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.

Transit Bus Diesel Retrofit Module

The module estimates emission reductions for retrofitting diesel[6] transit buses of a given model year with a specified retrofit technology. Emission reductions are estimated by calculating the reduction in running, start, and crankcase emissions from pre- to post-retrofit based on the pollutant and technology.

This document is organized into three sections – 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 by the tool to calculate emission reductions, and includes all equations used within the tool. This Tool Methodology also includes a table of emission reductions rates for the retrofits provided in the tool. The Examples section aims to give some examples of how to properly input information into the tool. An appendix provides information on different retrofit technologies included in the tool.

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

[6] Other fuels were considered, but retrofit test data was only available for diesel vehicles.

APPENDIX: Retrofit Technologies 13

USER GUIDE

This section lists the units and description 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 provided.

User Inputs

The Transit Bus Retrofit tool's input section functions like a wizarding tool, with questions intending to help the user input proper information for emission reductions calculations in a step-by-step process. The inputs for this tool should be specific to only the transit buses being retrofit. 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.
(2a)	Activity data: vehicle miles traveled (check box)	-----	Click on the box if you know the annual vehicle miles traveled for the diesel transit buses to be retrofit. This option may be checked concurrently with the transit bus population option.
(2a)	Activity data: vehicle population (check box)	-----	Click on the box if you know the number of diesel transit buses to be retrofit. This option may be checked concurrently with the vehicle miles traveled option.
(2b)	Annual total vehicles miles traveled	miles	Input the total value of annual vehicle miles traveled for all the diesel transit buses to be retrofit (e.g. 60,000 miles each for 10 buses would result in an input of 600,000 miles).
(2b)	Retrofit bus population	vehicles	Input the number of transit buses to be retrofit. The default value is one bus.
(3)	Retrofit type	-----	Use the drop-down menu to choose the appropriate retrofit type. For more detailed descriptions of the retrofit technologies, please refer to the appendix.
(4)	Model year of the transit buses to be retrofit	-----	Input the model year of the buses to be retrofit. If you have a range of years, you may either input the individual years of buses separately or input a representative[7] year for all buses to be retrofit. The model year cannot be later than the project evaluation year or more than 30 years prior to it.

[7] "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

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

The tool uses vehicle miles traveled to calculate running emissions and the number of transit buses to calculate start emissions. While only one piece of activity information is required to use this tool, users can supply both vehicle miles traveled and number of transit buses. In the case where one piece of activity information is provided, the tool utilizes MOVES3 national activity values 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 diesel retrofit project.

Vehicle Type

This module applies to one vehicle type: Transit Bus. MOVES uses the National Transit Database's motor bus (MB) definition[8], a transit mode comprised of rubber-tired passenger vehicles operating on fixed routes and schedules over roadways. Transit buses in this tool can only be powered by diesel engines, as the retrofit test data was only available for diesel vehicles. This tool pertains to standard 40-foot low floor transit buses, as described in procurement guidelines from the American Public Transportation Association (APTA).[9]

Transit buses are regulated under separate emission standards.[10] 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.[11]

Retrofit Type

The module includes six possible diesel retrofit selections, which are listed below in Table 2. Users can find further descriptions of the retrofit technologies in the appendix and specific percent emission reductions for each possible retrofit in the Tool Methodology section.

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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.

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

[9] American Public Transportation Association, "Standard Bus Procurement Guidelines – Low Floor Diesel," http://www.apta.com/resources/reportsandpublications/Documents/lfdiesel.pdf.

[10] See 40 CFR 86.091-2, Legal Information Institute, Cornell University Law School, https://www.law.cornell.edu/cfr/text/40/86.091-2

[11] Population and Activity of On-road Vehicles in MOVES3 https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=541815

Table 2 Retrofit Types

Retrofit Type
Diesel Oxidation Catalyst
Diesel Oxidation Catalyst + Closed Crankcase Ventilation
Diesel Oxidation Catalyst + Diesel Particulate Filter
Diesel Particulate Filter
Exhaust Gas Recirculation + Diesel Particulate Filter
Selective Catalytic Reduction + Diesel Particulate Filter

Tool Outputs

Fleet Performance

The fleet performance (non-emission) outputs for this type of retrofit project are detailed below in Table 3. These outputs are particularly useful when relying on national default estimates for annual miles traveled.

Table 3 Transit Bus Performance Output

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

Emission reductions are calculated for five pollutants – Carbon Monoxide (CO), Particulate Matter 2.5 micrometers or smaller (PM2.5), Particulate Matter 10 micrometers or smaller (PM10), Nitrogen Oxides (NOx), and Volatile Organic Compounds (VOC) in kilograms/day, which is used for CMAQ emission reductions reporting. Dis-benefits are displayed as negative values in tool outputs, and no benefit is displayed as zero. To calculate annual emission reductions, multiply this value by 365. 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 in a year (e.g., 250 working days).

Other CMAQ tools, including the Replacement module of this tool, will also calculate reductions for greenhouse gases 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. However, the Diesel Retrofit tool relies on the EPA's Diesel Emissions Quantifier for reductions, and as that tool does not provide factors for these emissions, the tool does not calculate these reductions.

Error Messages

The error and warning messages that the user may encounter in this tool, the reason for these error messages, and possible solutions are listed in Table 4 below. Once you correct the error, please press 'Calculate Output' to estimate emissions again.

Table 4 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
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 being retrofit	Input an appropriate model year between the evaluation year and 30 years prior to that evaluation year
ERROR: Please completely fill out inputs before calculating output.	No input for any of the following questions (1), (3), (4) or no activity type in question (2a) is selected	Either make selections or input values. Note that you need to select at least one activity type
WARNING: There is not test data available to estimate either the emissions or the national default activity. For these model years or fuel types, the tool will report zero emission reductions and activities.	Invalid input for model year or fuel type of the transit buses being retrofit	Input an appropriate model year between the evaluation year and 30 years prior to that evaluation year, or change the fuel type

TOOL METHODOLOGY

Emission reductions, reported in kilograms/day for the total number of retrofit transit buses, are calculated for a given pollutant as shown in the following equation:

$$reduced\ emissions = X\left[\left(e_{running} \cdot VMT\right) + \left(e_{starts} \cdot POP\right)\right]/365 \quad (1)$$

in which,

X = emissions savings for a given pollutant for a specified retrofit type (%),

$e_{running}$ = running emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/mile),

e_{starts} = start emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/bus),

VMT = total annual vehicle miles traveled for the transit buses to be retrofit (miles), and

POP = total number of transit buses to be retrofit.

The above equation does not include crankcase emissions and applies generally for all diesel retrofit types. For retrofit types that specify closed crankcase ventilation, the emissions calculation is completed using the following equation:

$$\begin{aligned} reduced\ emissions \\ &= \left\{(X-5)\left[\left(e_{running} \cdot VMT\right) + \left(e_{starts} \cdot POP\right)\right]\right. \\ &+ \left.\left[\left(e_{running\ Crankcase} \cdot VMT\right) + \left(e_{starts\ Crankcas\ e} \cdot POP\right)\right]\right\}/365 \end{aligned} \quad (2)$$

in which,

$X-5$ = emission savings for a given pollutant for a specified retrofit type (%), applying a 5% loss in effectiveness for when closed crankcase ventilation is used,

$e_{running}$ = running emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/mile),

e_{starts} = start emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/mile),

$e_{running\ Crankcase}$ = crankcase running emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/mile), and

$e_{starts\ Crankcase}$ = crankcase start emission rate for a diesel transit bus of a specified model year in the given project year (kilogram/mile).

Retrofit Emission Reductions

A list of retrofits available in this tool and their estimated emission savings for each CMAQ-relevant pollutant is given in Table 5 below. The data provided in this table comes from the EPA's Diesel Emissions Quantifier (DEQ) calculator tool.[12] Based on guidance from EPA, the tool applies a 5-percent

[12] US Environmental Protection Agency, Diesel Emission Quantifier, https://www.epa.gov/cleandiesel/diesel-emissions-quantifier-deq

loss in effectiveness of DEQ start and running emission reductions when closed crankcase ventilation is utilized.

Table 5 Retrofit Emissions Reductions by Pollutant

Retrofit Type	Reduction by Pollutant (%)				
	CO	$PM_{2.5}$	PM_{10}	NOX	VOC
Diesel Oxidation Catalyst	40	20	20	0	50
Diesel Oxidation Catalyst + Closed Crankcase Ventilation	34	28	28	0	50
Diesel Oxidation Catalyst + Diesel Particulate Filter	50	90	90	0	0
Diesel Particulate Filter	75	90	90	0	85
Exhaust Gas Recirculation + Diesel Particulate Filter	0	85	85	40	0
Selective Catalytic Reduction + Diesel Particulate Filter	85	90	90	70	90

Some general descriptions of retrofit technologies included in this tool can be found in the appendix of this document. Both vehicle miles traveled and transit bus population are required for proper calculation of emission reductions. These activity values may be provided by the user or calculated by the tool. If only one activity is provided by the user, the other activity is calculated based on national activity values from MOVES using the applicable equations below:

$$VMT = POP_{user} \left(\frac{VMT_{national}}{POP_{national}}\right) \quad (3)$$

$$POP = VMT_{user} \left(\frac{POP_{national}}{VMT_{national}}\right) \quad (4)$$

in which

POP_{user} = number of transit buses to be retrofit, provided by the user,

VMT_{user} = vehicle miles traveled for retrofit transit buses, provided by the user (miles),

$POP_{national}$ = national population for diesel transit buses of the specified model year in the given project year, and

$VMT_{national}$ = national vehicle miles traveled for diesel transit buses of specified model year in the given project year.

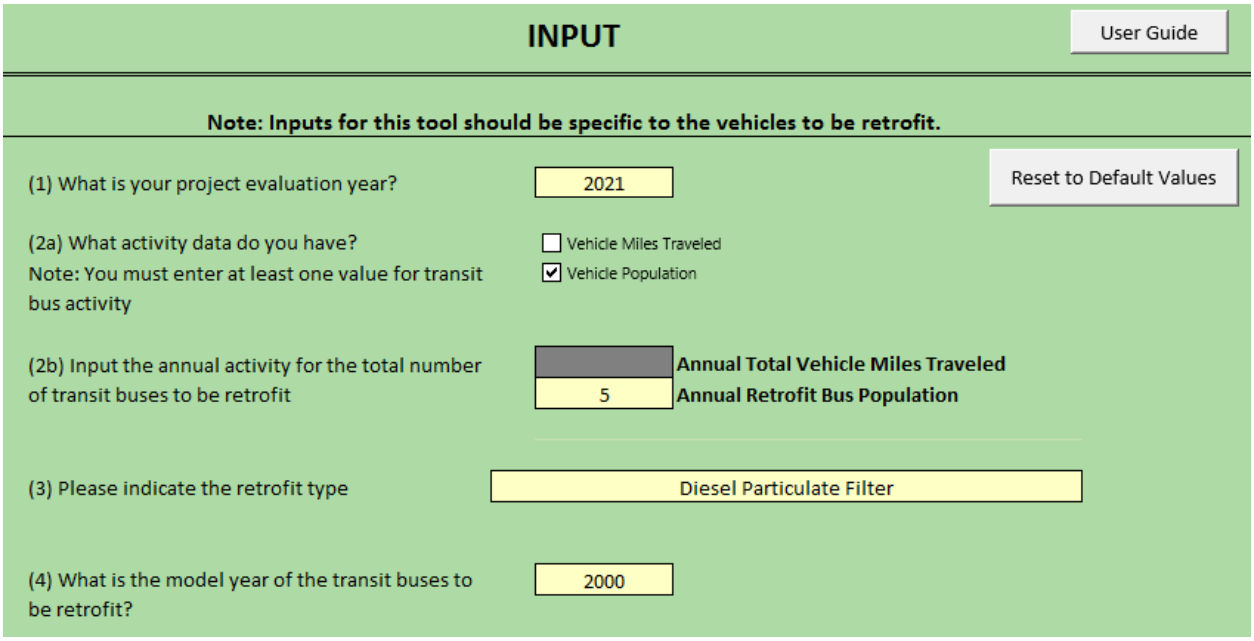
The activity, emission rates, and reductions are calculated using annual values, and the tool reports daily values in kilograms/day.

EXAMPLES

Example 1a: Retrofitting Transit Buses (Population Known)

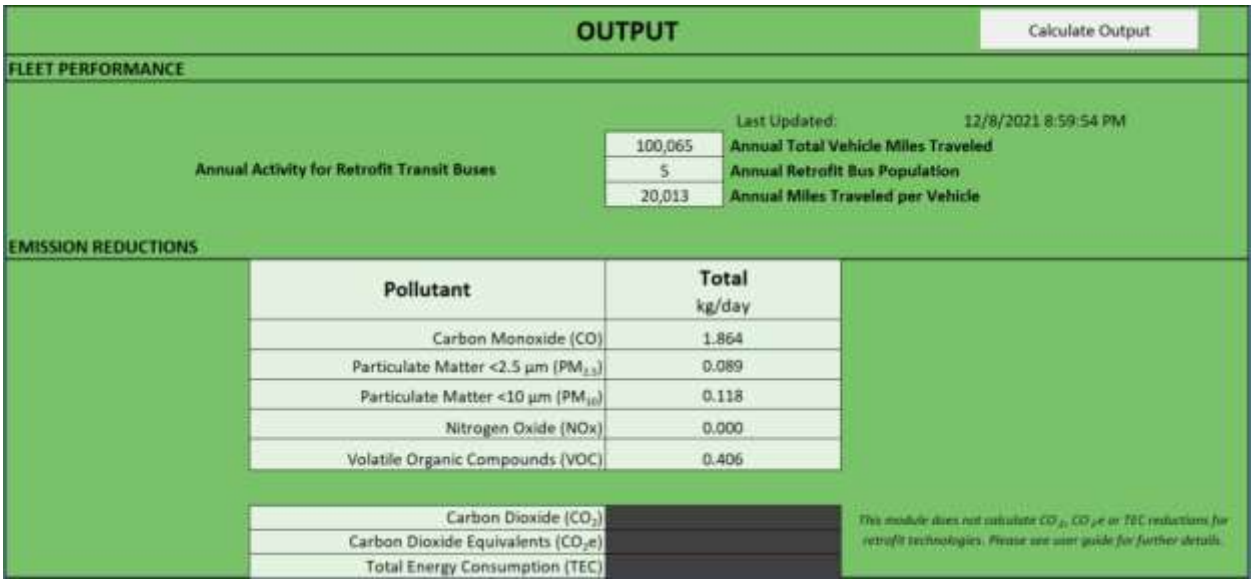
Scenario: County Z in State AA would like to retrofit five of their diesel transit buses from 1998 with diesel particulate filters.

In the retrofit tool, the following inputs would be chosen, as shown in the image below:



Project Year: 2021
Vehicle Mile Traveled [check box]: Unselected
Transit Bus Population [check box]: Selected
Retrofit Transit Bus Population: 5
Retrofit Type: Diesel Particulate Filter
Model Year for Retrofit Transit Buses: 2000

Once the inputs are put in, select the Calculate button to estimate emissions from applying this retrofit, as shown below:



OUTPUT

Calculate Output

FLEET PERFORMANCE

Last Updated: 12/8/2021 8:59:54 PM

Annual Activity for Retrofit Transit Buses

100,065	**Annual Total Vehicle Miles Traveled**
5	**Annual Retrofit Bus Population**
20,013	**Annual Miles Traveled per Vehicle**

EMISSION REDUCTIONS

Pollutant	Total kg/day
Carbon Monoxide (CO)	1.864
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.089
Particulate Matter <10 µm (PM_{10})	0.118
Nitrogen Oxide (NOx)	0.000
Volatile Organic Compounds (VOC)	0.406

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

This module does not calculate CO_2, CO_2e or TEC reductions for retrofit technologies. Please see user guide for further details.

In the absence of retrofit-specific vehicle miles traveled data, this tool utilizes national rates from MOVES to calculate emission reductions. This tool estimates that 100,065 miles are traveled by five model-year 2000 transit buses.

The emission reductions for all five pollutants are:

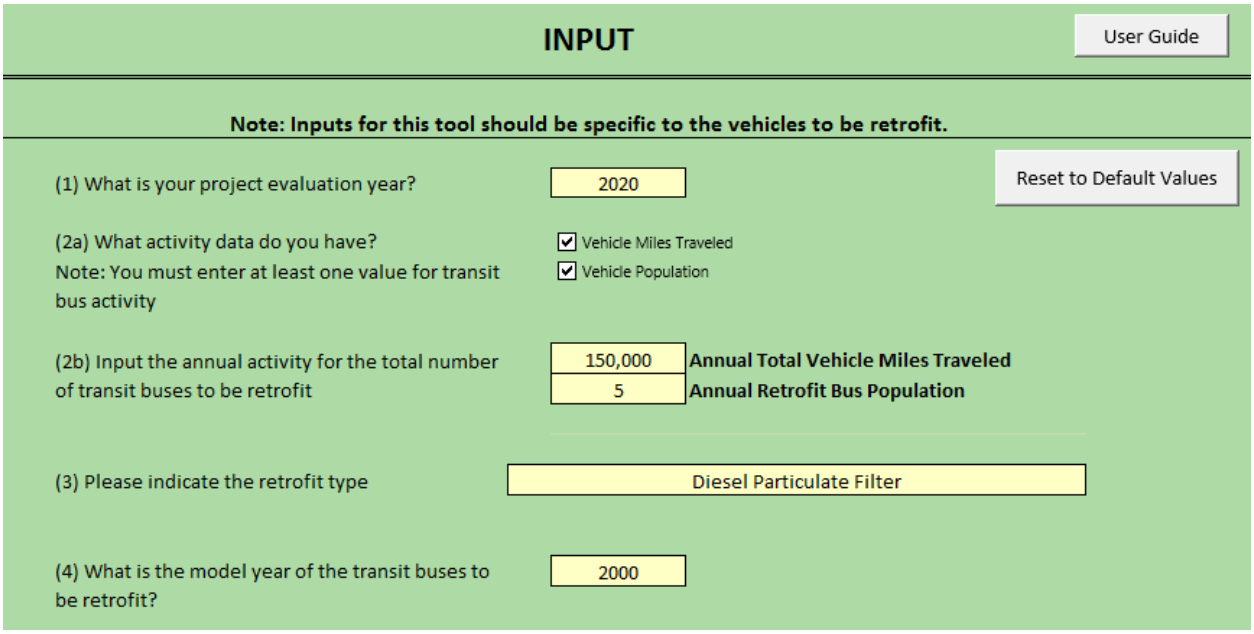
Carbon Monoxide (CO): 1.864
Particulate Matter ($PM_{2.5}$): 0.089
Particulate Matter (PM_{10}): 0.118
Nitrogen Oxide (NOx): 0.000
Volatile Organic Compounds (VOC): 0.406

Carbon Dioxide (CO_2): *N/A*
CO2e (CO_2e): *N/A*
Total Energy Consumption (TEC): *N/A*

The retrofit tool does not output CO_2, CO_2e, or TEC calculations because the tool uses EPA's Diesel Emissions Quantifier for reductions, which does not provide factors for these emissions.

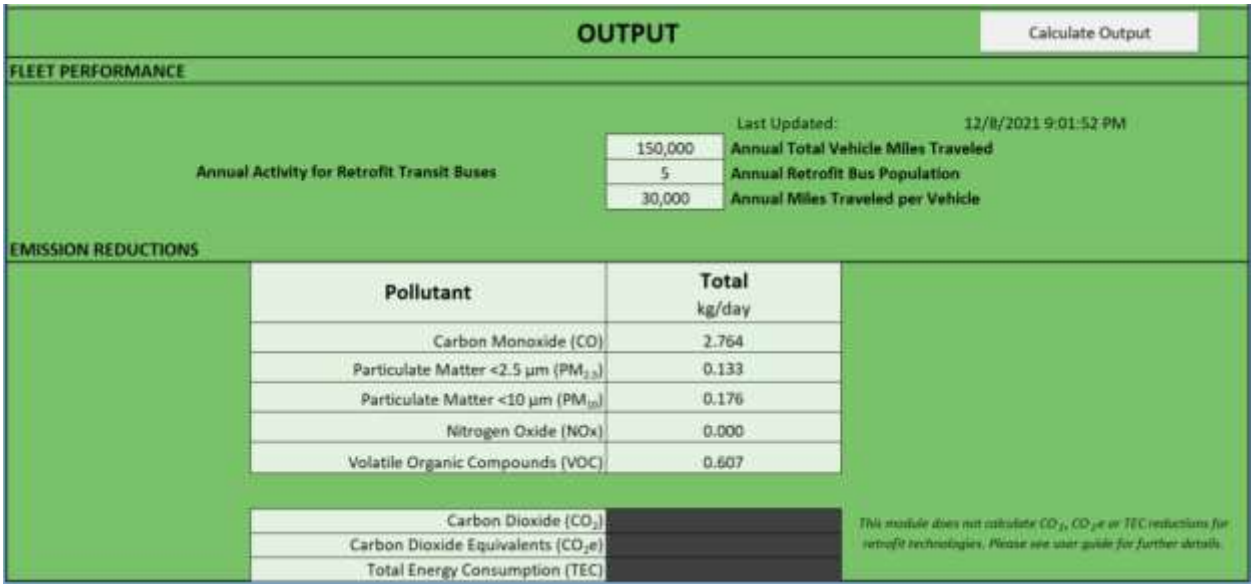
Example 1b: Retrofitting Transit Buses (Population and VMT Known)

Scenario: County Z knows that the 5 diesel transit buses from 1998 that they want to retrofit are each driven an average of 30,000 miles annually, or a total of 150,000 miles for all 5 buses. In this case, the inputs for the tool may be given as shown below:



Project Year: 2025
Vehicle Miles Traveled [check box]: Selected
Transit Bus Population [check box]: Selected
Vehicle Miles Traveled: 150,000 (total for the 5 buses)
Transit Bus Population: 5
Retrofit Type: Diesel Particulate Filter
Model Year of Retrofit Transit Buses: 2000

Pressing the Calculate button computes emission benefits from retrofitting the 1998 transit buses, as given below:



OUTPUT

Calculate Output

FLEET PERFORMANCE

Last Updated: 12/8/2021 9:01:52 PM

Annual Activity for Retrofit Transit Buses	150,000	Annual Total Vehicle Miles Traveled
	5	Annual Retrofit Bus Population
	30,000	Annual Miles Traveled per Vehicle

EMISSION REDUCTIONS

Pollutant	Total kg/day
Carbon Monoxide (CO)	2.764
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.133
Particulate Matter <10 µm (PM_{10})	0.176
Nitrogen Oxide (NOx)	0.000
Volatile Organic Compounds (VOC)	0.607

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

This module does not calculate CO_2, CO_2e or TEC reductions for retrofit technologies. Please see user guide for further details.

Please note in this example that the annual activity reported in the tool matches the inputs to the tool.

The emission reductions for all five pollutants are:

Carbon Monoxide (CO): 2.764
Particulate Matter ($PM_{2.5}$): 0.133
Particulate Matter (PM_{10}): 0.176
Nitrogen Oxide (NOx): 0.000
Volatile Organic Compounds (VOC): 0.607

Carbon Dioxide (CO_2): *N/A*
CO2e (CO_2e): *N/A*
Total Energy Consumption (TEC): *N/A*

The retrofit tool does not output CO_2, CO_2e, or TEC calculations because the tool uses EPA's Diesel Emissions Quantifier for reductions, which does not provide factors for these emissions.

APPENDIX: Retrofit Technologies

Brief descriptions of the different retrofit technologies available in this tool have been provided below. Users are encouraged to consult the references for more detailed information on these technologies.

Diesel oxidation catalysts (DOC) improve the chemical oxidation process of commonly regulated pollutants, including carbon monoxide (CO), unburned hydrocarbons (HC), and nitric oxide (NO),[13] as well as the soluble organic fraction (SOF) of diesel particulates. In addition, sulfur dioxide (SO_2) is also oxidized which may increase the total particulate emissions even while decreasing SOF. To meet stringent emission standards, modern DOCs have been designed to maximize HC and SOF oxidation while minimizing SO_2 oxidation.[14]

Closed crankcase ventilation (CCV) stops the engine blow-by from escaping into the atmosphere, greatly reducing the release of particulate matter. After EPA's 2007 heavy-duty vehicle emission standards, new engines are required to control crankcase emissions, typically achieved by a system with a multistage filter, which collects and returns lubrication oil to the engine's reservoir and exhaust gases to the engine's intake, and a series of instruments to balance pressure differentials.[15]

Diesel particulate filters (DPF) physically capture particulates before they can enter the atmosphere. DPF are most efficient with the capture of the solid fraction of diesel particulates like elemental carbon (soot) while having little-to-no effect on the non-solid fractions like SOF.[16] A soot removal process called filter regeneration is needed periodically or continuously to keep the DPF from clogging. The conventional practice is to use continuous regeneration using nitrogen dioxide (NO_2) at relatively lower temperatures than just O_2 to oxidize and effectively burn off the soot captured by the filter during ordinary engine operation.[17]

Exhaust gas recirculation (EGR) reduces the NOx emissions from a majority of diesel engines. EGR is able to accomplish this through lowering the oxygen concentration in the combustion chamber, and through heat absorption.[18] Cooling the exhaust gas prior to recirculation increases the engine's volumetric efficiency and subsequent NOx emission reductions.[19] In order for EGR to be implemented without an increase in fuel consumption, other regulated pollutants, and engine degradation, it needs to be coupled with other engine controls like increased fuel injection pressure and advanced after-treatment

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[13] April Russell and William S. Epling (2011), "Diesel Oxidation Catalysts," *Catalysis Reviews*, Vol. 53, Issue 4, http://dx.doi.org/10.1080/01614940.2011.596429

[14] W. Addy Majewski, "Diesel Oxidation Catalyst," *DieselNet*, https://www.dieselnet.com/tech/cat_doc.php

[15] Manufacturers of Emission Controls Association (2007), *Emission Control Technologies for Diesel-Powered Vehicles*, http://www.meca.org/galleries/files/MECA_Diesel_White_Paper_12-07-07_final.pdf

[16] W. Addy Majewski, "Diesel Particulate Filters," *DieselNet*, https://www.dieselnet.com/tech/dpf.php

[17] Jong Hun Kim et al. (2010), "NO_2-Assisted Soot Regeneration Behavior in a Diesel Particulate Filter with Heavy-Duty Diesel Exhaust Gases," *Numerical Heat Transfer, Part A: Applications*, Vol. 58, Issue 9, http://dx.doi.org/10.1080/10407782.2010.523293

[18] Hannu Jääskeläinen and Magdi K. Khair, "Exhaust Gas Recirculation," *DieselNet*, https://www.dieselnet.com/tech/engine_egr.php

[19] Jaffar Hussain et al. (2012), "Effect of Exhaust Gas Recirculation (EGR) on Performance and Emission characteristics of a Three Cylinder Direct Injection Compression Ignition Engine," *Alexandria Engine Journal*, Vol. 51, Issue 4, http://dx.doi.org/10.1016/j.aej.2012.09.004

systems. Many engine manufacturers could meet the EPA's 2007 HD NOx standards with EGR alone but not the more stringent 2010 standards. Most manufacturers then went to a combination of cooled EGR and selective catalytic reduction (SCR).[18]

Selective catalytic reduction (SCR) is a technology used to control NOx emissions using nitrogen compounds. By injecting these compounds, such as ammonia or urea, into the flue gas stream, the resulting chemical reactions reduce NOx to elemental nitrogen. The reaction weighs heavily on controlling the injection rate of nitrogen compounds.[20] Initial questions about reductant dosing technology, catalyst optimization, and urea infrastructure have largely been resolved and now manufacturers often employ SCR for NOx emission reductions in HD truck applications.[21]

[20] W. Addy Majewski, "Selective Catalytic Reduction," *DieselNet*, https://www.dieselnet.com/tech/cat_scr.php
[21] Diesel Technology Forum, "What is SCR?" http://www.dieselforum.org/about-clean-diesel/what-is-scr