CMAQ EMISSIONS CALCULATOR TOOLKIT

The purpose of the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) is to help a user with limited modeling experience estimate emission reductions associated with implementation of a CMAQ-funded project. The CMAQ Toolkit uses emission rates and activity data based on national-scale runs of the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES). This document explains the use and methodology of the Bicycle and Pedestrian Improvements Tool.

Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses. For further information regarding the specific setup of MOVES used to generate the emission rates provided in this tool, please refer to the Emissions Data Documentation associated with this emissions calculator.

On-Road Diesel Retrofits

The diesel retrofit project emission reductions calculator estimates emission reductions for fitting heavy-duty diesel vehicles (excluding transit vehicles) of a given model year with a specified retrofit technology.[1] Emission reductions are estimated by calculating the reduction in both running and starts emissions for the retrofit vehicles, given the emission reductions defined by the retrofit.[2]

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, as well as any assumptions that are made by the tool. This Tool Methodology includes all equations used within the tool, as well as 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, including some examples for use with the optional Activity Calculator, for advanced analysis.

---

[1] CMAQ projects must benefit air quality through demonstrated emission reductions. See the CMAQ guidance at www.fhwa.dot.gov/environment/air_quality/cmaq/ for a full list of projects that may be eligible for CMAQ funds.
[2] The most current version is dated December 2021. 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.

Contents

USER GUIDE 3
User Inputs 3
Tool Outputs 5
Error Messages 5
Other Assumptions 6
TOOL METHODOLOGY 7
Retrofits 8
EXAMPLES 10
Example 1a: Retrofitting Single Unit Short-Haul Trucks (Population Known) 10
Example 1b: Retrofitting Single Unit Short-Haul Trucks (Population and VMT Known) 12
Example 2: Retrofitting Single Unit Short-Haul Trucks (Advanced Example with Activity Calculator) 13
APPENDIX: Retrofit Technologies 17

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 inherent in the tool are provided.

User Inputs

The On-Road Diesel Retrofits 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 vehicles that will be retrofit. The user-defined inputs for this type of project are described below:

Table 1. User Inputs

User Input	Units	Description
Evaluation year	-----	Use the drop-down menu to choose a year between 2018 and 2040.
Vehicle miles traveled (check box)	-----	Click on the box if you have annual vehicle miles traveled for the vehicles to be retrofit. This option may be checked concurrently with the vehicle population option.
Vehicle population (check box)	-----	Click on the box if you the number of vehicles to be retrofit. This option may be checked concurrently with the vehicle miles traveled option. The default value is 'checked'
Total vehicles miles traveled	miles	Input the total value of annual vehicle miles traveled for all the vehicles to be retrofit (e.g. 60,000 miles each for 10 vehicles would result in an input of 600,000 miles).
Retrofit vehicle population	vehicles	Input the number of vehicles to be retrofit. The default value is 1 vehicle.
Retrofit vehicle type	-----	Use the drop-down menu to choose the appropriate vehicle type among heavy-duty diesel (non-transit) vehicles. Vehicle types include: school bus, refuse truck, single unit short-haul truck, single unit long-haul truck, combination short-haul truck, and combination long-haul truck. See table below for more information.
Retrofit type	-----	Use the drop-down menu to choose the appropriate retrofit type. For more information about the types of retrofit and their emission benefits, please refer to the "Retrofit type" section in Tool Methodology.

User Input	Units	Description
Retrofit vehicle model year	-----	Input the model year of the vehicles to be retrofit. If you have a range of years, you may either input the individual years and vehicles separately or input a representative year for the vehicles to be retrofit. The model year cannot be later than the project year. Please refer to CMAQ policy for guidance regarding appropriate model years eligible for funding.

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.

Vehicle Type

The table below lists the vehicle types provided in this tool. Any vehicles with a gross vehicle weight of 10,000 pounds or more are considered heavy-duty and any vehicles less than 10,000 pounds are considered light-duty. "Long-haul" trucks are defined as trucks for which most trips are 200 miles or more.

Table 2. Vehicle Types

Vehicle Type	MOVES Source Type ID	FHWA Vehicle Class[3]
School Bus	43	Class 4 vehicles designed to carry students or other passengers to between their residence and school
Refuse Truck	51	
Single Unit Short-haul Truck	52	Classes 5, 6, and 7
Single Unit Long-haul Truck	53	Classes 5, 6, and 7
Combination Short-haul Truck	61	Classes 8, 9, 10, 11, 12, and 13
Combination Long-haul Truck	62	Classes 8, 9, 10, 11, 12, and 13

[3] US Federal Highway Administration (2013), *Travel Monitoring Guide*, https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm

Tool Outputs

Fleet Performance

The tool-produced outputs for this type of project are detailed below:

Table 3. Fleet Performance Outputs

Output	Units	Description
Total vehicle miles traveled, annual activity for retrofit vehicles	miles	The total vehicle miles traveled annually by the retrofit vehicles, either input by the user or calculated from vehicle population using national activity rates.
Retrofit vehicle population, annual activity for retrofit vehicles	vehicles	The number of vehicles to be retrofit, either input by the user or calculated from total retrofit vehicle miles traveled using national activity rates

Emission Reductions

Emission reductions are calculated for five pollutants – carbon monoxide (CO), particulate matter with diameters of 2.5 microns or less ($PM_{2.5}$), particulate matter with diameters of 10 microns or less (PM_{10}), nitrogen oxides (NOx), volatile organic compounds (VOC).

To get annual emission reductions, multiply these values by 365. In the event that a different annualization is desired, users are recommended to multiply their daily results by 365 and then divide by their chosen number of working days in a year, e.g. 250 working days.

Other CMAQ tools, including the Repower and Replacement module of this tool, will also calculate reductions for greenhouse gases in terms of carbon dioxide equivalent (CO_2e) and carbon dioxide (CO_2) 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 (see Retrofits section for more detail).

Error Messages

The error messages that the user may encounter in this tool, the reason for these error messages and their remedy is listed in the table below: (Note: Once you correct the error, please press 'Calculate Output' to clear errors)

Table 4. Error Messages

Error Message	Reason for Error	Solution

Error! Choose at least one activity type	No activity type was chosen	Please choose an activity type to use the tool
Error! Model years cannot be later than project year Year Input Error: This tool includes model years between 1989 and 2030. Please choose appropriate years within this range.	Invalid input for retrofit model year	Input a model year that is no earlier than 1989 and no later than the project evaluation year
Error! Please completely fill out inputs before calculating output	All of the inputs required for emission reductions calculations have not been chosen	Please choose an appropriate project year, retrofit vehicle type, retrofit type, and/or model year
Warning: less than one vehicle is represented by the input activity values	The result is representative of a partial vehicle, based on national ratios of VMT to vehicle population	Only a warning. Inputs provided are acceptable to sufficient to calculate results.

Other Assumptions

While only one piece of activity information is required to use this tool, activity for vehicle miles traveled and vehicle population are, in fact, required for proper calculation of emission reductions. In the case where one piece of activity information is provided, the tool utilizes national activity rates from MOVES3 for the activity not provided to calculate emission reductions. Providing both activities for this tool may provide a more accurate estimate of emission reductions from a diesel retrofit project.

TOOL METHODOLOGY

Emission reductions, reported in kilograms/day for the total number of retrofit vehicles, 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 (%),

$e_{running}$ = annual running diesel emissions for a given vehicle type and model year in the given project year (kilogram/mile),

e_{starts} = annual start diesel emissions for a given vehicle type and model year in the given project year (kilogram/vehicle),

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

POP = total retrofit vehicles.

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

$e_{running}$ = annual running diesel emissions for a given vehicle type and model year in the given project year (kilogram/mile),

e_{starts} = annual start diesel emissions for a given vehicle type and model year in the given project year (kilogram/mile),

$e_{runningCrankcase}$ = annual crankcase running diesel emissions for a given vehicle type and model year in the given project year (kilogram/mile),

$e_{startsCrankcase}$ = annual crankcase start diesel emissions for a given vehicle type and model year in the given project year (kilogram/mile),

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

POP = total retrofit vehicles.

Retrofits

A list of retrofits available in this tool and their estimated emission savings for each CMAQ-relevant pollutant is given in the table below. The data provided in this table comes from the Environmental Protection Agency's (EPA) Diesel Emissions Quantifier (DEQ) calculator tool.[4] Based on guidance from EPA, the tool applies a 5 percent loss in effectiveness of DEQ start and running emission reductions when closed crankcase ventilation is utilized.

Table 5. Retrofit Emissions Savings

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 this tool's retrofit technologies have been included in the appendix of this document. Both vehicle miles traveled and vehicle population are required for proper calculation of emission reductions. These activity values may be provided by the user. If only one activity is provided by the user, the other activity is calculated leveraging national values using the applicable equations:

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

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

in which

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

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

$POP_{national}$ = national population for diesel vehicles of the specified model year and vehicle type in the given project year, and

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

[4] US Environmental Protection Agency, Diesel Emission Quantifier, https://www.epa.gov/cleandiesel/diesel-emissions-quantifier-deq. Note that the DEQ tool does not provide CO_2e and TEC reduction percentages for retrofit technologies, and so neither does this CMAQ Toolkit module.

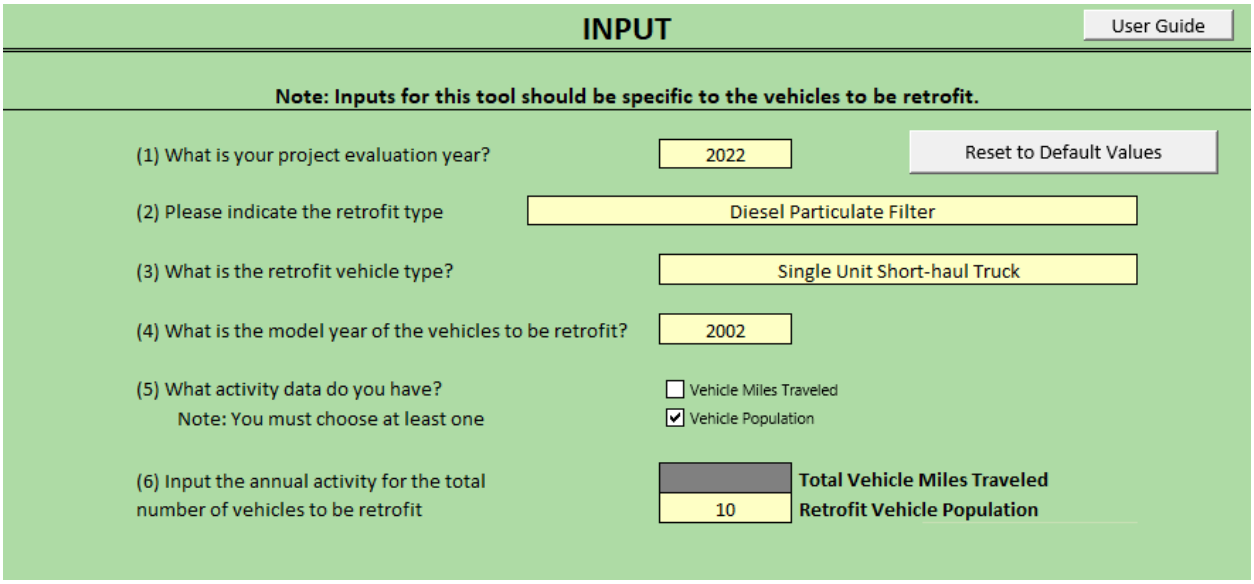
The activity, emission rates and savings are calculated using annual values. This is divided by 365 to get daily values, which are reported in kilograms/day in the tool. In the event that a different annualization is desired, users are recommended to multiply their daily results by 365 and then divide by their chosen number of working days in a year, e.g. 250 working days.

EXAMPLES

Example 1a: Retrofitting Single Unit Short-Haul Trucks (Population Known)

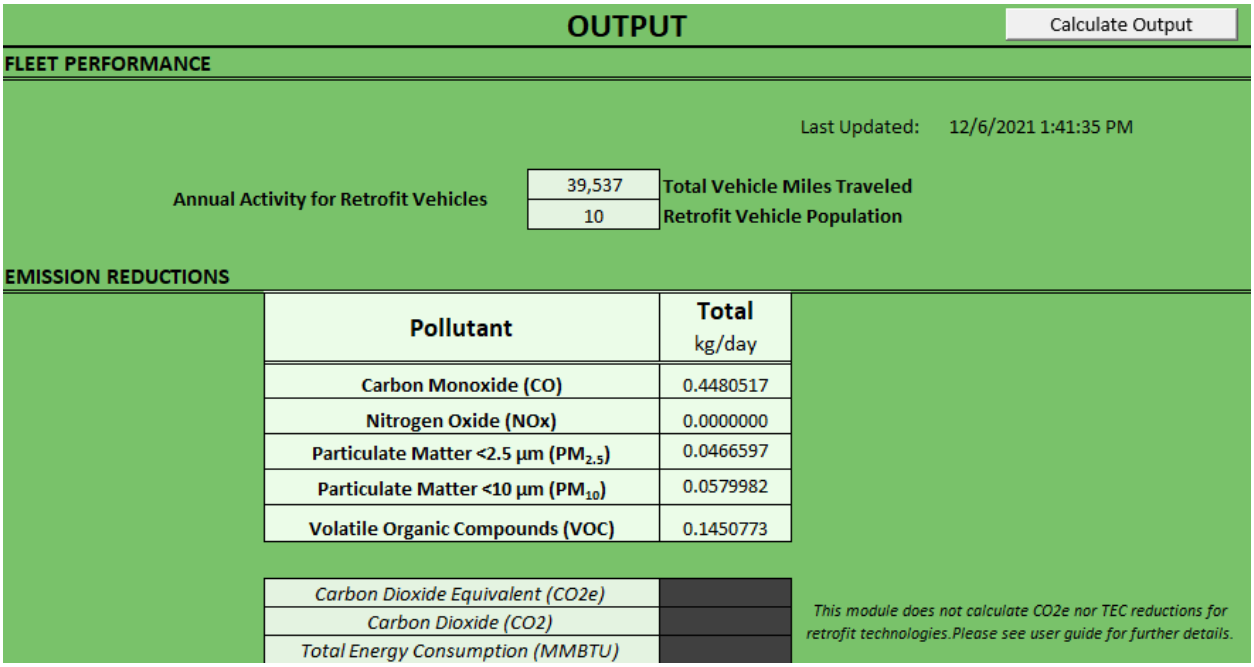
Scenario: County Z in State AA would like to retrofit their 10 short-haul trucks from 2002 with diesel particulate filters.

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



Project Year: 2022
Vehicle Population [check box]: Selected
Retrofit Vehicle Population: 10
Vehicle Type: Single Unit Short-Haul Truck
Retrofit Type: Diesel Particulate Filter
Model Year for Retrofit Vehicles: 2002

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



OUTPUT — Calculate Output

FLEET PERFORMANCE

Last Updated: 12/6/2021 1:41:35 PM

Annual Activity for Retrofit Vehicles	39,537	Total Vehicle Miles Traveled
	10	Retrofit Vehicle Population

EMISSION REDUCTIONS

Pollutant	Total kg/day
Carbon Monoxide (CO)	0.4480517
Nitrogen Oxide (NOx)	0.0000000
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.0466597
Particulate Matter <10 µm (PM_{10})	0.0579982
Volatile Organic Compounds (VOC)	0.1450773

Carbon Dioxide Equivalent (CO2e)	
Carbon Dioxide (CO2)	
Total Energy Consumption (MMBTU)	

This module does not calculate CO2e nor TEC reductions for retrofit technologies.Please see user guide for further details.

Annual activity for retrofit vehicles is:

Total VMT: 39,537

Retrofit vehicle population: 10

The emission reductions in kg/day and TEC reductions in millions of British Thermal Units (MMBTU) are:

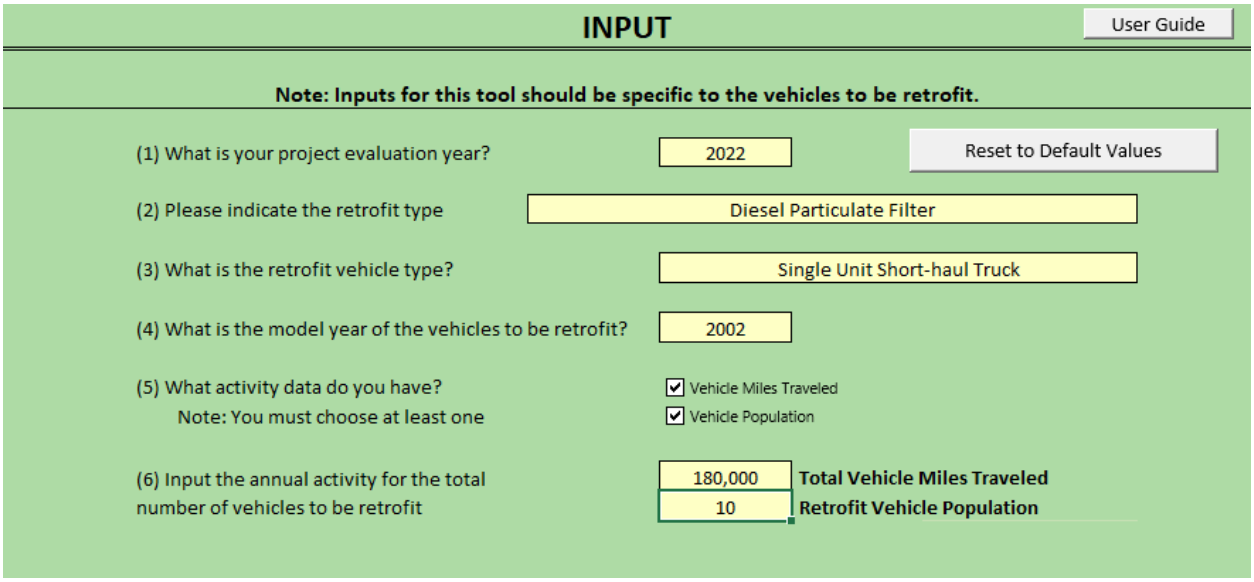
Carbon Monoxide (CO): 0.44805
Nitrogen Oxide (NOx): 0.000000
Particulate Matter (PM2.5): 0.04666
Particulate Matter (PM10): 0.057998
Volatile Organic Compounds (VOC): 0.14508

Carbon Dioxide Equivalent (CO_2e): [blank]
Carbon Dioxide (CO_2): [blank]
Total Energy Consumption (TEC): [blank]

In the absence of retrofit-specific vehicle miles traveled data, this tool utilizes national rates to calculate emission benefits. For single unit short-haul trucks, this tool estimates that 5,785 miles are traveled by each 2002 vehicle, which may be an appropriate value for the retrofit project.

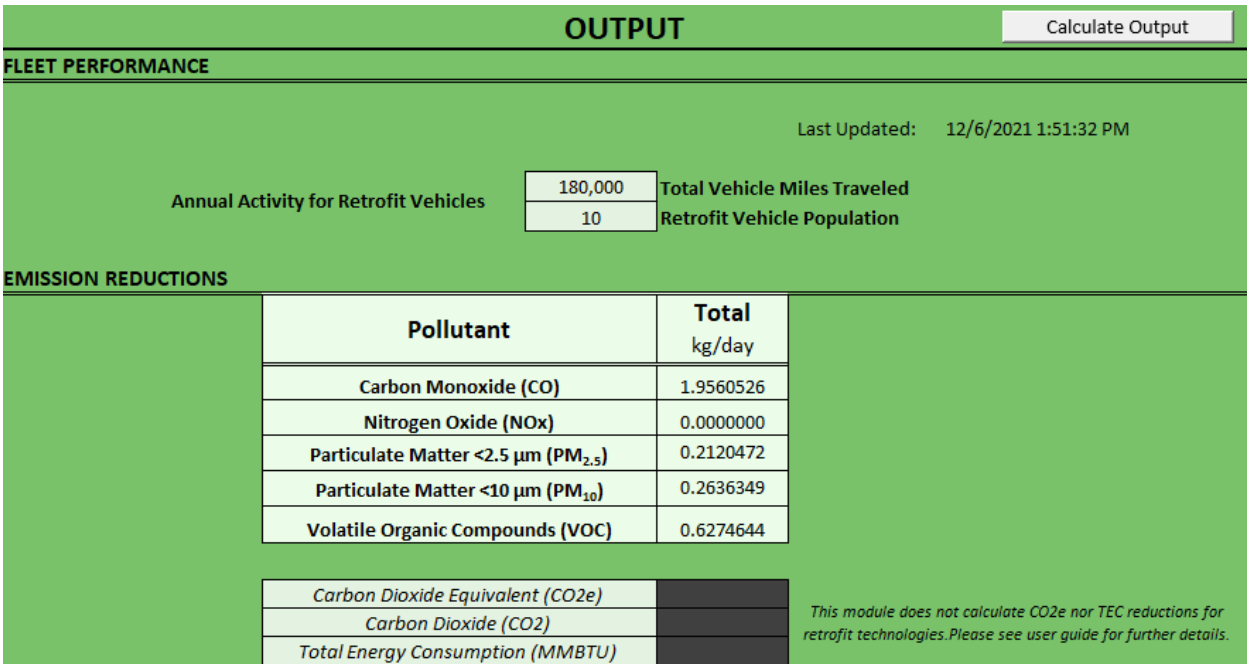
Example 1b: Retrofitting Single Unit Short-Haul Trucks (Population and VMT Known)

County Z knows that the 10 single unit short-haul trucks from 2002 that they want to retrofit are driven an average of 18,000 miles annually. In this case, the inputs for the tool may be given as shown below:



Project Evaluation Year: 2022
Vehicle Miles Traveled [check box]: Selected
Vehicle Miles Traveled: 180,000 (total for the 10 vehicles)
Vehicle Population [check box]: Selected
Vehicle Population: 10
Vehicle Type: Single Unit Short-haul Truck
Retrofit Type: Diesel Particulate Filter
Model Year of Retrofit Vehicles: 2002

Pressing the Calculate button computes emission benefits from retrofitting the short-haul trucks, as shown below:



OUTPUT Calculate Output

FLEET PERFORMANCE

Last Updated: 12/6/2021 1:51:32 PM

Annual Activity for Retrofit Vehicles	180,000	Total Vehicle Miles Traveled
	10	Retrofit Vehicle Population

EMISSION REDUCTIONS

Pollutant	Total kg/day
Carbon Monoxide (CO)	1.9560526
Nitrogen Oxide (NOx)	0.0000000
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.2120472
Particulate Matter <10 µm (PM_{10})	0.2636349
Volatile Organic Compounds (VOC)	0.6274644

Carbon Dioxide Equivalent (CO2e)	
Carbon Dioxide (CO2)	
Total Energy Consumption (MMBTU)	

This module does not calculate CO2e nor TEC reductions for retrofit technologies.Please see user guide for further details.

Annual activity for retrofit vehicles is:

Total VMT: 180,000

Retrofit vehicle population: 10

The emission reductions in kg/day and TEC reductions in millions of British Thermal Units (MMBTU) are:

Carbon Monoxide (CO): 1.9561
Nitrogen Oxide (NOx): 0.00000
Particulate Matter (PM2.5): 0.21205
Particulate Matter (PM10): 0.26363
Volatile Organic Compounds (VOC): 0.62746

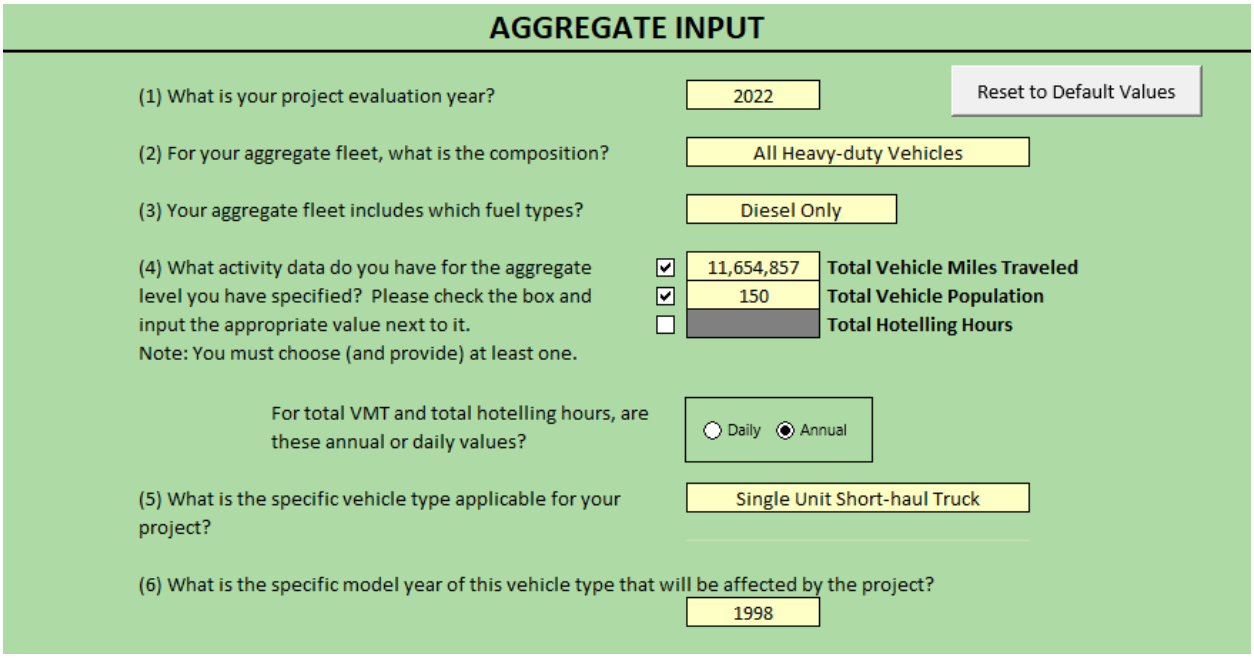
Please note in this example that the annual activity reported in the tool matches the inputs to the tool. CO_2e, CO_2 and TEC are not calculated in this module.

Example 2: Retrofitting Single Unit Short-Haul Trucks (Advanced Example with Activity Calculator)

County Z in State AA would like to retrofit 10 single unit short-haul trucks from 1998 with a diesel particulate filter. Let's suppose that County Z knows that their fleet of short-haul trucks

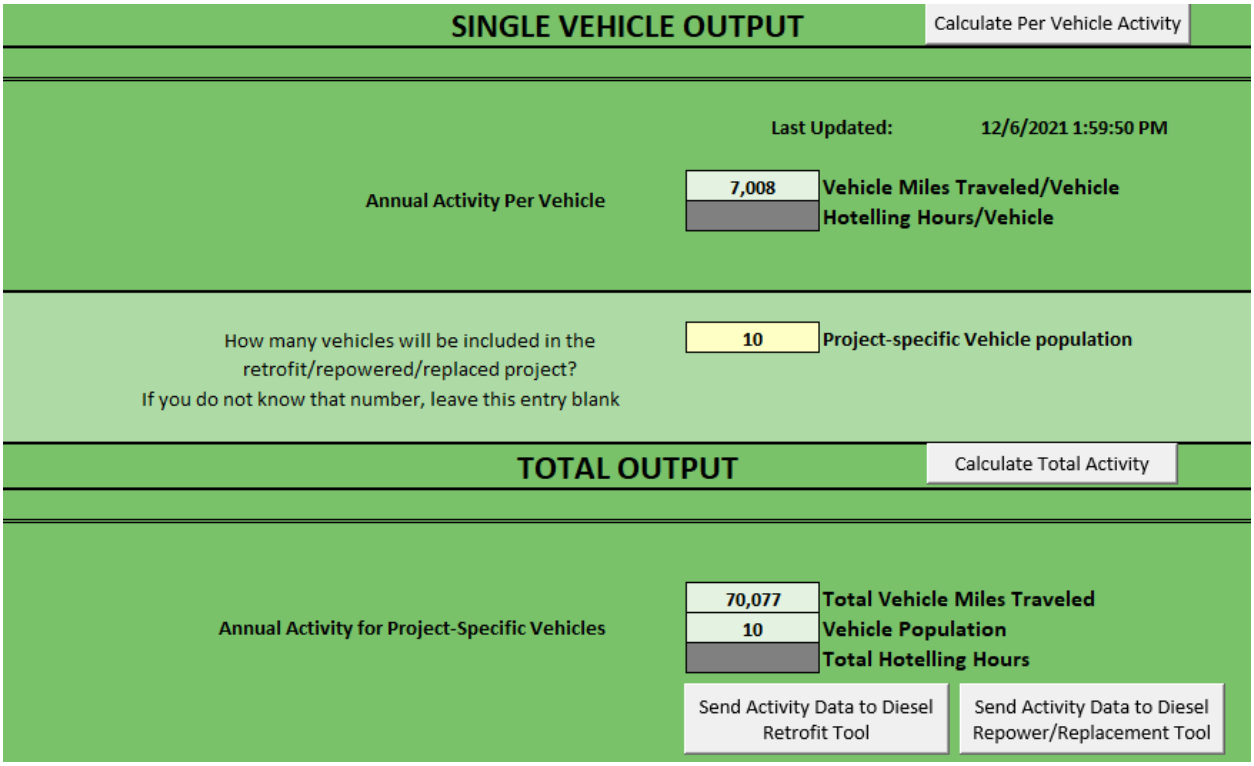
drive more than the average short-haul truck, but they do not have specific information for the vehicles that are being retrofit. However, County Z does have total annual activity for all of the heavy-duty diesel vehicles in their county. For the 150 vehicles in the county's heavy-duty fleet, the total annual vehicle miles traveled are 11,654,857 miles.

In this case, the activity calculator can first be used to determine the information that is specific for the vehicles to be retrofit. Going to the activity calculator tab, the following information be input as shown in the image below:



Project Evaluation Year: 2022
Fleet Composition: All Heavy-duty Vehicles
Fuel Type: Diesel Only
Total Vehicle Miles Traveled [check box]: Selected
Total Vehicle Miles Traveled: 11,654,857
Total Vehicle Population [check box]: Selected
Total Vehicle Population: 150
Daily/Annual: Annual
Vehicle Type: Single Unit Short-haul Truck
Model Year of affected Vehicles: 1998

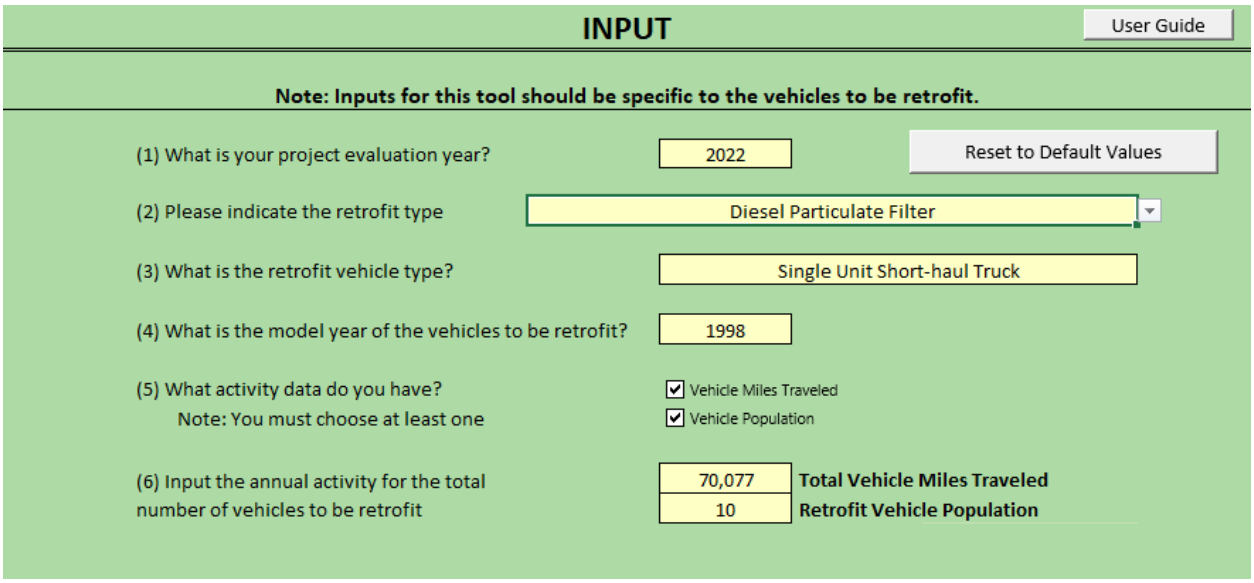
Pressing the Calculate button gives an intermediate step of calculating annual activity for the vehicles that will be retrofit, as in the image below:



The annual activity for the single unit short-haul trucks is 7,008 miles per vehicle, which is greater than the national average. Next, the retrofit-specific vehicle population can be input. Here, the number of vehicles that will be retrofit – ten – is input.

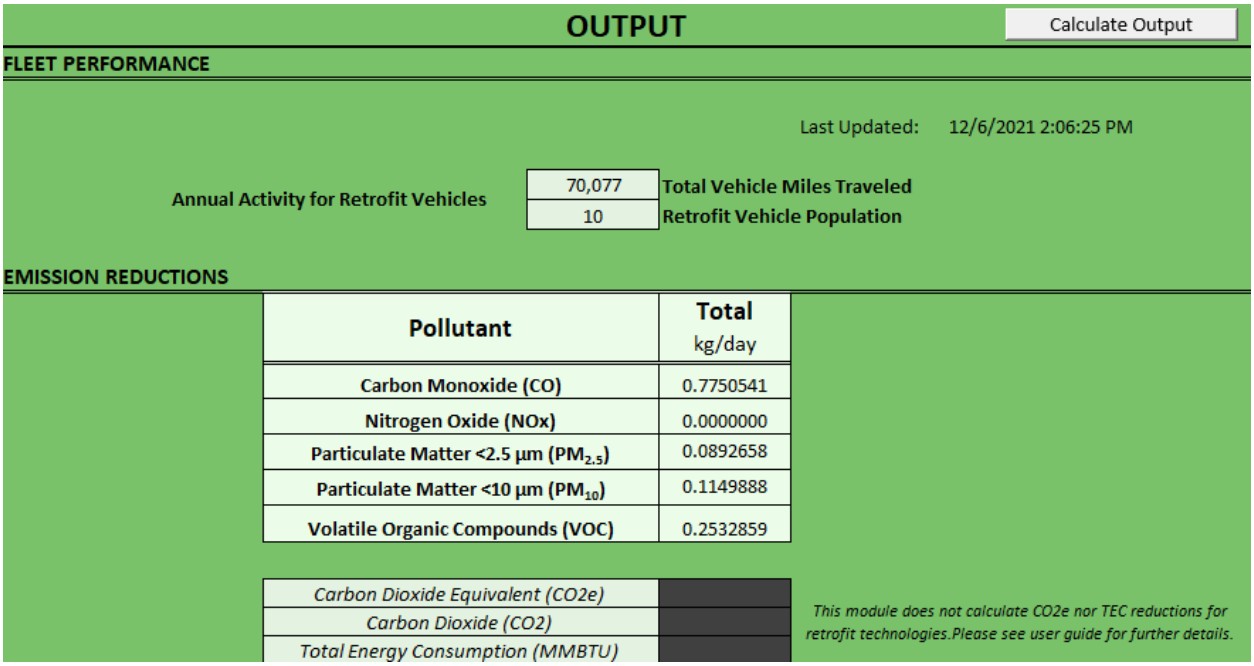
A second calculate button is then pushed to give specific activity values for the single unit short-haul trucks to be retrofit, as shown above. This gives 70,077 for total VMT and 10 for the vehicle population. These values can be sent to the retrofit tool by pressing the button labeled, “Send Activity to Diesel Retrofit Tool”.

Once the activity data have been sent to the retrofit tool, the retrofit tool will look as shown in the image below:



The only additional input that needs to be provided for proper calculation of the emission benefits is the retrofit type. In this example, the retrofit selected is the diesel particulate filter.

Emission benefits are then calculated and reported, as follows:



Annual activity for retrofit vehicles is:

Total VMT: 70,077

Retrofit vehicle population: 10

The emission reductions in kg/day and TEC reductions in millions of British Thermal Units (MMBTU) are:

Carbon Monoxide (CO): 0.77505
Nitrogen Oxide (NOx): 0.00000
Particulate Matter (PM2.5): 0.08927
Particulate Matter (PM10): 0.11499
Volatile Organic Compounds (VOC): 0.25329

Note that CO_2e, CO_2, and TEC are not calculated in this module.

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),[5] 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.[6]

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.[7]

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.[8] A soot removal process called filter regeneration is needed periodically or continuously to keep the DPF from clogging. Convention is 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.[9]

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.[10] Cooling the exhaust gas prior to recirculation

---

[5] 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

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

[7] 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

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

[9] 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

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

increases the engine's volumetric efficiency and subsequent NOx emission reductions.[11] 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 aftertreatment 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).[10]

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.[12] 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.[13]

[11] 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

[12] W. Addy Majewski, "Selective Catalytic Reduction," *DieselNet*, https://www.dieselnet.com/tech/cat_scr.php

[13] Diesel Technology Forum, "What is SCR?" http://www.dieselforum.org/about-clean-diesel/what-is-scr