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 emissions reductions from the implementation of a CMAQ-funded project. The CMAQ Toolkit uses emissions rates based on national-scale runs 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. Emissions 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 emissions rates and guidance on incorporating user-supplied emissions rates can be found in the accompanying Emissions Data documentation.

Construction & Intermodal Equipment, Diesel Engine Retrofit and Replacement Tool

Day-to-day operations of equipment at construction sites and intermodal facilities (e.g., ports, railyards) have notable contributions to air pollution. This tool estimates emissions benefits of CMAQ-funded projects that reduce these emissions by implementing (a) diesel engine retrofitting or (b) repowering and/or replacement diesel equipment. This tool is specific to CMAQ-eligible equipment. Table A1 includes a list of equipment types commonly used at construction and intermodal sites.

Please note that this tool does not model vehicles themselves. To estimate emissions benefits from retrofitting non-road vehicles, refer to the Locomotive & Marine Engine Retrofit and Replacement Tool. To estimate emission benefits from onroad vehicles, refer to the Diesel Truck & Engine Retrofit and Replacement Tool or Transit Bus Retrofits and Replacement Tool.

Retrofit technologies[1] that reduce emissions from diesel-powered construction or intermodal equipment include diesel oxidation catalysts (DOC), diesel particulate filters (DPF), and selective catalytic reduction (SCR). These technologies and their associated emissions reductions are based on the U.S. Environmental Protection Agency's (EPA) online Diesel Emissions Quantifier (DEQ).[2,3] Refer to the Glossary for further details about each retrofit technology.

Alternatively, emissions reductions may be achieved by replacing or repowering the engine in the construction or intermodal equipment. Since newer engines are held to more stringent emissions standards, replacement of old engines may result in overall reductions in emissions for a fleet of

[1] Retrofit technologies in this tool are verified technologies (as defined in section 791 of the Energy Policy Act of 2005 (42 U.S.C. 16131)) for non-road vehicles and non-road engines (as defined in section 216 of the Clean Air Act (42 U.S.C. 7550)) that are used in construction projects or port-related freight operations, as required in 23 USC 149(b)(8)(A)(ii).

[2] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

[3] EPA maintains a list of Verified Technologies for Clean Diesel: https://www.epa.gov/verified-diesel-tech/verified-technologies-list-clean-diesel

equipment. Different fuel types vary in emissions rates, thus repowering an engine with a new fuel type may also result in overall reductions in emissions for a fleet of equipment.

This document is organized into three sections—User Guide, Tool Methodology, and Examples—to aid the user in using the tool and interpreting results. The User Guide provides direction on how to properly input values into the tool and definitions of the user inputs and tool outputs. The Tool Methodology section outlines the steps used within the tool to calculate emissions reductions and describes any associated assumptions. The Examples section provides instructive examples about how to use the tool for different types of project analyses.

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USER GUIDE

This section describes each user input and tool output, the emissions reductions report, error messages, and other assumptions present in the tool. The tool is composed of two modules: Diesel Engine Retrofits and Engine Repower and/or Replacement.

User Inputs – Diesel Engine Retrofit Module

The Diesel Engine Retrofit module includes a series of questions to guide the user in inputting information for emission reduction calculations in a step-by-step process. The inputs for this tool should be specific to the equipment being retrofit. The user-defined inputs for this module are defined in Tabl. Note that the baseline equipment is assumed to operate on diesel fuel.

Table 1. User Inputs – Diesel Engine Retrofit Module

Question	User Input	Units	Description
(1)	Project evaluation year	----	Use the drop-down menu to select a year between 2018 and 2040.
(2)	Equipment sector	----	Use the drop-down menu to select the sector in which the equipment being retrofit best belongs. Refer to Table A1. Suggested Equipment Mappings by Sector or the Equipment Types tab within the tool for suggested equipment mappings by sector.
(3)	Equipment activity	---- hr/yr (per single equipment)	Enter (i) the load factor and (ii) the annual operating hours for one piece of equipment that is being retrofit. Refer to Output emissions rates from MOVES are embedded with default load factors values. These load factors vary by equipment type and fuel type. Table A2 lists the default load factor for each equipment type and fuel type modeled by this tool. Default load factor values were derived from the default MOVES database. Grayed out cells indicate equipment/fuel type combinations that are not modeled by MOVES. Table A2 or the Default Load Factors tab within the tool for a list of default load factor values.
(4)	Number of equipment	----	Enter the number of pieces of equipment in the fleet being retrofit.
(5)	Baseline engine specifications	hp ----	Select (i) the rated engine power bin and enter (ii) the model year for the baseline engine being retrofit.
(6)	Retrofit technology	----	Use the drop-down menu to select the diesel engine retrofit technology being implemented.

The list of equipment sectors in Question 2 is derived from the MOVES3 NONROAD model. The three sectors listed (Airport Support, Construction, and Industrial) those include construction and intermodal equipment relevant to highway projects. Refer to Table A1 or the Equipment Types tab within the tool itself for a list of suggested equipment types within each sector.

The available retrofit technologies in Question 6 are based on EPA's DEQ. Refer to Table B1 for the emission reduction factors for each retrofit technology.

In Question 4, the user should enter '1' if a single piece of equipment is being retrofit. Alternatively, if a fleet of equipment is being retrofit, the user may input the total number of pieces of equipment in the fleet being retrofit. The tool assumes that all equipment in the fleet have the same characteristics. If the user intends to calculate emissions reductions for multiple construction or intermodal equipment types with different characteristics (e.g., operating hours, model years), they should run the tool multiple times and sum the emissions reductions results to calculate total emissions reductions for all of the different types.

User Inputs – Engine Repower or Replacement Module

The Engine Repower or Replacement module is similar to the Diesel Engine Retrofit module. The inputs for the Repower or Replacement module are also specific to the construction or intermodal equipment type being analyzed and must be entered in sequential order. The user-defined inputs for this module are described in Table 2. Note that the baseline equipment is assumed to operate on diesel fuel.

Table 2. User Inputs – Engine Repower or Replacement Module

Question	User Input	Units	Description
(1)	Project evaluation year	----	Use the drop-down menu to select a year between 2018 and 2040.
(2)	Equipment sector	----	Use the drop-down menu to select the sector in which the equipment being repowered/ replaced best belongs. Refer to Table A1. Suggested Equipment Mappings by Sector or the Equipment Types tab within the tool for suggested equipment mappings by sector.
(3)	Repower/ Replacement Fuel	----	Select the fuel type of the repower/replacement equipment.
(4)	Equipment Activity	hr/yr (per single equipment)	Input the annual operating hours for one piece of equipment that is being repowered/ replaced.
(5)	Number of equipment	----	Enter the number of pieces of equipment in the fleet being repowered/replaced.
(6)	Model year	----	Enter the model year of the baseline and repower/replacement engine.
(7)	Engine power	hp	Select the rated engine power bin of the baseline and repower/replacement engine.

Question	User Input	Units	Description
(8)	Load factor	----	Enter the load factor of the baseline and repower/replacement engine. Refer to Output emissions rates from MOVES are embedded with default load factors values. These load factors vary by equipment type and fuel type. Table A2 lists the default load factor for each equipment type and fuel type modeled by this tool. Default load factor values were derived from the default MOVES database. Grayed out cells indicate equipment/fuel type combinations that are not modeled by MOVES. Table A2 or the Default Load Factors tab within the tool for a list of default load factor values.

The list of available fuel types in Question 3 depends on the non-road sector selected in Question 2 (the non-road sector options are the same as the Diesel Engine Retrofit module). Once a sector is selected, the list of available fuel types will automatically become available. The hybrid eco-crane replacement option only applies to rubber tired gantry (RTG) cranes which are mapped to the Industrial sector (see Table A1). For hybrid eco-crane and all-electric replacement options, the tool uses the appropriate emission reduction factor from EPA's DEQ (see Table B2) to calculate emission reductions. As a result, only the baseline engine inputs are needed to calculate emissions. For all other repower/replacement fuel type selections, the tool uses emission rates derived from EPA's MOVES model, so information is needed for both the baseline and repower/replacement equipment. If there is no change between the baseline and repower/replacement equipment for any given input, the user should input the same information for both the baseline and repower/replacement equipment.

As in the Diesel Engine Retrofit module, the tool assumes that all equipment in the fleet have the same characteristics. If the user intends to calculate emissions reductions for multiple pieces of construction or intermodal equipment with different characteristics (e.g., operating hours, model years), they should run the tool multiple times and sum the emissions reductions results to calculate total emissions reductions for the entire fleet.

Tool Outputs

To generate tool outputs, users need to click the 'Calculate Output' button. If any changes are made to the inputs after running the tool, users need to click this button again. The tool will not update the reported emissions reductions automatically.

This tool calculates equipment fleet activity performance and emissions reductions. The emissions reductions represent the decrease in emissions resulting from retrofitting a diesel engine with an emissions control technology (Diesel Engine Retrofit module) or from repowering/replacing the equipment outright (Engine Repower or Replacement module). A positive emissions reduction indicates

a decrease in emissions (i.e., emissions benefit) whereas a negative value is interpreted as an increase in emissions (i.e., emissions disbenefit).

Changes in emissions are calculated for five pollutants—carbon monoxide (CO), particulate matter with diameters < 2.5 µm ($PM_{2.5}$), particulate matter with diameters < 10 µm (PM_{10}), nitrogen oxides (NO_x), and volatile organic compounds (VOC)—in kilograms per day (kg/d) for CMAQ reporting. Reductions in carbon dioxide and carbon dioxide equivalents (CO_2e) are also calculated and reported in kg/d. For the Diesel Engine Retrofits module, CO_2e only includes carbon dioxide (CO_2); however, note that none of the retrofit technologies are designed to reduce CO_2 emissions (see Table B1). For the Engine Repower or Replacement module, CO_2e only includes CO_2 emissions for hybrid eco-cranes and all-electric repower/replacement projects (Table B2). For all other repower/replacement fuel types, CO_2e only includes CO_2 and methane (CH_4). MOVES NONROARD does not report N_2O or calculate CO_2e directly.

Although other CMAQ tools report reductions in Total Energy Consumption (TEC), TEC is not calculated or reported in the Construction & Intermodal Equipment Engine Retrofit and Replacement Tool due to insufficient energy efficiency data for these equipment types.

For users who are interested in estimating "before" and "after" project emissions, in addition to net emissions benefits, you may access additional data by un-hiding these two tabs: internalRR and internalRetrofit. To view hidden tabs, right click on any tab in the bottom bar and selected 'Unhide'.

Error Messages

Error messages that the user may encounter in this tool, the reason for the error messages, and the solutions are listed in Table 3 for the Diesel Engine Retrofit module and Table 4 for the Engine Repower or Replacement module.

Click 'Calculate Output' to recalculate the results once errors are resolved.

Table 3. Error Messages – Diesel Engine Retrofit Module

Error Message	Reason for Error	Solution
ERROR (Q1): Missing project evaluation year.	No input provided for project evaluation year.	Select a project evaluation year from the drop-down menu.
ERROR (Q2): Missing sector.	No input provided for baseline equipment sector.	Select a sector from the drop-down menu.
ERROR (Q3): Missing load factor.	No input provided for the equipment load factor.	Enter the load factor for the equipment being retrofit.
ERROR (Q3): Missing annual operating hours.	No input provided for the annual operating hours.	Enter the annual operating hours for the equipment being retrofit.
ERROR (Q4): Missing fleet size.	No input provided for the fleet size.	Enter the number of equipment in the fleet being retrofit. Enter '1' for a single piece of equipment.

Error Message	Reason for Error	Solution
ERROR (Q5): Missing rated engine power of baseline equipment.	No input provided for the baseline equipment rated engine power.	Select the rated engine power (in hp) bin for the baseline equipment using the drop-down menu.
ERROR (Q5): Missing model year of baseline equipment.	No input provided for the baseline equipment model year.	Enter a model year for the baseline equipment.
ERROR (Q5): Model year cannot be greater than project evaluation year.	The model year cannot be greater than the project evaluation year.	Enter a model year that is less than the project evaluation year.
ERROR (Q6): Missing retrofit technology.	No input provided for the retrofit technology.	Select a retrofit technology from the drop-down menu.
ERROR: This evaluation year, sector, hp, and model year combination for the diesel baseline equipment is not modeled by MOVES.	There is no corresponding MOVES emission rate for this combination of evaluation year, sector, model year, and rated engine power for a diesel equipment type.	Recheck the evaluation year, sector, hp, and model year provided.

Table 4. Error Messages – Engine Repower or Replacement Module

Error Message	Reason for Error	Solution
ERROR (Q1): Missing project evaluation year.	No input provided for project evaluation year.	Select a project evaluation year from the drop-down menu.
ERROR (Q2): Missing sector.	No input provided for the equipment sector.	Select a sector from the drop-down menu.
ERROR (Q3): Missing fuel type of repower/ replacement equipment.	No input provided for repower/replacement engine fuel type.	Select a fuel type from the drop-down menu. If there is no change in fuel type, select 'Diesel'.
ERROR (Q4): Missing annual operating hours.	No input provided for the annual operating hours.	Enter the annual operating hours for a single piece of equipment being repowered/replaced.
ERROR (Q5): Missing fleet size.	No input provided for the fleet size.	Enter the number of pieces of equipment in the fleet being repowered/replaced. Enter '1' for a single piece of equipment.
ERROR (Q6): Missing model year of baseline equipment.	No input provided for the baseline engine model year.	Enter a model year for the baseline equipment.
ERROR (Q6): Missing model year of repower/replacement equipment.	No input provided for the repower/replacement engine model year.	Enter a model year for the repower/ replacement equipment. If there is no change, enter the same model year as indicated for the baseline equipment.

Error Message	Reason for Error	Solution
ERROR (Q6): Model year cannot be greater than project evaluation year.	The model year cannot be greater than the project evaluation year.	Enter a model year for the baseline and/or repower/replacement equipment that is less than the project evaluation year.
ERROR (Q6): New model year cannot be less than baseline model year.	The model year of the new engine cannot be less than the model year of the baseline engine.	Enter a new model year that is greater than or equal to the baseline engine model year.
ERROR (Q7): Missing rated engine power of baseline equipment.	No input provided for the baseline rated engine power.	Select the rated engine power (in hp) bin for the baseline equipment using the drop-down menu.
ERROR (Q7): Missing rated engine power of repower/ replacement equipment.	No input provided for the repower/replacement rated engine power.	Select the rated engine power (in hp) bin for the repower/ replacement equipment using the drop-down menu. If there is no change, select the same power bin as the baseline equipment.
ERROR (Q8): Missing baseline load factor.	No input provided for the baseline equipment load factor.	Enter the load factor for a single piece of baseline equipment.
ERROR (Q8): Missing repower/replacement load factor.	No input provided for the repower/replacement equipment load factor.	Enter the load factor for a single piece of repower/replacement equipment.
ERROR: This evaluation year, sector, hp, and model year combination for the diesel baseline equipment is not modeled by MOVES.	There is no corresponding MOVES emission rate for this combination of evaluation year, sector, model year, and rated engine power for a diesel equipment type.	Recheck the evaluation year, sector, hp, and model year provided for the baseline equipment.
ERROR: This evaluation year, sector, fuel type, hp, and model year combination for the repowered/replacement equipment is not modeled by MOVES.	There is no corresponding MOVES emission rate for this combination of evaluation year, sector, fuel type, model year, and rated engine power for an equipment type.	Recheck the evaluation year, sector, fuel type, hp, and model year provided for the repowered/ replacement equipment.

TOOL METHODOLOGY

Fleet activity performance for the Construction & Intermodal Equipment Engine Retrofit and Replacement Tool is the product of the user-supplied annual operating hours for one piece of equipment in hr/yr (opHr) and the user-supplied fleet size (fleet*)* (Equation 1).

$$total\ annual\ operating\ hours = opHr \times fleet \quad (1)$$

Emissions reductions for the Construction & Intermodal Equipment Engine Retrofit and Replacement Tool are based on the difference in emissions between the baseline equipment and the retrofitted equipment (Diesel Engine Retrofit module) or repowered/replacement equipment (Engine Repower or Replacement module).

For the Diesel Engine Retrofit module, the change in emissions in kilograms per day (kg/d) is described in Equation 2 where $ER_{baseline}$ is the emissions rate in kg/hr of the baseline equipment, $LF_{baseline}$ is the user-supplied load factor of the baseline equipment, and *RF* is the emissions reduction factor for the diesel retrofit option selected. Refer to Table B1 for the list of retrofit options and corresponding reduction factors.

$$\Delta Emissions_{retrofit} = ER_{baseline} \times LF_{baseline} \times opHr \times fleet \times \frac{1}{365} \times RF \quad (2)$$

For the Repower or Replacement (RR) module, the change in emissions in kg/d is shown in Equation 3. The annual operating hours and fleet size are assumed to be the same for both the baseline and repowered/replacement engine. LF_{RR} is the user-supplied load factor for the repowered/replacement equipment and ER_{RR} is the emissions rate in kg/hr of the repower/replacement equipment.

$$\Delta Emissions_{RR} = (ER_{baseline} \times LF_{baseline} - ER_{RR} \times LF_{RR}) \times opHr \times fleet \times \frac{1}{365} \quad (3)$$

Note that if an all-electric or hybrid eco-crane is selected for the repower/replacement fuel type, the change in emissions is calculated using Equation 2. Refer to Table B2 for the reduction factors for all-electric equipment and hybrid eco-cranes. Although fuel cells are not explicitly modeled by this tool, fuel cells have the same reduction factors as all-electric equipment. Note that these reduction factors do not account for emissions from upstream electricity generation.

Also note that this tool does not consider resuspended or fugitive dust emissions from non-road equipment. Please refer to EPA's AP-42 Compilation of Emission Factors or other local data sources to estimate dust emissions.

Emissions Rates Sources

Emissions rates were derived from national-scale runs of EPA's MOVES NONROAD model for the following sectors: Construction, Industrial, and Airport Support.[4] These three sectors were chosen because they encompass construction and intermodal equipment types (Table A1). Emissions rates were aggregated by evaluation year, pollutant, sector, fuel type, model year, and horsepower. Due to the large number of equipment types and high volume of subsequent emissions data, only sector-level (versus equipment-level) emissions rates are used within this tool. Refer to the Emissions Data Documentation for more details about the national-scale MOVES NONROAD run specifications and post-processing. Particulate matter emissions from brakewear and tirewear were assumed to be negligible.

[4] U.S. Environmental Protection Agency. 2018. MOVES2014b. Available at https://www.epa.gov/moves/moves-versions-limited-current-use.

Default equipment load factors (Table A2) are embedded in the MOVES output emissions rates. To allow users to input their own load factor values, each emission rate, ER_{LF}, was divided by the average default load factor across all equipment types in a given sector, LF_{avg}, to obtain emissions rates without embedded load factors, *ER* (Equation 4). See Figure A1 for the distribution of default load factors by sector and fuel type and Table A3 for the sector-average default load factor values. Users are encouraged to user local load factor inputs when possible.

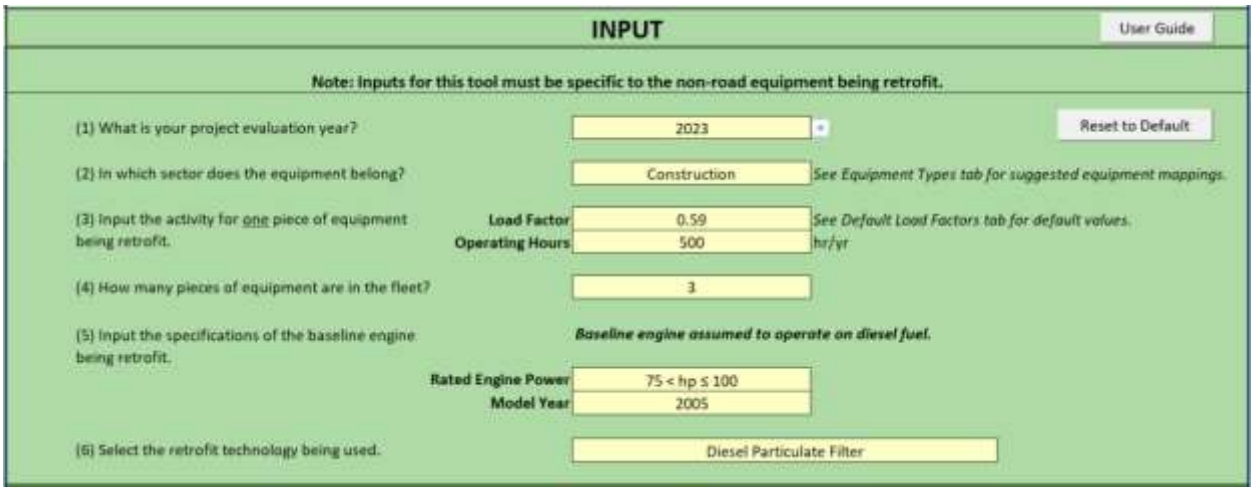
$$ER = \frac{ER_{LF}}{LF_{avg}} \quad (4)$$

EXAMPLES

Example 1: Retrofitting a Fleet of Excavators with Diesel Particulate Filters

A construction agency plans to retrofit its fleet of 3 excavators with diesel particulate filters in 2023. The current, 2005 engines are each 200 hp and operate on diesel fuel for 500 hr/year. Additionally, the engine load factor is assumed to be the default load factor value for a diesel excavator engine.

Based on this scenario, the user would enter the following inputs into the tool:



Project year: 2023

Sector: Construction (see Table A1)

Load factor: 0.59 (see Table A2)

Operating hours: 500 hr/yr

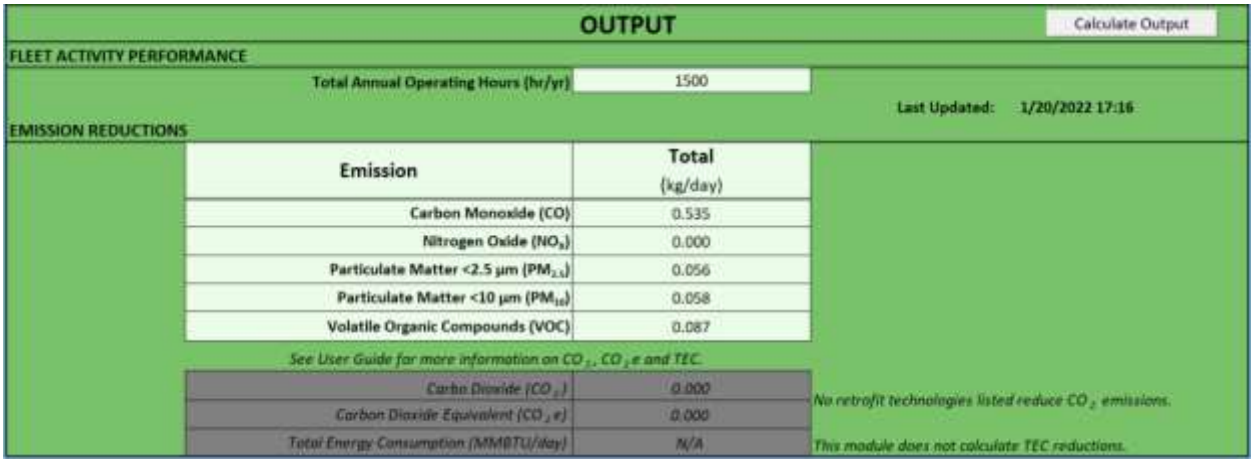
Fleet size: 3

Engine power: 175 < hp ≤ 300

Model year: 2005

Retrofit technology: Diesel Particulate Filter

Once the inputs are entered, click 'Calculate Output' to generate output. The estimated fleet activity performance and emission reductions are as follows:



OUTPUT — Calculate Output

FLEET ACTIVITY PERFORMANCE

Total Annual Operating Hours (hr/yr)	1500

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EMISSION REDUCTIONS

Emission	Total (kg/day)
Carbon Monoxide (CO)	0.535
Nitrogen Oxide (NO_x)	0.000
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.056
Particulate Matter <10 µm (PM_{10})	0.058
Volatile Organic Compounds (VOC)	0.087

See User Guide for more information on CO_2, CO_2e and TEC.

Carbo Dioxide (CO_2)	*0.000*
Carbon Dioxide Equivalent (CO_2e)	*0.000*
Total Energy Consumption (MMBTU/day)	*N/A*

No retrofit technologies listed reduce CO_2 emissions.

This module does not calculate TEC reductions.

Total annual operating hours: 1,500 hr/yr

CO: 0.535 kg/d

NO_x: 0.000 kg/d

$PM_{2.5}$: 0.056 kg/d

PM_{10}: 0.058 kg/d

VOC: 0.087 kg/d

CO_2: 0.00 kg/d

CO_2e: 0.000 kg/d

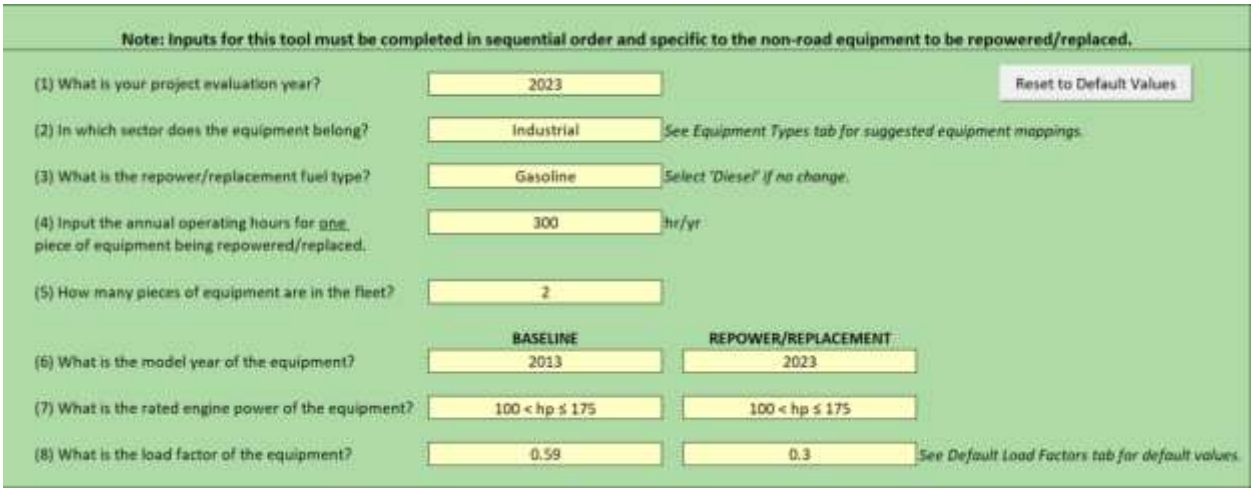
TEC: N/A

Note that diesel particulate filters do not produce NOx or CO_2e benefits (see Table B1).

Example 2: Repowering a Forklift

A transportation agency wishes to repower two older diesel forklifts with gasoline at a construction site. The agency will purchase two new 2023 engines to repower two 2013 forklifts and that each operate for 300 hours annually. The horsepower of each forklift will remain the same (110 hp) after repowering.

Based on this scenario, the user would enter the following inputs into the tool:



Project evaluation year: 2023

Sector: Industrial (see Table A1)

Fuel type: Gasoline

Operating hours: 300 hr/yr

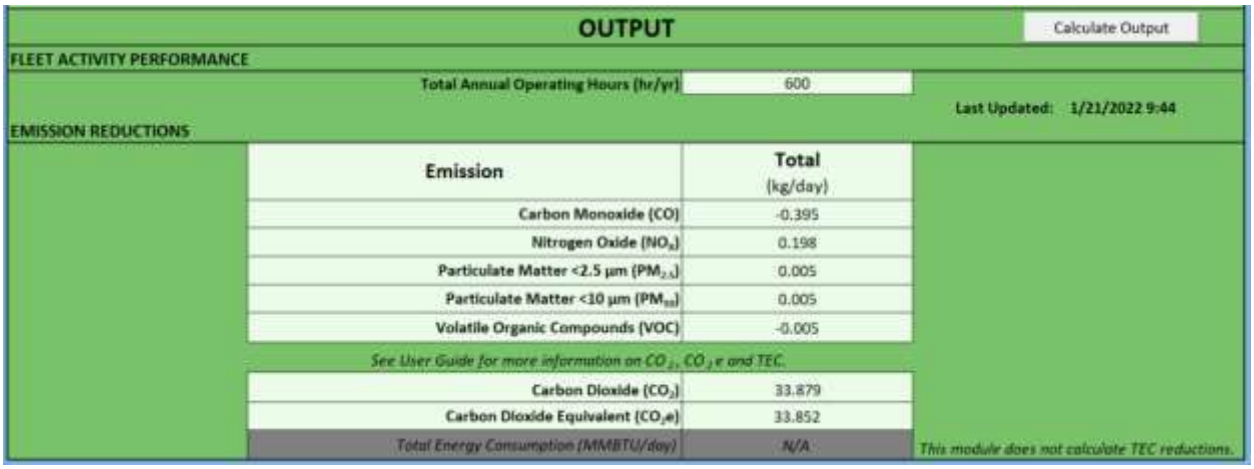
Fleet size: 2

Model year: 2013 (baseline), 2023 (repower)

Rated engine power: 100 < hp ≤ 175 (baseline), 100 < hp ≤ 175 (repower)

Load factor: 0.59 (baseline), 0.30 (repower) (see Table A2)

Once the inputs are entered, click 'Calculate Output' to generate output. The estimated fleet activity performance and emission reductions are as follows:



OUTPUT — Calculate Output

FLEET ACTIVITY PERFORMANCE

Total Annual Operating Hours (hr/yr)	600

Last Updated: 1/21/2022 9:44

EMISSION REDUCTIONS

Emission	Total (kg/day)
Carbon Monoxide (CO)	-0.395
Nitrogen Oxide (NO_x)	0.198
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.005
Particulate Matter <10 µm (PM_{10})	0.005
Volatile Organic Compounds (VOC)	-0.005

See User Guide for more information on CO_2, CO_2e and TEC.

Carbon Dioxide (CO_2)	33.879
Carbon Dioxide Equivalent (CO_2e)	33.852
Total Energy Consumption (MMBTU/day)	*N/A*

This module does not calculate TEC reductions.

Total annual operating hours: 600 hr/yr

CO: -0.395 kg/d

NO_x: 0.198 kg/d

$PM_{2.5}$: 0.005 kg/d

PM_{10}: 0.005 kg/d

VOC: -0.005 kg/d

CO_2: 33.879

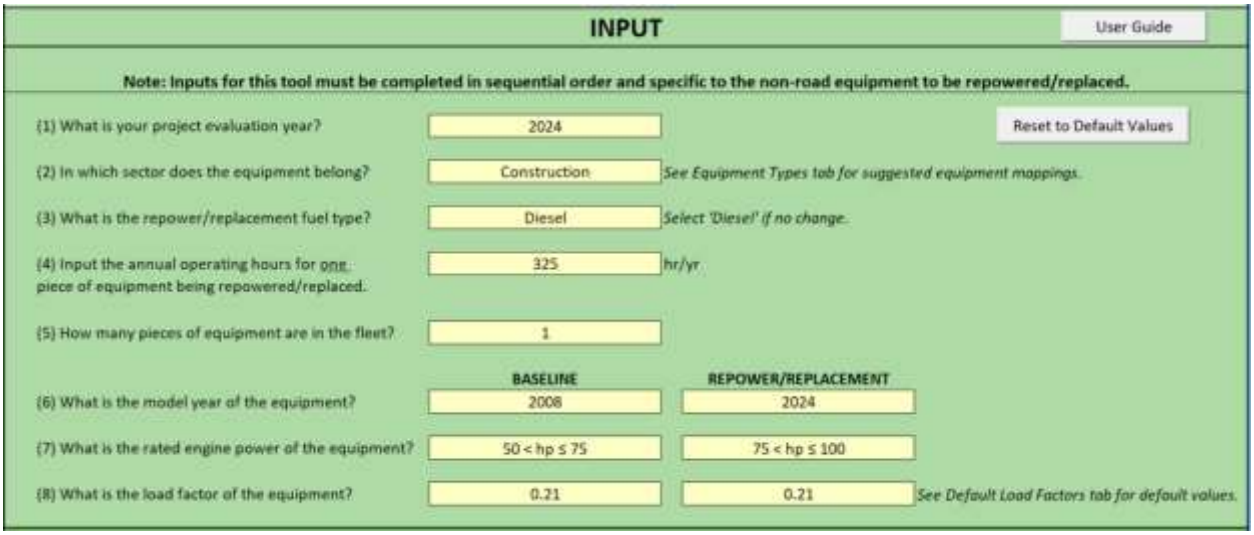
CO_2e: 33.852 kg/d

TEC: N/A

Example 3: Replacing a Skid Steer Loader with a Newer Model Year

A 2008 diesel-operated engine in a skid steer loader used at a construction site will be replaced with a 2024 model year engine in 2024. The newer engine will still operate on diesel fuel but will be 100 hp instead of 75 hp. This skid steer loader operates for approximately 325 hours each year.

Based on this scenario, the user would enter the following inputs into the tool:



INPUT

User Guide

Note: Inputs for this tool must be completed in sequential order and specific to the non-road equipment to be repowered/replaced.

Reset to Default Values

(1) What is your project evaluation year?	2024		
(2) In which sector does the equipment belong?	Construction	*See Equipment Types tab for suggested equipment mappings.*	
(3) What is the repower/replacement fuel type?	Diesel	*Select 'Diesel' if no change.*	
(4) Input the annual operating hours for one piece of equipment being repowered/replaced.	325	hr/yr	
(5) How many pieces of equipment are in the fleet?	1		
	BASELINE	**REPOWER/REPLACEMENT**	
(6) What is the model year of the equipment?	2008	2024	
(7) What is the rated engine power of the equipment?	50 < hp ≤ 75	75 < hp ≤ 100	
(8) What is the load factor of the equipment?	0.21	0.21	*See Default Load Factors tab for default values.*

Project evaluation year: 2024

Sector: Construction (see Table A1)

Fuel type: Diesel

Operating hours: 325 hr/yr

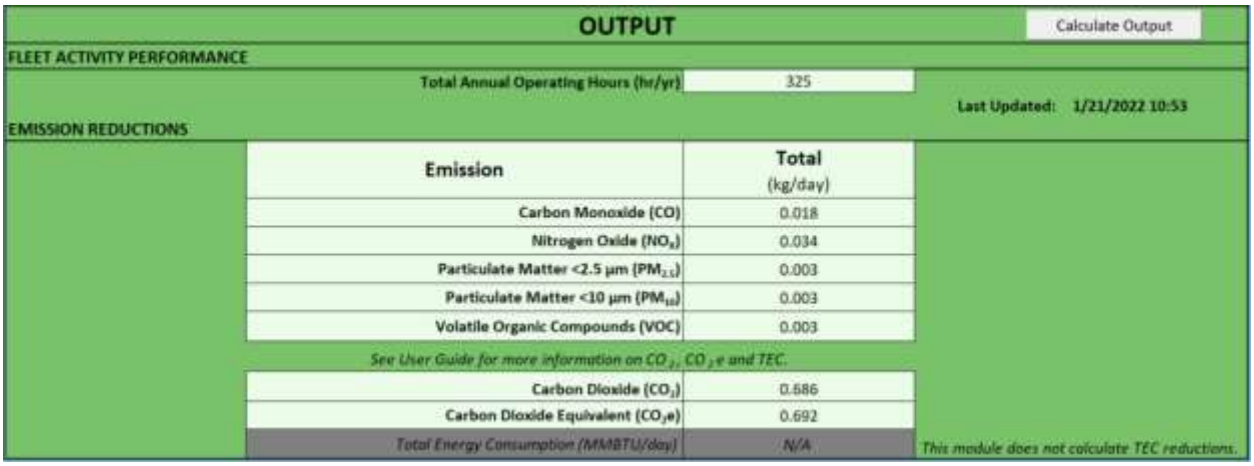
Fleet size: 1

Model year: 2008 (baseline), 2024 (replacement)

Rated engine power: 50 < hp ≤ 75 (baseline), 75 < hp ≤ 100 (replacement)

Load factor: 0.21 (baseline), 0.21 (replacement) (see Table A2)

Once the inputs are entered, click 'Calculate Output' to generate output. The estimated fleet activity performance and emission reductions are as follows:



OUTPUT

Calculate Output

FLEET ACTIVITY PERFORMANCE

Total Annual Operating Hours (hr/yr)	325

Last Updated: 1/21/2022 10:53

EMISSION REDUCTIONS

Emission	Total (kg/day)
Carbon Monoxide (CO)	0.018
Nitrogen Oxide (NO_x)	0.034
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.003
Particulate Matter <10 µm (PM_{10})	0.003
Volatile Organic Compounds (VOC)	0.003

See User Guide for more information on CO_2, CO_2e and TEC.

Carbon Dioxide (CO_2)	0.686
Carbon Dioxide Equivalent (CO_2e)	0.692
Total Energy Consumption (MMBTU/day)	*N/A*

This module does not calculate TEC reductions.

Total annual operating hours: 325 hr/yr

CO: 0.018 kg/d

NO_x: 0.034 kg/d

$PM_{2.5}$: 0.003 kg/d

PM_{10}: 0.003 kg/d

VOC: 0.003 kg/d

CO_2: 0.686 kg/d

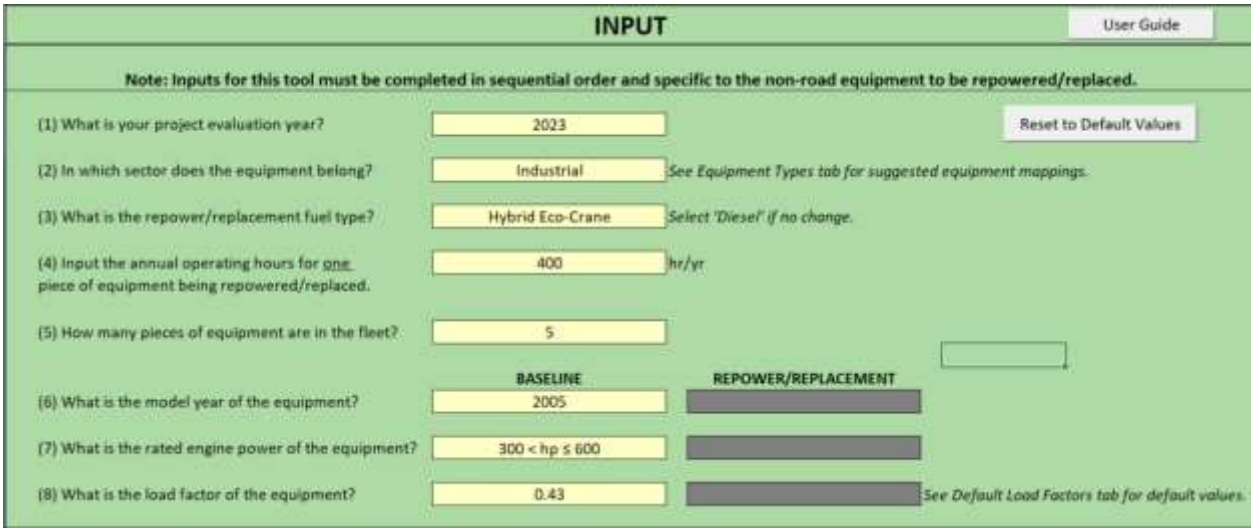
CO_2e: 0.692 kg/d

TEC: N/A

Example 4: Upgrading an RTG Crane

A fleet of 5 diesel-operated RTG cranes at a port will be upgraded to hybrid eco-cranes. Each crane has a 400-hp engine from 2005 and operates for 400 hr/yr hours annually.

Based on this scenario, the user would enter the following inputs into the tool:



Project evaluation year: 2023

Sector: Industrial (see Table A1)

Fuel type: Hybrid Eco-Crane

Operating hours: 400 hr/yr

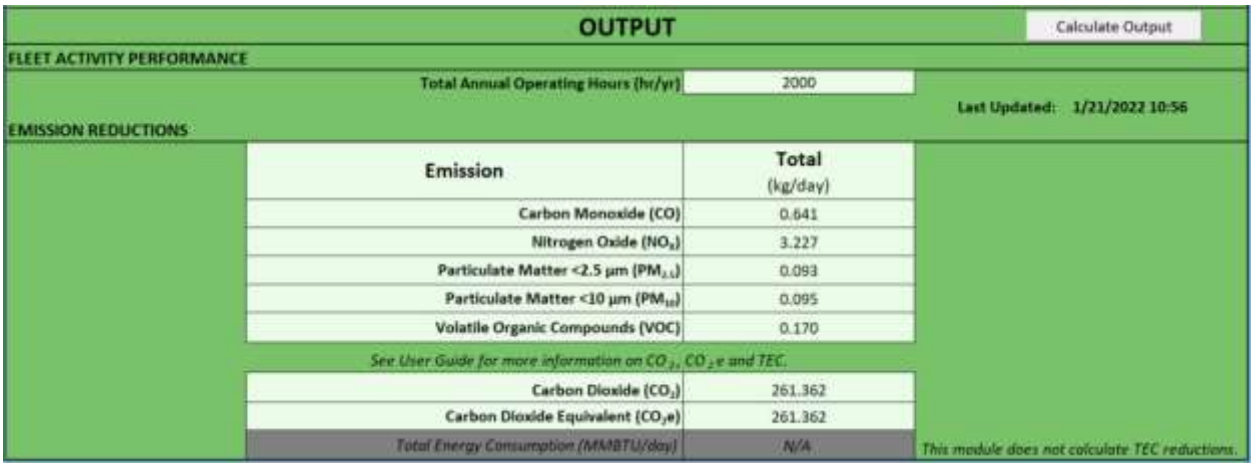
Fleet size: 5

Model year: 2005 (baseline), N/A (replacement)

Rated engine power: 300 < hp ≤ 600 (baseline), N/A (replacement)

Load factor: 0.43 (baseline), N/A (replacement) (see Table A2)

Once the inputs are entered, click 'Calculate Output' to generate output. The estimated fleet activity performance and emission reductions are as follows:



OUTPUT

Calculate Output

FLEET ACTIVITY PERFORMANCE

Total Annual Operating Hours (hr/yr)	2000

Last Updated: 1/21/2022 10:56

EMISSION REDUCTIONS

Emission	Total (kg/day)
Carbon Monoxide (CO)	0.641
Nitrogen Oxide (NO_x)	3.227
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.093
Particulate Matter <10 µm (PM_{10})	0.095
Volatile Organic Compounds (VOC)	0.170

See User Guide for more information on CO_2, CO_2e and TEC.

Carbon Dioxide (CO_2)	261.362
Carbon Dioxide Equivalent (CO_2e)	261.362
Total Energy Consumption (MMBTU/day)	*N/A*

This module does not calculate TEC reductions.

Total annual operating hours: 2,000 hr/yr

CO: 0.641 kg/d

NO_x: 3.227 kg/d

$PM_{2.5}$: 0.094 kg/d

PM_{10}: 0.095 kg/d

VOC: 0.170 kg/d

CO_2: 261.362 kg/d

CO_2e: 261.362 kg/d

TEC: N/A

Appendix A – Suggested Equipment Mappings and Default Load Factors

In the MOVES NONROAD module, the following sectors contain equipment types used at construction and intermodal facilities: Construction, Industrial, and Airport Support. To calculate emissions reductions, this tool uses emissions rates aggregated by sector. Table A1 provides suggested mappings of common construction and intermodal equipment types to the various sectors. These mappings are based on the default MOVES database and the Cargo Handling Equipment chapter of EPA's draft report for estimating port-related emissions.[5,6]

Table A1. Suggested Equipment Mappings by Sector

Construction	Industrial	Airport Support
• Bore/Drill Rigs • Cement & Mortar Mixers • Concrete/Industrial Saws • Cranes • Crawler Tractor/Dozers • Crushing/Proc. Equipment • Dumpers/Tenders • Excavators • Graders • Off-Highway Tractors • Off-Highway Trucks • Other Construction Equipment • Pavers • Paving Equipment • Plate Compactors • Rollers • Rough Terrain Forklifts • Rubber Tire Loaders • Scrapers • Signal Boards/Light Plants (including Light Towers) • Skid Steer Loaders • Surfacing Equipment • Tampers/Rammers • Tractors/Loaders/Backhoes • Trenchers	• Forklifts • Other General Industrial Equipment (e.g., Empty Container Handlers, Rail Pushers, Reach Stackers, RTG Cranes, Side Handlers, Top Handlers) • Other Material Handling Equipment • Terminal Tractors (including Yard Tractors)	• Airport Support Equipment *Airport support equipment may include conveyors, cargo transporters, loaders, and tow tractors. MOVES-nonroad does not distinguish separate equipment types within this category.

Output emissions rates from MOVES are embedded with default load factors values. These load factors vary by equipment type and fuel type. Table A2 lists the default load factor for each equipment type and

[5] U.S. Environmental Protection Agency. 2018. MOVES2014b. Available at https://www.epa.gov/moves/moves-versions-limited-current-use.

[6] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories* (Chapter 6). EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

fuel type modeled by this tool. Default load factor values were derived from the default MOVES database. Grayed out cells indicate equipment/fuel type combinations that are not modeled by MOVES.[7]

Table A2. Default Equipment Load Factors by Fuel Type

Equipment	Diesel	Gasoline[a]	CNG	LPG
Airport Support Equipment	0.59	0.56		0.56
Bore/Drill Rigs	0.43	0.79		0.79
Cement & Mortar Mixers	0.43	0.59		
Concrete/Industrial Saws[b]	0.59	0.78		0.78
Cranes	0.43	0.47		0.47
Crawler Tractor/Dozers	0.59			
Crushing/Proc. Equipment[b]	0.43	0.85		0.85
Dumpers/Tenders	0.21	0.41		
Excavators	0.59			
Forklifts	0.59	0.30	0.30	0.30
Graders	0.59			
Off-Highway Tractors	0.59			
Off-Highway Trucks	0.59			
Other Construction Equipment	0.59	0.48	0.48	0.48
Other General Industrial Equipment[b]	0.43	0.54	0.54	0.54
Other Material Handling Equipment	0.21	0.53		0.53
Pavers	0.59	0.66		0.66
Paving Equipment[b]	0.59	0.59		0.59
Plate Compactors[b]	0.43	0.55		
Rollers	0.59	0.62		0.62
Rough Terrain Forklifts	0.59	0.63		0.63
Rubber Tire Loaders	0.59	0.71		0.71
Scrapers	0.59			
Signal Boards/Light Plants[b]	0.43	0.72		
Skid Steer Loaders	0.21	0.58		0.58
Surfacing Equipment	0.59	0.49		0.49
Tampers/Rammers[b]	0.43	0.55		
Terminal Tractors	0.59	0.78	0.78	0.78
Tractors/Loaders/Backhoes	0.21	0.48		0.48
Trenchers	0.59	0.66		0.66

CNG = compressed natural gas

LPG = liquefied petroleum gas

[a] 4-stroke gasoline engines only unless otherwise stated.

[b] For these equipment types, the tool models 2-stroke gasoline engines in addition to 4-stroke gasoline engines. The default load factor is the same for both 2-stroke and 4-stroke engines.

Figure A1 shows the distribution of default load factors from Table A2 by fuel type and sector. The number of equipment types in each fuel type/sector combination is indicated by *n* in parentheses. As shown by the boxplots, not all equipment types within a sector have the same default load factor. The average default load factor within each sector for each fuel type was used to obtain sector-level

[7] U.S. Environmental Protection Agency. 2018. MOVES2014b. Available at https://www.epa.gov/moves/moves-versions-limited-current-use.

emissions rates without the embedded load factors for use in this tool. These sector-average default load factor values are tabulated in Table A3.

Figure A1. Distribution of Default Equipment Load Factors by Sector for Each Fuel Type

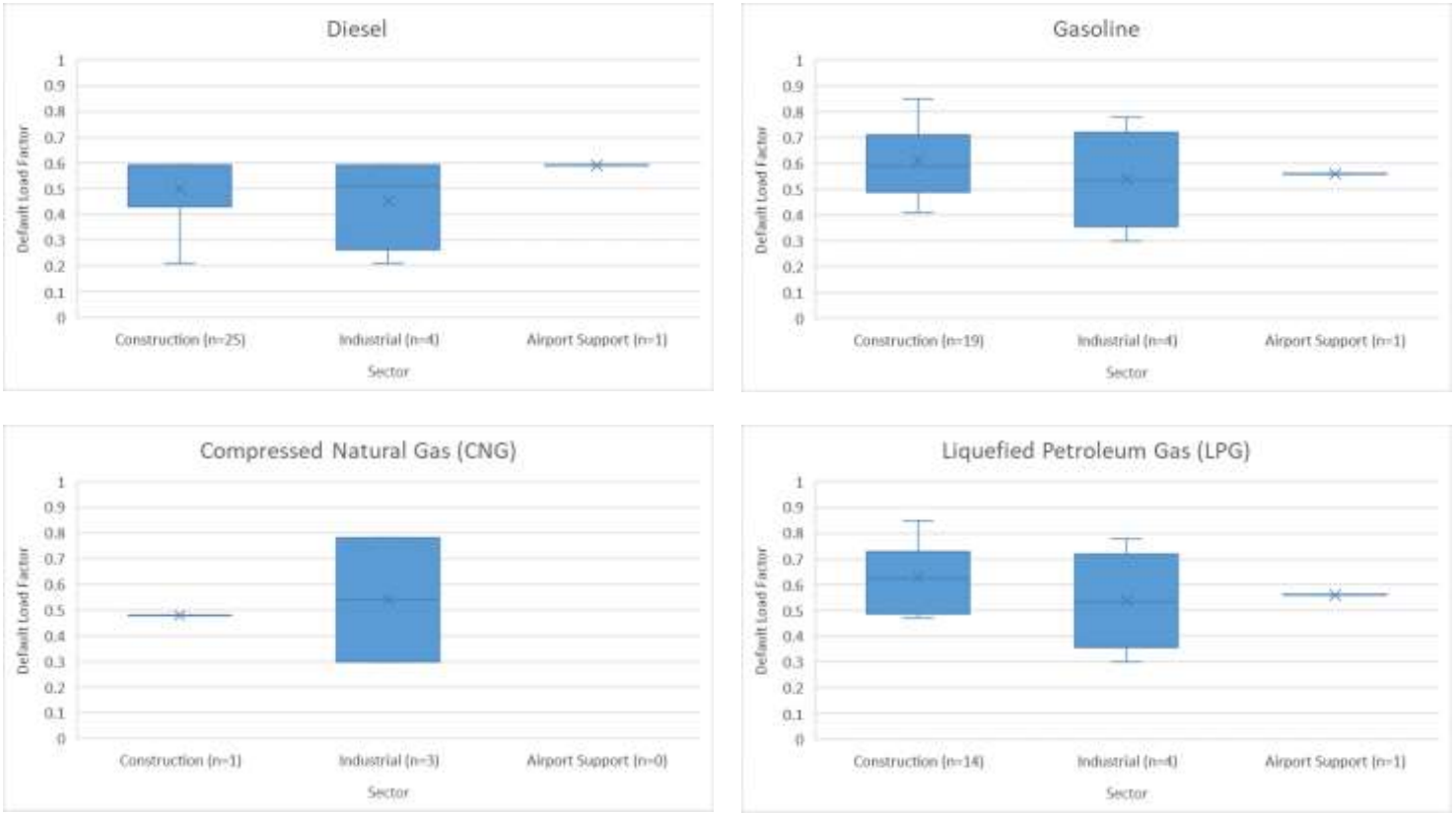


Table A3. Sector-Average Default Load Factors by Fuel Type

-	Diesel	Gasoline	Compressed Natural Gas (CNG)[a]	Liquefied Petroleum Gas (LPG)
Construction	0.4996	0.6111	0.4800	0.6279
Industrial	0.4550	0.5375	0.5400	0.5375
Airport Support	0.5900	0.5600	----	0.5600

[a] There is no CNG airport support equipment available in MOVES NONROAD.

Appendix B – Diesel Engine Retrofit and Replacement Technologies and Reduction Factors

Per EPA's DEQ, diesel engine retrofit technologies and their subsequent emissions reduction factors depend on whether the equipment being retrofitted is stationary or non-stationary. All equipment types modeled by this tool are non-stationary. Table B1 lists the available retrofit technologies and corresponding emissions reduction factors for non-stationary equipment.[8]

Table B1. Emissions Reduction Factors for Diesel Engine Retrofits of Non-Stationary Equipment

Retrofit Technology	CO	NOx	PM2.5[a]	PM10[a]	VOC[b]	CO_2e[c]
Diesel Oxidation Catalyst	0.90	0.00	0.20	0.20	0.80	0.00
Diesel Oxidation Catalyst + Diesel Particulate Filter	0.00	0.00	0.85	0.85	0.00	0.00
Diesel Particulate Filter	0.90	0.00	0.90	0.90	0.95	0.00
Selective Catalytic Reduction	0.85	0.65	0.00	0.00	0.90	0.00
Selective Catalytic Reduction + Diesel Oxidation Catalyst	0.90	0.80	0.25	0.25	0.90	0.00
Selective Catalytic Reduction + Diesel Particulate Filter	0.95	0.85	0.85	0.85	0.60	0.00

[a] The DEQ only reports reduction factors for PM. Values for PM2.5 and PM10 were assumed to be the same as those for PM.

[b] The DEQ does not directly report VOC reduction factors. Values were assumed to be equivalent to the reduction factors for hydrocarbons.

[c] The DEQ only reports reduction factors for CO_2. Reduction factors for CO_2e are only based on CO_2.

[8] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

As summarized in Table B2, the DEQ also provides emissions reductions factors for replacing a diesel engine with an all-electric engine or a diesel crane with a hybrid eco-crane.[9]

Table B2. Emissions Reduction Factors for Diesel Engine Replacements

Replacement Technology	CO	NO_x	$PM_{2.5}$[b]	PM_{10}[b]	VOC[c]	CO_2e[d]
All-Electric	1	1	1	1	1	1
Hybrid Eco-Crane[a]	0.71	0.84	0.74	0.74	0.96	0.58

Note: These reduction factors do not account for emissions from upstream electricity generation

[a] Only applicable for diesel rubber tired gantry cranes.

[b] The DEQ only reports reduction factors for PM. Values for $PM_{2.5}$ and PM_{10} were assumed to be the same as those for PM.

[c] The DEQ does not directly report VOC reduction factors. Values were assumed to be equivalent to the reduction factors for hydrocarbons.

[d] The DEQ only reports reduction factors for CO_2. Reduction factors for CO_2e are only based on CO_2.

[9] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

Glossary

Brief descriptions of the different retrofit and replacement technologies available in this tool are 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),[10] as well as the soluble organic fraction (SOF) of diesel particulates. 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.[11]

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.[12] A soot removal process called filter regeneration is needed periodically or continuously to keep the DPF from clogging. The convention is to utilize continuous regeneration using nitrogen dioxide (NO_2) at relatively lower temperatures (instead of only O_2) to oxidize and effectively burn off the soot captured by the filter during ordinary engine operation.

Hybrid eco-cranes are approved by the EPA for MJ EcoPower Hybrid Systems, Inc. EcoCrane Hybrid System. This system replaces generators with a Tier 0, Tier 1, or Tier 2 nonroad diesel engine on rubber tired gantry cranes with a new genset equipped with a new diesel engine, battery energy storage system, rectifier, auxiliary inverter and regenerative brake/energy recovery system integration.[13]

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.[14] 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 heavy-duty truck applications.[15]

[10] 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
[11] W. Addy Majewski, "Diesel Oxidation Catalyst," *DieselNet*, https://www.dieselnet.com/tech/cat_doc.php
[12] W. Addy Majewski, "Diesel Particulate Filters," *DieselNet*, https://www.dieselnet.com/tech/dpf.php
[13] U.S. EPA. (2013). "MJ EcoPower Hybrid Systems, Inc.—EcoCrane Hybrid System." https://www.epa.gov/verified-diesel-tech/mj-ecopower-hybrid-systems-inc-ecocrane-hybrid-system
[14] W. Addy Majewski, "Selective Catalytic Reduction," *DieselNet*, https://www.dieselnet.com/tech/cat_scr.php
[15] Diesel Technology Forum, "What is SCR?" http://www.dieselforum.org/about-clean-diesel/what-is-scr