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.

Alternative Fuel Vehicles and Infrastructure

The Alternative Fuel Vehicles and Infrastructure Tool estimates the emission benefits of adopting alternative fuels in the current on-road transportation system. This tool is based on emission rates from the US Environmental Protection Agency's latest Motor Vehicle Emission Simulator (MOVES3)[1] and emission rate adjustment factors from the US Department of Energy's Alternative Fuel Lifecycle Environmental and Economic Transportation (AFLEET 2020) Tool[2] for alternative fuel vehicles not included in MOVES. This tool considers only operating emissions[3] of the vehicles and does not evaluate upstream (well-to-pump) emissions associated with production and transmission of the fuel or manufacturing of the vehicle. This Alternative Fuel Vehicles tool allows modeling of many passenger and commercial vehicle source use types in MOVES but excludes transit buses, which are included in the Transit Bus Upgrades and System Improvements tool. Note that this tool excludes electric vehicles (EV) and EV charging stations, which are included in the Electric Vehicles and EV Charging Infrastructure tool.

This tool currently contains two modules: 1) On-Road Alternative Fuel Fleet Purchase and Restricted Access Alternative Fuel Infrastructure and 2) Unrestricted Access Alternative Fuel Infrastructure. The first module can calculate emissions from an alternative fuel vehicle fleet purchase project and a restricted access infrastructure project separately, or together. The unrestricted infrastructure module for public fueling was developed separately and should not be combined with any other module.

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[1] US Environmental Protection Agency, Office of Transportation and Air Quality, Latest Version of MOtor Vehicle Emission Simulator (MOVES) | US EPA

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

[3] Emissions from running and start exhaust as well as brake and tire wear. Extended idling and APU emissions are only considered for long-haul combination trucks. Off-network idle and evaporative emissions are included for Fleet Purchase emissions; evaporative emissions are included for specific processes and road types for restricted access infrastructure emissions.

Unrestricted Access Alternative Fuel Infrastructure Module

Alternative fuel infrastructure with unrestricted access is open to the public, including personal vehicles and commercial fleets. This module calculates the emission reductions of building new unrestricted alternative fuel infrastructure and the adoption of alternative fuel vehicles. The tool assumes one-to-one replacement of conventional fuel vehicles with alternative fuel vehicles to be serviced at the new unrestricted access fueling infrastructure.

This document is organized into three sections for Alternative Fuel Unrestricted Infrastructure – 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. This tool has been updated since original publication, there is a change log tab that can unhidden for reference. The Tool Methodology outlines the steps taken to calculate emission reductions, and includes all equations used within the tool. The Examples section aims to give some examples of how to properly input information into the tool for advanced analysis.

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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 interface of the Alternative Fuel Unrestricted Access Infrastructure module functions as 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 the alternative fuel vehicles that will use the fueling facility. The user-defined inputs for this type of project are described in Table 1.

Table 1 User Inputs

User Input	Units	Description
Project evaluation year	-----	Use the drop-down menu to choose a year between 2019 and 2030.
Total vehicle count in study area	vehicles	Input the number of vehicles primarily fueled in some user-specified study area, though this may range from one fueling station to a regional corridor. The tool is not prescriptive about the approach of deriving the total vehicle count. Various methods, such as analysis of vehicle registrations or fuel sales and tank size, would be appropriate.
Alternative fuel type	-----	Use the drop-down menu to select the alternative fuel type of the vehicles.
Alternative fuel vehicle market share	-----	Insert a percentage for the projected market penetration of alternative fuel vehicles out of the total number of vehicles in the study area over the course of the evaluation year.
Source type distributions for vehicle activity and populations	-----	By selecting the “Fill Table” button above the table, this table populates with the average annual miles traveled per vehicle from the MOVES national default activity, number of existing conventional fuel vehicles using scaled MOVES default counts, and the subsequent number of alternative fuel vehicles based on the input market share to replace the existing conventional fuel vehicles in the given evaluation year. Results are presented by source type and any source type can be un/selected using the checkboxes on the left-hand side of the table. Users can also optionally override any specific value in the table.

A project’s **study area** is chosen by the user. Study areas can range from one public fueling pump to all unrestricted-access fueling infrastructure in a specified corridor, county, or region. Vehicles included in the analysis should be assumed to predominantly travel and fuel within the study area, ensuring that alternative fuel vehicle activity will directly replace conventional vehicle activity over the evaluation year. Certain vehicle source types, particularly transit buses, should be omitted from this unrestricted infrastructure analysis as alternative fuel transit buses are included in the Transit Bus Upgrades and System Improvements Tool. A detailed list of accepted source types can be found below.

Once the parameters are input, click on the 'Fill Table' button to populate the source type distributions and make any optional adjustments to the table described above and then click the 'Calculate Output' button to calculate emission reduction results. If a user changes the vehicle count by source type in the distribution table, the total vehicle count may no longer the same as the number entered in Question 2. All emission estimates will be derived from the source type distribution table. Users are responsible for ensuring that the total vehicle count in the distribution table is allocated appropriately. Emission reduction results will not automatically update, so anytime changes are made to the input parameters, the 'Calculate Output' button must be pushed to calculate the updated emission reductions. If you would like to return to default settings, please click on the 'Reset Inputs' button.

Vehicle Type

Table 2 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. MOVES light-duty vehicle source types consist of passenger cars, passenger trucks, and light commercial trucks. "Long-haul" trucks are defined as trucks for which most trips are 200 miles or more.

Table 2 Vehicle Type, Source Type ID, and Vehicle Class in Tool

Vehicle Source Type	MOVES sourceTypeID	FHWA Vehicle Class[4]
Passenger Car	21	Class 2 vehicles
Passenger Truck	31	Class 3 vehicles weighing less than or equal to 10,000 pounds used for non-commercial purposes
Light Commercial Truck	32	Class 3 vehicles weighing less than or equal to 10,000 pounds used for commercial purposes
School Bus	43	Class 4 vehicles designed to carry students or other passengers between their residence and school
Refuse Truck	51	Vehicles in Classes 5, 6, and 7 hauling landfill waste or recycling material
Single Unit Short-haul Truck	52	Vehicles in Classes 5, 6, and 7 typically driving less than 200 miles per trip
Single Unit Long-haul Truck	53	Vehicles in Classes 5, 6, and 7 typically driving 200 miles or more per trip
Combination Short-haul Truck	61	Vehicles in Classes 8, 9, 10, 11, 12, and 13 typically driving less than 200 miles per trip
Combination Long-haul Truck	62	Vehicles in Classes 8, 9, 10, 11, 12, and 13 typically driving 200 miles or more per trip

Alternative Fuels and Advanced Engine Technologies

The AFLEET Tool has adjustment factors to conventional fuel emission rates for a variety of alternative fuels and advanced engine technologies. This CMAQ tool utilizes AFLEET adjustment factors for different hybrids, renewable fuels, natural gas, and propane. Since fuel cell vehicles have zero tailpipe emissions,

[4] FHWA, https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm

their emission rates are simply copied from MOVES national defaults for brake and tire wear of gasoline light-duty vehicles (LDV) and diesel heavy-duty vehicles (HDV) for the respective source types. Some basic definitions of these alternative fuels and technologies have been included in Appendix A. Methodology on how the AFLEET adjustment factors were created can be found in documentation of the tool.[5]

Tool Outputs

The Unrestricted Infrastructure module generates emission reductions by calculating the difference in emissions between the portion of existing conventional fuel vehicles being replaced by alternative fuel vehicles in the given evaluation year. Users can control alternative fuel, the number of replacement alternative fuel vehicles, and the average annual miles traveled per vehicle through the tool interface.

Emission reductions are calculated for five criteria pollutants – carbon monoxide (CO), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), particulate matter less than 10 microns in diameter (PM_{10}), NOx (nitrogen oxides), and VOC (volatile organic compounds). In addition, carbon dioxide (CO_2) and carbon dioxide equivalent (CO_2e) in kilograms/year as well as total energy consumption (TEC) generated in MMBTU/year are also included. Each pollutant is divided by 365 for the CMAQ daily emission reductions reported in kilograms/day and energy becomes MMBTU/day. 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 days annually, i.e. 250 working days.

Error Messages

Table 3 below summarizes any error and warning messages associated with the unrestricted infrastructure 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
Please select a valid project evaluation year for analysis.	Invalid Input: Project Evaluation Year	Select an evaluation year from the pull-down list
Please enter a valid fleet size estimate.	Invalid Input: Fleet Size	Enter the number of vehicles in the appropriate fleet
Please select a valid alternative fuel for analysis.	Invalid Input: Alternative Fuel	Select an alternative fuel from the pull-down list
Please enter a valid market share for the alternative fuel vehicle fleet.	Invalid Input: Market Share	Input a market share between 0 and 100%
Input Error - Alternative fuel vehicle market penetration percentage must be between 0 and 100.	Invalid input for market penetration of replacement alternative fuel vehicles	Input an appropriate penetration percentage

[5] DOE, https://greet.es.anl.gov/files/afleet-tool-2016-user-guide

WARNING: $fuelTypeName$ lacks data and will not produce emissions for the following vehicle source types: $sourceTypeName$. Please assign these vehicles to different source type(s) and recalculate.	Invalid input for distribution of source types ($sourceTypeName$) for an entered alternative fuel ($fuelTypeName$)	Follow the warning message instructions according to the vehicle source type-fuel type matrix below to find the appropriate distribution of vehicle source types for an entered alternative fuel

Note that the warning message above will appear for any alternative fuel which does not have AFLEET data for the full distribution of nine source types. The variables $fuelTypeName$ and $sourceTypeName$ will change according to information in the source type-fuel type matrix below. This document only displays the generic warning in lieu of a full list of warning messages.

Vehicle source type-fuel type combinations: Not every vehicle type and fuel type combination 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 by source type. Since MOVES contains emissions for light-duty E85-capable vehicles and most heavy-duty CNG-capable vehicles, those rates were pulled directly from MOVES instead of an estimate with an AFLEET factor. AFLEET provides E85 factors for some heavy-duty source types, namely school buses, short-haul single unit trucks, and long-haul single unit trucks, and CNG factors for some light-duty source types, and these factors have been used in this CMAQ tool. As consistent with AFLEET, FCV emissions output is non-zero only for particulate matter.

As noted above, for combinations without AFLEET data such that the alternative fuel factors are zero, warnings will pop up and any subsequent emission reductions will appear as zero. For more information on the AFLEET factors, please consult the GREET documentation on analyzing heavy-duty vehicle emission rate[6] and updating GREET emission factors with MOVES data[7] accordingly.

[6] DOE, https://greet.es.anl.gov/publication-heavy-duty
[7] DOE, https://greet.es.anl.gov/publication-vehicles-13

Table 4 Vehicle source type-fuel type combinations in tool

Vehicle Source Type	Fuel Type									
	Dual Fuel	B100	B20	CNG	E85	FCV	HEV	HHV	LNG	LPG
Passenger Car		A	A	A	M	A	A		A	A
Passenger Truck		A	A	A	M	A	A		A	A
Light Commercial Truck		A	A	A	M	A	A		A	A
School Bus		A	A	M	A	A	A	A	A	A
Refuse Truck	A	A	A	M		A	A	A	A	
Single Unit Short-haul Truck	A	A	A	M	A	A	A	A	A	A
Single Unit Long-haul Truck	A	A	A	M	A	A	A	A	A	A
Combination Short-haul Truck	A	A	A	M		A	A	A	A	
Combination Long-haul Truck	A	A	A	A		A	A	A	A	

In this Unrestricted Infrastructure module, the default setting is to calculate for all source types. Certain alternative fuel-source type combinations highlighted in the table above cannot be estimated using this tool. Error messages will direct users about which source types to exclude for a specific alternative fuel.

For reference, the AFLEET factors are based on gasoline for light-duty vehicles (LDV) and diesel for heavy-duty vehicles (HDV). For simplicity, this tool assumes that any conventional fuel LDVs replaced will have been gasoline fueled and any conventional fuel HDVs replaced will be diesel fueled. Table 5 below indicates which conventional fuel is the baseline estimate for each AFLEET factor according to source type. Since MOVES can be used for LDV emission rates of ethanol (E85) vehicles[8] and HDV emission rates of compressed natural gas (CNG) vehicles, the CMAQ tool prioritizes those modal MOVES rates over AFLEET-adjusted emission rates. Only the alternative fuel vehicle types with MOVES rates, as well as FCVs of all source types, will produce CO_2, CO_2e or TEC; all of the other the alternative fuel vehicles will report "N/A" for greenhouse gases and energy. FCVs, like electric vehicles, have zero tailpipe emissions and only generate emissions for particulate matter from brakewear and tirewear.

Table 5 Source type and baseline conventional fuel for AFLEET factor

sourceTypeID	Vehicle Source Type	AFLEET Baseline Fuel
21	Passenger Car	Gasoline
31	Passenger Truck	Gasoline
32	Light Commercial Truck	Gasoline
43	School Bus	Diesel
51	Refuse Truck	Diesel
52	Single Unit Short-haul Truck	Diesel

[8] This CMAQ tool assumes that E85 is utilized 100 percent of the time in flexible fuel vehicles.

53	Single Unit Long-haul Truck	Diesel
61	Combination Short-haul Truck	Diesel
62	Combination Long-haul Truck	Diesel

Evaluation years: 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 push warning messages if a user selects an erroneous year.

TOOL METHODOLOGY

Annual emission reductions, which are divided by 365 to be reported in kilograms/day for the total number of conventional fuel vehicles being replaced by alternative fuel vehicles, are calculated for a given pollutant as followed:

$$reduced\ emissions = \sum_{i \epsilon I} \frac{(e_{conv\ replace\ _i} - e_{alt_i}) \cdot MPV_i \cdot n_i}{365} \quad (1)$$

where for E85, electric, and fuel cell LDVs,

$$e_{alt\ i} = e_{alt_MOVES_i} \quad (2)$$

and where for all other alternative fuel vehicles,

$$e_{alt_i} = e_{conv\ purchase_i} \cdot A_{alt\ i} \quad (3)$$

such that,

$$MPV_i = \frac{VMT_{MOVES_i}}{POP_{MOVES_i}} \quad (4)$$

$$n_i = p\left(N \cdot \frac{POP_{MOVES_i}}{\sum_{i \epsilon I} POP_{MOVES_i}}\right) \quad (5)$$

$e_{conv_{replace_i}}$ = annual conventional fuel (diesel or gasoline) emission rate for a given source type i and model year of the vehicles to be replaced (kilogram/mile),
e_{alt_i} = annual alternative fuel emission rate for a given source type i and model year of the alternative fuel vehicles that will replace conventional vehicles (kilogram/mile),
$e_{alt_MOVES_i}$ = alternative fuel emission rate pulled directly from MOVES (kilogram/mile),
MPV_i = average annual miles driven by a vehicle in the MOVES national default fleet for a given source type i, and

n_i = number of replacement alternative fuel vehicles for a given source type i,
i = index for unique vehicle source type,
I = number of unique vehicle source types,
$i \epsilon I$ = any unique source types in the set of all unique source types,
$e_{conv_{purchase_i}}$ = annual conventional fuel (diesel or gasoline) emission rate for a given source type i and model year of the vehicles to be purchased (kilogram/mile),
A_{alt_i} = AFLEET factor for a specified alternative fuel, determined by vehicle source type i and pollutant,
POP_{MOVES_i} = total population of vehicles in the MOVES national default fleet for a given source type i and evaluation year,
VMT_{MOVES_i} = total vehicle miles traveled in the MOVES national default fleet for a given source type i and evaluation year,
p = market penetration percentage of projected alternative fuel vehicles as replacements for conventional fuel vehicles over the evaluation year, and
N = number of conventional fuel vehicles for a specified study area across all source types.

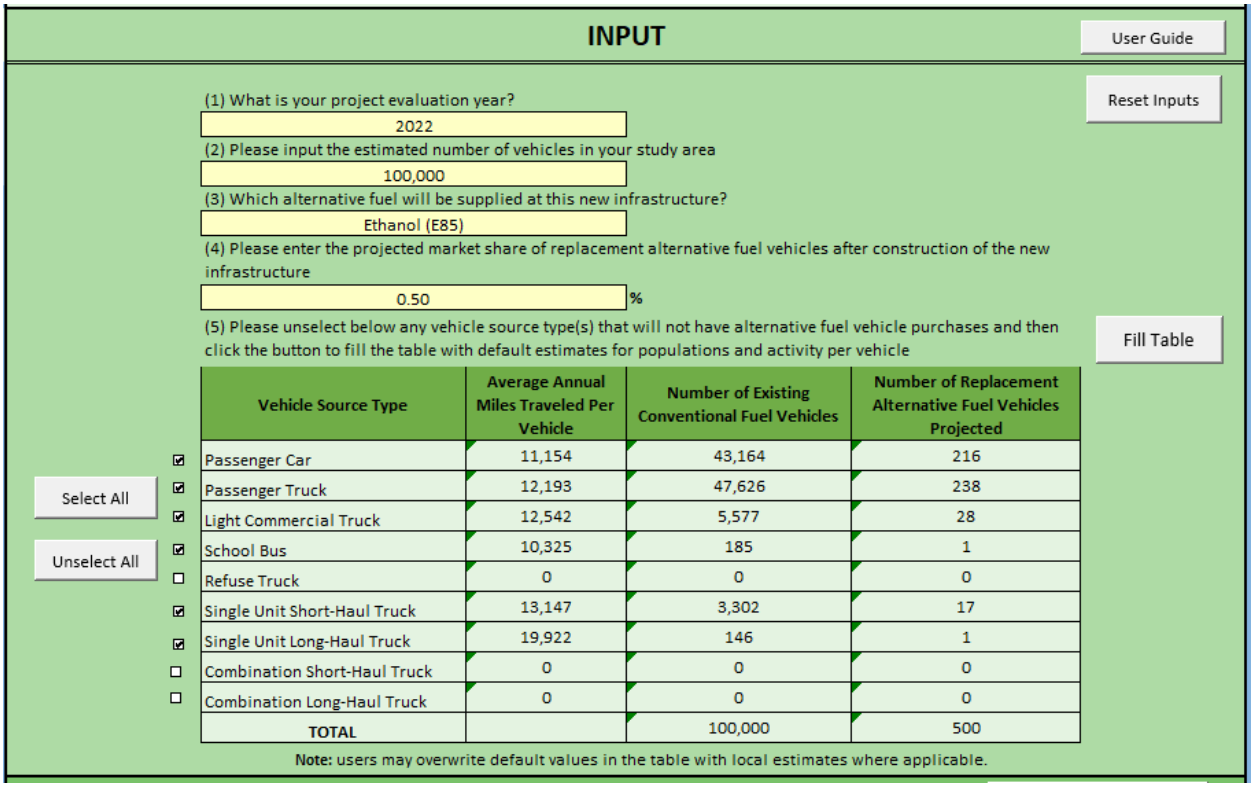
Unlike the Alternative Fuel Vehicles Fleet Purchase module which specifies only one particular vehicle source type for a vehicle fleet, this unrestricted infrastructure module assumes the replacement will be over a distribution of vehicle source types and therefore a summation in the emissions calculation is required. The MPV_i and n_i are represented within the source type distribution table in the interface while the emission rates come from backend look-up tables.

Since the tool only requires users to enter the total vehicle count in a study area, it must estimate the number of vehicles by source type by scaling to MOVES national defaults, unless the user inputs the distribution. As indicated in the formula for alternative fuel vehicle counts by source type n_i above, the total input vehicle count is multiplied by the fraction of MOVES national default populations by source type to the total MOVES national default population across all source types and multiplied by the alternative fuel vehicle market penetration. As noted earlier, the tool assumes that only gasoline LDVs and diesel HDVs will be replaced by comparable alternative fuel vehicles.

EXAMPLES

Example 1: Building Unrestricted Infrastructure for Ethanol (E85) Fueling

County X in State AA has recently decided to build new unrestricted access infrastructure for E85 fueling. They estimate there is 100,000 conventional vehicles that predominantly fuel within their county and project that 500 (0.5%) of those vehicles could be replaced by new E85 fueled vehicles. The inputs for this example are shown below:



INPUT

User Guide | Reset Inputs | Fill Table

(1) What is your project evaluation year?
2022

(2) Please input the estimated number of vehicles in your study area
100,000

(3) Which alternative fuel will be supplied at this new infrastructure?
Ethanol (E85)

(4) Please enter the projected market share of replacement alternative fuel vehicles after construction of the new infrastructure
0.50 %

(5) Please unselect below any vehicle source type(s) that will not have alternative fuel vehicle purchases and then click the button to fill the table with default estimates for populations and activity per vehicle

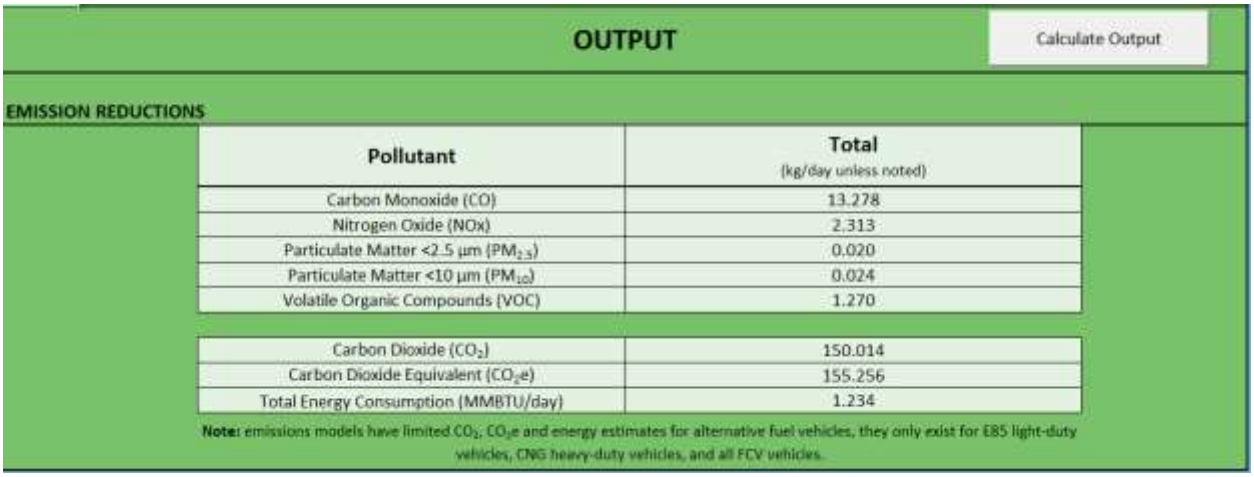
Select All | Unselect All

	Vehicle Source Type	Average Annual Miles Traveled Per Vehicle	Number of Existing Conventional Fuel Vehicles	Number of Replacement Alternative Fuel Vehicles Projected
☑	Passenger Car	11,154	43,164	216
☑	Passenger Truck	12,193	47,626	238
☑	Light Commercial Truck	12,542	5,577	28
☑	School Bus	10,325	185	1
☐	Refuse Truck	0	0	0
☑	Single Unit Short-Haul Truck	13,147	3,302	17
☑	Single Unit Long-Haul Truck	19,922	146	1
☐	Combination Short-Haul Truck	0	0	0
☐	Combination Long-Haul Truck	0	0	0
	TOTAL		100,000	500

Note: users may overwrite default values in the table with local estimates where applicable.

Project Year: 2022
Vehicles in Study Area: 100,000
Alternative Fuel: Ethanol (E85)
Alternative Fuel Vehicle Market Penetration: 0.5%
Source Type Selected: Passenger Car, Passenger Truck, Light Commercial Truck, School Bus, Single Unit Short-Haul Truck, and Single Unit Long-Haul Truck

As shown above, most of the 500 replacement alternative fuel vehicles will be passenger cars and trucks, but there will be also be some replacement commercial vehicles and buses. Note that this example excludes the source types that do not have E85 AFLEET factors available, namely refuse trucks, short-haul and long-haul combination trucks. Shown above are the inputs for this example after the 'Fill Table' button has pressed and the appropriate source types have been unselected. The tool output is shown below:



OUTPUT Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless noted)
Carbon Monoxide (CO)	13.278
Nitrogen Oxide (NOx)	2.313
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.020
Particulate Matter <10 µm (PM_{10})	0.024
Volatile Organic Compounds (VOC)	1.270
Carbon Dioxide (CO_2)	150.014
Carbon Dioxide Equivalent (CO_2e)	155.256
Total Energy Consumption (MMBTU/day)	1.234

Note: emissions models have limited CO_2, CO_2e and energy estimates for alternative fuel vehicles, they only exist for E85 light-duty vehicles, CNG heavy-duty vehicles, and all FCV vehicles.

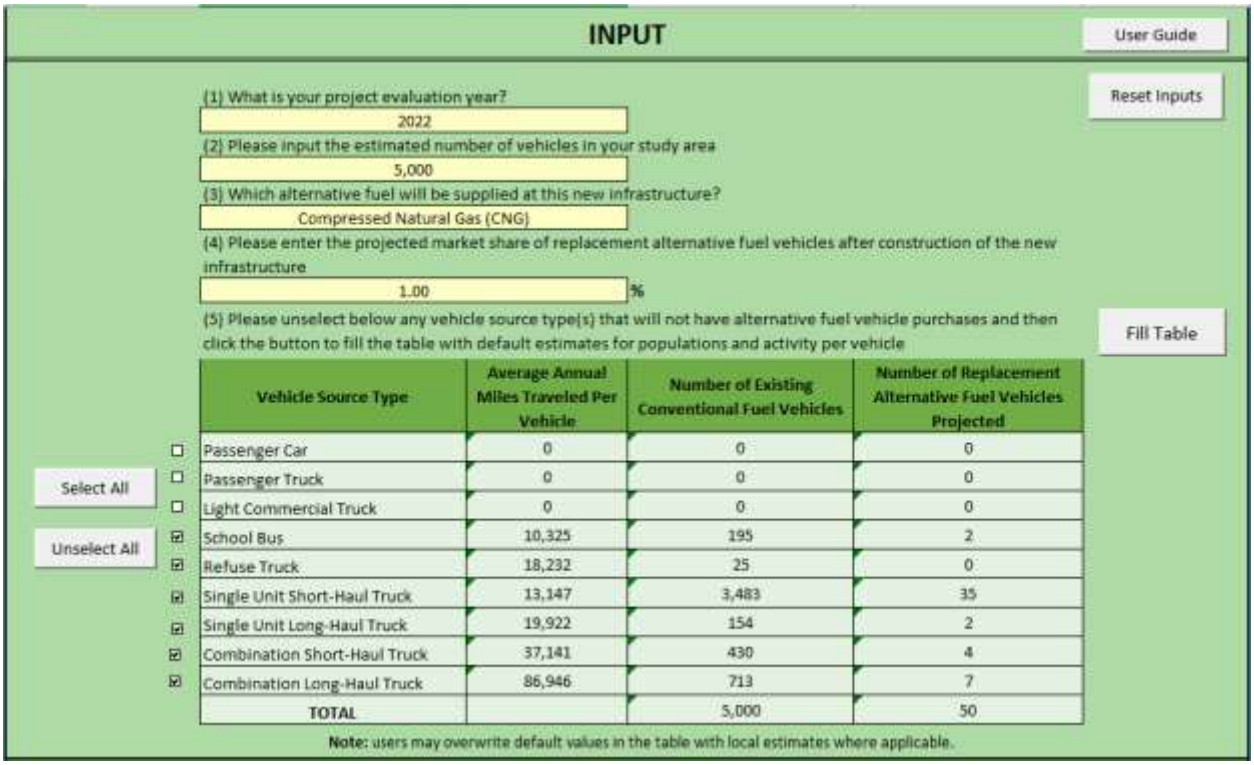
The emission reductions in kg/day for all pollutants as well as the energy reduction in MMBTU/day are:

Carbon Monoxide (CO): 13.278
Nitrogen Oxide (NOx): 2.313
Particulate Matter (PM2.5): 0.020
Particulate Matter (PM10): 0.024
Volatile Organic Compounds (VOC): 1.270

Carbon Dioxide (CO_2): 150.014
Carbon Dioxide Equivalent (CO_2e): 155.256
Total Energy Consumption (TEC): 1.234

Example 2: Building Unrestricted Infrastructure for Compressed Natural Gas (CNG) Fueling of Heavy-Duty Vehicles

Scenario: County X in State AA is working with some corporate fleets and wants to build some compressed natural gas (CNG) infrastructure across the county. The county estimates that there are 5,000 heavy-duty vehicles that fuel exclusively within their study area and predicts that roughly 1% of those vehicles could be replaced by CNG vehicles. Shown below are the inputs for this example after the 'Fill Table' button has pressed and the LDV source types have been unselected:



INPUT

User Guide | Reset Inputs

(1) What is your project evaluation year?
2022

(2) Please input the estimated number of vehicles in your study area
5,000

(3) Which alternative fuel will be supplied at this new infrastructure?
Compressed Natural Gas (CNG)

(4) Please enter the projected market share of replacement alternative fuel vehicles after construction of the new infrastructure
1.00 %

(5) Please unselect below any vehicle source type(s) that will not have alternative fuel vehicle purchases and then click the button to fill the table with default estimates for populations and activity per vehicle

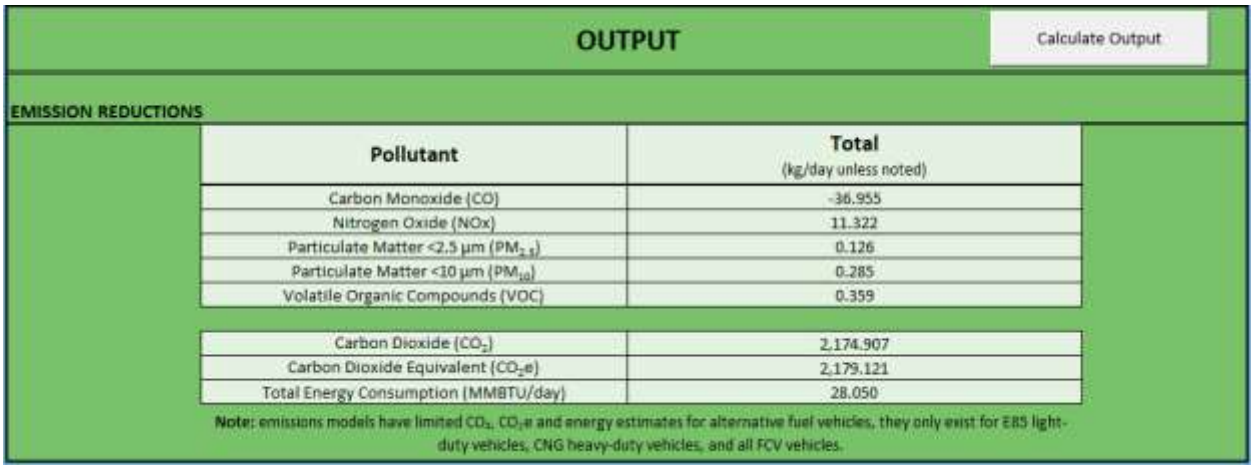
Fill Table | Select All | Unselect All

	Vehicle Source Type	Average Annual Miles Traveled Per Vehicle	Number of Existing Conventional Fuel Vehicles	Number of Replacement Alternative Fuel Vehicles Projected
☐	Passenger Car	0	0	0
☐	Passenger Truck	0	0	0
☐	Light Commercial Truck	0	0	0
☑	School Bus	10,325	195	2
☑	Refuse Truck	18,232	25	0
☑	Single Unit Short-Haul Truck	13,147	3,483	35
☑	Single Unit Long-Haul Truck	19,922	154	2
☑	Combination Short-Haul Truck	37,141	430	4
☑	Combination Long-Haul Truck	86,946	713	7
	TOTAL		5,000	50

Note: users may overwrite default values in the table with local estimates where applicable.

Project Year: 2022
Vehicles in Study Area: 5,000
Alternative Fuel: Compressed Natural Gas (CNG)
Alternative Fuel Vehicle Market Penetration: 1.0%
Source Type Selected: School Bus, Refuse Truck, Single Unit Short-Haul Truck, Single Unit Long-Haul Truck, Combination Short-Haul Truck, and Combination Long-Haul Truck

This example calculates the emissions reductions for building unrestricted infrastructure for fueling compressed natural gas (CNG) heavy-duty vehicles. The tool output is shown below:



OUTPUT Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless noted)
Carbon Monoxide (CO)	-36.955
Nitrogen Oxide (NOx)	11.322
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.126
Particulate Matter <10 µm (PM_{10})	0.285
Volatile Organic Compounds (VOC)	0.359

Carbon Dioxide (CO_2)	2,174.907
Carbon Dioxide Equivalent (CO_2e)	2,179.121
Total Energy Consumption (MMBTU/day)	28.050

Note: emissions models have limited CO_2, CO_2e and energy estimates for alternative fuel vehicles, they only exist for E85 light-duty vehicles, CNG heavy-duty vehicles, and all FCV vehicles.

The emission reductions in kg/day for all pollutants as well as the energy reduction in MMBTU/day are:

Carbon Monoxide (CO): -36.955
Nitrogen Oxide (NOx): 11.322
Particulate Matter (PM2.5): 0.126
Particulate Matter (PM10): 0.285
Volatile Organic Compounds (VOC): 0.359

Carbon Dioxide (CO_2): 2,174.907
Carbon Dioxide Equivalent (CO_2e): 2,179.121
Total Energy Consumption (TEC): 28.050

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.[9] 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.[10] Hydraulic hybrids also offer better fuel economy and often lower emissions than comparable non-hybridized vehicles.

A **fuel cell vehicle (FCV)** runs on an electric motor which is powered by hydrogen fuel cells rather than electricity stored in batteries.[11] Most commonly for vehicle applications, the fuel cells efficiently convert stored hydrogen fuel into electrical energy through a polymer electrolyte membrane (PEM) design that splits the hydrogen's protons and electrons and then uses the electrons to do work across an external circuit creating electricity and some waste heat.[12] The (positive) hydrogen ions are reformed with the free electrons and oxygen, such that FCVs do not emit any harmful tailpipe exhaust—only water vapor and warm air.[13] Like for electric vehicles, many FCVs utilize regenerative braking to charge an onboard battery that provides supplemental power to the electric motor.[12]

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 cryogenic fuel tanks.[14] 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.

Similar to natural gas, **propane** is a byproduct of petroleum refining, also called **liquefied petroleum gas (LPG)**, and is stored onboard the vehicle in pressurized tanks. Propane can be injected into the

[9] US Department of Energy, http://www.afdc.energy.gov/vehicles/electric_basics_hev.html
[10] US Environmental Protection Agency, https://archive.epa.gov/otaq/technology/web/html/research-hhvs.html
[11] DOE, http://www.afdc.energy.gov/vehicles/fuel_cell.html
[12] DOE/EPA, https://www.fueleconomy.gov/feg/fcv_PEM.shtml
[13] Smithsonian Institution, http://americanhistory.si.edu/fuelcells/basics.htm
[14] DOE, http://www.afdc.energy.gov/fuels/natural_gas_basics.html

combustion chamber as a vapor or as a liquid. Liquid injection improves engine performance over vapor injection.[15]

Renewable fuels such as corn ethanol and soy biodiesel are also included in the CMAQ tool. For this tool, **ethanol** is only available in one blend—85 percent plant-based ethanol and 15 percent gasoline, known colloquially as **E85**, although actual blends may contain less ethanol depending on location and time of year.[16] **Biodiesel** comes in two blends for this tool, either 20 percent biodiesel and 80 percent petrol-based diesel (**B20**) or 100 percent biodiesel (**B100**).[17]

Note that electric vehicles are included in the Electric Vehicles and Infrastructure Tool.

[15] DOE, http://www.afdc.energy.gov/vehicles/propane.html
[16] DOE, http://www.afdc.energy.gov/fuels/ethanol_fuel_basics.html
[17] DOE, http://www.afdc.energy.gov/fuels/biodiesel_basics.html