2024 SmartWay Barge Carrier Partner Tool:

Technical Documentation

U.S. Version 1.0
(Data Year 2023)

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Transportation and Climate Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

EPA-420-B-24-012
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1.0 Emission Factors and Associated Activity Inputs

Emission factors form the basis for the emission calculations in the Barge Tool. The Tool uses the latest and most comprehensive emission factors available for marine propulsion and auxiliary engines. The following discusses the data sources used to compile the emission factors used in the Tool, and the fleet characteristic and activity data inputs needed to generate fleet performance metrics.

1.1 AVAILABLE EMISSION FACTORS

Propulsion Engines

CO_2 emissions are calculated using fuel-based factors, expressed in grams per gallon of fuel. Available fuel options include marine distillate (diesel – both low and ultra-low sulfur), biodiesel, and liquefied natural gas (LNG). The Barge Tool uses the same gram/gallon fuel factors for CO_2 that are used in the other carrier tools (Truck, Rail, and Multi-modal), as shown in Table 1. These factors are combined directly with the annual fuel consumption values input into the Tool to estimate mass emissions for propulsion and auxiliary engines. (The fuel consumption inputs are summed across both engine types). The factors for biodiesel are a weighted average of the diesel and B100 factors shown in the table, weighted by the biodiesel blend percentage.

Table 1. CO_2 Factors by Fuel Type*

	g/gal	Source[1]
Diesel	10,180	(i)
Biodiesel (B100)	9,460	(ii)
LNG	4,394	(iii)

* 100% combustion (oxidation) assumed

The Barge Tool uses emission factors expressed in g/kW-hr to estimate NO_x, PM and black carbon emissions. For marine distillate fuel, the Tool uses emission factors presented in EPA's 2020 Port Emissions Inventory Guidance. The emission factors for main propulsion engines using ultra-low (15 ppm) sulfur distillate fuel are a function of year of manufacture (or rebuild) and rated engine power (in kW). These factors, presented in Appendix A, are combined with estimated engine activity in kW-hrs to estimate mass emissions, as described in Section 2. The PM_{10} factors are multiplied by 0.97 to obtain $PM_{2.5}$ estimates, consistent with the conversion factors in the Port Emissions Inventory Guidance.

[1] i) Fuel economy calculations in 40 C.F.R 600.113 available at https://www.govinfo.gov/content/pkg/CFR-2004-title40-vol28/pdf/CFR-2004-title40-vol28-sec600-113-93.pdf. Accessed 1-16-24.
ii) Tables IV.A.3-2 and 3-3 in A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1001ZA0.pdf. Accessed 1-16-24.
iii) Assuming 21,240 Btu/lb. lower heating value (http://www.afdc.energy.gov/afdc/fuels/properties.html - Accessed 1-16-24.), 3.518 lbs/gal and 0.059 g/Btu.

NO_x and PM emission factors for biodiesel were based on the findings from an EPA study, A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions (EPA420-P-02-001, October 2002). This study developed regression equations to predict the percentage change in NO_x and PM emission rates relative to conventional diesel fuel, as a function of biodiesel blend percentage, expressed in the following form:

Equation 1

$$\% \text{ change in emissions} = \{\exp[a \times (\text{vol\% biodiesel})] - 1\} \times 100\%$$

Where:

a = 0.0009794 for NO_x, and

a = -0.006384 for PM and Black Carbon[2]

For example, the NO_x reduction associated with B20 is calculated as follows

$$[\text{Exp}(0.0009747 \text{ x } 20)-1] \text{ x } 100 = 1.9\%$$

To obtain the final NO_x emissions the unadjusted NO_x is multiplied by (1-0.019) = 0.981,

Using Equation 1, adjustment factors were developed for biodiesel blends based on the percentage of the biofuel component, and then these adjustment factors were applied to the appropriate conventional diesel emission factors in Appendix A. Ultra-low sulfur diesel fuel (15 ppm sulfur) is assumed as the basis for adjustments.

Emission factors were also developed for LNG derived from a variety of data sources including EPA, U.S. Department of Transportation (DOT), Swedish EPA, and the California Energy Commission. The following emission factors were assumed, corresponding to slow-speed engines operating on natural gas.

- 5.084 g NO_x/kW-hr
- 0.075 g PM_{10}/kW-hr

For LNG, NO_x and PM emission factors are assumed to be independent of model year and engine size. In addition, as LNG PM emissions are primarily the result of lube oil combustion, the Barge Tool assumes $PM_{2.5}$ emissions equal 97% of PM_{10} emissions, consistent with the conversion used for diesel fuel.

Black carbon emission factors for LNG engines are based on emission rates for heavy-duty onroad trucks. The MOVES3 model was run for the 2021 calendar year at the national level to estimate the ratio of black carbon to $PM_{2.5}$ grams per mile rates for class 8b LNG trucks. Ratios vary by engine model year group:

- Pre-2002: BC = 0.082 x $PM_{2.5}$

[2] The study's biodiesel emissions testing did not characterize black carbon. Black carbon reductions are assumed to scale one to one with PM reductions.

- 2002+: BC = 0.035 x $PM_{2.5}$

Auxiliary Engines

NO_x, PM, and black carbon emissions associated with diesel auxiliary engine operation depend on kW and engine model year (see Table A-1 in Appendix A).[3] Alternative fuels and retrofits are not allowed for auxiliary engines at this time.

APU emissions are calculated by multiplying the appropriate factors by the kW-hr inputs from the tool, and the default engine load factors for harbor craft APUs.[4]

1.2 ACTIVITY DATA INPUTS

The Barge Tool requires Partners to input vessel and barge characterization and activity data. The input data required to calculate emissions and associated performance metrics include:

- Total number of barges and tugs
- Vessel-specific information –
  - Propulsion engine model/rebuild year
  - EPA Engine Class (1 or 2)
  - Fuel type (diesel – 15 or 500 ppm, biodiesel, and LNG)
  - Retrofit information (technology and/or % NO_x and/or PM reduction, if applicable)
  - Annual fuel use (gallons or tons) – Total for propulsion and auxiliary engines
  - Vessel towing capacity (tons)[5] – optional input
  - Propulsion engine operation
    - # engines (1, 2 or 3)
    - Total rated power (HP or kW – sum if two engines)
    - Hours of operation per year (underway and maneuvering)[6]
  - Auxiliary engine operation (for each engine)[7]
    - Engine age

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[3] See https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf. Accessed 1-16-24.

[4] Load factor = 0.43 for auxiliary engines. From U.S. EPA 2020, Port Emissions Inventory Guidance, Table 4.4.

[5] Used to establish upper bound validation limit for total payload ton-mile entries. Not expressed in Bollard Pull since that unit does not uniquely correspond to payload.

[6] Hours of operation estimates are for engines used for propulsion, not auxiliary engines. Underway operations are defined as when the power unit is towing a barge configuration, e.g., a 15 barge collection, whereas Maneuvering is defined as movement around ports for fueling or maintenance or moving individual barges into place to hook up for a haul. Users should provide their best estimate for allocating hours between the two, **but this will not currently impact your emission estimates**. However, it is important for the sum of these two estimates to equal your total hours of propulsion engine operation.

[7] **Note** – the Barge Tool assumes all auxiliary engines are diesel powered.

- Rated power (HP or kW)
- Hours of operation per year

- Barge operation information
  - Barge type (hopper, covered cargo, tank, deck, container, other)
  - Barge size, by type (150, 175, 195-200 and 250-300 feet in length)
  - For each type/size combination:
    - Number
    - Average cargo volume utilization (%) – for each size/type combination
    - Average annual loaded miles per barge (nautical)
    - Average annual empty miles per barge (nautical)
    - Average loaded payload per barge (short tons)
- Total annual fleet activity (used for validation – must match totals calculated from barge operation information to within 5%)
  - Ton-miles
  - Loaded barge-miles
  - Unloaded barge-miles

Vessel and barge characterization and activity data are needed for three reasons:

1. To convert the hours of engine operation to kilowatt-hours, it is necessary to know the kilowatt or horsepower rating of the vessel's propulsion and auxiliary engines. Given hours of operation, the Tool can then calculate kilowatt-hours — which is compatible with the available emission factors for both engine types.
2. To classify which regulations the vessel is subject to. EPA engine class is required to identify the correct NO_x and PM emission factors for propulsion engines. Rated power is used to determine the appropriate emission category for auxiliary engines.
3. To combine mass emission estimates with barge-mile and ton-mile activity to develop fleet and company-level performance metrics. (Note, total emissions are also calculated and reported at the vessel-specific level.)

The following section describes how the activity data inputs and the emission factors are combined to generate mass emission estimates and associated performance metrics.

2.0 Emission Estimation

The following sections discuss how emissions are calculated, beginning with selection of emission factors.

2.1 CO_2 CALCULATION

Annual vessel-specific fuel consumption values may be input in the Barge Tool in gallons or tons. Entries in tons are converted to gallons using the following factors:

- Diesel – 284 gallons/ton[8]
- Biodiesel (B100) – 274 gallons/ton[9]
- LNG – 573 gallons/ton[10]

Once all fuel consumption values have been converted to gallons, CO_2 mass emission estimates are calculated for each vessel using the factors shown in Table 1, converted to short tons (1.1023×10^{-6} short tons/gram), and summed across vessels to obtain tons of CO_2 per year for the entire vessel fleet.

2.2 NO_X, PM_{10} AND BLACK CARBON CALCULATIONS

NO_x, PM_{10} and black carbon are calculated based on kW-hr activity estimates. This approach allows emission calculations to account for the size of the vessel's propulsion and auxiliary engines and the amount of time a vessel operates. Equation 2 presents the general equation for calculating NO_x, PM_{10} and black carbon emissions for each engine using diesel fuel.[11] The equation is used for each unique combination of engine type (propulsion or auxiliary), vessel type (linehaul, locking, canal, etc.), engine power rating group, and engine model year.

Equation 2

$$EM_p = Pw \times 0.7457 \times Hr \times LF/100 \times EF / 1{,}102{,}300$$

Where:

EM_p	=	Marine vessel emissions for pollutant (p) (tons/year)
Pw	=	Sum of the power ratings for each of the vessel's engines (hp or kW)[12]

[8] Iowa State Extension Outreach Ag Decision Maker. Last accessed 2-14-20.

[9] Converted from 7.3 lbs/gallon. See https://www.nrel.gov/docs/fy17osti/66521.pdf, Table 2, Accessed 1-16-24.

[10] Midwest Energy Solutions. Energy Volume & Weight. Last accessed 1-31-21.

[11] Note: the PM emission factors used in the Barge Tool estimate direct or "primary" PM produced as a result of incomplete combustion. Estimates do not include indirect PM emissions associated with sulfur gas compounds aerosolizing in the atmosphere.

[12] This approach assumes that multiple propulsion engines entered in a single row of the Tool are of the same type, power, and age, and operate in tandem.

0.7457	=	Conversion factor from horsepower to kilowatts, if needed (kW/hp - Perry's Chemical Engineer's Handbook)
Hr_e	=	Total annual hours of operation for each engine (hr)
LF	=	Load factor - see Table 3 (percentage)
EF	=	Emission factor for pollutant p (grams/kW-hr) – see Appendix A
1,102,300	=	Conversion factor from grams to short tons

If the vessel's power is provided in terms of kilowatts, then the conversion from horsepower to kilowatts is not needed.

The load factors used in the above equation are provided in EPA's Port Emissions Inventory Guidance (Table 4.4) and are shown in Table 3 below.

Table 2. Marine Vessel Engine Load Factors (%)

Engine Type	Vessel Type[13]	Load Factor
Propulsion	**Linehaul (towboat)**	68%
Propulsion	**Locking (tugboat)**	50%
Propulsion	**Canal (tugboat)**	50%
Propulsion	**Harbor (tugboat)**	50%
Propulsion	**Coastwise (towboat)**	68%
Propulsion	**Articulated barge (towboat)**	68%
Propulsion	**Other (Miscellaneous C1/C2)**	52%
Auxiliary	**All types**	43%

If biodiesel is used, NO_x and PM emissions are calculated assuming ultra-low sulfur diesel fuel as the basis, with the emission factors adjusted according to the fuel blend percentage as described in Section 1.1.

If LNG is used, NO_x and PM emissions are calculated by simply multiplying the g/kW-hr factors presented in Section 1.1 by the effective kW-hrs of operation (hours of use x load factor), summed across operation type (underway and maneuvering).

2.3 RETROFIT EFFECTIVENESS

The Barge Tool allows the user to select from a variety of propulsion engine retrofit options. Options were only identified for diesel marine engines and were based on emission adjustment factors developed for EPA's MARKAL model.[14] The reduction factors assumed for each of these control options are presented in

[13] The vessel categories included in the Barge Tool are associated with specific ship types presented in EPA's Port Emissions Inventory Guidance to assign default load factors. EPA ship category assignments are shown in parentheses.

[14] Eastern Research Group, "MARKAL Marine Methodology", prepared for Dr. Cynthia Gage, US EPA, December 30, 2010.

Table 4. The Barge Tool only allows the user to specify one retrofit for a given propulsion engine – combinations are not permitted at this time.

Table 3. Diesel Propulsion Engine Retrofit Reduction Factors

Control	Reduction Factor	
	NO_x	PM
Fuel Injection Engine Improvements	0.12	0.12
Selective Catalytic Reduction (SCR)	0.8	0
Common rail	0.1	0.1
Diesel Electric	0.2	0.2
Humid Air Motor (HAM)	0.7	0
Hybrid Engines	0.35	0.35
Diesel Oxidation Catalyst	0	0.2
Lean NO_x Catalyst	0.35	0

Barge Tool users may also specify details and assumed emission reductions for other control measures not listed in the table above, although detailed text descriptions should be provided justifying the use of any alternative factors.

If retrofit Information has been entered for a vessel, the NO_x and PM emissions calculated above are adjusted by the factors shown in Table 4.[15] For example, a 20% reduction in PM emissions associated with a diesel oxidation catalyst would require an adjustment factor of 1 – 0.2 (0.8) to be applied to the calculated PM values.

Finally, NO_x and PM emissions are summed across all vessels and source types (propulsion and auxiliary) to obtain fleet and company-level mass emission estimates.

[15] The Barge Tool assumes that retrofits are only applied to main propulsion engines, not auxiliary engines.

3.0 Performance Metrics

The Barge Tool is designed to apply the calculated emissions to a variety of operational parameters. This provides performance metrics that are used as a reference point to evaluate a Partner's environmental performance relative to other SmartWay Partners across different transportation modes. In this way the metrics presented here are made comparable to the metrics used in the other carrier tools.

For these comparisons to be most precise, it may be necessary to group the data into comparable operating characteristic bins to ensure that similar operations are being compared. For example, open-water barge operations may need to be considered separately from river barge operations because these vessels and their activities are very different. For this reason, the Barge Tool collects a variety of vessel and barge characteristic information that may be used to differentiate barge operations in the future.

The following summarizes how the Barge Tool performance metrics are calculated for a given pollutant. Note: all distances are reported in nautical miles.[16]

3.1 GRAMS PER BARGE-MILE

Equation 3

grams / (loaded + unloaded barge-miles - from Total Fleet Activity entry)

3.2 GRAMS PER LOADED BARGE-MILE

Equation 4

grams / (loaded barge-miles - from Total Fleet Activity entry)

3.3 GRAMS PER TON-MILE

Equation 5

grams / (total ton-miles - from Total Fleet Activity entry)

[16] 1 nautical mile = 1.15 statute miles.

3.4 FLEET AVERAGE CALCULATIONS

The Barge Tool calculates fleet-level average payloads for use in the SmartWay Carrier Data File. In order to calculate average payload the Tool first calculates total ton-miles for each row on the Barge Operations screen as follows:

Row-Level ton-miles = Average Payload Value * Avg Loaded Miles * Number of Barges

Next, the Tool sums the row-level ton-miles as well as the total barge miles (Avg Loaded Miles * Number of Barges) across all rows. The tool then divides the summed ton-miles by the summed total miles to obtain the fleet average payload.

3.5 PUBLIC DISCLOSURE REPORTS

The Barge Tool provides a report summarizing Scope 1 emissions for public disclosure purposes. Mass emissions are presented in metric tonnes for CO_2 (biogenic and non-biogenic), NO_x, and PM[17] for all fleets. Biogenic CO_2 emissions estimates are assumed to equal 2 percent of total CO_2 emissions, as per U.S. requirements for biomass-based diesel from the EPA Renewable Fuel Standard program final volume requirements.[18]

CO_2 equivalent (CO_2e) emissions are also provided in the tool's Public Disclosure report and are calculated by multiplying CO_2 values by a scaling factor of 1.1056. The scaling factor was based on data from Table 2-13 in the most recent EPA Emissions and Sinks Report. The factor was derived by dividing the Ships and Boats emissions for each greenhouse gas excluding CO_2 (CH_4, N_2O, and HFCs) by the total emissions including CO_2, and then summing the ratios to obtain the total scaling factor.

[17] Emissions from CH_4, N_2O, HFC's, PFC's, SF_6 and NF_3 have been deemed immaterial, comprising less than 5% of overall GHG emissions and are therefore excluded for reporting purposes.

[18] As stated in the Final Rule (Table I.B.7-1 – see https://www.govinfo.gov/content/pkg/FR-2020-02-06/pdf/2020-00431.pdf, Accessed https://www.nrel.gov/docs/fy17osti/66521.pdf), the volume requirements for biomass-based diesel in 2020 is 2.10%, rounded to equal 2% for calculation purposes. The percentage will be updated annually in the Tool.

4.0 Data Validation

The Barge Tool employs limited validation to ensure the consistency of Partner data inputs. Cross-validation of barge and ton-mile inputs are conducted on the Barge Operations screen. These checks ensure that the values entered in the Fleet Totals section of the screen for total ton-miles, loaded and unloaded barge-miles are consistent with the data entered at the row level for the different barge type/size combinations. These three values must be within 5% of the totals calculated as follows:

Equation 6

Total Ton-miles = [$\sum_b$ (number of barges x Annual Loaded Miles per Barge x Average Loaded Payload per Barge)]

Equation 7

Loaded Barge-Miles = [$\sum_b$ (number of barges x Annual Loaded Miles per Barge)]

Equation 8

Unloaded Barge-Miles = [$\sum_b$ (number of barges x Annual Empty Miles per Barge)]

The Barge Tool also conducts a validation check to confirm product densities are within a reasonable range, with payloads flagged if the calculated cargo density is greater than 0.6 tons per cubic foot or less than 0.003 tons per cubic foot.[19]

Barge volumes were estimated for each barge type/size combination using standardized assumptions regarding depth and width. Volumes are summarized below in Table 5 and Table 6.

Table 4. Barge Capacity by Type/Length Combination (1,000 cubic feet)

	Barge Volume (1,000 cubic feet)			
Barge Type*	*250-300'*	*195-200'*	*175'*	*150'*
Hopper Barge	182	90	81	69
Covered cargo barge[20]	165	82	74	63
Tank Barges	160	56	48	41
Deck Barges	182	90	81	69
Container Barges	218	82	65	49

* "Other" barge types require volumes input by the user

[19] High end approximately equal to that of gold, low end to density of potato chips. See http://www.aqua-calc.com/page/density-table/substance/Snacks-coma-and-blank-potato-blank-chips-coma-and-blank-white-coma-and-blank-restructured-coma-and-blank-baked. Accessed 1-16-24.

[20] Assumed maximum volume for covered cargo barge for 250-300 was 265 ft long 52 ft wide and 12 feet deep = 165,360; 195-200 was 195 long 35 ft wide and 12 ft deep; 175 and 150 had the same width and depth of the 195 ft barge.

Volumes for articulated/integrated barges were derived from a listing of 134 bluewater units protected by US cabotage law, 114 of which included volume estimates.[21] Four barge size groupings were defined as shown in Table 5.

Table 5. Articulated/Integrate Barge Capacity by Volume Category (barrels)

Size Category	Average Volume
< 100,000	373,591
100,000 < 150,000	683,827
150,000 < 200,000	944,121
200,000 +	1,583,898

The Barge Tool performs one other validation check, ensuring that the fleet's total payload, as determined from the Barge Operations screen, does not exceed the maximum possible payload based on the reported towing capacities reported on the Vessel Operations screen.

[21] US Maritime Administration data compiled by Tradeswindsnews.com; provided by Terrence Houston, American Waterway Operators, December 15, 2016.

5.0 Future Enhancements

The following enhancements are being considered for future versions of the Barge Tool:

- Develop validation ranges for barge-mile, ton-mile, payload, towing capacity, rated power, and other inputs based on Partner data submissions and/or other sources.
- Compile list of common data sources for vessel and barge data, based on Partner data submissions.
- Add option for dual-fuel propulsion engines.
- Allow user-specified propulsion engine load factors.
- Develop default average volume utilization and payloads based on commodity type and other Partner data.

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Appendix A: Marine Engine Emission Factors (g/kWhr)[22]

Table A-1. Auxiliary Engine Emission Factors (g/kWhr)

Model Year	Engine Size	NO_x	PM_{10}	BC
Pre-1999	0 < kW ≤ 8	13.410	1.213	0.906
Pre-1999	8 < kW ≤ 19	11.399	1.079	0.806
Pre-1999	19 < kW ≤ 37	9.253	0.945	0.706
Pre-1999	37 < kW ≤ 600	10.081	0.292	0.218
Pre-1999	600 < kW ≤ 1000	10.406	0.212	0.158
Pre-1999	1000 < kW ≤ 1400	10.947	0.191	0.143
Pre-1999	1400 < kW ≤ 2000	11.000	0.190	0.142
1999	0 < kW ≤ 8	13.410	1.213	0.906
1999	8 < kW ≤ 19	11.399	1.079	0.806
1999	19 < kW ≤ 37	6.343	0.328	0.245
1999	37 < kW ≤ 600	10.081	0.292	0.218
1999	600 < kW ≤ 1000	10.406	0.212	0.158
1999	1000 < kW ≤ 1400	10.947	0.191	0.143
1999	1400 < kW ≤ 2000	11.000	0.190	0.142
2000	0 < kW ≤ 8	7.014	0.475	0.355
2000	8 < kW ≤ 19	5.954	0.234	0.175
2000	19 < kW ≤ 37	6.343	0.328	0.245
2000	37 < kW ≤ 600	10.081	0.292	0.218
2000	600 < kW ≤ 1000	10.406	0.212	0.158
2000	1000 < kW ≤ 1400	10.947	0.191	0.143
2000	1400 < kW ≤ 2000	11.000	0.190	0.142
2001	0 < kW ≤ 8	7.014	0.475	0.355
2001	8 < kW ≤ 19	5.954	0.234	0.175
2001	19 < kW ≤ 37	6.343	0.328	0.245
2001	37 < kW ≤ 600	10.081	0.292	0.218
2001	600 < kW ≤ 1000	10.406	0.212	0.158
2001	1000 < kW ≤ 1400	10.947	0.191	0.143

[22] Emission factors are from EPA's 2020 Port Emissions Inventory Guidance - https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf – Accessed 1-16-24.

Model Year	Engine Size	NO_x	PM_{10}	BC
2001	1400 < kW ≤ 2000	11.000	0.190	0.142
2002	0 < kW ≤ 8	7.014	0.475	0.355
2002	8 < kW ≤ 19	5.954	0.234	0.175
2002	19 < kW ≤ 37	6.343	0.328	0.245
2002	37 < kW ≤ 600	10.081	0.292	0.218
2002	600 < kW ≤ 1000	10.406	0.212	0.158
2002	1000 < kW ≤ 1400	10.947	0.191	0.143
2002	1400 < kW ≤ 2000	11.000	0.190	0.142
2003	0 < kW ≤ 8	7.014	0.475	0.355
2003	8 < kW ≤ 19	5.954	0.234	0.175
2003	19 < kW ≤ 37	6.343	0.328	0.245
2003	37 < kW ≤ 600	10.081	0.292	0.218
2003	600 < kW ≤ 1000	10.406	0.212	0.158
2003	1000 < kW ≤ 1400	10.947	0.191	0.143
2003	1400 < kW ≤ 2000	11.000	0.190	0.142
2004	0 < kW ≤ 8	7.014	0.475	0.355
2004	8 < kW ≤ 19	5.954	0.234	0.175
2004	19 < kW ≤ 37	4.975	0.295	0.221
2004	37 < kW ≤ 600	6.373	0.190	0.142
2004	600 < kW ≤ 1000	7.621	0.166	0.124
2004	1000 < kW ≤ 1400	9.195	0.191	0.143
2004	1400 < kW ≤ 2000	9.200	0.190	0.142
2005	0 < kW ≤ 8	5.887	0.497	0.371
2005	8 < kW ≤ 19	4.868	0.242	0.181
2005	19 < kW ≤ 37	4.975	0.295	0.221
2005	37 < kW ≤ 600	6.105	0.157	0.117
2005	600 < kW ≤ 1000	7.621	0.166	0.124
2005	1000 < kW ≤ 1400	9.195	0.191	0.143
2005	1400 < kW ≤ 2000	9.200	0.190	0.142
2006	0 < kW ≤ 8	5.887	0.497	0.371
2006	8 < kW ≤ 19	4.868	0.242	0.181
2006	19 < kW ≤ 37	4.975	0.295	0.221
2006	37 < kW ≤ 600	6.105	0.157	0.117
2006	600 < kW ≤ 1000	7.621	0.166	0.124
2006	1000 < kW ≤ 1400	9.195	0.191	0.143
2006	1400 < kW ≤ 2000	9.200	0.190	0.142

Model Year	Engine Size	NO_x	PM_{10}	BC
2007	0 < kW ≤ 8	5.887	0.497	0.371
2007	8 < kW ≤ 19	4.868	0.242	0.181
2007	19 < kW ≤ 37	4.975	0.295	0.221
2007	37 < kW ≤ 600	5.962	0.154	0.115
2007	600 < kW ≤ 1000	6.100	0.139	0.104
2007	1000 < kW ≤ 1400	6.100	0.139	0.104
2007	1400 < kW ≤ 2000	6.100	0.139	0.104
2008	0 < kW ≤ 8	5.887	0.497	0.371
2008	8 < kW ≤ 19	4.868	0.242	0.181
2008	19 < kW ≤ 37	4.975	0.295	0.221
2008	37 < kW ≤ 600	5.962	0.154	0.115
2008	600 < kW ≤ 1000	6.100	0.139	0.104
2008	1000 < kW ≤ 1400	6.100	0.139	0.104
2008	1400 < kW ≤ 2000	6.100	0.139	0.104
2009	0 < kW ≤ 8	4.390	0.240	0.179
2009	8 < kW ≤ 19	3.630	0.190	0.142
2009	19 < kW ≤ 37	3.710	0.180	0.134
2009	37 < kW ≤ 600	5.962	0.151	0.113
2009	600 < kW ≤ 1000	6.100	0.139	0.104
2009	1000 < kW ≤ 1400	6.100	0.139	0.104
2009	1400 < kW ≤ 2000	6.100	0.139	0.104
2010	0 < kW ≤ 8	4.390	0.240	0.179
2010	8 < kW ≤ 19	3.630	0.190	0.142
2010	19 < kW ≤ 37	3.710	0.180	0.134
2010	37 < kW ≤ 600	5.962	0.151	0.113
2010	600 < kW ≤ 1000	6.100	0.139	0.104
2010	1000 < kW ≤ 1400	6.100	0.139	0.104
2010	1400 < kW ≤ 2000	6.100	0.139	0.104
2011	0 < kW ≤ 8	4.390	0.240	0.179
2011	8 < kW ≤ 19	3.630	0.190	0.142
2011	19 < kW ≤ 37	3.710	0.180	0.134
2011	37 < kW ≤ 600	5.962	0.151	0.113
2011	600 < kW ≤ 1000	6.100	0.139	0.104
2011	1000 < kW ≤ 1400	6.100	0.139	0.104
2011	1400 < kW ≤ 2000	6.100	0.139	0.104
2012	0 < kW ≤ 8	4.390	0.240	0.179

Model Year	Engine Size	NO_x	PM_{10}	BC
2012	8 < kW ≤ 19	3.630	0.190	0.142
2012	19 < kW ≤ 37	3.710	0.180	0.134
2012	37 < kW ≤ 600	5.924	0.148	0.111
2012	600 < kW ≤ 1000	5.608	0.115	0.086
2012	1000 < kW ≤ 1400	4.954	0.083	0.062
2012	1400 < kW ≤ 2000	4.890	0.080	0.060
2013	0 < kW ≤ 8	4.390	0.240	0.179
2013	8 < kW ≤ 19	3.630	0.190	0.142
2013	19 < kW ≤ 37	3.710	0.180	0.134
2013	37 < kW ≤ 600	5.661	0.128	0.095
2013	600 < kW ≤ 1000	5.492	0.110	0.082
2013	1000 < kW ≤ 1400	4.884	0.080	0.060
2013	1400 < kW ≤ 2000	4.890	0.080	0.060
2014	0 < kW ≤ 8	4.390	0.240	0.179
2014	8 < kW ≤ 19	2.320	0.190	0.142
2014	19 < kW ≤ 37	2.320	0.180	0.134
2014	37 < kW ≤ 600	4.580	0.085	0.063
2014	600 < kW ≤ 1000	4.819	0.080	0.060
2014	1000 < kW ≤ 1400	4.884	0.080	0.060
2014	1400 < kW ≤ 2000	4.890	0.080	0.060
2015	0 < kW ≤ 8	4.390	0.240	0.179
2015	8 < kW ≤ 19	2.320	0.190	0.142
2015	19 < kW ≤ 37	2.320	0.180	0.134
2015	37 < kW ≤ 600	4.580	0.085	0.063
2015	600 < kW ≤ 1000	4.819	0.080	0.060
2015	1000 < kW ≤ 1400	4.884	0.080	0.060
2015	1400 < kW ≤ 2000	4.890	0.080	0.060
2016	0 < kW ≤ 8	4.390	0.240	0.179
2016	8 < kW ≤ 19	2.320	0.190	0.142
2016	19 < kW ≤ 37	2.320	0.180	0.134
2016	37 < kW ≤ 600	4.580	0.085	0.063
2016	600 < kW ≤ 1000	4.819	0.080	0.060
2016	1000 < kW ≤ 1400	4.884	0.080	0.060
2016	1400 < kW ≤ 2000	1.300	0.030	0.022
2017	0 < kW ≤ 8	4.390	0.240	0.179
2017	8 < kW ≤ 19	2.320	0.190	0.142

Model Year	Engine Size	NO_x	PM_{10}	BC
2017	19 < kW ≤ 37	2.320	0.180	0.134
2017	37 < kW ≤ 600	4.580	0.085	0.063
2017	600 < kW ≤ 1000	4.819	0.080	0.060
2017	1000 < kW ≤ 1400	1.300	0.030	0.022
2017	1400 < kW ≤ 2000	1.300	0.030	0.022
2018+	0 < kW ≤ 8	4.390	0.240	0.179
2018+	8 < kW ≤ 19	2.320	0.190	0.142
2018+	19 < kW ≤ 37	2.320	0.180	0.134
2018+	37 < kW ≤ 600	4.580	0.077	0.058
2018+	600 < kW ≤ 1000	1.300	0.030	0.022
2018+	1000 < kW ≤ 1400	1.300	0.030	0.022
2018+	1400 < kW ≤ 2000	1.300	0.030	0.022

Table A-2. Propulsion Engine Emission Factors (g/kWhr)

Model Year	Engine Size	NO_x	PM_{10}	BC
Pre-1999	37 < kW ≤ 600	10.076	0.242	0.181
Pre-1999	600 < kW ≤ 1000	10.247	0.208	0.155
Pre-1999	1000 < kW ≤ 1400	10.454	0.217	0.162
Pre-1999	1400 < kW ≤ 2000	11.799	0.197	0.147
Pre-1999	2000 < kW ≤ 3700	13.360	0.210	0.157
Pre-1999	3700+ kW	13.360	0.210	0.157
1999	37 < kW ≤ 600	10.076	0.242	0.181
1999	600 < kW ≤ 1000	10.247	0.208	0.155
1999	1000 < kW ≤ 1400	10.454	0.217	0.162
1999	1400 < kW ≤ 2000	11.799	0.197	0.147
1999	2000 < kW ≤ 3700	13.360	0.210	0.157
1999	3700+ kW	13.360	0.210	0.157
2000	37 < kW ≤ 600	10.076	0.242	0.181
2000	600 < kW ≤ 1000	10.247	0.208	0.155
2000	1000 < kW ≤ 1400	10.454	0.217	0.162
2000	1400 < kW ≤ 2000	11.799	0.197	0.147
2000	2000 < kW ≤ 3700	13.360	0.210	0.157
2000	3700+ kW	13.360	0.210	0.157
2001	37 < kW ≤ 600	10.076	0.242	0.181
2001	600 < kW ≤ 1000	10.247	0.208	0.155
2001	1000 < kW ≤ 1400	10.454	0.217	0.162
2001	1400 < kW ≤ 2000	11.799	0.197	0.147
2001	2000 < kW ≤ 3700	13.360	0.210	0.157
2001	3700+ kW	13.360	0.210	0.157
2002	37 < kW ≤ 600	10.076	0.242	0.181
2002	600 < kW ≤ 1000	10.247	0.208	0.155
2002	1000 < kW ≤ 1400	10.454	0.217	0.162
2002	1400 < kW ≤ 2000	11.799	0.197	0.147
2002	2000 < kW ≤ 3700	13.360	0.210	0.157
2002	3700+ kW	13.360	0.210	0.157
2003	37 < kW ≤ 600	10.076	0.242	0.181
2003	600 < kW ≤ 1000	10.247	0.208	0.155
2003	1000 < kW ≤ 1400	10.454	0.217	0.162
2003	1400 < kW ≤ 2000	11.799	0.197	0.147

Model Year	Engine Size	NO_x	PM_{10}	BC
2003	2000 < kW ≤ 3700	13.360	0.210	0.157
2003	3700+ kW	13.360	0.210	0.157
2004	37 < kW ≤ 600	6.502	0.131	0.098
2004	600 < kW ≤ 1000	7.828	0.160	0.120
2004	1000 < kW ≤ 1400	7.278	0.147	0.110
2004	1400 < kW ≤ 2000	9.657	0.197	0.147
2004	2000 < kW ≤ 3700	10.550	0.210	0.157
2004	3700+ kW	10.550	0.210	0.157
2005	37 < kW ≤ 600	6.456	0.129	0.096
2005	600 < kW ≤ 1000	7.828	0.160	0.120
2005	1000 < kW ≤ 1400	7.278	0.147	0.110
2005	1400 < kW ≤ 2000	9.657	0.197	0.147
2005	2000 < kW ≤ 3700	10.550	0.210	0.157
2005	3700+ kW	10.550	0.210	0.157
2006	37 < kW ≤ 600	6.456	0.129	0.096
2006	600 < kW ≤ 1000	7.828	0.160	0.120
2006	1000 < kW ≤ 1400	7.278	0.147	0.110
2006	1400 < kW ≤ 2000	9.657	0.197	0.147
2006	2000 < kW ≤ 3700	10.550	0.210	0.157
2006	3700+ kW	10.550	0.210	0.157
2007	37 < kW ≤ 600	6.058	0.123	0.092
2007	600 < kW ≤ 1000	6.061	0.124	0.092
2007	1000 < kW ≤ 1400	6.218	0.137	0.102
2007	1400 < kW ≤ 2000	6.789	0.183	0.137
2007	2000 < kW ≤ 3700	8.330	0.309	0.231
2007	3700+ kW	8.330	0.309	0.231
2008	37 < kW ≤ 600	6.058	0.123	0.092
2008	600 < kW ≤ 1000	6.061	0.124	0.092
2008	1000 < kW ≤ 1400	6.218	0.137	0.102
2008	1400 < kW ≤ 2000	6.789	0.183	0.137
2008	2000 < kW ≤ 3700	8.330	0.309	0.231
2008	3700+ kW	8.330	0.309	0.231
2009	37 < kW ≤ 600	6.058	0.123	0.092
2009	600 < kW ≤ 1000	6.061	0.124	0.092
2009	1000 < kW ≤ 1400	6.218	0.137	0.102
2009	1400 < kW ≤ 2000	6.789	0.183	0.137

Model Year	Engine Size	NO_x	PM_{10}	BC
2009	2000 < kW ≤ 3700	8.330	0.309	0.231
2009	3700+ kW	8.330	0.309	0.231
2010	37 < kW ≤ 600	6.058	0.123	0.092
2010	600 < kW ≤ 1000	6.061	0.124	0.092
2010	1000 < kW ≤ 1400	6.218	0.137	0.102
2010	1400 < kW ≤ 2000	6.789	0.183	0.137
2010	2000 < kW ≤ 3700	8.330	0.309	0.231
2010	3700+ kW	8.330	0.309	0.231
2011	37 < kW ≤ 600	6.058	0.123	0.092
2011	600 < kW ≤ 1000	6.061	0.124	0.092
2011	1000 < kW ≤ 1400	6.218	0.137	0.102
2011	1400 < kW ≤ 2000	6.789	0.183	0.137
2011	2000 < kW ≤ 3700	8.330	0.309	0.231
2011	3700+ kW	8.330	0.309	0.231
2012	37 < kW ≤ 600	6.041	0.121	0.091
2012	600 < kW ≤ 1000	5.872	0.116	0.087
2012	1000 < kW ≤ 1400	6.051	0.130	0.097
2012	1400 < kW ≤ 2000	6.002	0.151	0.113
2012	2000 < kW ≤ 3700	8.330	0.309	0.231
2012	3700+ kW	8.330	0.309	0.231
2013	37 < kW ≤ 600	5.668	0.105	0.079
2013	600 < kW ≤ 1000	5.303	0.092	0.069
2013	1000 < kW ≤ 1400	5.659	0.105	0.078
2013	1400 < kW ≤ 2000	5.398	0.100	0.075
2013	2000 < kW ≤ 3700	8.330	0.185	0.138
2013	3700+ kW	8.330	0.309	0.231
2014	37 < kW ≤ 600	4.692	0.069	0.052
2014	600 < kW ≤ 1000	4.743	0.071	0.053
2014	1000 < kW ≤ 1400	4.826	0.074	0.055
2014	1400 < kW ≤ 2000	5.269	0.099	0.074
2014	2000 < kW ≤ 3700	1.300	0.182	0.136
2014	3700+ kW	1.300	0.180	0.134
2015	37 < kW ≤ 600	4.692	0.069	0.052
2015	600 < kW ≤ 1000	4.743	0.071	0.053
2015	1000 < kW ≤ 1400	4.826	0.074	0.055
2015	1400 < kW ≤ 2000	5.269	0.099	0.074

Model Year	Engine Size	NO_x	PM_{10}	BC
2015	2000 < kW ≤ 3700	1.300	0.182	0.136
2015	3700+ kW	1.300	0.180	0.134
2016	37 < kW ≤ 600	4.692	0.069	0.052
2016	600 < kW ≤ 1000	4.743	0.071	0.053
2016	1000 < kW ≤ 1400	4.826	0.074	0.055
2016	1400 < kW ≤ 2000	1.300	0.031	0.023
2016	2000 < kW ≤ 3700	1.300	0.034	0.025
2016	3700+ kW	1.300	0.180	0.134
2017	37 < kW ≤ 600	4.692	0.069	0.052
2017	600 < kW ≤ 1000	4.743	0.071	0.053
2017	1000 < kW ≤ 1400	1.300	0.030	0.022
2017	1400 < kW ≤ 2000	1.300	0.031	0.023
2017	2000 < kW ≤ 3700	1.300	0.034	0.025
2017	3700+ kW	1.300	0.046	0.034
2018+	37 < kW ≤ 600	4.692	0.061	0.046
2018+	600 < kW ≤ 1000	1.300	0.030	0.022
2018+	1000 < kW ≤ 1400	1.300	0.030	0.022
2018+	1400 < kW ≤ 2000	1.300	0.031	0.023
2018+	2000 < kW ≤ 3700	1.300	0.034	0.025
2018+	3700+ kW	1.300	0.046	0.034

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