SmartWay Transport Partnership
U.S. Environmental Protection Agency

# Barge Carrier Partner 2.0.13 Tool: Technical Documentation 2013 Data Year - United States Version

EPA United States Environmental Protection Agency

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

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Office of Transportation and Air Quality
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# SmartWay 2.0.13
# Barge Tool
# Technical Documentation
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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 of these 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 $NO_x$ and PM emissions. For marine distillate fuel, the Tool uses EPA emission factors developed to

[1] i) Fuel economy calculations in 40 C.F.R 600.113 available at http://edocket.access.gpo.gov/cfr_2004/julqtr/pdf/40cfr600.113-93.pdf.
ii) Tables IV.A.3-2 and 3-3 in A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, available at http://www.epa.gov/oms/models/analysis/biodsl/p02001.pdf
iii) Assuming 74,720 Btu/gal lower heating value (http://www.afdc.energy.gov/afdc/fuels/properties.html), and 0.059 g/Btu.

support its recent marine vessel rules. The $NO_x$ and $PM_{10}$ emission factors for main propulsion engines using low (500 ppm) and ultra-low (15 ppm) sulfur distillate fuel are a function of year of manufacture (or rebuild), as well as Engine Class (1 or 2 for tugs/tows), and rated engine power (in kW). These factors, presented in Tables A-1 and A-2 in the Appendix, 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 used by the EPA NONROAD model.

$NO_x$ 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

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

- [Exp(0.0009747 x 20)-1] x 100 = 1.9%

To obtain the final NOx emissions the unadjusted NOx is multiplied by (1-0.019) = 0.991,

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

Note that for LNG, 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.

Auxiliary Engines

$NO_x$ and PM emissions associated with diesel auxiliary engine operation are calculated in the exact same fashion as propulsion engine emissions, assuming all auxiliary engines fall into EPA engine category 1. Separate PM factors are used for low and ultra-low sulfur fuel. Alternative fuels and retrofits are not allowed for auxiliary engines at this time.

## 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)[2]
    - Propulsion engine operation
        - # engines (1 or 2)
        - Total rated power (HP or kW – sum if two engines)
        - Hours of operation per year (underway and maneuvering)
    - Auxiliary engine operation (for each engine)[3]
        - Engine age
        - 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

[2] 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.
[3] Note – the Barge Tool assumes all auxiliary engines are diesel powered.

        - 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, ton-mile and volume-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[4]
- Biodiesel (B100) – 271 gallons/ton[5]
- LNG – 526 gallons/ton[6]

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 ($1.1023 \times 10^{-6}$ short tons/gram), and summed across vessels to obtain tons of $CO_2$ per year for the entire vessel fleet.

### 2.2 $NO_x$ and PM Calculations

$NO_x$ and PM are calculated based on kW-hr activity estimates. This approach allows emission calculations to account for the size of the vessel's propulsion engine as well as auxiliary engines and the amount of time a vessel spends maneuvering in port and underway. Equation 2 presents the general equation for calculating $NO_x$ and PM emissions for each propulsion engine using diesel fuel.[7]

***Equation 2***

$$EM_{po} = (Pw / \#_e) \times 0.7457 \times Hr_o \times LF_o/100 \times EF_{cykasp} / 1{,}102{,}300$$

Where:

| | | |
|---|---|---|
| $EM_{po}$ | = | Marine vessel emissions for pollutant (p) and operation (o) (tons/year) |
| Pw | = | Total power rating of the vessel's propulsion engines (hp or kW) |

[4] http://www.extension.iastate.edu/agdm/wholefarm/html/c6-87.html
[5] for soy-based B100 at 70 degrees F: http://www.nrel.gov/vehiclesandfuels/pdfs/43672.pdf
[6] http://www.netl.doe.gov/technologies/oil-gas/publications/LNG/LNG_BasicFacts.pdf
[7] 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.

$\#_e$ = Number of propulsion engines (1 or 2)[8]
0.7457 = Conversion factor from horsepower to kilowatts, if needed (kW/hp - Perry's Chemical engineer's Handbook)
$Hr_o$ = Total annual hours of operation for the propulsion engines in operating mode o (hr)
LF = Load factor for operating mode o - see Table 2 (percentage)
$EF_{cykap}$ = Emission factor for operation mode o, fuel type a, engine category c and pollutant p (grams/kW-hr) – see Tables A-1 and A-2
1,102,300 = Conversion factor from grams to short tons

subscripts -
o = Operation (underway or maneuvering)
c = EPA Engine Category (1 or 2)
y = Year of manufacture
k = Kilowatt rating
a = Fuel type (low or ultra-low sulfur distillate)
p = Pollutant

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 equations are provided in Table 2 below. These load factors were compiled from a variety of sources and disaggregated into vessel categories used in this project. The data sources include: EPA's *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder* (EPA, 2008); *Commercial Marine Port Inventory Development 2002 and 2005 Inventories* (EPA, 2007b); *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories* (EPA, 2009); and European Commission/Entech study (EC, 2002).

**Table 2. Marine Vessel Engine Load Factors (%)**

| Engine Type | Load Factor (%) | |
|---|---|---|
| | Maneuvering | Underway |
| Propulsion | 20 | 80 |
| Auxiliary | 17[9] | |

[8] This approach assumes that multiple propulsion engines are of the same type, power, and age, and operate in tandem.
[9] Average auxiliary engine load factor for cruise operation, from ICF International, Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, prepared for USEPA, April 2009. Cruise conditions are assumed most prevalent; to the extent that auxiliary engines are also used during maneuvering and hotelling, load factors and emissions will be higher.

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).

*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.[10] The reduction factors assumed for each of these control options are presented in Table 3. 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**

| | Reduction Factor | |
|---|---|---|
| **Control** | **NOX** | **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 NOx 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 3.[11] 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.

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

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

## 3.0 Comparison 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.[12]

<u>Grams per Barge-Mile</u>

***Equation 3***

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

<u>Grams per Ton-Mile</u>

***Equation 4***

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

<u>Grams per 1,000 Total Cubic Foot-Miles</u>

***Equation 5***

grams / [ $\sum_b$ (# barges x # of 1,000 cubic feet per barge x (annual loaded + annual unloaded miles per barge))]

where $\sum_b$ indicates summation over all barge type/size combinations (i.e., the individual rows in the Barge Operations screen of the Barge Tool.)

Barge volumes were estimated for each barge type/size combination using standardized assumptions regarding depth and width. Volumes are summarized below in Table 4.

[12] 1 nautical mile = 1.15 statute miles.

**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[13] | 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

Grams per 1,000 Utilized Cubic Foot-Miles

***Equation 6***

grams / [ $\sum_b$ (# barges x # of 1,000 cubic feet per barge x (annual loaded miles per barge x average volume utilization))]

where $\sum_b$ indicates summation over all barge type/size combinations (i.e., the individual rows in the Barge Operations screen of the Barge Tool.)

[13] 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.

## 4.0 Data Validation

At this time 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. Specifically, these three values must be within 5% of the totals calculated as follows:

***Equation 7***

$$\text{Total Ton-miles} = \left[ \sum_{b} (\text{number of barges} \times \text{Annual Loaded Miles per Barge} \times \text{Average Loaded Payload per Barge}) \right]$$

***Equation 8***

$$\text{Loaded Barge-Miles} = \left[ \sum_{b} (\text{number of barges} \times \text{Annual Loaded Miles per Barge}) \right]$$

***Equation 9***

$$\text{Unloaded Barge-Miles} = \left[ \sum_{b} (\text{number of barges} \times \text{Annual Empty Miles per Barge}) \right]$$

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.

## 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.
- Expanding the list of pollutants to include methane and other greenhouse gases, $SO_x$.
- Add option for dual-fuel propulsion engines.
- Allow user-specified engine load factors (propulsion and auxiliary).
- Develop default average volume utilization and payloads based on commodity type and other Partner data.
- Allow for vessels with more than 2 propulsion engines.

## 6.0 References


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Wright International, Barge Brokerage, http://www.wright-international.com/brokerage-barges.php.

## Appendix A: Marine Propulsion and Auxiliary Engine Emission Factors[14]

[14] Emission factors are consistent with EPA's 2008 locomotive and marine Federal Rulemaking - http://www.epa.gov/otaq/marine.htm.

## Table A-1. Category 1 Distillate Emission Factors

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 1 | <600kW | 2018+ | 4.66 | 4.66 | 0.06 | 0.08 |
| 1 | <600kW | 2017 | 4.66 | 4.66 | 0.07 | 0.08 |
| 1 | <600kW | 2016 | 4.66 | 4.66 | 0.07 | 0.08 |
| 1 | <600kW | 2015 | 4.66 | 4.66 | 0.07 | 0.08 |
| 1 | <600kW | 2014 | 4.66 | 4.66 | 0.07 | 0.08 |
| 1 | <600kW | 2013 | 5.64 | 5.64 | 0.10 | 0.12 |
| 1 | <600kW | 2012 | 5.95 | 5.95 | 0.12 | 0.13 |
| 1 | <600kW | 2011 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | <600kW | 2010 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | <600kW | 2009 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | <600kW | 2008 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | <600kW | 2007 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | <600kW | 2006 | 6.34 | 6.34 | 0.14 | 0.16 |
| 1 | <600kW | 2005 | 6.34 | 6.34 | 0.14 | 0.16 |
| 1 | <600kW | 2004 | 6.49 | 6.49 | 0.15 | 0.17 |
| 1 | <600kW | 2003 | 9.72 | 9.72 | 0.35 | 0.36 |
| 1 | <600kW | 2002 | 9.72 | 9.72 | 0.35 | 0.36 |
| 1 | <600kW | 2001 | 9.72 | 9.72 | 0.35 | 0.36 |
| 1 | <600kW | 2000 | 9.72 | 9.72 | 0.35 | 0.36 |
| 1 | <600kW | pre-2000 | 10.00 | 10.00 | 0.25 | 0.26 |
| 1 | 600<kW<=1000 | 2018+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 1 | 600<kW<=1000 | 2017 | 4.71 | 4.71 | 0.07 | 0.09 |
| 1 | 600<kW<=1000 | 2016 | 4.71 | 4.71 | 0.07 | 0.09 |
| 1 | 600<kW<=1000 | 2015 | 4.71 | 4.71 | 0.07 | 0.09 |
| 1 | 600<kW<=1000 | 2014 | 4.71 | 4.71 | 0.07 | 0.09 |
| 1 | 600<kW<=1000 | 2013 | 5.32 | 5.32 | 0.09 | 0.11 |
| 1 | 600<kW<=1000 | 2012 | 5.82 | 5.82 | 0.11 | 0.13 |
| 1 | 600<kW<=1000 | 2011 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 600<kW<=1000 | 2010 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 600<kW<=1000 | 2009 | 6.00 | 6.00 | 0.12 | 0.14 |

## Table A-1. Category 1 Distillate Emission Factors (Cont.)

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 1 | 600<kW<=1000 | 2008 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 600<kW<=1000 | 2007 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 600<kW<=1000 | 2006 | 7.67 | 7.67 | 0.21 | 0.23 |
| 1 | 600<kW<=1000 | 2005 | 7.67 | 7.67 | 0.21 | 0.23 |
| 1 | 600<kW<=1000 | 2004 | 7.67 | 7.67 | 0.21 | 0.23 |
| 1 | 600<kW<=1000 | 2003 | 9.44 | 9.44 | 0.31 | 0.32 |
| 1 | 600<kW<=1000 | 2002 | 9.44 | 9.44 | 0.31 | 0.32 |
| 1 | 600<kW<=1000 | 2001 | 9.44 | 9.44 | 0.31 | 0.32 |
| 1 | 600<kW<=1000 | 2000 | 9.44 | 9.44 | 0.31 | 0.32 |
| 1 | 600<kW<=1000 | pre-2000 | 10.16 | 10.16 | 0.21 | 0.22 |
| 1 | 1000<kW<=1400 | 2017+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 1 | 1000<kW<=1400 | 2016 | 4.72 | 4.72 | 0.07 | 0.09 |
| 1 | 1000<kW<=1400 | 2015 | 4.72 | 4.72 | 0.07 | 0.09 |
| 1 | 1000<kW<=1400 | 2014 | 4.72 | 4.72 | 0.07 | 0.09 |
| 1 | 1000<kW<=1400 | 2013 | 0.68 | 0.68 | 0.10 | 0.12 |
| 1 | 1000<kW<=1400 | 2012 | 0.68 | 0.68 | 0.11 | 0.12 |
| 1 | 1000<kW<=1400 | 2011 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 1000<kW<=1400 | 2010 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 1000<kW<=1400 | 2009 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 1000<kW<=1400 | 2008 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 1000<kW<=1400 | 2007 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | 1000<kW<=1400 | 2006 | 7.26 | 7.26 | 0.19 | 0.20 |
| 1 | 1000<kW<=1400 | 2005 | 7.26 | 7.26 | 0.19 | 0.20 |
| 1 | 1000<kW<=1400 | 2004 | 7.26 | 7.26 | 0.19 | 0.20 |
| 1 | 1000<kW<=1400 | 2003 | 9.55 | 9.55 | 0.31 | 0.33 |
| 1 | 1000<kW<=1400 | 2002 | 9.55 | 9.55 | 0.31 | 0.33 |
| 1 | 1000<kW<=1400 | 2001 | 9.55 | 9.55 | 0.31 | 0.33 |
| 1 | 1000<kW<=1400 | 2000 | 9.55 | 9.55 | 0.31 | 0.33 |
| 1 | 1000<kW<=1400 | pre-2000 | 10.27 | 10.27 | 0.21 | 0.23 |
| 1 | kW>1400 | 2016+ | 1.30 | 1.30 | 0.03 | 0.05 |

## Table A-1. Category 1 Distillate Emission Factors (Cont.)

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 1 | kW>1400 | 2015 | 4.81 | 4.81 | 0.07 | 0.09 |
| 1 | kW>1400 | 2014 | 4.81 | 4.81 | 0.07 | 0.09 |
| 1 | kW>1400 | 2013 | 4.81 | 4.81 | 0.07 | 0.09 |
| 1 | kW>1400 | 2012 | 4.81 | 4.81 | 0.07 | 0.09 |
| 1 | kW>1400 | 2011 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | kW>1400 | 2010 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | kW>1400 | 2009 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | kW>1400 | 2008 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | kW>1400 | 2007 | 6.00 | 6.00 | 0.12 | 0.14 |
| 1 | kW>1400 | 2006 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2005 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2004 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2003 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2002 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2001 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | 2000 | 9.20 | 9.20 | 0.29 | 0.31 |
| 1 | kW>1400 | pre-2000 | 11.00 | 11.00 | 0.19 | 0.21 |

## Table A-2. Category 2 Distillate Emission Factors

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 2 | <600kW | 2013+ | 5.97 | 5.97 | 0.11 | 0.13 |
| 2 | <600kW | 2012 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2011 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2010 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2009 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2008 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | <600kW | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2002 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | <600kW | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |
| 2 | 600<=kW<1000 | 2018+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 2 | 600<=kW<1000 | 2017 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 600<=kW<1000 | 2016 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 600<=kW<1000 | 2015 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 600<=kW<1000 | 2014 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 600<=kW<1000 | 2013 | 5.97 | 5.97 | 0.11 | 0.13 |
| 2 | 600<=kW<1000 | 2012 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2011 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2010 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2009 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2008 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |

## Table A-2. Category 2 Distillate Emission Factors (Cont.)

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 2 | 600<=kW<1000 | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2002 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 600<=kW<1000 | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |
| 2 | 1000<=kW<1400 | 2017+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 2 | 1000<=kW<1400 | 2016 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 1000<=kW<1400 | 2015 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 1000<=kW<1400 | 2014 | 1.30 | 1.30 | 0.11 | 0.13 |
| 2 | 1000<=kW<1400 | 2013 | 5.97 | 5.97 | 0.11 | 0.13 |
| 2 | 1000<=kW<1400 | 2012 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2011 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2010 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2009 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2008 | 5.97 | 5.97 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2002 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1000<=kW<1400 | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |
| 2 | 1400<=kW<2000 | 2016+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 2 | 1400<=kW<2000 | 2015 | 6.17 | 6.17 | 0.16 | 0.17 |
| 2 | 1400<=kW<2000 | 2014 | 6.17 | 6.17 | 0.16 | 0.17 |
| 2 | 1400<=kW<2000 | 2013 | 6.55 | 6.55 | 0.16 | 0.17 |
| 2 | 1400<=kW<2000 | 2012 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2011 | 8.33 | 8.33 | 0.31 | 0.33 |

## Table A-2. Category 2 Distillate Emission Factors (Cont.)

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 2 | 1400<=kW<2000 | 2010 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2009 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2008 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2002 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 1400<=kW<2000 | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |
| 2 | 2000<=kW<3700 | 2016+ | 1.30 | 1.30 | 0.03 | 0.05 |
| 2 | 2000<=kW<3700 | 2015 | 1.30 | 1.30 | 0.18 | 0.20 |
| 2 | 2000<=kW<3700 | 2014 | 1.30 | 1.30 | 0.18 | 0.20 |
| 2 | 2000<=kW<3700 | 2013 | 8.33 | 8.33 | 0.19 | 0.20 |
| 2 | 2000<=kW<3700 | 2012 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2011 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2010 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2009 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2008 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2002 | 10.55 | 10.55 | 0.00 | 0.33 |
| 2 | 2000<=kW<3700 | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | 2000<=kW<3700 | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |

## Table A-2. Category 2 Distillate Emission Factors (Cont.)

| Category | Engine Size | Model Year | $NO_X$ Weighted EF g/kW-hr (Distillate – 15 ppm) | $NO_X$ Weighted EF g/kW-hr (Distillate 500 ppm) | PM10 Weighted EF g/kW-hr (Distillate – 15 ppm) | PM10 Weighted EF g/kW-hr (Distillate 500 ppm) |
|---|---|---|---|---|---|---|
| 2 | kW>=3700 | 2017+ | 1.30 | 1.30 | 0.05 | 0.06 |
| 2 | kW>=3700 | 2016 | 1.30 | 1.30 | 0.05 | 0.06 |
| 2 | kW>=3700 | 2015 | 1.30 | 1.30 | 0.05 | 0.06 |
| 2 | kW>=3700 | 2014 | 1.30 | 1.30 | 0.18 | 0.20 |
| 2 | kW>=3700 | 2013 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2012 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2011 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2010 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2009 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2008 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2007 | 8.33 | 8.33 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2006 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2005 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2004 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2003 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2002 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2001 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | 2000 | 10.55 | 10.55 | 0.31 | 0.33 |
| 2 | kW>=3700 | pre-2000 | 13.36 | 13.36 | 0.21 | 0.23 |