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 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. 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.

Locomotive & Marine Engine Retrofit and Replacement Tool

This tool provides estimates of emission reductions for CMAQ-funded projects that reduce emissions from locomotive and marine vessels by implementing engine retrofitting or engine repowering and replacement.[1]

Retrofit technologies to reduce emissions from diesel-powered locomotives or marine vessels available with this tool are selective catalytic reduction (SCR) and particulate filters, respectively. These two technologies and their associated emissions reductions are based on the U.S. Environmental Protection Agency's (EPA) online Diesel Emissions Quantifier (DEQ).[2] Alternatively, emissions reductions are achieved by repowering or replacing the diesel engine in the locomotive or marine vessel. Newer engines are held to more stringent emissions standards, thus replacement of older engines may result in overall reductions in fleet emissions.

This document is organized into three sections – User Guide, Tool Methodology, and Examples – to aid the user in understanding and interpreting results from the calculator. The User Guide provides direction on how to properly input values into the tool and definitions of both user inputs and tool outputs. The Tool Methodology section outlines the steps taken by the tool to calculate emission reductions, as well as any associated assumptions. The Examples section provides instructive examples of how to use the tool for different types of project analysis.

[1] The most current version of Locomotive & Marine Engine Retrofit and Replacement Tool is dated July 2020.

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

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USER GUIDE

This section describes each user input and tool output, as well as the emissions reductions report, error messages, and other assumptions present in the tool. The tool is composed of two modules, one for engine retrofits and one for engine repowering or replacements.

User Inputs – Engine Retrofit

The Engine Retrofit module contains 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 that is being retrofitted. Pre-retrofit emissions are estimated using the emissions Tier that the baseline equipment was held to, where the Tier is the relevant EPA emission standard for a particular application. Refer to the appendix for a list of relevant emission factors for both locomotives and marine vessels (Tables A1 & A2). The user-defined inputs for this tool are described in Table 1.

Table 1. User Inputs – Engine Retrofit

Question	User Input	Units	Description
(1)	Project evaluation year	-	Use the drop-down menu to select a year between 2019 and 2030.
(2)	Baseline equipment	-	Use the drop-down menu to select the baseline equipment associated with the project.
(3)	Emissions Tier	-	Use the drop-down menu to select the emissions standard the baseline equipment is held to. Refer to Tables A1-A3 for help in determining the correct emissions Tier.
(4)	Number of equipment	-	Enter the total number of locomotives or engines for a single marine vessel that will be retrofitted.
(5)	Equipment activity	Per single equipment	Enter the activity-related values for the equipment that will be retrofit. For locomotives, enter the annual fuel use in gallons. For marine vessels, enter the annual total hours of operation and the engine power rating in kilowatts (kW).

Baseline Equipment: The user may select one of four different types of equipment: line-haul locomotive (large and small), switch locomotive, C1 or C2 marine vessel, or C3 marine vessel. The C1 to C3 designation corresponds to the category (C) of marine vessel being retrofit and is determined by the vessel's engine power rating and displacement.[3] For this tool, C3 marine vessels are all vessels with a propulsion-engine displacement >30 liters. All other marine vessels are classified as the combined category of "C1 or C2 marine vessel" in this tool. C1 and C2 vessels are typically harbor craft (e.g., work boats, pilots, tugs), while C3 vessels are typically ships transporting cargo and/or people from one port to another (e.g., large ferry).

[3] U.S. Environmental Protection Agency, Office of Transportation and Air Quality. 2016. *Federal Marine Compression-Ignition (CI) Engines: Exhaust Emission Standards* (table, Note a), EPA-420-B-16-025. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA0B.pdf.

Only two retrofit technologies are currently available for use in this tool (as defined by EPA's DEQ[4]), and are automatically selected given the baseline equipment. If a locomotive is selected for the baseline equipment, selective catalytic reduction (SCR) will be the retrofit technology applied. If a marine vessel is selected for the baseline equipment, a diesel particulate filter will be the retrofit technology applied.

Emissions Tier: The user may select the emissions Tier that corresponds to the EPA emissions standard to which their equipment is held. If the emissions Tier is unknown, the appendix provides guidance to help identify the appropriate Tier. Table 2 below identifies which appendix table to refer to given the baseline equipment and its condition.

Table 2. Relevant Appendix Table Given Baseline Equipment

Baseline Equipment	Condition of Baseline Equipment	Relevant Appendix Table
Locomotive (line-haul or switch)	Not remanufactured or remanufactured pre-2008	A1 (use Tiers without '+' symbol)
Locomotive (line-haul)	Remanufactured in 2008+ and original year of manufacture was pre-2012	A1 (if Tier 0-2, use Tier with '+' symbol)*
Locomotive (switch)	Remanufactured in 2008+ and original year of manufacture was pre-2011	A1 (if Tier 0-2, use Tier with '+' symbol)*
C1 or C2 Marine Vessel	Any	A3‡
C3 Marine Vessel	Any	A2

*EPA holds remanufactured locomotives to a higher emissions standard.

‡ Reprinted from EPA's *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories.*[5]

Number of Equipment: The user may input any value greater than 0 that corresponds to the total number of equipment being retrofit. The tool assumes that all equipment included in this total have the same characteristics, including engine power for marine vessels. If users wish to calculate emissions reductions for multiple locomotives or vessels with different characteristics (e.g., fuel use, operating hours, power ratings) they should run the tool multiple times and sum the benefits from all results to calculate total emissions reductions for the entire fleet.

Equipment Activity: The user is expected to enter fuel use (for locomotive applications) or operating hours and power rating (for marine applications).

Locomotive Inputs

Fuel Use: Total amount of diesel fuel used (in gallons) annually by a single locomotive.

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

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

Marine Vessel Inputs

Operating Hours: Total annual operating time (in hours) for a single marine vessel.

Power Rating: Engine power rating (in kW) of the marine vessel to be retrofit. If the engine power rating is given in horsepower (hp), multiply the engine power rating by 0.7457 to convert hp into kW (1 hp = 0.7457 kW).

User Inputs – Engine Repower or Replacement

The Engine Repower or Replacement module is similar to the Engine Retrofit module. As with the Retrofit module, the inputs for the Repower or Replacement module are specific to the type of locomotive or marine vessel that will be analyzed. An additional feature with this module is the option to provide separate inputs for propulsion and auxiliary engines for marine vessels. If only propulsion or only auxiliary engines will be repowered/replaced, users only need to enter information for that engine category. The user-defined inputs for this module are described in Table 3.

Table 3. User Inputs – Engine Repower or Replacement

Question	User Input	Units	Description
(1)	Project evaluation year	-	Use the drop-down menu to select a year between 2019 and 2030.
(2)	Baseline equipment	-	Use the drop-down menu to select the baseline equipment associated with the project.
(3)	Emissions Tier of baseline equipment	-	Use the drop-down menu to select the emissions standard to which the baseline equipment is held. Refer to Tables A1-A3 for help in determining the correct emissions Tier.
(4)	Emissions Tier of repowered/replacement equipment	-	Use the drop-down menu to select the emissions standard to which the repowered/replacement equipment will be held.
(5)	Number of equipment	-	Enter the total number of locomotives or engines for a single marine vessel that will be repowered or replaced.
(6)	Engine type	-	Use the drop-down menu to select the engine type associated with the repowered/replacement equipment.
(7)	Equipment activity	Per single equipment	Enter the activity-related values for the equipment that will be repowered/replaced. For locomotives, enter the annual fuel use in gallons. For marine vessels, enter the engine load factor, annual total hours of operation and the engine power rating in kW.

Engine Type: The user may select one of four different engine types for the repowered or replacement equipment: diesel, diesel GenSet, liquefied natural gas (LNG), diesel-electric hybrid, or all electric or equivalent (e.g., batteries, hydrogen fuel cells, or grid power via overhead lines). For this tool it should

be noted that the diesel GenSet option is currently only available for switch locomotives and the diesel-electric hybrid option is only available for marine vessels.

Equipment Activity: Fuel use (for locomotive applications) or load factor(s), operating hours, and power rating(s) (for marine applications).

Locomotive Inputs

Fuel Use: Total amount of diesel fuel used (in gallons) annually by a single locomotive.

Marine Vessel Inputs

Load Factor (by engine category): The load factor (unitless) is the annual average power an engine is generating as a fraction of its rated power and ranges from 0 to 1. If the load factor is unknown, users can estimate this value from defaults provided in Table A4 (reprinted from EPA's *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*[6]). Separate load factors are required for propulsion and auxiliary engines if both engine categories are being included in the emissions reductions calculation.

Operating Hours: Total annual operating time (in hours) for a single marine vessel.

Power Rating (by engine category): Engine power rating (in kW) of the marine vessel to be repowered/replaced. If the engine power rating is given in hp, multiply the engine power rating by 0.7457 to convert hp into kW (1 hp = 0.7457 kW). Separate power ratings are required for propulsion and auxiliary engines if both engine categories are being included in the emissions reductions calculation.

Refer to the Engine Retrofits section for definitions of baseline equipment, emissions Tier, and number of equipment.

Tool Outputs

Emission benefits are derived from the decrease in emissions resulting from retrofitting the engine or engine exhaust with an emissions control device (in the Engine Retrofit module) or from repowering or replacing the equipment outright (in the Engine Repower or Replacement module). In the tool output, a positive change in emissions is equivalent to an emissions reduction (benefit), while a negative value can be interpreted as an emissions increase (disbenefit). Emission reductions (i.e., benefits) are calculated for five pollutants – CO, NO_X, $PM_{2.5}$, PM_{10}, and VOC – reported in kilograms per day (kg/day). Reductions in carbon dioxide equivalents (CO_2e) are also reported (in kg/day). While Total Energy Consumption (TEC) is reported for other CMAQ tools, TEC is not calculated or reported in the Locomotive & Marine Engine Retrofit and Replacement Tool due to insufficient energy efficiency data for these equipment.

[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* (Appendix B). EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

Note that users will need to click 'Calculate Output' again if any changes are made to the inputs after running the tool. The tool will not update the reported emissions reductions automatically.

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 4. The errors and corresponding solutions are relevant to both the Retrofit and the Repower or Replacement modules.

Table 4. Error Messages

Error Message	Reason for Error	Solution
ERROR: Missing project evaluation year.	No input provided for project evaluation year.	Select a project evaluation year from the pull-down menu.
ERROR: No baseline equipment selected.	No input provided for baseline equipment type.	Select an equipment type from the pull-down menu.
ERROR: Missing emissions Tier for [baseline or repowered/replacement] equipment.	No input provided for emissions Tier.	Select an emissions Tier from the pull-down menu. Refer to Tables A1-A3 for help determining an appropriate Tier.
ERROR: There are currently no Tier 4 standards for C3 marine vessels.	Invalid Tier input for the equipment selected.	Select a different emissions Tier from the pull-down menu. Refer to Table A2 for help determining an appropriate Tier.
ERROR: Uncontrolled emissions and Tiers with '+' are relevant to locomotives only.	Invalid Tier input for the equipment selected.	Select a different emissions Tier from the pull-down menu. Refer to Tables A2 and A3 for help determining an appropriate Tier.
ERROR: Missing number of locomotives or marine vessel engines to be [retrofit or repowered/replaced].	No input provided for number of equipment.	Input a whole number greater than 0.
ERROR: Missing engine type of the repowered/replacement equipment.	No input provided for the engine type of the repowered/replacement equipment.	Select an engine type from the pull-down menu.
ERROR: The Diesel GenSet option in this tool is currently only available for switch locomotives.	The diesel GenSet engine is not available for the equipment type selected.	Select a different engine type from the pull-down menu or change the baseline equipment to 'Switch Locomotive'.

Table 4. Error Messages Continued

Error Message	Reason for Error	Solution
ERROR: The Diesel-Electric Hybrid option in this tool is currently only available for marine vessels.	The diesel-electric hybrid engine is not available for the equipment type selected.	Select a different engine type from the pull-down menu.
ERROR: Engine characteristics have been input for [propulsion or auxiliary] engine(s), but load factor is currently set to zero.	User-input was provided for one or more of the questions 3-6, but the load factor for the same engine is zero.	Input a load factor between 0 and 1 for the propulsion or auxiliary engine(s), or click 'Reset to Default Values' button and start over.
ERROR: Missing annual fuel use for the locomotive being analyzed.	No input provided for locomotive activity.	Input a number greater than 0 gal/yr.
ERROR: Missing annual operating hours for the marine vessel being analyzed.	No input provided for marine vessel activity.	Input a number greater than 0 hours.
ERROR: Invalid engine power rating for the [marine vessel or engine] being analyzed.	Invalid input for marine vessel engine power rating.	Input a power rating between 0 and 90,000 kW.

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

TOOL METHODOLOGY

Emissions reductions for the Locomotive & Marine Engine Retrofit and Replacement Tool are based on the comparison of the emissions from the baseline equipment with either that same equipment with an emissions control retrofit (Engine Retrofit module) or with repowered or replacement equipment (Engine Repower or Replacement module). The Tool assumes all baseline equipment operate with diesel fuel. In the Engine Repower or Replacement module, users have the option to repower their locomotives or marine vessels with alternative fuels (i.e., liquefied natural gas or electricity).

Diesel engine emission rates for both locomotives[7] and marine vessels[8] are based on EPA emission factors. For locomotives, the emission factors are given in units of grams of pollutant per brake horsepower hour (g/bhp-hr), while for marine vessels the emission factors are in grams of pollutant per kilowatt hour (g/kWh). For both locomotive and marine vessel applications, the Engine Retrofit module calculates retrofitted equipment emissions based on a percent reduction of emissions by pollutant given the retrofit technology used. In the Engine Repower or Replacement module, repowered or replacement equipment emissions are based on newer engines meeting the more stringent EPA standards. It should be noted that this tool assumes the same amount of diesel fuel (or equivalent) is

[7] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

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

used post repower or replacement, except for the GenSet option for switch locomotives which includes a fuel-savings component in the emissions reduction calculation.

Emission benefits of CO_2e are calculated based on the difference in carbon content of the baseline equipment fuel versus the repowered or replacement equipment. Thus, except for the GenSet case, if a repowered or replacement engine uses the same fuel as the baseline equipment, there is no associated CO_2e benefit. Also note that the two verified retrofit technologies in this tool do not reduce CO_2 emissions; thus, CO_2e emissions reductions will always be reported as 0 kg/day in the tool output.

Emission Rates Sources

Emission rates for both locomotive and marine applications can be found in Tables A1 and A2 in the appendix of this document as well as the Emissions Data document that accompanies this User Guide. Emission rates for electric locomotives or the equivalent (e.g., battery- or hydrogen-fuel-cell-powered locomotives) are zero for all pollutants reported in this tool. Liquefied natural gas (LNG) emission rates for locomotive engines (Table A1) are based on an industry report on the use of natural gas for locomotives;[9] emission rates for LNG-powered marine vessels are based on the EPA draft Ports document;[10] emission rates for the diesel-electric hybrid marine vessel engine are based on emissions reductions reported in the EPA DEQ.[11] Additional information on the emission rates and tool calculations can be found in the Emissions Data documentation.

EXAMPLES

The three examples below highlight how the tool calculates emissions savings by applying user-provided operational data for either using a retrofit technology or completely repowering or replacing an engine or equipment. While users will likely have specific operational data available, these typical activity values may provide a helpful reference:

- Average annual fuel consumption for line-haul locomotive = 130,000 gallons diesel
- Average annual fuel consumption for switch locomotive = 30,000 gallons diesel
- Average annual operating hours for marine vessel = 1,000 – 3,000 hours

Example 1: Line-Haul Locomotive with Selective Catalytic Reduction

A rail company is seeking to reduce emissions of its line-haul locomotives in a push to be billed as one of the cleanest freight-hauling companies in the U.S. A project will retrofit 20 line-haul locomotives, all built between 1995 and 2000, with SCR technology. The retrofit project will be implemented in the year

[9] BNSF Railway Company, Union Pacific Railroad Company, The Association of American Railroads, and California Environmental Associates. 2007. *An Evaluation of Natural Gas-fueled Locomotives* (report). Available at: https://ww3.arb.ca.gov/railyard/ryagreement/112807lngqa.pdf.

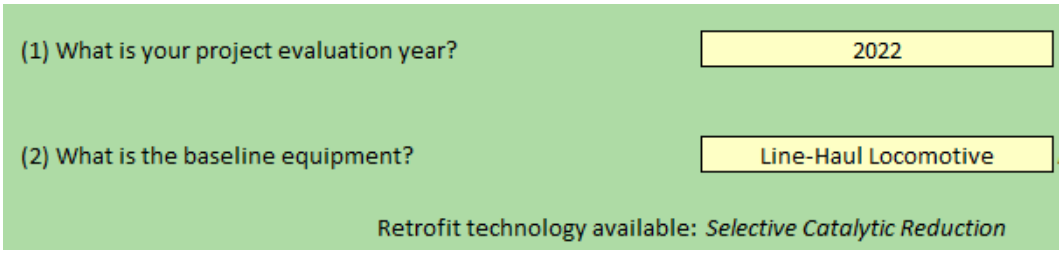
[10] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

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

2022. The company consumes approximately 2.5 million gallons of diesel fuel annually across all 20 trains.[12]

In the Engine Retrofit module, the user would select the following inputs as shown below:

Question 1: Project Evaluation Year: **2022**
Question 2: Baseline Equipment: **Line-Haul Locomotive**
Retrofit technology available: *Selective Catalytic Reduction* (automatically selected by the tool)



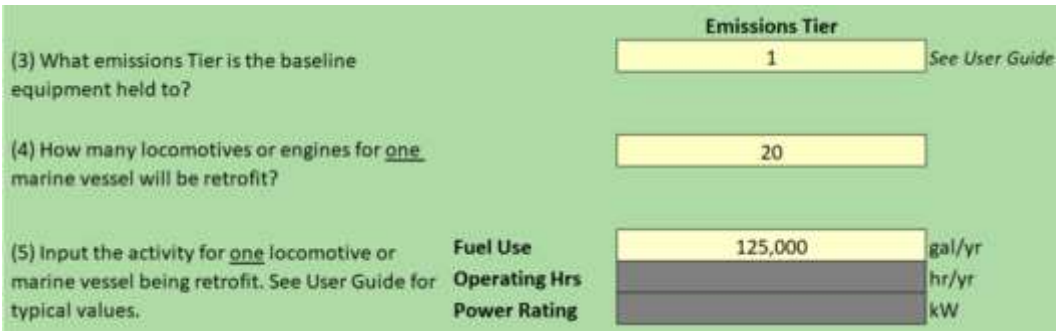
Question 3: Emission Tier of baseline equipment: **1**

If the emissions Tier of the baseline equipment is unknown, the user could refer to Table A1 – Locomotive Emission Standards in the Appendix of this document. Line-haul locomotives built between 1995 and 2000 fall under the Tier 1 EPA standards.

Fuel Type	Year of Manufacture	Tier
Diesel (Line-haul)	Pre-1973	Uncontrolled
	1973-1992	Tier 0
	1973-1992	Tier 0+
	1993-2004	Tier 1
	1993-2004	Tier 1+
	2005-2011	Tier 2
	2005-2011	Tier 2+
	2012-2014	Tier 3
	2015+	Tier 4

Question 4: Number of Locomotives to be retrofit: **20**
Question 5: Input activity (annual fuel use in gallons of diesel): **125,000**
Note that the input activity is for one locomotive, not the entire company's operational fuel use. 2.5 million gallons of diesel divided by 20 locomotives gives an annual average of 125,000 gallons per locomotive.

[12] U.S. Department of Transportation, Bureau of Transportation Statistics. 2019. Class I Rail Freight Fuel Consumption and Travel (table). Available at: https://www.bts.gov/content/class-i-rail-freight-fuel-consumption-and-travel.



		Emissions Tier	
(3) What emissions Tier is the baseline equipment held to?		1	See User Guide
(4) How many locomotives or engines for one marine vessel will be retrofit?		20	
(5) Input the activity for one locomotive or marine vessel being retrofit. See User Guide for typical values.	Fuel Use	125,000	gal/yr
	Operating Hrs		hr/yr
	Power Rating		kW

Operating hours and power rating are not relevant to line-haul locomotives and so will remain grayed out.

Once inputs are entered, click the 'Calculate Output' button to estimate emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

EMISSION REDUCTIONS

Emission	Total kg/day
Carbon Monoxide (CO)	127.649
Nitrogen Oxide (NO_X)	668.164
Particulate Matter <2.5 µm ($PM_{2.5}$)	4.422
Particulate Matter <10 µm (PM_{10})	4.559
Volatile Organic Compounds (VOC)	63.457
Carbon Dioxide Equivalent ($CO2_e$)	0.000
Total Energy Consumption (MMBTU/day)	*N/A*

CO = 127.649 kg/day
NO_X = 668.164 kg/day
$PM_{2.5}$ = 4.422 kg/day
PM_{10} = 4.559 kg/day
VOC = 63.457 kg/day
CO_2e = 0.000 kg/day

Note that TEC is not calculated for retrofit technologies in the Engine Retrofit module.

Example 2: Switch Locomotive Replaced with Fuel Cell Powered Model

A state has implemented stricter air pollution regulations. To comply with the new rules, a rail yard decided to replace their three 1980s-era switch locomotives (that have not been remanufactured post 2007) with a new hydrogen fuel cell model[13] that has no regulated emissions (only water vapor). The rail

[13] Demonstration of a hydrogen fuel-cell locomotive: https://pdfs.semanticscholar.org/bc5b/8df3251a993d608295aad4ae795678c046cf.pdf.

yard currently consumes 100,000 gallons of diesel fuel annually across the three switchers. The project will be implemented in 2021.

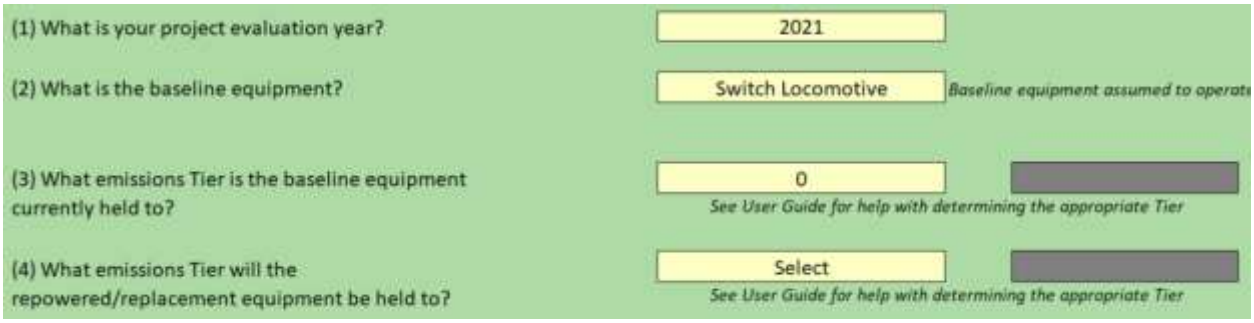
In the Engine Repower or Replacement module, the user would select the following inputs as shown below:

Question 1: Project Evaluation Year: **2021**
Question 2: Baseline Equipment: **Switch Locomotive**
Question 3: Emission Tier of baseline equipment: **0**

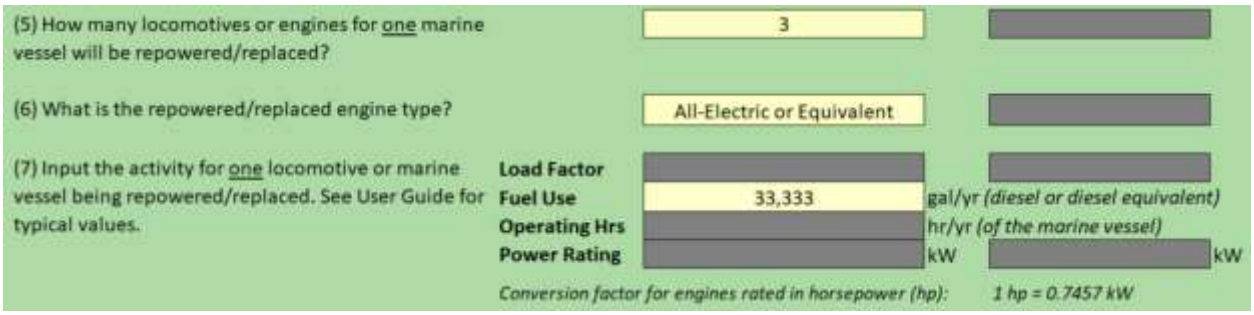
If the emissions Tier of the baseline equipment is unknown, the user could refer to Table A1 – Locomotive Emission Standards in the Appendix of this document. Switch locomotives built in the 1980s that have not been remanufactured post 2007 fall under the Tier 0 EPA standards.

	Pre-1973	Uncontrolled
Diesel (Switch)	1973-2001	Tier 0
	1973-2001	Tier 0+
	2002-2004	Tier 1
	2002-2004	Tier 1+
	2005-2010	Tier 2
	2005-2010	Tier 2+
	2011-2014	Tier 3
	2015+	Tier 4

Question 4: Emission Tier of repowered/replacement equipment: **(leave as 'Select')**
Since the replacement locomotive is not powered by diesel fuel and therefore not held to EPA's diesel locomotive Tiers, the user can leave this question blank. If a value is input for Question 4 by mistake, the tool will still run correctly.



Question 5: Number of Locomotives to be retrofit: **3**
Question 6: Engine type of repowered/replacement equipment: **All-Electric or Equivalent**
Since hydrogen fuel cells do not generate regulated emissions (only water vapor), the user can select the 'All-Electric or Equivalent' option for this question as the fuel cell is equivalent to all-electric. Additionally, once the 'All-Electric or Equivalent' option is selected, the Question 4 input cell will be grayed out.
Question 7: Input activity (annual fuel use in gallons of diesel): **33,333**
Note that the input activity is for one locomotive, not the entire rail yard operation. 100,000 gallons of diesel divided by 3 locomotives gives an annual average of 33,333 gallons per switcher.



Load factor, operating hours, and power rating are not used in the emissions calculation for locomotives and will remain grayed out.

Once the inputs are entered, click the 'Calculate Output' button to estimate emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

EMISSION REDUCTIONS

Emission	Total (kg/day)
Carbon Monoxide (CO)	7.621
Nitrogen Oxide (NO_X)	52.471
Particulate Matter <2.5 µm ($PM_{2.5}$)	1.777
Particulate Matter <10 µm (PM_{10})	1.832
Volatile Organic Compounds (VOC)	4.429
Carbon Dioxide Equivalent ($CO2_e$)	876.704
Total Energy Consumption (MMBTU/day)	*N/A*

CO = 7.621 kg/day
NO_X = 52.471 kg/day
$PM_{2.5}$ = 1.777 kg/day
PM_{10} = 1.832 kg/day
VOC = 4.429 kg/day
CO_2e = 876.704 kg/day

Note that TEC is not calculated for retrofit technologies in the Engine Retrofit module.

Example 3: C2 Marine Vessel Repowered with Newer Engine

A state has implemented a clean-air program for ports and is repowering marine vessels with newer, cleaner diesel engines. A port planning to repower its Category-2 marine vessel (tug boat) built between 1995 and 2000 is interested in applying for funding. The vessel has a 4,000-kW propulsion engine with a displacement of 20 liters/cylinder and will be repowered with a similarly-sized engine manufactured in 2015. In addition, the tug has two auxiliary engines for electrical loads rated at 125 kW each. These

auxiliary engines will be replaced with two 125-kW Tier 3 generators. The vessel operates approximately 2,000 hours annually, but records of average load factors for each of the engines is unavailable. The project will be implemented in 2023.

In the Engine Repower or Replacement module, the user would select the following inputs as shown below:

Question 1: Project Evaluation Year: **2023**
Question 2: Baseline Equipment: **C1 or C2 Marine Vessel**
Question 3 (Propulsion): Emission Tier of baseline equipment: **0**
Question 3 (Auxiliary): Emission Tier of baseline equipment: **0**

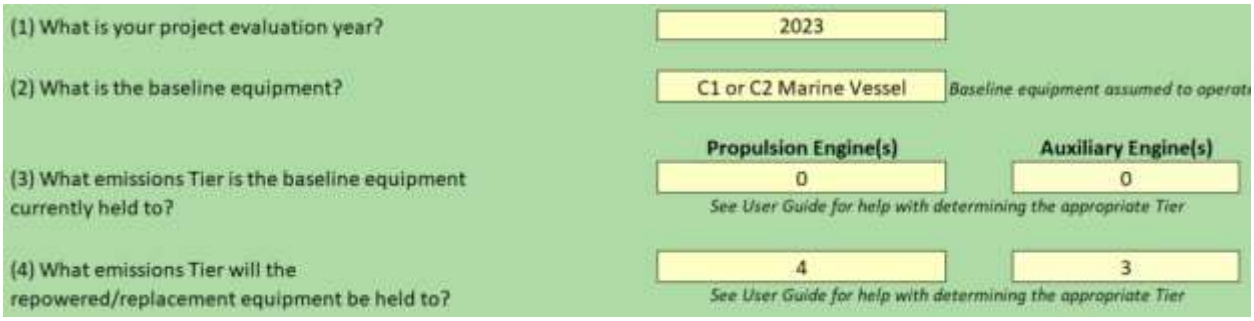
If the emissions Tier of the baseline equipment is unknown, the user could refer to Table A3 – Category 1 and 2 Marine Vessel Engine Tiers – in the appendix of this document. C2 marine vessels built pre-2004 with the engine characteristics given (for both the propulsion and auxiliary engines) fall under the Tier 0 EPA standards (i.e., uncontrolled).

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
All	0 < kW ≤ 19	Pre-2000	Uncontrolled (Tier 0)
	19 < kW ≤ 37	Pre-1999	
Disp < 5	kW > 37	Pre-2004	
5 ≤ Disp < 30	All	Pre-2004	

Question 4 (Propulsion): Emission Tier of repowered/replacement equipment: **4**
Question 4 (Auxiliary): Emission Tier of repowered/replacement equipment: **3**

If the emissions Tier of the repowered/replacement equipment is unknown, the user could refer to Table A3 in the appendix of this document. For the propulsion engine, C2 marine vessels engines built in 2015 with the engine characteristics given fall under the Tier 4 EPA standards.

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
1.2 ≤ Disp < 7	600 < kW ≤ 1000	2018+	Tier 4
1.2 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	
3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	
	kW > 1400	2016+	
7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	
	1000 < kW ≤ 1400	2017+	
	1400 < kW ≤ 2000	2016+	
	2000 < kW ≤ 3700	2014+	
	kW > 3700	2014-2016	
	kW > 3700	2017+	
15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	
	2000 < kW ≤ 3700	2014+	
	kW > 3700	2014-2016	
	kW > 3700	2017+	



(1) What is your project evaluation year?	2023	
(2) What is the baseline equipment?	C1 or C2 Marine Vessel	*Baseline equipment assumed to operat*
	Propulsion Engine(s)	**Auxiliary Engine(s)**
(3) What emissions Tier is the baseline equipment currently held to?	0	0
	See User Guide for help with determining the appropriate Tier	
(4) What emissions Tier will the repowered/replacement equipment be held to?	4	3
	See User Guide for help with determining the appropriate Tier	

Question 5 (Propulsion): Number of engines for one marine vessels that will be replaced: **1**

Question 5 (Auxiliary): Number of engines for one marine vessels that will be replaced: **2**

Note that this tool calculates emission reductions for a single marine vessel at a time. Users wanting to estimate emission reductions for multiple marine vessels will need to run the tool separately for each marine vessel and sum the results.

Question 6 (Propulsion): Engine type of repowered/replacement equipment: **Diesel**

Question 6 (Auxiliary): Engine type of repowered/replacement equipment: **Diesel**

Question 7 (Propulsion): Input activity (load factor): **0.5**

Question 7 (Auxiliary): Input activity (load factor): **0.43**

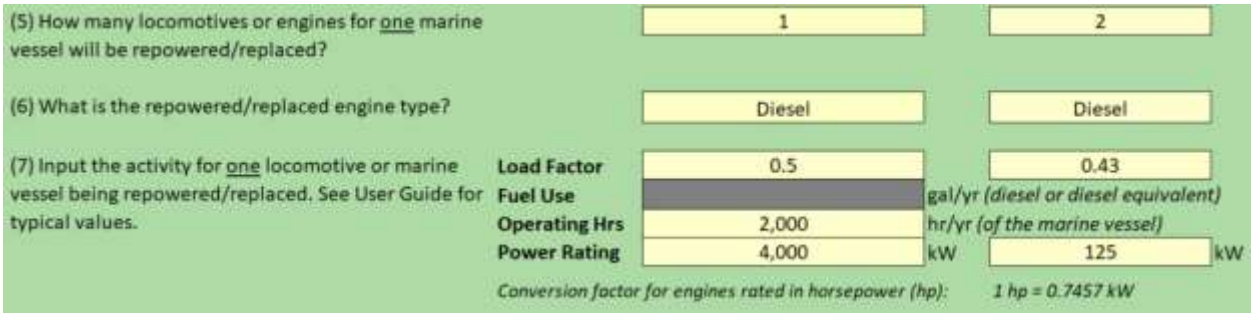
If the load factors are unknown for the propulsion or auxiliary engine(s), users can refer to Table A4 to estimate these values. For tug boats, the default load factors as given in Table A4 are 0.5 for propulsion engines and 0.43 for auxiliary engines.

Question 7: Input activity (annual operating hours): **2,000**

Note that the input activity is for the marine vessel, not the individual engines.

Question 7 (Propulsion): Input activity (engine power rating in kW): **4,000**

Question 7 (Auxiliary): Input activity (engine power rating in kW): **125**



(5) How many locomotives or engines for one marine vessel will be repowered/replaced?		1	2	
(6) What is the repowered/replaced engine type?		Diesel	Diesel	
(7) Input the activity for one locomotive or marine vessel being repowered/replaced. See User Guide for typical values.	**Load Factor**	0.5	0.43	
	Fuel Use		gal/yr *(diesel or diesel equivalent)*	
	Operating Hrs	2,000	hr/yr *(of the marine vessel)*	
	Power Rating	4,000 kW	125	kW
	Conversion factor for engines rated in horsepower (hp):		*1 hp = 0.7457 kW*	

Fuel use is not used in the emissions calculation for marine vessels and will remain grayed out.

Once the inputs are entered, click the 'Calculate Output' button to estimate emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

EMISSION REDUCTIONS		
	Emission	**Total** (kg/day)
	Carbon Monoxide (CO)	8.013
	Nitrogen Oxide (NO_X)	101.686
	Particulate Matter <2.5 µm ($PM_{2.5}$)	2.534
	Particulate Matter <10 µm (PM_{10})	2.612
	Volatile Organic Compounds (VOC)	1.973
	See User Guide for more information on CO2e and TEC.	
	Carbon Dioxide Equivalent ($CO2_e$)	0.000
	Total Energy Consumption (MMBTU/day)	*N/A*

CO = 8.013 kg/day
NO_X = 101.686 kg/day
$PM_{2.5}$ = 2.534 kg/day
PM_{10} = 2.612 kg/day
VOC = 1.973 kg/day
CO_2e = 0.000 kg/day

Note that TEC is not calculated for repowered for replacement equipment in the Engine Repower or Replacement module.

Appendix – Emissions Tables & Load Factors

Table A 1. Locomotive Emission Factors[14]

			Emission Factors (g/bhp-hr)			
Fuel Type	**Year of Manufacture**	**Tier**	**NO_X**	**PM**	**HC**	**CO**
Diesel (Line-haul)	Pre-1973	Uncontrolled	13.00	0.32	0.48	1.28
	1973-1992	Tier 0	8.60	0.32	0.48	1.28
	1973-1992	Tier 0+	7.20	0.20	0.30	1.28
	1993-2004	Tier 1	6.70	0.32	0.47	1.28
	1993-2004	Tier 1+	6.70	0.20	0.29	1.28
	2005-2011	Tier 2	4.95	0.18	0.26	1.28
	2005-2011	Tier 2+	4.95	0.08	0.13	1.28
	2012-2014	Tier 3	4.95	0.08	0.13	1.28
	2015+	Tier 4	1.00	0.015	0.04	1.28
Diesel (Switch)	Pre-1973	Uncontrolled	17.40	0.44	1.01	1.83
	1973-2001	Tier 0	12.60	0.44	1.01	1.83
	1973-2001	Tier 0+	10.60	0.23	0.57	1.83
	2002-2004	Tier 1	9.90	0.43	1.01	1.83
	2002-2004	Tier 1+	9.90	0.23	0.57	1.83
	2005-2010	Tier 2	7.30	0.19	0.51	1.83
	2005-2010	Tier 2+	7.30	0.11	0.26	1.83
	2011-2014	Tier 3	4.50	0.08	0.26	1.83
	2015+	Tier 4	1.00	0.015	0.08	1.83
GenSet*	2015+	Tier 4	1.00	0.015	0.08	1.83
LNG‡	All	N/A	2.4	0.15	5.5	3.7
Electric (or equivalent)◊	All	N/A	0.0	0.0	0.0	0.0

Tiers with '+' are applicable only to locomotives that were originally manufactured in the corresponding Year of Manufacture range and remanufactured in 2008 or later; EPA holds these remanufactured locomotives to a higher emissions standard.

* Emission rates are estimated at the Tier 4 switch locomotive emission rates (refer to Emissions Data document for details).

‡ Emission rates take into account energy difference for equal volume of fuel type (i.e., 1.7 gal LNG = 1.00 gal diesel in energy equivalence).

◊ Source: U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2.

[14] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

Table A 2. Marine Vessel Emission Factors[15]

Fuel Type	Vessel Category	Year of Manufacture	Tier*	Emission Factors (g/kWh)			
				NO_X	PM	VOC	CO
Diesel (as ultra low sulfur diesel; ULSD)	C1 or C2	-	Tier 0	10.2	0.26	0.30	1.61
	C1 or C2	-	Tier 1	9.6	0.26	0.30	1.61
	C1 or C2	-	Tier 2	5.6	0.15	0.30	0.92
	C1 or C2	-	Tier 3	4.7	0.08	0.12	0.92
	C1 or C2	-	Tier 4	1.3	0.03	0.12	0.92
Diesel (as marine diesel oil; MDO)	C3 (propulsion)	Pre-2000	Tier 0	13.2	0.19	0.53	1.1
	C3 (propulsion)	2000-2010	Tier 1	12.2	0.19	0.53	1.1
	C3 (propulsion)	2011-2015	Tier 2	10.5	0.19	0.53	1.1
	C3 (propulsion)	2016+	Tier 3	2.6	0.19	0.53	1.1
	C3 (auxiliary)	Pre-2000	Tier 0	10.9	0.19	0.42	1.1
	C3 (auxiliary)	2000-2010	Tier 1	9.8	0.19	0.42	1.1
	C3 (auxiliary)	2011-2015	Tier 2	7.7	0.19	0.42	1.1
	C3 (auxiliary)	2016+	Tier 3	2.0	0.19	0.42	1.1
Diesel-Electric Hybrid◊	Any	Any	N/A	Refer to information below			
LNG	Any	Any	N/A	1.3	0.03	0.0	1.3
Electric (or equivalent) ◊	Any	Any	N/A	0.0	0.0	0.0	0.0

* Refer to Table A3 for assistance in determining the appropriate Tier for C1 and C2 marine vessels.

◊ Source: U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2.

Emission factors for diesel-electric hybrid engines are based on percent reductions on the baseline equipment emissions Tier. The reductions are: NO_X = 30%, PM = 25%, VOC = 15%, CO = 35%, and CO_2 = 30%. For example, if the baseline equipment was a Tier 3 C2 vessel, the NO_X emission factor for the diesel-electric hybrid repowering would be a 30% reduction from the 4.7 g/kWh NO_X Tier 3 emission factor, or 3.3 g/kWh.

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

Table A 3. Category 1 and 2 Marine Vessel Engine Tiers[16]

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
All	0 < kW ≤ 19	Pre-2000	Uncontrolled (Tier 0)
	19 < kW ≤ 37	Pre-1999	
Disp < 5	kW > 37	Pre-2004	
5 ≤ Disp < 30	All	Pre-2004	
All	0 < kW ≤ 19	2000-2004	Tier 1
	19 < kW ≤ 37	1999-2003	
Disp < 0.9	kW > 37	2004	
2.5 ≤ Disp < 5	kW > 37	2004-2006	
5 ≤ Disp < 30	All	2004-2006	
All	0 < kW ≤ 19	2005-2008	Tier 2
	19 < kW ≤ 37	2004-2008	
Disp < 0.9	37 < kW ≤ 75	2005-2008	
	75 < kW ≤ 600	2005-2011	
0.9 ≤ Disp < 1.2	kW > 37	2004-2012	
1.2 ≤ Disp < 2.5	kW > 37	2004-2013	
2.5 ≤ Disp < 3.5	kW > 37	2007-2012	
3.5 ≤ Disp < 5	kW > 37	2007-2011	
5 ≤ Disp < 15	All	2007-2012	
15 ≤ Disp < 30	All	2007-2013	

[16] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories* (Appendix B, Table B.1). EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

Table A 3. Category 1 and 2 Marine Vessel Engine Tiers Continued

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
All	0 < kW ≤ 37	2009+	Tier 3
Disp < 0.9	37 < kW ≤ 75	2009+	
	75 < kW ≤ 600	2012+	
0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	
1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	
2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	
3.5 ≤ Disp < 7	kW ≤ 600	2012+	
1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014-2017	
2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013-2017	
3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012-2017	
1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2014-2016	
2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013-2016	
3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012-2016	
	kW > 1400	2012-2015	
7 ≤ Disp < 15	kW ≤ 600	2013+	
	600 < kW ≤ 1000	2013-2017	
	1000 < kW ≤ 1400	2013-2016	
	1400 < kW ≤ 2000	2013-2015	
15 ≤ Disp < 30	1400 < kW ≤ 2000	2014-2015	
1.2 ≤ Disp < 7	600 < kW ≤ 1000	2018+	Tier 4
1.2 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	
3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	
	kW > 1400	2016+	
7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	
	1000 < kW ≤ 1400	2017+	
	1400 < kW ≤ 2000	2016+	
	2000 < kW ≤ 3700	2014+	
	kW > 3700	2014-2016	
	kW > 3700	2017+	
15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	
	2000 < kW ≤ 3700	2014+	
	kW > 3700	2014-2016	
	kW > 3700	2017+	

Table A 4. Default Harbor Craft Propulsion and Auxiliary Engine Load Factors[17]

Ship Type	Propulsion Engine Load Factor	Auxiliary Engine Load Factor
Barge	--	0.43
Crew and Supply	0.45	0.43
Excursion	0.42	0.43
Fishing (C1/C2)	0.52	0.43
Government	0.45	0.43
Harbor Ferry (C1/C2)	0.42	0.43
Miscellaneous (C1/C2)	0.52	0.43
Pilot	0.51	0.43
Towboat/Pushboat	0.68	0.43
Tug Boat	0.50	0.43
Work Boat	0.45	0.43

[17] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories* (Table 4.4). EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.