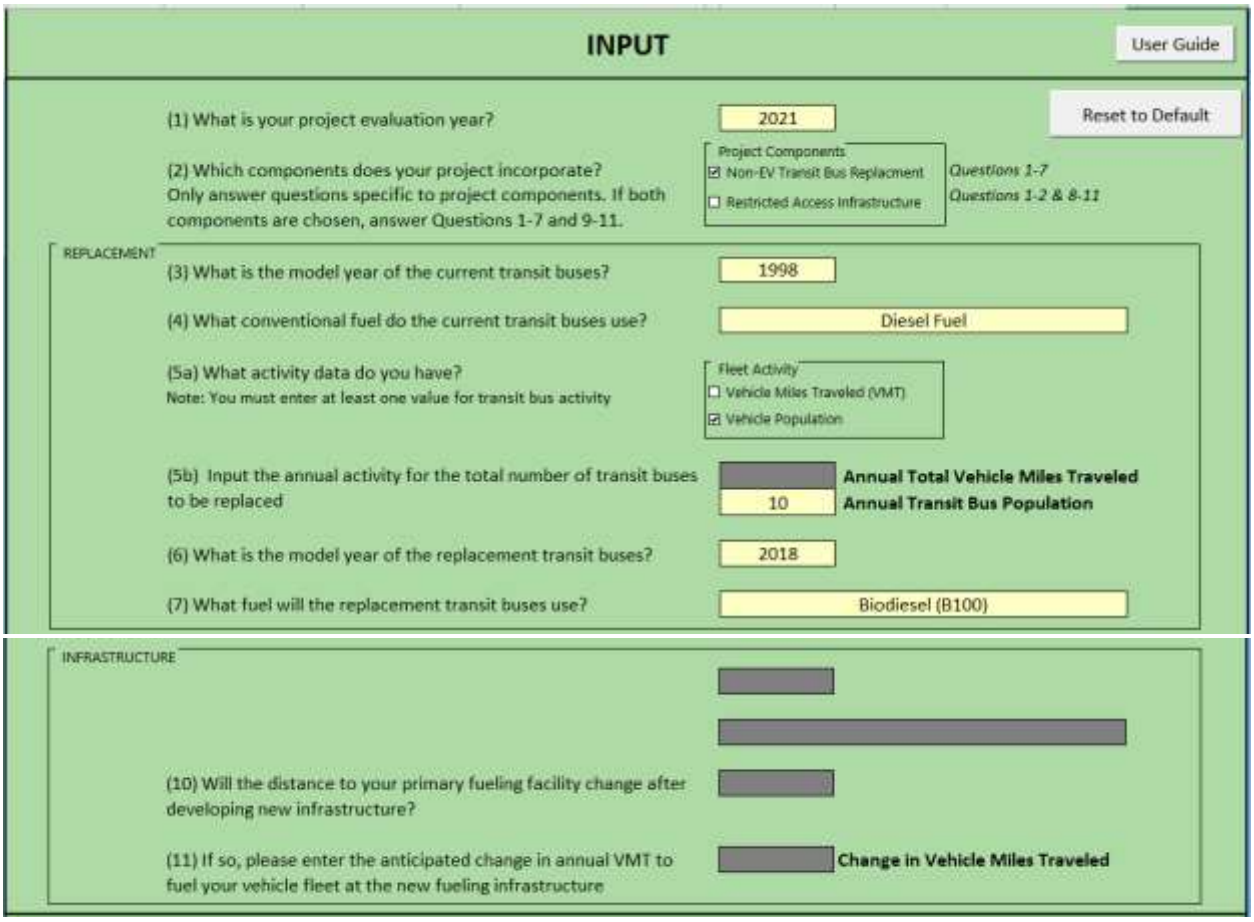
A_{alt} = AFLEET factor for transit buses with a specified alternative fuel, determined by pollutant, and

ΔVMT_{fleet} = change in annual distance traveled to refuel the alternative fuel fleet after construction of restricted access infrastructure (miles).

EXAMPLES

Example 1: Replacing diesel-fueled transit buses with biodiesel (B100) (Population Known, VMT Unknown), No restricted access infrastructure component

A county transportation provider would like to replace 10 diesel-fueled buses with 10 B100-fueled buses for their transit fleet. The county does not have activity data for the conventional fuel fleet being replaced, so they will rely on national default values of annual miles traveled per vehicle. The project will not include the addition of any restricted access fueling infrastructure. The following inputs would be chosen, as shown in the screen shot below:

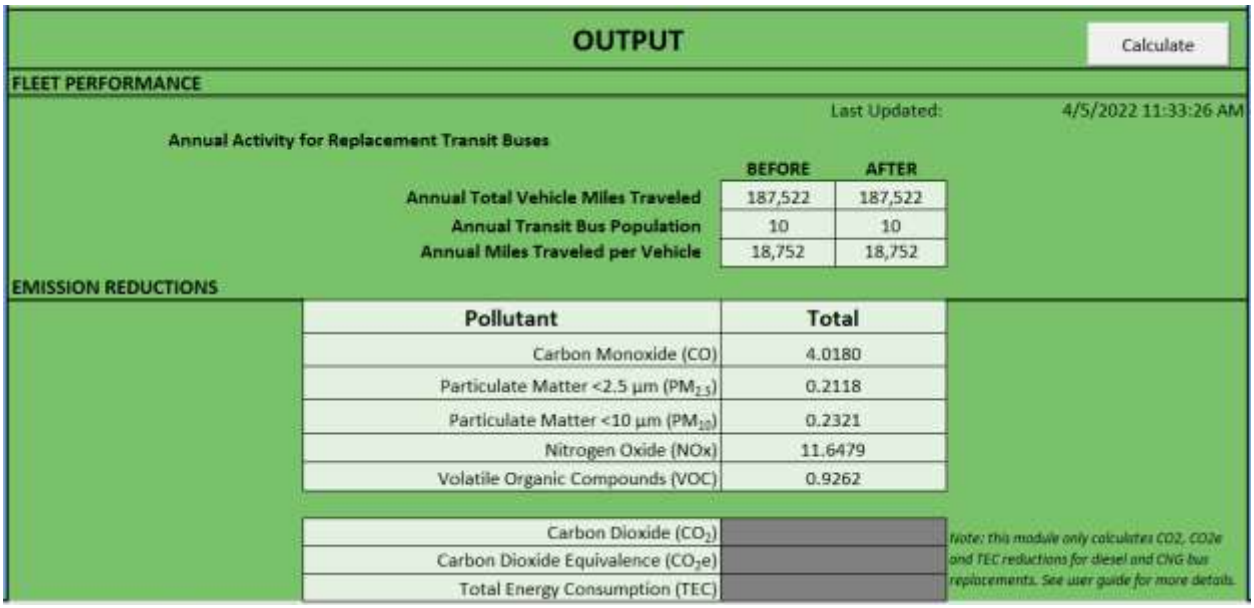


Project Year: 2021
Non-EV Transit Bus Replacement [check box]: Selected
Restricted Access Infrastructure [check box]: Unselected
Model Year for Conventional Fuel Buses: 1998
Conventional Fuel: Diesel
Vehicle Miles Traveled [check box]: Unselected
Transit Bus Population [check box]: Selected
Transit Bus Population: 10

Model Year of Alternative Fuel Buses: 2018
Alternative Fuel: Biodiesel (B100)

Questions 8 & 9 (grayed out) and questions 10 & 11 are only applicable if the restricted access infrastructure project component check box is selected and can thus be skipped for this example.

Once the inputs are entered, select the 'Calculate Output' button to estimate fleet performance and emission for the project, as shown below:



OUTPUT Calculate

FLEET PERFORMANCE

Last Updated: 4/5/2022 11:33:26 AM

Annual Activity for Replacement Transit Buses

	BEFORE	AFTER
Annual Total Vehicle Miles Traveled	187,522	187,522
Annual Transit Bus Population	10	10
Annual Miles Traveled per Vehicle	18,752	18,752

EMISSION REDUCTIONS

Pollutant	Total
Carbon Monoxide (CO)	4.0180
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.2118
Particulate Matter <10 µm (PM_{10})	0.2321
Nitrogen Oxide (NOx)	11.6479
Volatile Organic Compounds (VOC)	0.9262
Carbon Dioxide (CO_2)	
Carbon Dioxide Equivalence (CO_2e)	
Total Energy Consumption (TEC)	

Note: this module only calculates CO2, CO2e and TEC reductions for diesel and CNG bus replacements. See user guide for more details.

In the absence of user-supplied vehicle miles traveled data, this tool uses national rates to calculate VMT. For this example, the tool estimates that a total of 187,522 miles are traveled by ten, 20 year-old buses in the fleet.

The emission reductions for all five pollutants are:

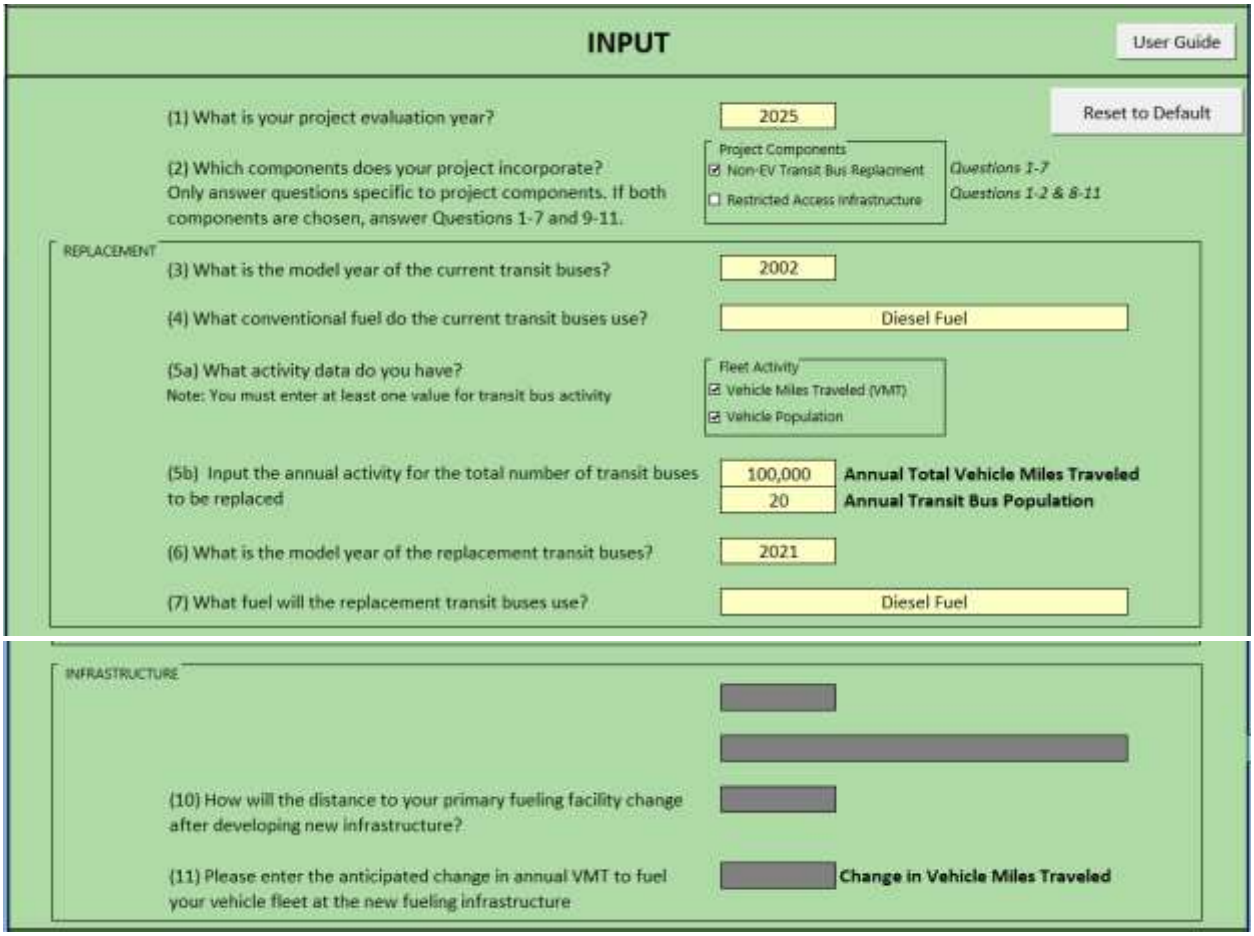
Carbon Monoxide (CO): 4.0180
Particulate Matter ($PM_{2.5}$): 0.2118
Particulate Matter (PM_{10}): 0.2321
Nitrogen Oxide (NOx): 11.6479
Volatile Organic Compounds (VOC): 0.926

Carbon Dioxide (CO_2): N/A
Carbon Dioxide Equivalents (CO_2e): N/A
Total Energy Consumption (TEC): N/A

This tool does not calculate results for CO_2, CO_2eq, or TEC for alternative fuel types, such as Biodiesel (B100) as in this example.

Example 2: Replacing old diesel-fueled transit buses with newer diesel-fueled transit buses (Population and VMT Known), No restricted access infrastructure component

A county transit provider is interested in replacing 20 old diesel-fueled buses with 20 newer diesel-fueled buses for their transit fleet, and knows its activity rates of the fleet. It is possible to use the tool for this situation by selecting diesel under both the conventional fuel (question #4) and the replacement fuel (question #7).

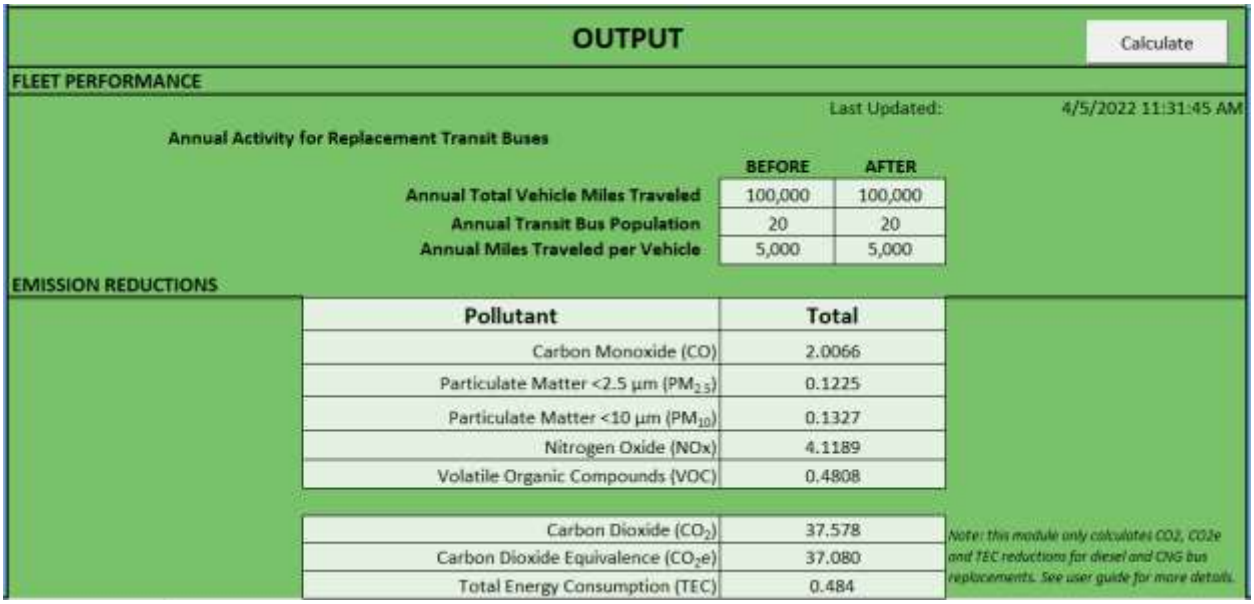


Project Year: 2025
Non-EV Transit Bus Replacement [check box]: Selected
Restricted Access Infrastructure [check box]: Unselected
Model Year for Conventional Fuel Transit Buses: 2002
Conventional Fuel: Diesel
Vehicle Miles Traveled [check box]: Selected
Transit Bus Population [check box]: Selected
Vehicle Miles Traveled: 100,000 (total for 20 buses)
Transit Bus Population: 20

Model Year of Alternative Fuel Transit Buses: 2021
Replacement Fuel: Diesel

Questions 8 & 9 (grayed out) and questions 10 & 11 are only applicable if the restricted access infrastructure project component check box is selected and can thus be skipped for this example.

Pressing the Calculate Output button computes fleet performance and emission reductions of the 20 diesel transit buses being replaced with newer diesel buses, as shown below:



OUTPUT

Calculate

FLEET PERFORMANCE

Last Updated: 4/5/2022 11:31:45 AM

Annual Activity for Replacement Transit Buses

	BEFORE	AFTER
Annual Total Vehicle Miles Traveled	100,000	100,000
Annual Transit Bus Population	20	20
Annual Miles Traveled per Vehicle	5,000	5,000

EMISSION REDUCTIONS

Pollutant	Total
Carbon Monoxide (CO)	2.0066
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.1225
Particulate Matter <10 µm (PM_{10})	0.1327
Nitrogen Oxide (NOx)	4.1189
Volatile Organic Compounds (VOC)	0.4808

Carbon Dioxide (CO_2)	37.578
Carbon Dioxide Equivalence (CO_2e)	37.080
Total Energy Consumption (TEC)	0.484

Note: this module only calculates CO2, CO2e and TEC reductions for diesel and CNG bus replacements. See user guide for more details.

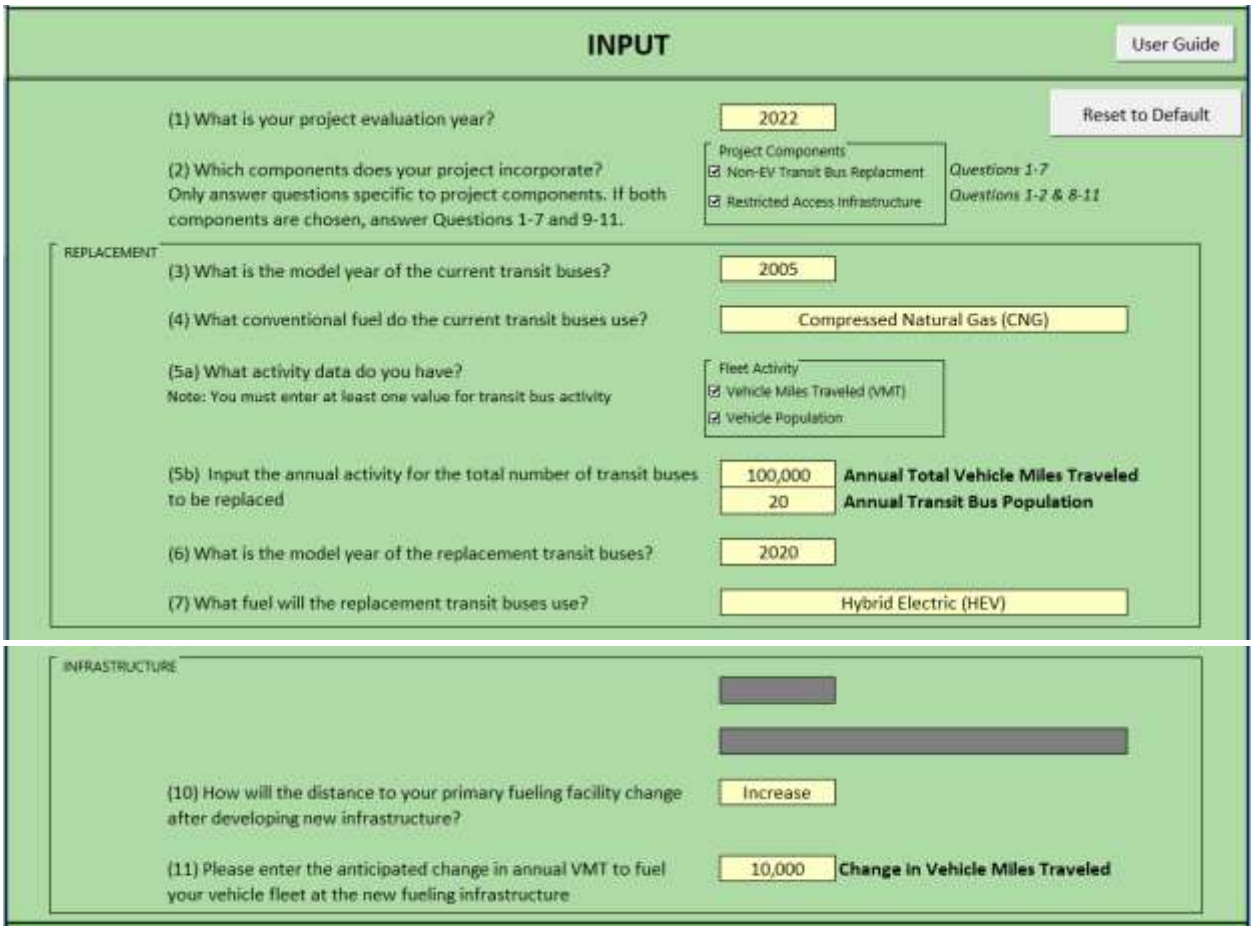
The emission reductions for all five pollutants are:

Carbon Monoxide (CO): 2.0006
Particulate Matter ($PM_{2.5}$): 0.1225
Particulate Matter (PM_{10}): 0.1327
Nitrogen Oxide (NOx): 4.1189
Volatile Organic Compounds (VOC): 0.4808

Carbon Dioxide (CO_2): 37.578
Carbon Dioxide Equivalents (CO_2e): 37.080
Total Energy Consumption (TEC): 0.484

Example 3: Replacing CNG-fueled transit buses with hybrid electric (HEV) buses (Population and VMT Known) with the addition of new restricted access infrastructure

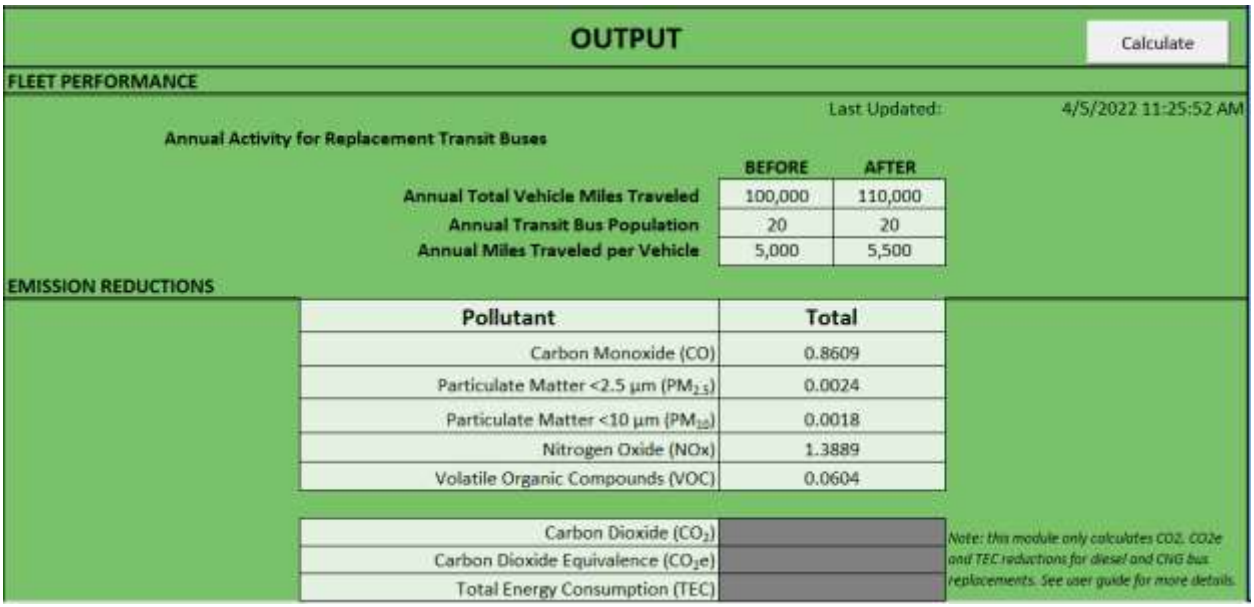
The county transit provider would like to replace 20 of their CNG transit buses with HEV transit buses, and knows activity rates of its bus fleet. In this case, the county provides both the vehicle miles traveled and population. The county is also planning to build a new restricted access bus depot for the HEV buses that increases the total VMT of the fleet by 10,000. For this example, the following inputs have been selected:



Project Year: 2022
Non-EV Transit Bus Replacement [check box]: Selected
Restricted Access Infrastructure [check box]: Selected
Model Year for Conventional Fuel Transit Buses: 2005
Fuel to be replaced: Compressed Natural Gas (CNG)
Vehicle Miles Traveled [check box]: Selected
Transit Bus Population [check box]: Selected
Vehicle Miles Traveled: 100,000 (total for 20 buses)
Transit Bus Population: 20

Model Year of Alternative Fuel Transit Buses: 2020
Alternative Fuel: Hybrid Electric (HEV)
Type of Change in Distance: Increase
Change in VMT: 10,000

Pressing the Calculate Output button computes fleet performance and emission reductions of the 20 CNG transit buses being replaced with HEV buses with the addition of building new restricted infrastructure, as shown below:



OUTPUT

Calculate

FLEET PERFORMANCE

Last Updated: 4/5/2022 11:25:52 AM

Annual Activity for Replacement Transit Buses

	BEFORE	AFTER
Annual Total Vehicle Miles Traveled	100,000	110,000
Annual Transit Bus Population	20	20
Annual Miles Traveled per Vehicle	5,000	5,500

EMISSION REDUCTIONS

Pollutant	Total
Carbon Monoxide (CO)	0.8609
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.0024
Particulate Matter <10 µm (PM_{10})	0.0018
Nitrogen Oxide (NOx)	1.3889
Volatile Organic Compounds (VOC)	0.0604

Carbon Dioxide (CO_2)	
Carbon Dioxide Equivalence (CO_2e)	
Total Energy Consumption (TEC)	

Note: this module only calculates CO2, CO2e and TEC reductions for diesel and CNG bus replacements. See user guide for more details.

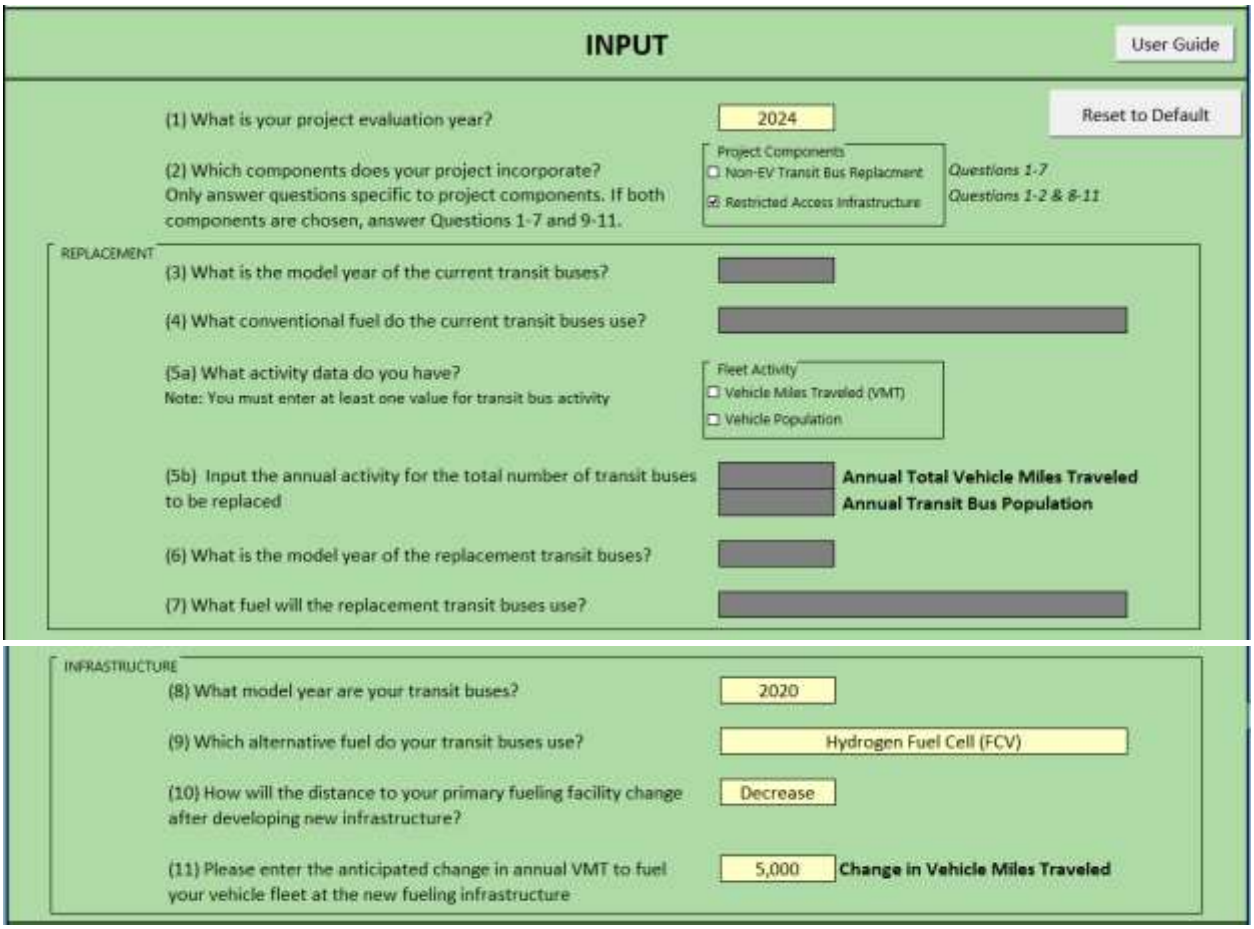
The emission reductions for all five pollutants are:

Carbon Monoxide (CO): 0.8609
Particulate Matter ($PM_{2.5}$): 0.0024
Particulate Matter (PM_{10}): -0.0018
Nitrogen Oxide (NOx): 1.3889
Volatile Organic Compounds (VOC): 0.0604

Carbon Dioxide (CO_2): N/A
CO_2e (CO_2e): N/A
Total Energy Consumption (TEC): N/A

Example 4: Building Restricted Infrastructure for a Hydrogen Fuel Cell Transit Bus Fleet

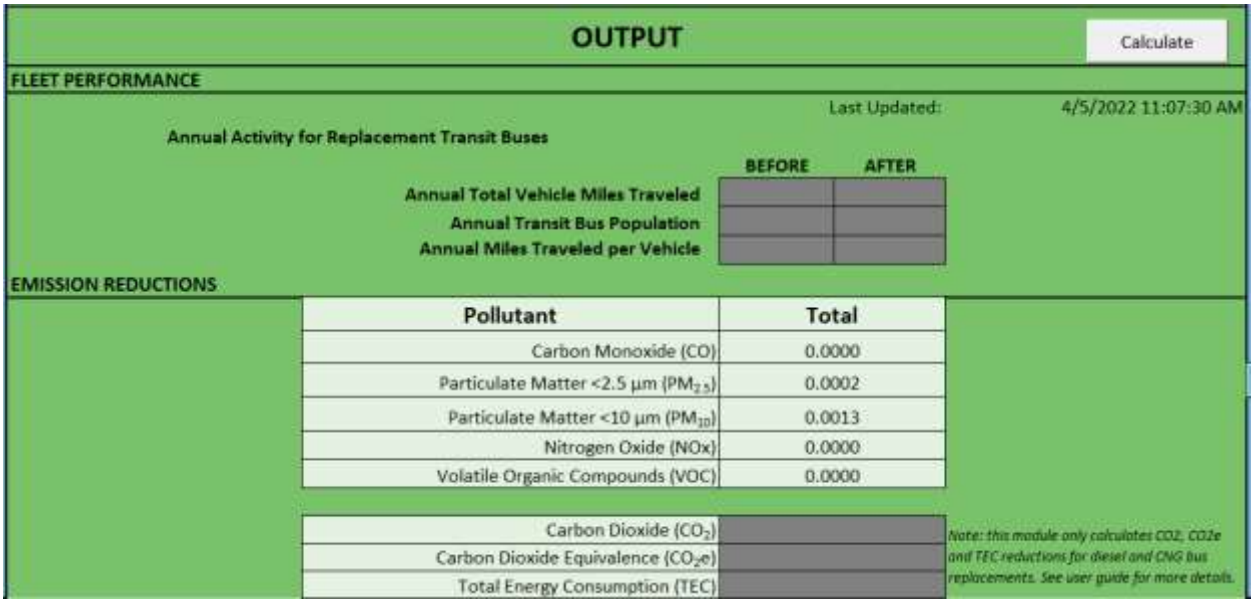
A county transit provider recently bought model year 2020 hydrogen fuel cell transit buses and would like to build new restricted access infrastructure to fuel the buses in 2024. The transit provider estimates that the new hydrogen fuel cell infrastructure will allow the fleet to avoid 5,000 miles per year to fuel elsewhere. For this example, the following inputs have been selected:



Project Year: 2024
Non-EV Transit Bus Replacement [check box]: Unselected
Restricted Access Infrastructure [check box]: Selected
Model Year of Alternative Fuel Transit Buses: 2020
Alternative Fuel: Hydrogen Fuel Cell (FCV)
Type of Change in Distance: Decrease
Change in VMT: 5,000

Questions 3 through 7 are applicable only to replacement projects and may be skipped for this example.

Pressing the Calculate Output button computes fleet performance and emission reductions of building a new restricted access fueling facility that decreases annual VMT by 5,000 miles, as shown below:



OUTPUT

Calculate

FLEET PERFORMANCE

Last Updated: 4/5/2022 11:07:30 AM

Annual Activity for Replacement Transit Buses

	BEFORE	AFTER
Annual Total Vehicle Miles Traveled		
Annual Transit Bus Population		
Annual Miles Traveled per Vehicle		

EMISSION REDUCTIONS

Pollutant	Total
Carbon Monoxide (CO)	0.0000
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.0002
Particulate Matter <10 µm (PM_{10})	0.0013
Nitrogen Oxide (NOx)	0.0000
Volatile Organic Compounds (VOC)	0.0000

Carbon Dioxide (CO_2)	
Carbon Dioxide Equivalence (CO_2e)	
Total Energy Consumption (TEC)	

Note: this module only calculates CO2, CO2e and TEC reductions for diesel and CNG bus replacements. See user guide for more details.

Appendix A: Alternative Fuels and Advanced Engine Technologies

A **hybrid electric vehicle (HEV)** uses a combination of an electric motor and an internal combustion engine to propel the vehicle. Usually hybrids have downsized engines, this coupled with power from an on-board battery system to the electric drivetrain, leads to better fuel efficiency than non-hybridized models.[21] The most common example of a gasoline HEV is a Toyota Prius, which charges its batteries through regenerative braking. At low speeds, a Prius is powered entirely by its batteries and electric motor. Specialized designs such as plug-in hybrid electric vehicles (PHEVs) and extended range electric vehicles (EREVs) are part of this broader hybrid electric category.

A **hydraulic hybrid vehicle (HHV)** utilizes a pressurized fluid system rather than batteries for chemical energy storage but operates much in the same way as a hybrid electric vehicle. Hydraulic hybrids, like HEVs, capture energy for storage through regenerative braking.[22] Hydraulic hybrids also offer better fuel economy and often lower emissions than comparable non-hybridized vehicles.

A **battery electric vehicle (BEV)**, or an all-electric vehicle, uses a battery pack to store electrical energy that powers the motor entirely. EVs are charged through plugging the vehicle into an electric power source, and even though electricity production may contribute to air pollution based on the power source makeup of the electrical grid, the EPA classifies EVs as zero-emission vehicles due to their lack of direct exhaust and tailpipe emissions.[23] Any emissions associated with EVs come from brakewear and tirewear particulate matter emissions.

A **hydrogen electric vehicle (FCV)** also uses an electric motor instead of an internal combustion engine and therefore has no smog-related or greenhouse gas tailpipe emissions. FCVs are not recharged through plugging in to a power source like EVs, instead generating electricity through the combination of hydrogen (H_2) gas from the fuel tank and oxygen (O_2) from the air. The only byproducts of this process are water and heat. FCVs can be refueled at designated hydrogen dispensers at public stations and refill within 5 minutes. The fuel economy of FCVs can be close to 70 miles per gasoline gallon equivalent (MPGe). Similar to EVs, emissions associated with FCVs come from brakewear and tirewear particulate matter emissions.[24]

Natural gas is increasingly being used as a transportation fuel. Most commonly natural gas is distributed as a pressurized gas or in liquid form. Some original equipment manufacturers (OEMs) produce natural gas vehicles like the now discontinued Honda Civic GX that ran on **compressed natural gas (CNG)**, but many natural gas vehicles are retrofitted conventional fuel vehicles with aftermarket conversion kits. These vehicles may be either dedicated for natural gas or use a system that runs on a conventional fuel and natural gas. A **dual fuel vehicle** uses diesel for pilot ignition and natural gas for propulsion. CNG is dispensed at 3000 or 3600 pounds per square inch (psi) and stored on the vehicle in high-pressure fuel tanks. **Liquefied natural gas (LNG)** is super-cooled and then stored at extremely cold temperatures in

[21] US Department of Energy, http://www.afdc.energy.gov/vehicles/electric_basics_hev.html
[22] US Environmental Protection Agency, https://archive.epa.gov/otaq/technology/web/html/research-hhvs.html
[23] US Department of Energy, Alternative Fuels Data Center: All-Electric Vehicles (energy.gov)
[24] US EPA, Hydrogen Fuel Cell Vehicles | US EPA

cryogenic fuel tanks.[25] Natural gas has a lower energy density than either gasoline or diesel, which results in less range for natural gas vehicles across equivalent fuel volumes.

Renewable fuels such as soy biodiesel are also included in the CMAQ tool. **Biodiesel** comes in two blends for this tool, either 20 percent biodiesel and 80 percent petrol-based diesel (**B20**) or 100 percent biodiesel (**B100**).[26]

[25] DOE, http://www.afdc.energy.gov/fuels/natural_gas_basics.html
[26] DOE, http://www.afdc.energy.gov/fuels/biodiesel_basics.html