January 9, 2018

DRAFT MEMORANDUM

To: Environmental Defense Fund and Diesel Technology Forum
From: Ramboll
Subject: Emission reductions and cost effectiveness for marine and locomotive projects - Update

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Introduction

This purpose of this memo is to summarize our general approaches to conduct the emissions reduction and cost effectiveness (CE) calculations for engine and equipment replacement/modernization or retrofits projects associated with locomotives or commercial marine vessels for discussion with the Diesel Technology Forum (DTF) and Environmental Defense Fund (EDF). One objective of this technical memorandum is to describe the emissions reduction and CE analysis methodology used to develop the emission reductions and CE Tool for this project and provide example calculations based on input data from stakeholders.

We followed the EPA guidance and emission inventory calculations and the States of Texas and California cost effectiveness approaches and develop a tool to evaluate cost effectiveness emissions reductions projects for locomotives and commercial marine vessels.

The emission and cost-effectiveness analysis methodologies that Ramboll Environ used in the past projects, along with examples of locomotive and marine vessel projects, are discussed in the following section.

Emission and Cost-Effectiveness Analysis Methodologies

EPA[1] guidance for emission reductions is generally described in a document with regard to how to incorporate voluntary mobile source emission reductions (VMEPs) in State Implementation Plans (SIPs). This guidance lays out the goals and key criteria for evaluating and crediting the emissions reductions from these programs. These criteria are briefly described here and how the proposed locomotive and marine projects meet the EPA guidance.

1. Quantifiable: Essentially the emissions reductions must be able to measured, and the engine certifications essentially guarantee the emission reductions. We will quantify the emissions using the same approach that EPA or individual states (e.g. Texas or California) use when developing emission inventories for air quality SIPs.

[1] EPA 1997, "Guidance on Incorporating Voluntary Mobile Source Emission Reduction Programs in State Implementation Plans (SIPs)," https://www.epa.gov/sites/production/files/2016-05/documents/vmep-gud.pdf

2. Surplus: This criteria is meant to demonstrate that emissions reductions would not have occurred without the project.
3. Enforceable: A SIP measure must be enforceable by the State or the Federal government. Again, the engine certification meets this criteria.
4. Permanent: This criteria is meant to ensure that the emission reduction persists during life of the project. For example, replacing the engine and scrapping the older engine ensures that this criteria is met, though there are other methods.
5. Adequately Supported: Staff oversight and enforcement administration is a necessary component of the project. For example, adequately funding is needed to oversee the installation of new engines, and provide program oversight and accounting to ensure that new engines are being used and that the replaced older engines are appropriate removed from service or recertified new emission standards.

Cost effectiveness is determined using the Texas Emission Reduction Plan (TERP) guidance described in equations 1-4. The TERP guidance[2] provides a method and a discount rate to converted project cost to an annualized figured using the capital recovery factor (CRF) to amortize the project. The amortization depends upon project (or activity) life, which for engine replacement programs is the estimated remaining life of the vehicle to be replaced.

[Eqn. 1]

$$\textit{Annual emission reduction} = \textit{Activity} * (\textit{Emission Rate}_{berfore} - \textit{Emission Rate}_{after})$$

[Eqn. 2]

$$\textit{Cost Effectiveness} = \textit{Annualized Cost} / \textit{Annual NOx Emission Reduction}$$

[Eqn. 3]

$$\textit{Annualized Cost} = \textit{Project Cost} * CRF$$

[Eqn. 4]

$$CRF = [(1 + i)^n\,(i)] / [(1 + i)^n - 1]$$

Where:

i = discount rate (0.03) (This discount rate will be easily manipulated in our product.)
n = activity life

[2] TCEQ 2017. "Texas Emissions Reduction Plan: Guidelines for Emission Reduction Incentive Grants," https://www.tceq.texas.gov/publications/rg/rg-388_index.html

The California Carl Moyer Program[3] outlines a similar approach to TERP. One difference is the discount rate (of return) changes each year and is currently 1.25%. Another difference is that Carl Moyer also counts benefits in hydrocarbon (as reactive organic gas, ROG) and particulate matter (PM) emissions reductions weighting PM to be 20 times more important on a per-ton basis than NOx emissions benefits as shown in Equation 5.

[Eqn. 5]

$$\textit{Weighted Emission Reduction (tons/year)} = NOx + ROG + 20 * PM$$

To evaluate the emission reductions, we will use the EPA guidance and other documentation for calculating emission inventories for locomotives and commercial marine vessels. In many cases, the SIP emission inventories have relied on the EPA approaches and emission results.

<u>Locomotives Emissions</u>

The basic EPA guidance for locomotive emissions estimates are found in two documents.[4, 5] EPA has used two different methods to estimate emissions; one based on fuel consumption (gallons) and another based on the hours of operation and average load factor. We are providing both options in our benefits and cost effectiveness calculator tool.

The fuel consumption method relies on the locomotive operator to provide fuel consumption activity of the locomotives. For line-haul locomotives, some railroads will know or can accurately estimate the fuel consumption based on the gross ton-miles of train activity. For switching locomotives that are locally refuelled, the railroads may have dispensed gallons. EPA provides conversion factors for gallons of fuel consumed by type of locomotive shown in Table 1.

Table 1. Locomotive Conversion Factors (Hp-hr/gallon)[4]

Locomotive Application	Conversion Factor
Class 1 Railroad Line-Haul	20.8
Small Railroad Line-Haul	18.2
Switching	15.2

The emissions estimate for locomotives is then straight forward where emissions factors are provided in Tables 2 and 3.

[3] ARB 2017. "Carl Moyer Program Guidelines," https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm
[4] EPA 2009. "Emission Factors for Locomotives," Office of Transportation and Air Quality EPA-420-F-09-025, April 2009.
[5] EPA 2008. "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder," Assessment and Standards Division, Office of Transportation and Air Quality, Environmental Protection Agency, EPA 420-R-08-001, March 2008.

Emissions = Fuel consumption * Conversion Factor * Emission Factor

Table 2. Locomotive – EPA projected emissions factors (g/hp-hr) for line-haul engines.

Engine Type	Applicable Year	HC (g/hp-hr)	CO (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)
Unregulated (Uncontrolled)	**Pre-1973**	**0.48**	**1.28**	**13.0**	**0.32**
Tier 0 – original	1973 – 2001	0.48	1.28	8.60	0.32
Tier 0+ – final[1]	2010	0.30	1.28	7.20	0.20
Tier 1 – original	2002 – 2004	0.47	1.28	6.70	0.32
Tier 1+ – final[1]	2010	0.29	1.28	6.70	0.20
Tier 2 – original	2005	0.26	1.28	5.50	0.18
Tier 2+ – final[1]	2013	0.13	1.28	4.95	0.08
Tier 3	2012 – 2014	0.13	1.28	4.95	0.08
Tier 4	2015+	0.04	1.28	1.00	0.015

[1] These are estimated emissions at the time of rebuild with many exceptions for older Tier 0 engines.

Table 3. Locomotive – EPA projected emission factors for switching (duty cycle) engines.

Engine Type	Applicable Year	HC (g/hp-hr)	CO (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)
Uncontrolled (Uncontrolled)	**Pre-1973**	**1.01**	**1.83**	**17.4**	**0.44**
Tier 0 – original	1973 – 2001	1.01	1.83	14.0	0.44
Tier 0+ – final[1]	2010	0.57	1.83	10.62	0.23
Tier 1 – original	2002 – 2004	1.01	1.83	9.9	0.43
Tier 1 – final[1]	2010	0.57	1.83	9.9	0.23
Tier 2 – original	2005	0.51	1.83	7.3	0.19
Tier 2 – final[1]	2013	0.26	1.83	7.3	0.11
Tier 3	2011 - 2015	0.26	1.83	4.5	0.08
NREC Gen. Set	<2015	0.10	1.09	2.67	0.065
Tier 4	2015+	0.08	1.83	1.00	0.015

[1] These are estimated emissions at the time of rebuild with many exceptions for older Tier 0 engines.

The alternative method relies on the locomotive rated power, hours of operation and a load factor to estimate the work (hp-hr) performed where EPA[5] provided average activity and load factor estimates. The emission estimates include an estimation of the work performed by each locomotive as shown in this equation:

Work = H × LF × N × P × RUF

Where,

Work = Combined annual work output for all locomotives remaining in the fleet that were originally manufactured in model year i.

H = Number of hours per year that a newly manufactured locomotive is projected to be used.

LF = Typical average load factor (0.275 line-haul or 0.1 switch)[5] or (26.891% for line-haul or 8.2715% for switch)[6].

N_i = Number of locomotives remaining in the fleet that were originally manufactured in model year i.

P_i = Average rated power of locomotives remaining in the fleet that were originally manufactured in model year i.

RUF_i = Relative use factor for locomotives remaining in the fleet that were originally manufactured in model year i.

RUF_i = [H – Relative Use Adjustment x (Age – Threshold Age)] / H

RUF = 1 until threshold age is reached
Hours (new) = Adjusted to Fleet Fuel Consumption
Relative Use Adjustment = 81.6 hours/year for line-haul; 66.75 hours/year for switch
Threshold Age = 8 years for line-haul; 50 years for switch

EPA assumed that hours per year were estimated to depend upon the age of the locomotive using the relative use factor (RUF). EPA estimated that the line-haul locomotives were used 4350 hours per year when new, and, after the first 8 years of use (threshold age), decline by 81.6 hours per year to an end of life at 40 years. Likewise, EPA estimated that switch locomotives are used at a rate of 4450 hours per year for the first 50 years of use (threshold age) and then decline by 66.75 hours per year until the end of life, assumed to be 70 years.

Of course for any specific project, the actual number of hours that a locomotive operates may be known. Once the work performed has been estimated, emissions are estimated by multiplying by the emission factor for the older engine(s) and the new replacement engine(s).

Example Locomotive Projects

From the Texas TERP 2015 project list, one precontrolled 1500 hp switcher locomotive had its engine replaced with a Tier 3 compliant engine. A ten-year remaining life was estimated with a grant of $785,750 out of a total cost of $948,438. Current annual activity was estimated at 42500 gallons of fuel consumed or about 2800 hours per year using the EPA conversion factor.

Emission Reduction = 1500 x 0.1 x 2800 x (17.4 – 5.4) = 5.56 tons per year

Cost = $78,575 per year (0% interest rate)

Cost Effectiveness = $14, 132 per ton

In addition, stakeholders provided the cost for three switch locomotive projects; two retrofit and an engine replacement to new certified engines. The retrofit projects included engine

[6] EPA 2017. Diesel Emissions Quantifier Tool Release Notes. https://www.epa.gov/sites/production/files/2017-04/documents/diesel_emission_quantifer_deq_release_notes.pdf

upgrades to meet Tier 0+ or, for a select engine model, upgrade to meet Tier 3 emission standards. Tier 4 engines are available for direct replacement in locomotives.

The engine retrofit projects are cost effective because they are significantly less expensive than a full engine replacement despite not meeting the lowest emission standard. The cost effectiveness for retrofit or replacement projects depend on what standard the original engine met prior to retrofit. Older engines are not required to be upgraded to the original Tier 0 or final Tier 0+ emission standards and so can demonstrate benefits with an upgrade. Likewise, older engines that can meet Tier 0+ standards could benefit from an upgrade to Tier 3, which is available for some engine models, or a full engine replacement to Tier 4.

Table 4 provides the cost effectiveness estimates for the projects supplied by the stakeholders. The primary inputs are the cost of the engine upgrade or replacement, the engine power and activity, and initial and final emission standards that the engine meets. As described in this memorandum, EPA estimates that engines can remain in service up to 70 years, so the estimate of remaining service life in the table could be considerably longer making these projects proportionally more cost effective.

Table 4. Locomotive projects summaries

Project Description			Engine Input Data				Emission Factor (EF)		Results			Cost Effectiveness	
Original Engine Tier Level	New Engine Tier Level	Parts and Labor Cost	Average Power (hp)	Load Factor	Activity (hr/yr)	Remaining Service Life (years)	Original EF (g/hp-hr)	New EF (g/hp-hr)	Original Engine NOx (tons/year)	New Engine NOx (tons/year)	NOx Reduction (tons/year)	Full Cost ($/ton)	40% of Full Cost ($/ton)
Unreg.	Tier 0+ [a]	$210,000	3,150	0.10	3,250	20	17.4	10.6	19.64	11.96	7.67	$1,368	$547
Unreg.	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	17.4	4.5	19.64	5.08	14.56	$945	$378
Tier 0	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	12.6	4.5	14.22	5.08	9.14	$1,504	$602
Tier 0+	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	10.6	4.5	11.96	5.08	6.88	$1,997	$799
Unreg.	Tier 4	$2,600,000	2,000	0.10	3,250	20	17.4	1	12.47	0.72	11.75	$11,063	$4,425
Tier 0	Tier 4	$2,600,000	2,000	0.10	3,250	20	12.6	1	9.03	0.72	8.31	$15,641	$6,256
Tier 0+	Tier 4	$2,600,000	2,000	0.10	3,250	20	10.6	1	7.59	0.72	6.88	$18,900	$7,560

a – Tier 2 Engine retrofit upgrades (all others are full engine replacements)

The cost of a new engine retrofitted into a rebuilt locomotive is relatively high, however the emission reduction rate was expected to be sufficient to have comparable or lower cost effectiveness than other nonroad emission reduction projects.

Commercial Marine Vessel Emissions

For commercial marine vessel emissions estimates, we relied on the EPA[7] best practice for emission inventory development and EPA[8] regulatory impact analysis for input and emissions

[7] EPA 2009. "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories Final Report, April 2009.

[8] EPA 2008. "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder," EPA420-R-08- 001, March; reviewed via personal communication with Penny Carey, EPA 2011.

factors. The emission factors provided by EPA[8] are expressed in units of gram per kW-hr, so it is necessary to estimate the kW-hrs work performed.

Work = Rated Power * Load Factor * Hours of Operation

The load factor is least understood input factor because estimates have relied on personal experience rather than in-use activity estimates. EPA[7] has provided estimates which did not distinguish between vessel types. ARB[9] provided alternative load factors unique by vessel type. Both are shown in Table 5.

Table 5. Harbor Craft Load Factor Estimates

Vessel / Aux Engine	Vessel Type	Load Factor
EPA Estimates		
Category 2 (Propulsion)	Various	0.85
Category 1 (Propulsion) <805 Hp	Various	0.45
Category 1 (Propulsion) >805 Hp	Various	0.79
Category 1 (Auxiliary) <805 Hp	Various	0.56
Category 1 (Auxiliary) >805 Hp	Various	0.65
California Air Resources Board		
Propulsion	Commercial Fishing	0.27
Propulsion	Charter Fishing	0.52
Propulsion	Ferries	0.42
Propulsion	Crew and Supply	0.38
Propulsion	Pilot Vessels	0.51
Propulsion	Tug Boats	0.50
Propulsion	Tow Boats / Push Boats	0.68
Propulsion	Work Boats	0.45
Propulsion	Others	0.52
Propulsion	Barges	0.45
Propulsion	Dredges	0.45
Auxiliary Engine	Commercial Fishing Generator	0.43
Auxiliary Engine	Charter Fishing Generator	0.43
Auxiliary Engine	Ferries Generator	0.43
Auxiliary Engine	Crew and Supply Generator	0.32
Auxiliary Engine	Pilot Vessels Generator	0.43
Auxiliary Engine	Tug Boats Generator	0.31
Auxiliary Engine	Tow Boats / Push Boats Generator	0.43
Auxiliary Engine	Work Boats Generator	0.43
Auxiliary Engine	Others Generator	0.43
Auxiliary Engine	Compressor	0.54
Auxiliary Engine	Crane	0.42
Auxiliary Engine	Deck Door Engine	0.89
Auxiliary Engine	Dredger	0.51
Auxiliary Engine	Barge/Dredge Generator	0.75
Auxiliary Engine	Hoist Swing Winch	0.31
Auxiliary Engine	Other	0.80
Auxiliary Engine	Pump	0.71

[9] ARB 2017. Mobile Source Emissions Inventory – Categories, Commercial Harbor Craft, https://www.arb.ca.gov/msei/categories.htm

The hours of operation can be difficult to estimate especially for auxiliary engines. Often vessels have twin propulsion and twin auxiliary engines, so each engine does not necessarily work the same number of hours as its twin. Auxiliary engines may also be used more than propulsion engines such as when the vessel is tied up as well as when the vessel is transiting or away from dock.

EPA[8] provided the emission factors that reflect the regulation standards and are parsed by the cylinder displacement, model year, and power density (kW/liter displacement). The emission factors for smaller commercial marine engines are found in the Appendix. The emission factors multiplied by the engine work result in the emission estimate for any vessel.

Example Marine Projects

For the example project, the EDF[10] report on the Clean Vessels for Texas Waters present example projects with activity and other input factors. We chose one replacing propulsion engines with newer updated technology Tier 3 engines from the same manufacturer. The project life could be longer than 10 years given that the engines were less than 15 years old; for example, the historic TERP projects for marine engine replacement range from 5 to 14 years remaining life on the old engine. The approximate cost based on similar TERP projects would be $100,000 per engine for new Tier 3 engines.

Replaced Engines – 2 x 2003 Cummins KTA-19M

(bore 159 mm , stroke 159 mm, 3.2 l/cylinder)

(6 cylinders at 53 – 87 kW/cylinder or total power of 316 – 522 kW)

Activity – 3,500 hours per year; 92,400 gallons

Fuel Consumption, 92,400 gallons = 316 kW x 2 x Load Factor x 3500 hours x 213.089 g/kW-hr / 3200 grams/ gallon

Load Factor = 0.627

Emissions = 316 x 2 x 3500 x 0.627 x (9.1 - 4.69 g/kW-hr) = 6.7 tons per year

Cost Effectiveness = $200,000 / 10 years / 6.7 tons per year = $2,966/ton

The fuel consumption affords an independent and more realistic understanding of the load factor. While the final emission standard for smaller engines (those less than 600 kW) is not as low as for larger engines (at 1.3 g/kW-hr), the emission reduction is still cost effective.

In addition, stakeholders provided input data for engine replacement projects on commercial marine vessels. The input data included sample projects for push (also called tow) boats and harbor tugs. The push boats function is to push barges on river and inland waters over long

[10] EDF 2012. “The Houston Barge System, A Brief Review of Operations and Opportunities,” Environmental Defense Fund.

distance, and harbor tugs assist in moving ships or barges near docks. For this reason, the push boats typically have higher load factors and more operational time.

The stakeholders described the replacement projects in terms emission standard that the replacement engine would meet, which we have translated into expected model year. Pre-controlled (unregulated) engines are any year 1999 or earlier, so we have assumed that the model year of the replacement engine was 1998. Likewise, we have assumed that engines have a life of 40 years for the original engines without an initiative to replace these engines, so the project life was calculated as the difference between 40 and the age of the engine in 2018.

Table 6 provides the summary estimates per engine. Most tugs have two propulsion engines so total emissions reductions are double those reported in the table. The push boat projects were more cost effective because the load factor and activity (hours/year) were higher than those for harbor tugs.

Table 6. Harbor Craft Load Factor Estimates

Project Description							Engine Input Data				Emission Factor		Results per Engine			Cost Effectiveness	
Vessel Type	Original Engine Tier and Model Year		Retrofit or Replacement New Engine Tier and Model Year		Engine Cylinder Displacement	Parts and Labor Cost	Engine Rated Power (kW)	Load Factor	Activity (hr/yr)	Remaining Service Life (years)	Original (g/kW-hr)	New (g/kW-hr)	Original Engine NOx (tons/year)	New Engine NOx (tons/year)	NOx Reduction (tons/year)	Full Cost ($/ton)	40% Cost ($/ton)
Push Boats	Unreg.	1998	Tier 3	2013	11.6	$1,100,000	3,729	0.60	6000	20	13.36	8.33	197.7	123.3	74.43	$739	$296
Push Boats	Unreg.	1998	Tier 2a	2012	10.4	$545,000	1,417	0.60	6000	20	13.36	8.33	75.1	46.8	28.28	$963	$385
Push Boats	Unreg.	1998	Tier 2a	2010	4.9	$468,000	1,570	0.60	6000	20	11	6	68.5	37.4	31.15	$751	$300
Push Boats	Tier 2	2010	Tier 4	2018	11.6	$1,400,000	2,983	0.60	6000	32	8.33	1.3	98.6	15.4	83.22	$526	$210
Push Boats	Unreg.	1998	Tier 3	2017	2.7	$650,000	746	0.60	6000	20	10	4.69	29.6	13.9	15.72	$2,067	$827
Tug Boats	Unreg.	1998	Tier 3	2013	11.6	$1,100,000	3,729	0.30	2500	20	13.36	8.33	41.2	25.7	15.51	$3,547	$1,419
Tug Boats	Unreg.	1998	Tier 2a	2010	10.4	$620,000	2,289	0.30	2500	20	13.36	8.33	25.3	15.8	9.52	$3,257	$1,303
Tug Boats	Tier 2	2010	Tier 4	2018	11.6	$1,400,000	2,983	0.30	2500	32	8.33	1.3	20.5	3.2	17.34	$2,524	$1,009
Tug Boats	Unreg.	1998	Tier 3	2015	4.9	$1,700,000	2,350	0.30	2500	20	11	4.81	21.4	9.3	12.03	$7,068	$2,827
Tug Boats	Tier 1	2005	Tier 2a	2010	4.9	$468,000	1,870	0.30	2000	27	9.2	6	11.4	7.4	3.96	$4,380	$1,752

a – Tier 2 Engine retrofit upgrades (all others are full engine replacements)

Attachment A

EPA Commercial Marine Engine Emission Factors

A. Commercial Marine Propulsion Engines

Tier	Year <=Last Applied	Displacement (l/cylinder) Low	Displacement (l/cylinder) <High	Power (kW) Low	Power (kW) <High	Power Density kW/l	Emission Factors (g/kW-hr) HC	CO	NOx	PM10	Fuel
0	1999	0	0.9	0	8		2.01	6.71	13.41	1.21	248.3961
0	1999	0	0.9	8	19		2.28	6.71	11.4	1.08	248.3961
0	1999	0	0.9	19	37		2.41	6.71	9.25	0.94	248.3961
0	1999	0	0.9	37	100000		0.41	1.6	10	0.43	213.0849
0	1999	0.9	1.2	0	100000		0.32	1.6	10	0.36	213.0849
0	1999	1.2	2.5	0	100000		0.27	1.6	10	0.23	213.0849
0	1999	2.5	3.5	0	100000		0.27	1.6	10	0.19	213.0849
0	1999	3.5	5	0	100000		0.27	1.8	11	0.19	216.4091
0	1999	5	15	0	100000		0.134	2.48	13.36	0.21	213.0849
0	1999	15	20	0	100000		0.134	2.48	13.36	0.21	213.0849
0	1999	20	25	0	100000		0.134	2.48	13.36	0.21	213.0849
0	1999	25	30	0	100000		0.134	2.48	13.36	0.21	213.0849
1	2004	0	0.9	0	8		1.02	5.51	7.013	0.47	248.3961
1	2004	0	0.9	8	19		0.59	2.9	5.95	0.23	248.3961
1	2003	0	0.9	19	37		0.375	2.05	6.34	0.33	248.3961
1	2004	0	0.9	37	100000		0.41	1.6	9.8	0.43	213.0849
1	2003	0.9	1.2	0	100000		0.32	1.6	9.8	0.36	213.0849
1	2003	1.2	2.5	0	100000		0.27	1.6	9.8	0.23	213.0849

Tier	Year <=Last Applied	Displacement (l/cylinder)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
1	2006	2.5	3.5	0	100000		0.27	1.6	9.1	0.19	213.0849
1	2006	3.5	5	0	100000		0.27	1.8	9.2	0.19	213.0849
1	2006	5	15	0	100000		0.134	2.48	10.55	0.21	213.0849
1	2006	15	20	0	100000		0.134	2.48	10.55	0.21	213.0849
1	2006	20	25	0	100000		0.134	2.48	10.55	0.21	213.0849
1	2006	25	30	0	100000		0.134	2.48	10.55	0.21	213.0849
2	2008	0	0.9	0	8		0.91	5.51	5.89	0.50	248.3961
2	2008	0	0.9	8	19		0.28	2.9	4.87	0.24	248.3961
2	2008	0	0.9	19	37		0.724	2.05	4.98	0.29	248.3961
2	2008	0	0.9	37	75		0.41	1.6	5.7	0.22	213.0849
2	2011	0	0.9	75	100000		0.41	1.6	5.7	0.22	213.0849
2	2012	0.9	1.2	0	100000		0.32	0.9	6.1	0.11	213.0849
2	2013	1.2	2.5	0	100000		0.19	1.1	6	0.12	213.0849
2	2012	2.5	3.5	0	100000		0.19	1.1	6	0.12	213.0849
2	2011	3.5	5	0	100000		0.19	1.1	6	0.12	213.0849
2	2011	5	7	0	100000		0.134	2	8.33	0.31	213.0849
2	2012	7	15	0	3700		0.134	2	8.33	0.31	213.0849
2	2013	7	15	3700	100000		0.134	2	8.33	0.31	213.0849
2	2013	15	20	0	100000		0.134	2	8.33	0.31	213.0849
2	2013	20	25	0	100000		0.134	2	8.33	0.31	213.0849
2	2013	25	30	0	100000		0.134	2	8.33	0.31	213.0849
3	2050	0	0.9	0	8		0.58	5.51	5.89	0.32	213.0849
3	2013	0	0.9	8	19		0.282	2.9	4.87	0.26	213.0849
3.1	2050	0	0.9	8	19		0.282	2.9	3.11	0.26	213.0849
3	2013	0	0.9	19	37		0.55	2.05	4.975	0.24	213.0849
3.1	2050	0	0.9	19	37		0.55	2.05	3.11	0.24	213.0849

Tier	Year <=Last Applied	Displacement (l/cylinder)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
3	2013	0	0.9	37	75		0.3	1.6	5.7	0.17	213.0849
3.1	2050	0	0.9	37	75		0.3	1.6	3.56	0.17	213.0849
3	2050	0	0.9	75	100000	35	0.14	1.6	4.08	0.08	213.0849
3	2050	0.9	1.2	0	100000	35	0.13	0.9	4.54	0.05	213.0849
3	2017	1.2	2.5	0	600	35	0.1	1.1	4.69	0.07	213.0849
3.1	2050	1.2	2.5	0	600	35	0.1	1.1	4.69	0.06	213.0849
3	2050	0	0.9	75	100000	1000	0.15	1.6	4.38	0.08	213.0849
3	2016	0.9	1.2	0	100000	1000	0.14	0.9	4.89	0.05	213.0849
3	2050	1.2	2.5	0	600	1000	0.11	1.1	4.81	0.08	213.0849
3	2017	1.2	2.5	601	1000		0.1	1.1	4.69	0.07	213.0849
4	2050	1.2	2.5	601	1000		0.04	1.1	1.3	0.03	213.0849
3	2016	1.2	2.5	1001	100000		0.1	1.1	4.69	0.07	213.0849
4	2050	1.2	2.5	1001	100000		0.04	1.1	1.3	0.03	213.0849
3	2017	2.5	3.5	0	600		0.1	1.1	4.69	0.07	213.0849
3.1	2050	2.5	3.5	0	600		0.1	1.1	4.69	0.06	213.0849
3	2017	2.5	3.5	600	1000		0.1	1.1	4.69	0.07	213.0849
4	2050	2.5	3.5	600	1000		0.04	1.1	1.3	0.03	213.0849
3	2016	2.5	3.5	1000	100000		0.1	1.1	4.69	0.07	213.0849
4	2050	2.5	3.5	1000	100000		0.04	1.1	1.3	0.03	213.0849
3	2017	3.5	5	0	600		0.1	1.1	4.81	0.07	213.0849
3.1	2050	3.5	5	0	600		0.1	1.1	4.81	0.06	213.0849
3	2017	3.5	5	600	1000		0.1	1.1	4.81	0.07	213.0849
4	2050	3.5	5	600	1000		0.04	1.1	1.3	0.03	213.0849
3	2016	3.5	5	1000	1400		0.1	1.1	4.81	0.07	213.0849
4	2050	3.5	5	1000	1400		0.04	1.1	1.3	0.03	213.0849
3	2015	3.5	5	1400	100000		0.1	1.1	4.81	0.07	213.0849

Tier	Year <=Last Applied	Displacement (l/cylinder)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
4	2050	3.5	5	1400	100000		0.04	1.1	1.3	0.03	213.0849
3	2050	5	15	0	600		0.07	1.1	5.97	0.11	213.0849
3	2017	5	15	600	1000		0.07	2	5.97	0.11	213.0849
4	2050	5	15	600	1000		0.02	2	1.3	0.03	213.0849
3	2016	5	15	1000	1400		0.07	2	5.97	0.11	213.0849
4	2050	5	15	1000	1400		0.02	2	1.3	0.03	213.0849
3	2015	5	15	1400	2000		0.07	2	5.97	0.11	213.0849
4	2050	5	15	1400	2000		0.02	2	1.3	0.03	213.0849
3	2013	5	15	2000	3700		0.134	2	8.33	0.11	213.0849
3.1	2015	5	15	2000	3700		0.02	2	1.3	0.11	213.0849
4	2050	5	15	2000	3700		0.02	2	1.3	0.03	213.0849
3	2016	5	15	3700	100000		0.06	2	1.3	0.10	213.0849
4	2050	5	15	3700	100000		0.03	2	1.3	0.04	213.0849
3	2015	15	20	0	2000		0.09	2	6.77	0.30	213.0849
4	2050	15	20	0	2000		0.01	2	1.3	0.04	213.0849
3	2015	15	20	2000	3700		0.01	2	1.3	0.30	213.0849
4	2050	15	20	2000	3700		0.01	2	1.3	0.04	213.0849
3	2016	15	20	3700	100000		0.07	2	1.3	0.23	213.0849
4	2050	15	20	3700	100000		0.01	2	1.3	0.05	213.0849
3	2016	20	30	0	100000		0.07	2	1.3	0.23	213.0849
3	2050	20	30	0	100000		0.01	2	1.3	0.05	213.0849

B. Commercial Marine Auxiliary Engines

Tier	Year <= Last Applied	Displacement (l/cyl)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
0	1999	0	0.9	0	8		2.01	6.71	13.41	1.21	248.3961
0	1999	0	0.9	8	19		2.28	6.71	11.4	1.08	248.3961
0	1999	0	0.9	19	37		2.41	6.71	9.25	0.94	248.3961
0	1999	0	0.9	37	100000		0.41	2	11	0.73	213.0849
0	1999	0.9	1.2	0	100000		0.32	1.7	10	0.42	213.0849
0	1999	1.2	2.5	0	100000		0.27	1.5	10	0.23	213.0849
0	1999	2.5	3.5	0	100000		0.27	1.5	10	0.21	213.0849
0	1999	3.5	5	0	100000		0.27	1.8	11	0.19	213.0849
1	2004	0	0.9	0	8		1.02	5.51	7.013	0.47	248.3961
1	2004	0	0.9	8	19		0.59	2.9	5.95	0.23	248.3961
1	2003	0	0.9	19	37		0.375	2.05	6.34	0.33	248.3961
1	2004	0	0.9	37	100000		0.41	2	9.8	0.73	213.0849
1	2003	0.9	1.2	0	100000		0.32	1.7	9.8	0.42	213.0849
1	2003	1.2	2.5	0	100000		0.27	1.5	9.8	0.23	213.0849
1	2006	2.5	3.5	0	100000		0.27	1.5	9.1	0.21	213.0849
1	2006	3.5	5	0	100000		0.27	1.8	9.2	0.19	213.0849
2	2008	0	0.9	0	8		0.91	5.51	5.89	0.50	248.3961
2	2008	0	0.9	8	19		0.28	2.9	4.87	0.24	248.3961
2	2008	0	0.9	19	37		0.724	2.05	4.98	0.29	248.3961
2	2008	0	0.9	37	75		0.41	1.6	5.7	0.22	213.0849
2	2011	0	0.9	75	100000		0.41	1.6	5.7	0.22	213.0849
2	2012	0.9	1.2	0	100000		0.32	0.8	5.4	0.20	213.0849
2	2013	1.2	2.5	0	100000		0.21	0.9	6.1	0.14	213.0849
2	2012	2.5	3.5	0	100000		0.21	0.9	6.1	0.14	213.0849

Tier	Year <= Last Applied	Displacement (l/cyl)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
2	2011	3.5	5	0	100000		0.21	0.9	6.1	0.14	213.0849
3	2013	0	0.9	0	75		0.3	1.6	5.7	0.17	213.0849
3.1	2050	0	0.9	0	75		0.3	1.6	3.56	0.17	213.0849
3	2050	0	0.9	75	100000	35	0.14	1.6	4.08	0.08	213.0849
3	2050	0	0.9	75	100000	1000	0.15	1.6	4.38	0.08	216.4091
3	2050	0.9	1.2	0	600		0.13	0.8	4.02	0.08	213.0849
3	2016	0.9	1.2	600	100000		0.13	0.8	4.02	0.08	213.0849
4	2050	0.9	1.2	600	100000		0.04	0.8	1.3	0.03	213.0849
3	2017	1.2	2.5	0	600		0.11	0.9	4.77	0.08	213.0849
3.1	2050	1.2	2.5	0	600		0.11	0.9	4.77	0.07	213.0849
3	2017	1.2	2.5	600	1000		0.11	0.9	4.77	0.08	213.0849
4	2050	1.2	2.5	600	1000		0.04	0.9	1.3	0.03	213.0849
3	2016	1.2	2.5	1000	1400		0.11	0.9	4.77	0.08	213.0849
4	2050	1.2	2.5	1000	1400		0.04	0.9	1.3	0.03	213.0849
3	2015	1.2	2.5	1400	100000		0.11	0.9	4.77	0.08	213.0849
4	2050	1.2	2.5	1400	100000		0.04	0.9	1.3	0.03	213.0849
3	2017	2.5	3.5	0	600		0.11	0.9	4.77	0.08	213.0849
3.1	2050	2.5	3.5	0	600		0.11	0.9	4.77	0.07	213.0849
3	2017	2.5	3.5	600	1000		0.11	0.9	4.77	0.08	213.0849
4	2050	2.5	3.5	600	1000		0.04	0.9	1.3	0.03	213.0849
3	2016	2.5	3.5	1000	100000		0.11	0.9	4.77	0.08	213.0849
4	2050	2.5	3.5	1000	100000		0.04	0.9	1.3	0.03	213.0849
3	2017	3.5	5	0	600		0.11	0.9	4.89	0.08	213.0849
3.1	2050	3.5	5	0	600		0.11	0.9	4.89	0.07	213.0849
3	2017	3.5	5	600	1000		0.11	0.9	4.89	0.08	213.0849
4	2050	3.5	5	600	1000		0.04	0.9	1.3	0.03	213.0849

Tier	Year <= Last Applied	Displacement (l/cyl)		Power (kW)		Power Density	Emission Factors (g/kW-hr)				
		Low	<High	Low	<High	kW/l	HC	CO	NOx	PM10	Fuel
3	2016	3.5	5	1000	1400		0.11	0.9	4.89	0.08	213.0849
4	2050	3.5	5	1000	1400		0.04	0.9	1.3	0.03	213.0849
3	2015	3.5	5	1400	100000		0.11	0.9	4.89	0.08	213.0849
4	2050	3.5	5	1400	100000		0.04	0.9	1.3	0.03	213.0849