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.

Electric Vehicles and Charging Infrastructure

The Electric Vehicles (EV) and EV Charging Infrastructure Tool estimates the emission benefits of adopting electric vehicles 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. The Electric Vehicles tool considers only operating emissions[3] of the vehicles and does not evaluate upstream (well-to-pump) emissions associated with production and transmission of electricity or manufacturing of the vehicle or battery. The tool allows modeling of many passenger and commercial vehicle (including zero emissions medium- and heavy-duty 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 do not cover other alternative fuels (e.g., biodiesel, hybrid-electric, fuel cell, ethanol, etc.), which are included in the Alternative Fuel Vehicles and Infrastructure tool.

This tool currently contains two modules: 1) On-Road Electric Vehicle Fleet Purchase and Restricted Access EV Charging Infrastructure and 2) Unrestricted Access EV Charging Infrastructure. The first module can calculate emissions from an electric vehicle fleet purchase project and a restricted access infrastructure project separately, or together. The unrestricted access EV charging infrastructure module for public charging 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 Electric Vehicle Charging Infrastructure Module

EV charging 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 charging infrastructure and the adoption of electric vehicles. The tool assumes one-to-one replacement of conventional fuel vehicles with electric vehicles to be charged at the new unrestricted infrastructure.

This document is organized into three sections for Unrestricted Access Electric Vehicle Charging 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.

Contents

USER GUIDE 3
User Inputs 3
Vehicle Type 4
Tool Outputs 4
Error Messages 5
TOOL METHODOLOGY 6
EXAMPLES 8
Example 1: Building Unrestricted Access EV Charging Infrastructure 8
Example 2: Building Unrestricted Charging Infrastructure for Electric Passenger Cars 10
Appendix A: Electric Vehicles Definition 12

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 Unrestricted Access Electric Vehicle Charging 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 electric 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 2018 and 2040.
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 would be appropriate.
Electric vehicle market share	-----	Insert a percentage for the projected market penetration of electric 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 electric 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 electric 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 electric 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

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 electric vehicles in the given evaluation year. Users can control the number of replacement electric vehicles and the average annual miles traveled per vehicle through the tool interface.

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

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 equivalents (CO_2e) in kilograms/year, as well as total energy consumption (TEC) generated in MMBTU/year, are included. Each pollutant is divided by 365 for the CMAQ daily emission reductions reported in kilograms/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 enter a valid market share for the electric vehicle fleet.	Invalid Input: Market Share	Input a market share between 0 and 100%

Vehicle source type-fuel type combinations: Electric vehicle emissions are derived from the MOVES particulate matter (PM2.5 and PM10) emissions for the source type and baseline fuel combinations shown in Table 5 below, consistent with the AFLEET fuel factor baseline conventional fuel types. This tool will report "N/A" for greenhouse gases and energy. While more common scenarios will involve replacement of gasoline LDVs and diesel HDVs, users can replace diesel LDVs and gasoline HDVs if desired.

Table 4 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
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 electric 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 electric vehicle,

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

such that,

$$MPV_i = \frac{VMT_{MOVES_i}}{POP_{MOVES_i}} \quad (3)$$

$$n_i = p\left(N \cdot \frac{POP_{MOVES_i}}{\sum_{i \epsilon I} POP_{MOVES_i}}\right) \quad (4)$$

$e_{conv_{replace_i}}$ = 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 electric vehicle emission rate for a given source type i and model year of the electric vehicles that will replace conventional vehicles (kilogram/mile),
$e_{alt_MOVES_i}$ = electric vehicle emission rate pulled directly from MOVES for particulate matter brakewear and tirewear emissions only (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 electric 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),
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 electric 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.

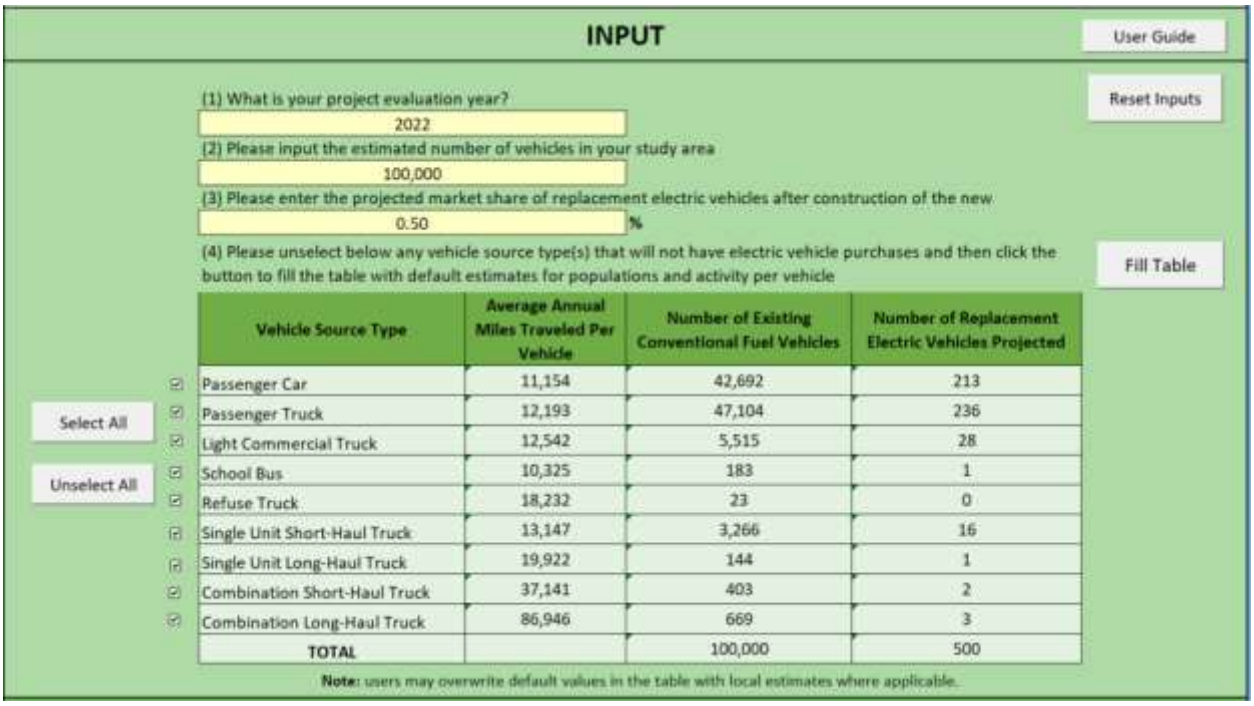
Unlike the Electric Vehicle Fleet Purchase module which specifies only one particular vehicle source type for a vehicle fleet, this unrestricted access EV charging infrastructure module assumes the replacement will be over a distribution of vehicle source types and therefore a summation in the emissions 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 electric 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 electric vehicle market penetration. As noted earlier, the tool assumes that only gasoline LDVs and diesel HDVs will be replaced by comparable electric vehicles.

EXAMPLES

Example 1: Building Unrestricted Access EV Charging Infrastructure

County X in State AA has recently decided to build new unrestricted access infrastructure for electric vehicle charging. 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 electric 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) Please enter the projected market share of replacement electric vehicles after construction of the new
0.50 %

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

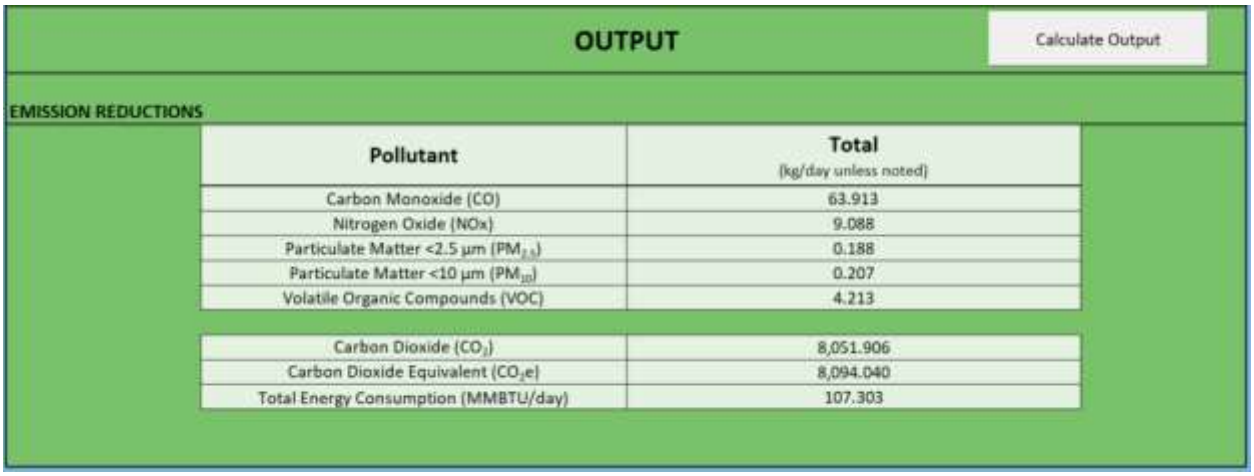
Select All | Unselect All

Vehicle Source Type	Average Annual Miles Traveled Per Vehicle	Number of Existing Conventional Fuel Vehicles	Number of Replacement Electric Vehicles Projected
Passenger Car	11,154	42,692	213
Passenger Truck	12,193	47,104	236
Light Commercial Truck	12,542	5,515	28
School Bus	10,325	183	1
Refuse Truck	18,232	23	0
Single Unit Short-Haul Truck	13,147	3,266	16
Single Unit Long-Haul Truck	19,922	144	1
Combination Short-Haul Truck	37,141	403	2
Combination Long-Haul Truck	86,946	669	3
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
Electric Vehicle Market Penetration: 0.5%
Source Type Selected: Passenger Car, Passenger Truck, Light Commercial Truck, School Bus, Refuse Truck, Single Unit Short-Haul Truck, Single Unit Long-Haul Truck, Combination Short-Haul Truck, Combination Long-Haul Truck

As shown above, most of the 500 replacement electric vehicles will be passenger cars and trucks, but there will be also be some replacement commercial vehicles and buses.



OUTPUT

Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless noted)
Carbon Monoxide (CO)	63.913
Nitrogen Oxide (NOx)	9.088
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.188
Particulate Matter <10 µm (PM_{10})	0.207
Volatile Organic Compounds (VOC)	4.213
Carbon Dioxide (CO_2)	8,051.906
Carbon Dioxide Equivalent (CO_2e)	8,094.040
Total Energy Consumption (MMBTU/day)	107.303

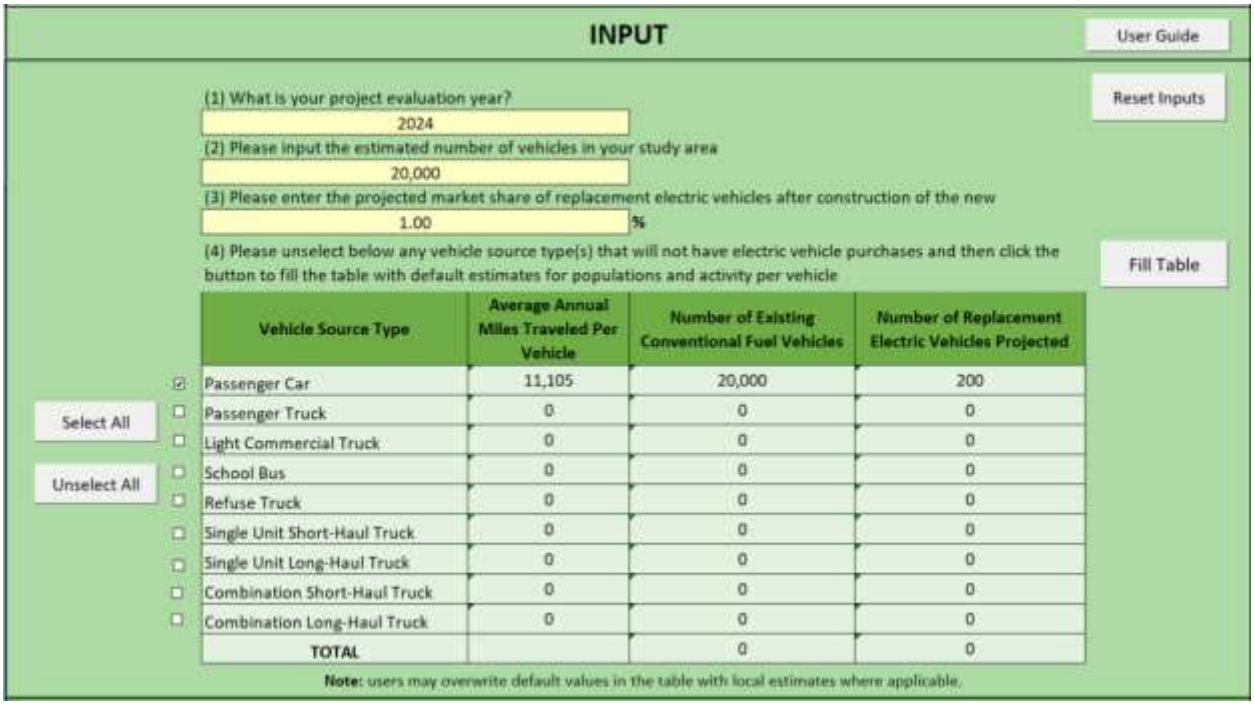
The emission reductions in kg/day for all pollutants as well as the energy reduction in MMBTU/day are:

Carbon Monoxide (CO): 63.913
Nitrogen Oxide (NOx): 9.088
Particulate Matter (PM2.5): 0.188
Particulate Matter (PM10): 0.207
Volatile Organic Compounds (VOC): 4.213

Carbon Dioxide (CO_2): 8,051.906
Carbon Dioxide Equivalent (CO_2e): 8,094.040
Total Energy Consumption (TEC): 107.303

Example 2: Building Unrestricted Charging Infrastructure for Electric Passenger Cars

Scenario: County X in State AA is working with some corporate passenger car fleets and wants to build some electric vehicle charging infrastructure across the county. The county estimates that there are 20,000 vehicles that fuel exclusively within their study area and predicts that roughly 1% of those vehicles could be replaced by electric vehicles. Shown below are the inputs for this example after the 'Fill Table' button has pressed and only passenger cars have been selected:



INPUT

User Guide

Reset Inputs

(1) What is your project evaluation year?

2024

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

20,000

(3) Please enter the projected market share of replacement electric vehicles after construction of the new

1.00 %

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

Fill Table

Select All

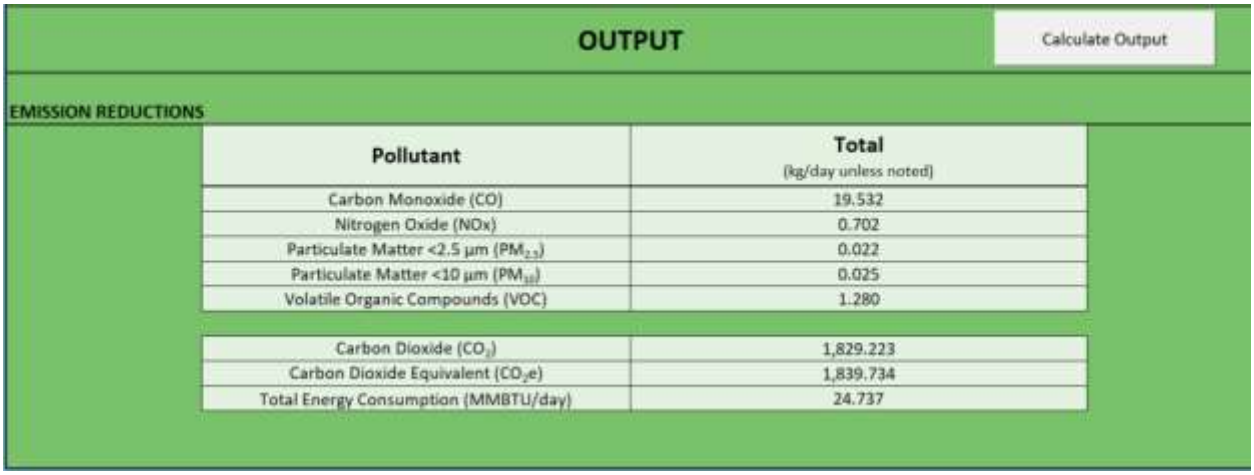
Unselect All

	Vehicle Source Type	Average Annual Miles Traveled Per Vehicle	Number of Existing Conventional Fuel Vehicles	Number of Replacement Electric Vehicles Projected
☑	Passenger Car	11,105	20,000	200
☐	Passenger Truck	0	0	0
☐	Light Commercial Truck	0	0	0
☐	School Bus	0	0	0
☐	Refuse Truck	0	0	0
☐	Single Unit Short-Haul Truck	0	0	0
☐	Single Unit Long-Haul Truck	0	0	0
☐	Combination Short-Haul Truck	0	0	0
☐	Combination Long-Haul Truck	0	0	0
	TOTAL		0	0

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

Project Year: 2024
Vehicles in Study Area: 5,000
Electric Vehicle Market Penetration: 1.0%
Source Type Selected: Passenger Cars

This example calculates the emissions reductions for building charging infrastructure for passenger cars, in 2024. The tool output is shown below:



OUTPUT Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless noted)
Carbon Monoxide (CO)	19.532
Nitrogen Oxide (NOx)	0.702
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.022
Particulate Matter <10 µm (PM_{10})	0.025
Volatile Organic Compounds (VOC)	1.280
Carbon Dioxide (CO_2)	1,829.223
Carbon Dioxide Equivalent (CO_2e)	1,839.734
Total Energy Consumption (MMBTU/day)	24.737

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

Carbon Monoxide (CO): 19.532
Nitrogen Oxide (NOx): 0.702
Particulate Matter (PM2.5): 0.022
Particulate Matter (PM10): 0.025
Volatile Organic Compounds (VOC): 1.280

Carbon Dioxide (CO_2): 1,829.223
Carbon Dioxide Equivalent (CO_2e): 1839.734
Total Energy Consumption (TEC): 24.737

Appendix A: Electric Vehicles Definition

A **battery electric vehicle (BEV)** is similar to the hybrid designs discussed but does not have an internal combustion engine. A BEV is instead powered solely by the electrical energy stored in its rechargeable battery system. The most popular BEVs on the market today are Tesla's Model S, Model X, and the Nissan Leaf.[5] All-electric vehicles do not produce any direct exhaust or tailpipe emissions.[6] However, the electricity used to power the vehicles does produce upstream emissions that are not accounted for in this tool. Lifecycle emission comparisons from a well-to-wheels (WTW) analysis between electric and conventional fuel vehicles will invariably yield different results than this CMAQ tool.

All other alternative fuel vehicles, including hybrid diesel-electric and hydrogen fuel cell (FCV) vehicles, can be found in the documentation for the Alternative Fuel Vehicles and Infrastructure Tool.

[5] InsideEVs, Monthly Plug-In Sales Scorecard, http://insideevs.com/monthly-plug-in-sales-scorecard/
[6] DOE, http://www.afdc.energy.gov/vehicles/electric_basics_ev.html