Ports Emissions Inventory Guidance:

Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions

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

United States Environmental Protection Agency

EPA-420-B-22-011
April 2022

NOTE:

This guidance is based on and supersedes the previous version from September 2020 with the same name. The U.S. Environmental Protection Agency (EPA) made following changes in this version:

- In Table 3.5, EPA updated the NOx emission factors for auxiliary engines of C3 vessels operating with fuel type marine gas oil/marine diesel oil. (The medium-speed and high-speed diesel engine type numbers had been inadvertently reversed in the September 2020 version).
- In Section 3.5.1, EPA included new guidance about accounting for ocean-going vessels with Tier III propulsion engines operating at low loads, which is found after Table 3.5.
- In Table 3.11, EPA defined ocean-going vessel transit mode as speeds greater than 1 knot (instead of 3 knots), based on EPA's experience since the previous guidance was issued.
- Throughout the document, EPA made minor updates to reflect EPA's latest MOVES model, MOVES3, and its documentation; most of these are in Section 7, Onroad Vehicles.

The September 2020 version of this guidance replaced the April 2009 document *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*. The September 2020 version was developed based on a public draft document titled *Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions Inventories*, released in February 2020. EPA appreciated the technical comments received during the informal public review, and like the September 2020 version of the guidance, this April 2022 version reflects that input as appropriate.

This guidance describes the latest, state-of-the-science methodologies that can be used to prepare a port-related and/or goods movement emissions inventory for the following mobile source sectors: ocean-going vessels, harbor craft, recreational marine, cargo handling equipment, onroad vehicles, and rail.

This guidance includes tabular data of emission factors, default activity assumptions, and other data. These tables are also available for download in comma-separated values (.csv) format from https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS ..... **VIII**

1 INTRODUCTION **1**
1.1 Purpose 1
1.2 Background 2
1.3 Importance of Port-related Emission Inventories 3
1.4 Organization of This Guidance 4
1.5 Guidance and Existing Requirements 4
1.6 Additional Information 4

2 PLANNING A PORT-RELATED EMISSIONS INVENTORY **5**
2.1 Overview 5
2.2 Purposes of the Inventory 5
2.3 General Inventory Approaches 6
2.4 Mobile Source Sectors 8
2.4.1 Ocean-Going Vessels 8
2.4.2 Harbor Craft 8
2.4.3 Recreational Marine Vessels 8
2.4.4 Cargo Handling Equipment 8
2.4.5 Onroad Vehicles 9
2.4.6 Rail 9
2.5 Pollutants of Concern 9
2.6 Geographical Domain 10
2.6.1 Marine Boundary 11
2.6.2 Land-side Boundary 11
2.6.3 Determining Geographical Scope 11
2.7 Time Domains and Future Inventories 13

3 OCEAN-GOING VESSELS **15**
3.1 Source Description 15
3.2 Emissions Estimation Overview 16
3.3 Vessel Characteristics 17
3.3.1 Vessel Identification 17
3.3.2 Engine Characteristics 18
3.3.2.1 Engine Category 18
3.3.2.2 Engine Type 19
3.3.3 Ship Type and Subtype 19
3.3.4 Engine Operating Power 21
3.3.5 Filling Gaps in Vessel Characteristic Data Sets 22
3.4 Vessel Activity Data Sources 23
3.4.1 Automatic Identification System 23

3.4.2 Local Logs 24
3.4.3 Survey Data 25
3.4.4 Entrances and Clearances 25
3.4.5 Waterborne Commerce 25
3.5 Emission Factors 26
3.5.1 Nitrogen Oxides (NOx) 26
3.5.2 Brake Specific Fuel Consumption (BSFC) 28
3.5.3 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC) 28
3.5.4 Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Methane (CH_4) 29
3.5.5 Nitrous Oxide (N_2O) 30
3.5.6 Carbon Dioxide (CO_2) 31
3.5.7 Sulfur Dioxide (SO_2) 31
3.6 Auxiliary Engine and Boiler Loads by Operating Mode 31
3.6.1 Transit 32
3.6.2 Maneuvering 32
3.6.3 Restricted Speed Zone 32
3.6.4 Hotelling 32
3.6.5 Anchorage 33
3.7 Low Load Adjustment Factors 33
3.8 AIS Inventory Calculations 34
3.8.1 Link Each AIS Record to Vessel Characteristic Data 34
3.8.2 Clean AIS Data 35
3.8.3 Fill Temporal Gaps in AIS Activity 35
3.8.4 Calculate Propulsion Engine Operating Power and Load Factor 36
3.8.5 Assign Operating Mode 37
3.8.6 Calculate Propulsion Engine Emissions 38
3.8.7 Calculate Auxiliary Engine and Boiler Emissions 39
3.8.8 Aggregate Emissions 39
3.8.9 Perform Quality Control Checks 40
3.9 Alternative Inventory Calculations 41
3.9.1 Link Each Vessel Call Record to Vessel Characteristic Data 41
3.9.2 Calculate Activity by Operating Mode 42
3.9.2.1 Transit 42
3.9.2.2 Restricted Speed Zone 43
3.9.2.3 Maneuvering 43
3.9.2.4 Hotelling 44
3.9.2.5 Anchorage 44
3.9.3 Calculate Propulsion Engine Operating Power and Emissions 44
3.9.3.1 Propulsion Engine Operating Power 44
3.9.3.2 Calculating Load Factor and Determining Low Load Adjustment Factor 45
3.9.3.3 Calculating Propulsion Engine Emissions 45
3.9.4 Calculate Auxiliary and Boiler Emissions 46
3.9.5 Aggregate Emissions 46
3.9.6 Perform Quality Control Checks 47

3.10 Projecting Future Emission Inventories 47

4 HARBOR CRAFT 50
4.1 Source Description 50
4.2 Emissions Estimation Overview 51
4.3 Vessel Characteristics 52
4.3.1 Vessel Identification 52
4.3.2 Engine Characteristics 53
4.3.3 Ship Type 54
4.3.4 Filling Gaps in Vessel Characteristic Data Sets 54
4.4 Vessel Activity Data Sources 54
4.4.1 Survey Data 54
4.4.2 Automatic Identification System 55
4.4.3 Other Vessel Activity Data Sources 56
4.5 Emission Factors 56
4.5.1 Nitrogen Oxides (NOx) 57
4.5.2 Brake Specific Fuel Consumption (BSFC) 57
4.5.3 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC) 57
4.5.4 Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Methane (CH_4) 58
4.5.5 Nitrous Oxide (N_2O) 58
4.5.6 Carbon Dioxide (CO_2) 58
4.5.7 Sulfur Dioxide (SO_2) 58
4.6 Load Factors 59
4.7 AIS Inventory Calculations 60
4.7.1 Link Each AIS Record to Vessel Characteristic Data 60
4.7.2 Clean AIS Data 60
4.7.3 Fill Temporal Gaps in AIS Activity 61
4.7.4 Assign Operating Mode and Calculate Emissions 62
4.7.5 Aggregate and/or Allocate Emissions 62
4.7.6 Perform Quality Control Checks 63
4.8 Alternative Inventory Calculations 64
4.8.1 Link Each Vessel to Vessel Characteristic Data 64
4.8.2 Assign Load Factors, Emission Factors, and Operating Hours 64
4.8.3 Calculate Vessel Emissions 65
4.8.4 Aggregate and/or Allocate Emissions 65
4.8.5 Perform Quality Control Checks 65
4.9 Projecting Future Emission Inventories 66

5 RECREATIONAL MARINE 68
5.1 Source Description 68
5.2 Emissions Estimation Overview 68
5.3 Vessel Characteristics 70
5.3.1 Vessel Type and Fuel Type 70
5.3.2 Engine Model Year 71

5.3.3 Rated Engine Power 71
5.4 Vessel Activity 72
5.5 Emission Factors 74
5.5.1 Running MOVES-Nonroad 74
5.5.2 Nitrous Oxide (N_2O) 75
5.5.3 Black Carbon (BC) 75
5.6 AIS Inventory Calculations 76
5.6.1 Assign Each Vessel the Appropriate Vessel Characteristics and Emission Factors 76
5.6.2 Clean AIS Data 76
5.6.3 Fill Temporal Gaps in AIS Activity 77
5.6.4 Calculate Vessel Activity and Emissions 77
5.6.5 Aggregate and/or Allocate Emissions 78
5.6.6 Perform Quality Control Checks 78
5.7 Alternative Inventory Calculations 79
5.7.1 Missing Model Year Data 79
5.7.2 Missing Hours of Use and/or Engine Power Data 80
5.7.3 Missing Vessel Count Data 80
5.8 Projecting Future Emission Inventories 80
5.8.1 Determine Projected Activity 81
5.8.2 Determine Projected Emission Factors 81
5.8.3 Calculate the Future Inventory 82

6 CARGO HANDLING EQUIPMENT 83
6.1 Source Description 83
6.2 Emissions Estimation Overview 84
6.3 Equipment Characteristics 85
6.3.1 Equipment Type and Fuel Type 85
6.3.2 Engine Model Year 88
6.3.3 Rated Engine Power 88
6.3.4 Equipment Retrofit and Replacement Projects 89
6.4 Equipment Activity 89
6.5 Emission Factors 90
6.5.1 Running MOVES-Nonroad 91
6.5.2 Nitrous Oxide (N_2O) 92
6.5.3 Black Carbon (BC) 92
6.6 Detailed Inventory Calculations 93
6.6.1 Calculating an Emissions Inventory Per Unit 93
6.6.2 Aggregating Per Unit Emissions 93
6.6.3 Perform Quality Control Checks 94
6.7 Alternative Inventory Calculations 94
6.7.1 Missing Model Year Data 95
6.7.2 Missing Equipment Hours of Use and/or Engine Power Data 95
6.8 Projecting Future Emission Inventories 95

7 ONROAD VEHICLES 97
7.1 Source Description 97
7.2 Overview of Approaches and Considerations for Developing an Onroad Vehicle Emissions Inventory 97
7.2.1 Inventory Purpose and Other Considerations 98
7.2.2 Geographical Scope 99
7.3 Overview of MOVES 100
7.3.1 Scale and Calculation Type 100
7.3.2 Pollutants and Processes 101
7.4 Port-Related Onroad Vehicle Inventory Data Needs 101
7.4.1 Fleet Characteristics 102
7.4.1.1 Vehicle Types 102
7.4.1.2 Vehicle Counts 104
7.4.1.3 Age Distribution 104
7.4.1.4 Vehicle Retrofits and Replacements 105
7.4.2 Vehicle Activity 105
7.4.2.1 Running Activity 106
7.4.2.2 Vehicles Parked and Starts 107
7.5 County Scale Approach for Developing an Onroad Vehicle Inventory 107
7.5.1 Setting up a County Scale RunSpec for a Port 108
7.5.2 Using the County Data Manager to Enter Port-Specific Data 109
7.5.2.1 Meteorology Data 109
7.5.2.2 Source Type Population 109
7.5.2.3 Age Distribution 109
7.5.2.4 Vehicle Type VMT 110
7.5.2.5 Hotelling 110
7.5.2.6 Fuel 110
7.5.2.7 I/M Programs 111
7.5.2.8 Retrofit Data 111
7.5.2.9 Road Type Distribution 111
7.5.2.10 Average Speed Distribution 111
7.5.2.11 Starts 111
7.5.2.12 Idle 112
7.5.2.13 Running MOVES 112
7.6 Project Scale Approach for Developing an Onroad Vehicle Emissions Inventory 112
7.6.1 Major Considerations for the Project Scale Approach 113
7.6.1.1 Number of Links 113
7.6.1.2 Number of Runs 113
7.6.1.3 Pollutants and Processes to Include 114
7.6.2 Project Scale Generic Link Approach 114
7.6.3 Creating a Run Specification for the Generic Link Approach 115
7.6.4 Using the Project Data Manager for the Generic Link Approach 116
7.6.4.1 Meteorology Data 116
7.6.4.2 Age Distribution 116

7.6.4.3 Fuel 117
7.6.4.4 I/M Programs 117
7.6.4.5 Retrofit Data 118
7.6.4.6 Links 118
7.6.4.7 Link Source Types 119
7.6.4.8 Off-Network 119
7.6.4.9 Operating Mode Distribution 119
7.6.4.10 Link Drive Schedules 120
7.6.5 Post-Processing Project Scale Output for Inventory Development 120
7.7 Projecting Future Emission Inventories 121

8 RAIL 123
8.1 Source Description 123
8.2 Emissions Estimation Overview 124
8.3 Locomotive Characteristics 124
8.4 Locomotive Activity 125
8.4.1 Activity Based on Fuel Consumption 125
8.4.2 Activity Based on Gross Ton-miles 126
8.4.3 Activity Based on Number of Trains 126
8.5 Emission Factors 127
8.5.1 Diesel 127
8.5.1.1 Nitrogen Oxides (NOx), Particulate Matter (PM), Black Carbon (BC), Volatile Organic Compounds (VOC), and Carbon Monoxide (CO) 127
8.5.1.2 Brake Specific Fuel Consumption (BSFC) 128
8.5.1.3 Carbon Dioxide (CO_2) 129
8.5.1.4 Methane (CH_4) 129
8.5.1.5 Nitrous Oxide (N_2O) 129
8.5.1.6 Sulfur Dioxide (SO_2) 129
8.5.2 LNG and LNG/Diesel Dual Fuel 130
8.6 Inventory Calculations 130
8.7 Alternative Methodologies 131
8.7.1 Activity Calculations 131
8.7.1.1 Switcher Locomotive Hours 131
8.7.1.2 Activity Based on Gross Ton-miles 132
8.7.1.3 Activity Based on Number of Trains 132
8.7.2 Fleet Average Emission Factors 133
8.8 Projecting Future Emission Inventories 135

9 REFERENCES 137

APPENDIX A ESTIMATING PORT-RELATED ENERGY CONSUMPTION 143
A.1 Ocean-Going Vessels 143
A.1.1 AIS Inventory Methodology 143
A.1.2 Alternative Inventory Methodology 144
A.2 Harbor Craft 145

A.2.1 AIS Inventory Methodology 145
A.2.2 Alternative Inventory Methodology 146
A.3 Recreational Marine 147
A.3.1 AIS Inventory Methodology 147
A.3.2 Alternative Inventory Methodology 147
A.4 Cargo Handling Equipment 148
A.5 Onroad Vehicles 148
A.6 Rail 148

APPENDIX B DETERMINING C1 AND C2 ENGINE TIERS 149

APPENDIX C FILLING GAPS IN VESSEL CHARACTERISTICS FOR OGV 151
C.1 Average Installed Propulsion Power, Maximum Speed, and Maximum Draft 151
C.2 Average Differences Between Keel-laid Year and Build Year 164

APPENDIX D HAP SPECIATION PROFILES FOR COMMERCIAL MARINE ENGINES 166

APPENDIX E DEFAULT OGV AUXILIARY ENGINE AND BOILER LOADS 168

APPENDIX F OGV SULFUR DIOXIDE LOW LOAD ADJUSTMENT FACTORS 172

APPENDIX G DEFAULT HARBOR CRAFT VESSEL CHARACTERISTICS AND ACTIVITY 173

APPENDIX H TABLES OF C1 AND C2 EMISSION FACTORS 175
H.1 Nitrogen Oxides (NOx) 175
H.2 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC) 179
H.2.1 ULSD 179
H.2.2 Other Diesel Fuels 184
H.3 Volatile Organic Compounds (VOC) and Methane (CH_4) 186
H.4 Carbon Monoxide (CO) 191
H.5 Average Emission Factors 193

APPENDIX I ADDITIONAL DETAILS FOR CALCULATING AN ONROAD INVENTORY 206
I.1 Project Scale Refined Approach 206
I.2 Hypothetical Port Example 206
I.2.1 Details of Hypothetical Port 207
I.2.2 PDM Tabs Inputs 207
I.2.3 Post-Processing Project Scale Output for Inventory Development 209

APPENDIX J HAP SPECIATION PROFILES FOR LOCOMOTIVE ENGINES 211

APPENDIX K ESTIMATING NUMBER OF TRUCKS AND RAIL CARS 216

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ARB	Air Resources Board (California)
AVFT	Alternative Vehicle and Fuels Technology (component of MOVES)
BC	black carbon
BSFC	brake specific fuel consumption
BTU	British thermal units
C1	Category 1 (commercial marine engines)
C2	Category 2 (commercial marine engines)
C3	Category 3 (commercial marine engines)
CAAAC	Clean Air Act Advisory Committee
CDM	County Data Manager (component of MOVES)
CFR	Code of Federal Regulations
CH_4	methane
CHE	cargo handling equipment
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DPM	diesel particulate matter
$DPM_{2.5}$	diesel particulate matter with an aerodynamic diameter less than or equal to 2.5 microns
DPM_{10}	diesel particulate matter with an aerodynamic diameter less than or equal to 10 microns
DOT	Department of Transportation
DWT	deadweight tonnage
E-85	a blend of gasoline and denatured ethanol containing up to 85% ethanol
E&C	Vessel Entrances and Clearances
ECA	Emissions Control Area
EF	emission factor
EPA	U.S. Environmental Protection Agency
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
g	gram
g/hp·h	gram per horsepower-hour
g/hr	gram per hour
g/kWh	gram per kilowatt-hour
g/mi	gram per mile
g/start	gram per vehicle start
gal	gallon
GHG	greenhouse gas
GIS	geographic information system
GPS	global positioning system
GT	gas turbine
GT-ED	electric drive gas turbine
GTM	gross ton-mile
GUI	graphical user interface
GVWR	gross vehicle weight rating
h	hour

HAP	hazardous air pollutant
HC	hydrocarbons
HFO	heavy fuel oil
hp	horsepower
hp·h	horsepower-hour
hp·h/gal	horsepower-hour per gallon
HPMS	Highway Performance Monitoring System
HSD	high-speed diesel
I/M	inspection and maintenance
ID	identifier
IMO	International Maritime Organization
in	inch
in^3	cubic inch
J	joule
kJ	kilojoule
kn	knot
kW	kilowatt
kWh	kilowatt-hour
L	liter
L/cyl	liter per cylinder
lb	pound
lb/ft^3	pound per cubic foot
LF	load factor
LLAF	low load adjustment factor
LNG	liquified natural gas
LPG	liquified petroleum gas
m	meter
m^2	square meter
m^3	cubic meter
MDO	marine diesel oil
MGO	marine gas oil
MMSI	Maritime Mobile Service Identity
MOVES	MOtor Vehicle Emission Simulator
mph	miles per hour
MSAT	mobile source air toxic
MSD	medium-speed diesel
MSD-ED	electric drive medium-speed diesel
MSTRS	Mobile Sources Technical Review Subcommittee
N/A	not applicable
N_2O	nitrous oxide
NAAQS	national ambient air quality standard
NEC	not elsewhere classified
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NOx	nitrogen oxides
OGV	ocean-going vessels
PAMS	portable activity measurement system
PDM	Project Data Manager (component of MOVES)

PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than or equal to 2.5 microns
PM_{10}	particulate matter with an aerodynamic diameter less than or equal to 10 microns
ppm	parts per million
reefer	refrigerated (vessel cargo)
RIA	Regulatory Impact Analysis
RM	residual marine (fuel oil)
RORO	roll-on/roll-off (vessel cargo)
rpm	revolutions per minute
RTG	rubber-tired gantry
RunSpec	run specification (component of MOVES)
RVP	Reid Vapor Pressure
SCC	source classification code
SCTG	Standard Classification of Transported Goods
SIP	state implementation plan
SITC	Standard International Trade Classification
SO_2	sulfur dioxide
SSD	slow-speed diesel
ST	steam turbine
STB	Surface Transportation Board
TEU	twenty-foot equivalent unit
ton	U.S. ton
ton/m^3	U.S. ton per cubic meter
ULSD	ultra-low sulfur diesel
U.S.	United States
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
VHT	vehicle hours traveled
VMT	vehicle miles traveled
VOC	volatile organic compounds
WCS	Waterborne Commerce Statistics
wt%	percentage by weight

1 INTRODUCTION

1.1 PURPOSE

This guidance describes how to develop a mobile source port-related air pollution emissions inventory, which is a quantification of all air emissions of selected pollutants that occur within a designated area by mobile sources for a given time period. The U.S. Environmental Protection Agency (EPA) intends this guidance to help port authorities and other port operators, state and local governments, Tribes, those doing business at ports (such as terminal operators, tenants, and shipping companies), communities, and other stakeholders who want to prepare emission inventories.

This document supersedes the previous versions of this guidance, including the September 2020 document with the same name, as well as the February 2020 draft document *Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions Inventories*.[a] EPA appreciated the technical comments received during the informal public review of the February 2020 draft document and this guidance continues to reflects that input as appropriate. (Note that the April 2009 document, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, has also been superseded, initially replaced by the September 2020 document.)This guidance may be used for voluntary and research purposes, as well as to develop inventories to meet regulatory requirements. Note that there are a few instances where alternative methodologies presented in this document would not be appropriate for regulatory purposes, and these instances are identified within the text. This guidance describes the data inputs, methods, and analysis approaches available for developing emission inventories of varying levels of detail based on user capacity, available resources, and the intended end use of the inventory. A variety of scales are included, such as project, terminal, sector, port, and regional levels.

This guidance covers base year and future inventories at different kinds of ports and associated port-related activity in the United States (U.S.), including activity occurring in:

- Seaports
- Great Lakes ports
- River ports
- Railyards
- Freight terminals
- Intermodal facilities
- Freight corridors

Those preparing inventories may elect to use this guidance in whole or in part depending on the purpose and scope of the port-related emissions inventory. For example, a seaport inventory may include all sectors addressed in this document, while an inland rail-to-truck intermodal transfer facility could apply the sections of this guidance that cover emissions from the onroad, cargo handling equipment, and rail sectors. While this guidance focuses on mobile source activity at ports and uses port-related terminology throughout the document, the methodologies and many of the data sources

are broadly applicable to other goods movement facilities, such as railyards and intermodal facilities. This guidance references existing resources, regulations, models, and best practices to ensure that these emission inventories are created using the latest methods, science, and data, commensurate with resource availability and the end purpose of the inventories.

This guidance does not repeat detailed information on how to run various models or tools that are included in other documents, but instead covers the various methodologies and sources of input data that are recommended for developing an inventory and refers readers to those other sources for "how-to" information. Note that this document also does not provide methodologies to quantify emission reductions that may result from specific strategies for reducing emissions at ports. EPA already has a number of other tools and documents that cover this information, such as the *National Port Strategy Assessment*,[1] *EPA and Port Everglades Partnership: Emission Inventories and Reduction Strategies*,[2] and the Diesel Emissions Quantifier,[3] among others.[b]

1.2 Background

Ports are key to the U.S. economy and serve as gateways to transport cargo, fuel, and passengers around the globe. Seaport cargo activity alone accounts for over a quarter of the U.S. Gross Domestic Product and supports the employment of nearly 31 million Americans.[4] Because ports are a significant part of the U.S. economy, it is critical to understand their potential impacts on air pollution, greenhouse gases (GHGs), and the people living, working, and recreating near ports. As part of its Ports Initiative, EPA recognizes the importance of working closely with ports to understand the on-the-ground, day-to-day operations and examine the methods available to estimate associated air pollution emissions.[c] This includes providing technical resources to help port stakeholders examine emission trends by source, identify potential opportunities for emission reductions, and prioritize future investment or operational changes to reduce emissions.

EPA formed the Ports Initiative Workgroup under the Mobile Sources Technical Review Subcommittee (MSTRS) of the Clean Air Act Advisory Committee (CAAAC) to advise on the development and implementation of an EPA-led voluntary initiative to improve port environmental performance and air quality for port communities. The CAAAC recommended, among other things, that EPA develop emissions inventory guidance, assess the guidance periodically, and update the guidance as needed. It also recommended that EPA should assist and encourage states to support port authorities and other port operators as needed to develop refined inventories of port-related operations.[5]

EPA developed the *National Port Strategy Assessment* to examine current and future emissions from a variety of diesel sources operating in port areas, and to explore the potential of a range of available strategies to reduce emissions from port-related mobile source activity.[1] Additionally, EPA worked with Broward County's Port Everglades of Southeast Florida through a voluntary partnership to study port-related mobile source emissions.[2] As a result of this partnership and other work, EPA developed methods, lessons learned, and practical examples that can be shared with other ports, related agencies, and stakeholders. The Port Everglades Partnership also informed this guidance, so that other U.S. ports, port-related industry, state and local governments, Tribes, and surrounding communities have clear

[b] Additional resources are available at https://www.epa.gov/state-and-local-transportation/policy-and-technical-guidance.

[c] For more information on EPA's Ports Initiative, see https://www.epa.gov/ports-initiative.

methodologies to estimate and understand emission inventories and potential reductions from port-related strategies in support of the Workgroup's recommendations.

1.3 Importance of Port-related Emission Inventories

A port-related emissions inventory may be developed for a variety of different purposes. Regulatory purposes include an inventory developed for state implementation plans (SIPs), National Environmental Policy Act (NEPA) analyses, transportation conformity determinations, or general conformity evaluations, among others. An emissions inventory may also be developed for research purposes. Voluntary purposes include evaluating the effectiveness of emission reduction strategies or creating a benchmark to make informed planning decisions. This guidance may be used for all these purposes and may also be a useful technical resource for state and local regulatory or voluntary implementation, as well as port- or freight-related research modeling. Section 2 of this guidance provides more discussion about inventory purposes.

Significant emissions from mobile source port-related activity come from diesel engines.[1] Emissions from diesel engines, especially particulate matter, nitrogen oxides, and air toxics such as benzene and formaldehyde, can contribute to significant health problems—including premature mortality, increased hospital admissions for heart and lung disease, and increased respiratory symptoms—for children, the elderly, outdoor workers, and other sensitive populations.[6] EPA has determined that diesel engine exhaust emissions are a likely human carcinogen,[7] and the World Health Organization has classified diesel emissions as carcinogenic to humans.[8] Other port-related diesel emissions, such as carbon dioxide and black carbon, contribute to climate change.[9] Many ports and port-related corridors are also located in areas with a high percentage of low income and minority populations who are often disproportionately impacted by higher levels of diesel emissions.[10]

An emissions inventory is an important tool that may be used by federal, state, and local governments, Tribes, port authorities and port operators, communities, and other stakeholders to reduce these impacts and enhance public health and environmental protection. It is also a benchmark against which to measure progress and enables informed decision making. With this information, a port can examine emission trends by source, identify potential opportunities for emission reductions, and prioritize future investment or operational changes to reduce emissions.

Ports are a nexus between transportation modes and activities that generate emissions on water and on land, both within the port boundary and on nearby transportation corridors. Quantifying all port-related mobile source emissions using local data can help stakeholders identify impacts and opportunities to reduce emissions. EPA's technology standards and fuel sulfur limits are expected to significantly reduce emissions as new diesel trucks, cargo handling equipment, ships, and locomotives enter the in-use fleet. However, implementing voluntary operational strategies or accelerating equipment replacement or retrofit rates could further reduce emissions, or reduce emissions sooner. The emission-reducing potential of a given strategy highly depends on a port's individual characteristics. Attributes such as the port's primary activity type and level; types of vessels, equipment, and fuels used; and the technologies and operations utilized onsite impact the emissions reduction potential of a given strategy.

In addition to supporting environmental goals, creating an inventory of emissions can help a port prioritize investments. Some of the voluntary strategies a port could adopt have potential co-benefits, such as reducing fuel usage and improving operational efficiencies that may enhance a port's

competitiveness. While this guidance does not cover how to quantify specific emission reduction strategies, an emissions inventory would be an important first step. EPA supports these efforts to reduce port-related emissions and encourages more areas to adopt and incentivize such programs.

1.4 Organization of This Guidance

The remainder of this guidance is organized as follows:

- Section 2 describes the purpose and scope of port-related emission inventories.
- Sections 3 through 8 detail how to develop inventories for the various source sectors at ports:
  - Section 3: Ocean-going vessels
  - Section 4: Harbor craft
  - Section 5: Recreational marine
  - Section 6: Cargo handling equipment
  - Section 7: Onroad vehicles
  - Section 8: Rail
- There are also several appendices that include emission factors, detailed methodologies, and other supporting material.

1.5 Guidance and Existing Requirements

The discussion in this document is intended solely as guidance. The statutory provisions and EPA regulations discussed in this document contain legally binding requirements. This document is not a substitute for statutory provisions and regulations, or is it a regulation itself. Thus, it does not impose legally binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA retains the discretion to consider and adopt approaches on a case-by-case basis that may differ from this guidance but still comply with the statute and applicable regulations. Any decisions regarding a specific SIP, conformity, or other regulatory analysis will be made based on the applicable statute and regulations. This document may be revised periodically without an opportunity for public comment.

1.6 Additional Information

For specific questions concerning the development of an inventory for a particular port, please contact the appropriate EPA Regional Office. A list of the EPA Regions, the states they cover, and contact information for staff that can coordinate work related to state implementation plans and state and local transportation can be found at the following website: www.epa.gov/state-and-local-transportation/epa-regional-contacts-regarding-state-and-local-transportation.

For specific questions about estimating emissions for the onroad, nonroad, and recreational marine source sectors using MOVES, please contact the MOVES team at mobile@epa.gov.

Any other general questions about this guidance can be directed to talkaboutports@epa.gov.

2 PLANNING A PORT-RELATED EMISSIONS INVENTORY

2.1 OVERVIEW

When planning a port-related emissions inventory, it is important to consider what sources and pollutants are to be included, the geographical area to be covered, and the timeframe of the inventory. The overall purpose, or end use, of the inventory should guide these decisions, as the purpose is the primary factor for determining the scope and level of detail:

- The scope of an inventory covers the sectors included, geographical boundaries, and time domains.
- The level of detail refers to the type of activity data underlying the inventory calculations and how refined those data are. Some purposes will necessitate more information than others.

This section includes a discussion of inventory purposes (Section 2.2) and general inventory approaches (Section 2.3), followed by subsections that cover scope-related decisions to be considered when planning an inventory:

- Mobile source sectors to include (Section 2.4)
- Pollutants to include (Section 2.5)
- The geographical area to be covered (Section 2.6)
- The time period to be covered (Section 2.7)

Emission inventories should be developed based on the latest local information available. Using local information results in more accurate and representative inventories, empowering stakeholders to make informed decisions. For example, if a port authority desires to evaluate the potential of various operational strategies to improve efficiency and reduce fuel use and emissions, having an inventory based on local information would allow for a port or terminal to tailor strategies and best practices to their particular circumstances, depending on their business and environmental goals.

2.2 PURPOSES OF THE INVENTORY

Inventories can have varying levels of detail, depending on the purpose of the inventory and the resources available to create it. The choice of modeling approach, geographical scope, and time domain covered by the inventory will depend on the purpose of the inventory. If the purpose of the inventory is regulatory, other EPA guidance is available for some sectors, and the reader is referred to those where appropriate. For example, a potential regulatory purpose could be for use in a state implementation plan (SIP), National Environmental Policy Act (NEPA) analysis, or general conformity evaluation. Note that existing SIP inventories for areas where ports are located may not have separately estimated the contribution from the port, but included these emissions in overall estimates. With this guidance, EPA hopes to improve the estimation of emissions from port-related and goods movement activity because they are a significant source of emissions from diesel engines.

Non-regulatory purposes for a port emissions inventory could include general port planning purposes, to provide information to the port and the surrounding community about emissions, or an analysis of an

individual transportation corridor. For these purposes, there can be additional flexibility in the approach and scope for an inventory.

Regardless of whether the purpose is regulatory or not, an inventory with a finer resolution may provide greater value for port authorities and terminal operators for identifying effective emission reduction strategies including operational efficiency improvements. A detailed emissions inventory, which reflects the latest modeling approaches and detailed activity information, could be valuable for larger ports and their stakeholders in nonattainment and maintenance areas for the applicable national ambient air quality standards (NAAQS), but also for ports where a screening level inventory would be insufficient for their planning purposes. A fine level of geographical and temporal detail would be necessary if the inventory is to be used in air quality dispersion or photochemical modeling. Additionally, fine level of detail may be needed if the purpose of the inventory is to analyze emission reduction strategies.

However, alternative approaches that do not include this same level of detail can be appropriate for various purposes as well. Some of the less-detailed approaches in this guidance would still provide valuable information to those undertaking the inventory. For example, a screening level emissions inventory could be valuable at ports that do not yet have a detailed emissions inventory and want to understand overall emissions and relative contributions of different mobile source sectors. A screening level emissions inventory can take many forms, but it typically involves a combination of port-specific data and default activity assumptions. This kind of inventory could be intended to provide an order of magnitude estimation of emissions to inform comprehensive port or terminal planning, or provide stakeholders a preliminary context for how emissions compare at a local or regional level.

Another option is an equipment-only inventory. While this type of inventory is not an emissions inventory, it could be relevant for smaller ports or ports without an emissions inventory to make certain fleet- or sector-level decisions. An equipment inventory could be useful even if it covers only one mobile source sector of interest, such as a port's or terminal's cargo handling equipment fleet. Including activity levels associated with an entire fleet or sector could inform clean air investments. For example, older equipment that is used most frequently could be prioritized for replacement with newer equipment that meet the most stringent emission standards. Such an inventory would be a first step towards developing a complete emissions inventory.

This guidance includes various methodologies to calculate emission inventories at the level of detail needed for the purpose of the inventory. Sections 3 through 8 describe:

- Best practices to develop a detailed emissions inventory based on the latest modeling approaches and detailed activity information
- Alternative methods that can be used to develop a less detailed inventory

2.3 General Inventory Approaches

Fundamentally, a quantitative emissions inventory is developed using the number (i.e., the population) of vessels, vehicles, and equipment operating in a specific area, along with data on their operational activity combined with appropriate emission factors. In addition to vessel, vehicle, and equipment counts, the population data also include other information, such as model year or engine tier, engine size, and fuel type, among others. This information allows the appropriate emission factor to be applied to the vessel, vehicle, or equipment's activity. The operational activity data can take many forms

depending on the sector and type of activity, but generally includes information on hours of use, engine load, and/or miles travelled.

In general, the better the data about the emission sources and their activity, the more precise the inventory will be. Inventory preparers should consider their resources and determine how best to allocate them in the gathering of data. Inventory preparers should also consider the entities that may have information relevant to inventory development, such as the port authority itself, the port tenants, terminal operators, or other agencies, and consider involving them early in the process of developing the inventory. Gaining the cooperation of these entities to share information would help to ensure that the inventory accurately reflects port-related emissions. The better the inventory, the more helpful it can be for making future decisions, such as investments in technologies or operational practices that could reduce emissions and result in a cleaner environment.

The subsequent sections of this guidance describe best practices as well as alternative methods to develop a port-related emissions inventory. Regardless of the method used in developing an inventory, there are specific elements that are important to inform decision-making:

1. The latest available information should be used whenever possible and feasible.
2. Local, state, or regional data should be used if available; however, national, default, or other surrogate data may be adequate, depending on the analysis.
3. Emission factors should reflect the latest EPA emission models and regulations for applicable vessels, vehicles, equipment, and fuels.
4. An inventory should be developed through consultation with the involved parties, including port authorities and other port operators, those doing business at ports (such as terminal operators, tenants, beneficial cargo owners, and shipping and rail companies), state and local governments, Tribes, local communities, federal agencies, and the public. In addition, the appropriate EPA Regional Office is a key resource and should be consulted from the beginning of inventory planning. Note also that inventories for some regulatory purposes will require specific interagency consultation processes that include EPA.
5. The resulting inventory and documentation describing how it was developed should be widely available to the public.
6. When the inventory purpose is regulatory, all components of an inventory must meet the relevant requirements, such as those for SIP development (where the inventory is to be based on the latest information available at the time the SIP is developed).[a]
7. Investments and enforceable commitments to support port-related emission reduction strategies need to be assured before being included in a projected future emissions inventory used for regulatory purposes.[b]

These elements should be used to inform decision-making pertinent to the purpose of the inventories. The remainder of this section provides background information useful for determining the scope of an emissions inventory.

[a] Based on the requirements of Clean Air Act section 172(c)(3).
[b] Based on the requirements of Clean Air Act section 110(a)(2)(A).

2.4 Mobile Source Sectors

This guidance focuses on port-related diesel emissions from the following mobile source sectors:

- Ocean-going vessels (OGV)
- Harbor craft
- Recreational marine
- Cargo handling equipment (CHE)
- Onroad vehicles
- Rail

While some or all these source sectors are present at most U.S. seaports, Great Lakes ports, and river ports, they may also be present in various combinations at inland rail or truck distribution centers, intermodal facilities, truck or rail corridors, railyards, and freight terminals. Each sector is briefly described below.

Note that there may also be other sources of air emissions present, such as electricity generation, fugitive dust, refineries, or fuel storage. While these sources may also be important to include in a comprehensive air emissions inventory, this guidance only covers the mobile source sector contributions.

2.4.1 Ocean-Going Vessels

The OGV source sector covers ships that transport cargo and/or people between different ports. "Ocean-going" is used here as a descriptive term, since many of these vessels operate in the oceans, either navigating internationally across oceans or operating extensively in coastal areas. However, this source sector also covers vessels that transport cargo and/or people between different ports in the Great Lakes and inland rivers.

OGV typically have Category 3 (C3) propulsion engines, which have a per-cylinder displacement of 30 liters or more; however, some OGV have smaller Category 1 (C1) or Category 2 (C2) engines. See Section 3 for more information about the OGV sector.

2.4.2 Harbor Craft

The harbor craft source sector covers all commercial marine vessels that are not considered in the OGV sector, such as tugboats and work boats. Unlike OGV, harbor craft typically spend most of their operating time in or near a single port or region, and they typically have C1 or C2 engines. See Section 4 for more information about the harbor craft sector.

2.4.3 Recreational Marine Vessels

Recreational marine vessels are operated primarily for pleasure, such as motorboats, cruisers, yachts, and other types of pleasure craft. See Section 5 for more information about the recreational marine sector.

2.4.4 Cargo Handling Equipment

The CHE sector encompasses equipment such as yard tractors and cranes used for moving cargo, products, and supplies around a port or other terminal, and on and off marine vessels, railcars, and onroad trucks. CHE are typically classified as "nonroad equipment," i.e., mobile equipment that do not operate on roads. See Section 6 for more information about the CHE sector.

2.4.5 Onroad Vehicles

The onroad vehicles sector is primarily comprised of heavy-duty diesel trucks, but it also includes cars, light-duty trucks, and buses. See Section 7 for more information about the onroad sector.

2.4.6 Rail

Two types of locomotives typically support port-related cargo operations: switcher locomotives and line-haul locomotives. Switchers, also referred to as "yard engines," assemble and disassemble trains. Line-haul locomotives are the engines that move cargo long distances and are typically larger than switchers. See Section 8 for additional information about what is included in the rail sector.

2.5 Pollutants of Concern

The pollutants included in a port-related emissions inventory should be determined by the purpose of the inventory. The pollutants of concern in a port-related emissions inventory could include criteria pollutants and precursors, climate-related pollutants, and air toxics. Criteria pollutants include common air pollutants that are identified by the Clean Air Act, such as particulate matter and ground-level ozone. Precursors are air pollutants that form criteria pollutants, such as nitrogen oxides and volatile organic compounds, which combine to form ground-level ozone. Climate-related pollutants include greenhouse gases, while air toxics are hazardous air pollutants that are known or suspected to cause serious health effects.

The preparer of an inventory should consider which pollutants to include at the beginning of the process and may want to consult with other agencies and stakeholders on this decision. Considerations include whether or not the port or terminal is located in a nonattainment or maintenance area for a criteria pollutant; if so, that pollutant and its precursors should be included. An inventory preparer may want to include any and all other pollutants from the start: for sectors that are estimated using EPA's MOVES model,[c] for example, it may save time to include every pollutant in the initial MOVES run rather than to determine later that another pollutant is needed, creating the need to run MOVES again for that additional pollutant.

This guidance includes specific information on how to develop inventories of the following pollutants:

- Criteria pollutants and precursors:
  - Nitrogen oxides (NOx)
  - Particulate matter with an aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$)
  - Particulate matter with an aerodynamic diameter less than or equal to 10 microns (PM_{10})
  - Sulfur dioxide (SO_2)
  - Volatile organic compounds (VOC)
- Climate-related pollutants:
  - Carbon dioxide (CO_2)

[c] EPA's MOtor Vehicle Emission Simulator (MOVES) is a state-of-the-science emission modeling system for mobile sources. For port-related emission inventories, it is used in the development of onroad, CHE, and recreational marine inventories as discussed in each of those sections of this guidance. For more information about MOVES, see https://www.epa.gov/moves.

    - Methane (CH_4)
    - Nitrous oxide (N_2O)
    - Black carbon (BC)
- Mobile source air toxics (MSATs):
    - Diesel particulate matter with an aerodynamic diameter less than or equal to 10 microns ($DPM_{2.5}$)
    - Diesel particulate matter with an aerodynamic diameter less than or equal to 2.5 microns (DPM_{10})

While this list generally applies broadly to all sectors, SO_2 port-related inventories are primarily relevant for the OGV sector. The non-OGV sectors at ports in the United States are required to use ultra-low sulfur diesel (ULSD)[11] [12] [13] and lower sulfur gasoline.[14] These cleaner-burning fuels have significantly reduced the SO_2 emissions from the sectors that use them. In addition, onroad SIP and transportation conformity inventories typically do not include SO_2 as the onroad sector has not been a significant portion of these emissions. However, this guidance includes best practice methods to estimate SO_2 emissions for all sectors for implementers that wish to include this pollutant.

Additionally, methods to develop inventories for the criteria pollutant carbon monoxide (CO) are included for those who wish to include this pollutant. Diesel-fueled equipment are not large sources of CO, so this is typically not a pollutant of concern for port-related inventories.

Note that methods to develop inventories of total hydrocarbons (HC) are also included throughout this guidance for modeling purposes, as VOC and CH_4 emissions are generally calculated from HC emissions.

Depending on the specific purpose and scope of an emissions inventory, it may be desirable to include additional pollutants, such as the MSATs benzene and formaldehyde. Where applicable, this guidance contains references to various resources available for including other pollutants that are not specifically discussed here. Similarly, while this guidance focuses on quantifying pollution that is directly emitted from primarily diesel-fueled vessels, equipment, and vehicles, road dust is also a mobile source of PM pollution for certain sectors in PM_{10} and in certain $PM_{2.5}$ nonattainment and maintenance areas; this guidance highlights these cases and references resources available for including road dust as appropriate.

In addition to the pollutants discussed above, energy consumption may be of interest. Energy consumption is an important measure of port-related activity and it may be useful to include as part of the inventory. Appendix A provides methods that can be used to estimate energy consumed for each source sector.

2.6 Geographical Domain

The area covered by an inventory (i.e., the geographical domain) will be closely tied to the inventory's purpose and scope. In general, an inventory should cover all source sectors and geographical areas of interest. This typically includes, at a minimum, the geographical area within the port authority or other port operator's jurisdiction. It frequently also includes port-related traffic in nearby transportation corridors, depending on the purpose of the inventory.

The following subsections describe how the marine and landside boundaries should be determined and concludes with a discussion of geographical scope.

2.6.1 Marine Boundary

The marine boundaries should be set so that all port-related activities of interest for the inventory's purpose and scope occur within them. Areas included in the marine portion of an emissions inventory generally include:

- Transit areas: Locations where vessels are typically traveling at normal cruising speed
- Restricted speed zones: Areas where travel speeds are limited due to safety or other reasons, typically within waterways leading to a port
- Maneuvering areas: Locations within a harbor area, where large vessels are typically moved with the assistance of tugs or other harbor craft
- Hotelling areas: Berthing, mooring, and docking areas where vessels can load or unload cargo or people
- Anchorage zones: Areas where vessels wait at anchor for an open berth

2.6.2 Land-side Boundary

The land-side boundaries should be set so that all port-related activities of interest for the inventory's purpose and scope occur within them. Areas included in the land-side portion of an emissions inventory generally include:

- Freight or intermodal terminals for the loading and unloading of cargo from ships, trucks, and/or trains
- Gates, queues, and staging areas for onroad vehicles, such as diesel trucks
- Railyards
- On-port roads
- Parking lots
- On-dock storage of cargo, product, or containers

Additional land-side activities and areas that may be included even though they occur outside the port authority or other port operator's jurisdiction, but still within the geographical domain of the inventory:

- Common drayage truck and other port-related vehicle routes
- Rail lines
- Intermodal facilities that handle and/or warehouse port-related cargo

Whether or not to include port-related transportation corridors (e.g., highways and rail lines) and other facilities in emission inventories is especially important when considering people living and working near these facilities. Additionally, analyzing emissions in transportation corridors can provide insight into the benefits of emission reduction strategies that could be realized beyond the boundaries of a port.

2.6.3 Determining Geographical Scope

The purpose of an inventory should be carefully considered when determining the geographical scope to ensure the inventory covers all areas of interest and can be used by all stakeholders to make informed decisions. Frequently, port-related inventories cover an entire port (as defined by the port authority or other port operator's jurisdictional boundaries). Generally, EPA recommends that the geographical

scope for each source sector also include emissions associated with moving freight through to the first intermodal transfer point. The following list includes geographical scope suggestions to be considered for each source sector:

- OGV: All restricted speed zones, maneuvering areas, hotelling areas, and anchorage zones that are within the port's boundaries, or are used by vessels when calling on the port. For coastal seaports, this could also include transit areas to the international boundary.
- Harbor craft: Typically, the harbor craft geographical scope should be the same as the OGV geographical scope. It should cover all areas where harbor craft support OGVs that call on the port, as well as all other activities by harbor craft that operate out of the port.
- Recreational marine: Typically, the recreational marine geographical scope should be the same as the OGV geographical scope.
- CHE: All areas where CHE activity occurs within the port's boundary.
- Onroad: All areas where heavy-duty truck activity occurs within the port's boundary, including gates, queues, on-port roads, and loading/unloading areas, in addition to off-port transportation corridors to the first intermodal transfer point.
- Rail: All railyards within the port's boundary and possibly nearby port-related line-haul activity.

However, some inventories may have a smaller geographical domain, such as:

- One or more terminals
- One or more mobile source sectors
- The marine geographical boundary only
- The landside geographical boundary only
- A port-related truck, rail, or vessel corridor
- An off-port freight distribution or intermodal facility

A smaller geographical domain may be useful if resources are limited and the purpose of the inventory is to answer specific questions or make decisions regarding only a portion of port-related activity. Alternatively, an inventory may have a larger geographical domain than an entire port for various purposes:

- An entire state (e.g., for a state freight plan)
- An entire nonattainment or maintenance area (e.g., for a SIP)

In these cases, the port-related inventory will be used in conjunction with other inventories (e.g., county inventories), and the geographical boundaries should be carefully considered to avoid double-counting emissions or missing any emission sources. If the emissions inventory will support regulatory purposes, the interagency consultation process should be used to determine the geographical boundaries and how to address and minimize double-counting or missing emissions. Furthermore, if the purpose of the emissions inventory is to support air quality modeling, a high level of geographical activity detail will be needed in each sector, as described in each of the subsequent sector sections.

Consider, for example, a hypothetical port inventory that will be used to quantify emissions in a nonattainment area as part of a SIP. In this case, the port inventory boundaries will need to be selected in such a way that they do not overlap with other inventories that quantify emissions in the rest of the nonattainment area. If overlap is unavoidable, the interagency consultation process should be used to

avoid or reduce the possibility of emissions being counted twice. In the example, onroad and rail emissions could be available in the county-wide inventory which includes all publicly accessible roads and the rail line extending outside the port's boundary. In this case, the port inventory could be calculated with two separate components: an "on-port" component, which includes the geographical area within the port's jurisdiction, and an "off-port" component, which covers the port-related traffic in nearby transportation corridors. By doing so, the on-port inventory could be combined with the county-wide inventory without double-counting some emissions.

Regardless of scope, the geographical domain of an inventory should be clearly documented, so that anyone reviewing it understands what is and what is not included.

2.7 Time Domains and Future Inventories

The purpose of the emissions inventory should be considered in determining the time domain and level of temporal detail used when calculating the inventory. While most port-specific base year emission inventories are annual, for some purposes, a seasonal or daily inventory may be needed (e.g., the scope for inventories used in SIPs would depend on the specific NAAQS involved). If inventories are to be used for multiple purposes, it may be useful to report emissions at multiple temporal levels (e.g., annual emissions for planning purposes and hourly emissions for air quality modeling purposes).

If the purpose of the emissions inventory is to support air quality modeling, a high level of temporal activity detail will be necessary in each sector. If emissions are calculated at the annual scale, they may need to be allocated to a finer level of detail, depending on the purpose of the inventory (e.g., a 24-hour period), as described in each of the subsequent sections.

Generally, the time domain should be a recent year that data is available or for which data can be collected. If future year emission inventories are needed (e.g., for SIPs or analyzing emission reduction strategies):

1. The base year inventory should be completed first (i.e., a retrospective inventory should be developed for a recent year with measured activity data).
2. Then the activity used in the base year inventory should be scaled to estimate activity levels in the future year inventory using local port and sector specific growth projections, if available.
3. Finally, any planned action that has been committed to that would influence future emissions as well as fleet turnover should be accounted for while estimating the future inventories. For example, if an emission reduction strategy is planned, its impact on future activity and/or emission factors should be included. However, the same emissions inventory methodology should be used to calculate both the base year and future year inventory.

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Using these local data sources in consultation with all involved stakeholders result in better data for a better inventory. If local port and sector specific growth projections are unavailable, the Freight Analysis Framework (FAF) can be used to forecast growth by sector.[15] The FAF contains projected tons of commodities flow by transport mode at the state and regional level for both historic and future years. Growth factors can be derived by dividing

the projected future tons of commodity flow by the appropriate historic year tons. These growth factors can then be applied to the base year inventory's activity to estimate future activity levels.

Each of the subsequent sections describe in more detail how a base year or future year emissions inventory can be calculated, and how the FAF can be used to estimate future activity when local port and sector specific growth projections are not available.

3 OCEAN-GOING VESSELS

3.1 SOURCE DESCRIPTION

The ocean-going vessels (OGV) source sector covers ships that transport cargo and/or people between different ports. "Ocean-going" is used here as a descriptive term, since many of these vessels operate in the oceans, either navigating internationally across oceans or operating extensively in coastal areas. However, this source sector also covers vessels that transport cargo and/or people between different ports in the Great Lakes and inland rivers.

OGV typically have Category 3 (C3) propulsion engines, which have a per-cylinder displacement of 30 liters or more; however, some OGV have smaller Category 1 (C1) or Category 2 (C2) engines. Table 3.1 lists the various ship types that comprise the OGV source sector. These ship types can be further described by various subtypes (see Section 3.3.3). Note that there may be specialized types of OGV that do not appear on this list. However, this source sector does not include harbor craft, which are discussed in Section 4 or recreational marine vessels or vessels with gasoline engines, which are discussed in Section 5.

Table 3.1. OGV Ship Types

Ship Type	Description
Bulk Carrier	Dry-cargo vessels that carry loose cargo (e.g., grain, ore)
Chemical Tanker	Liquid-cargo vessels that transport chemicals in bulk
Container Ship	Dry-cargo vessels that carry containerized cargo
Cruise	Passenger vessels used for commercial pleasure voyages
Ferry/Passenger (C3)*	Passenger vessels used for transport
Ferry/Roll-on/Passenger (C3)	Passenger vessels used for transporting people and their vehicles
Fishing (C3)	C3 vessels used in commercial fishing operations
General Cargo	Dry-cargo vessels that are not specialized for a particular type of cargo
Liquified Gas Tanker	Cargo vessels specifically designed to transport liquified gas at high pressure and/or low temperature
Miscellaneous (C3)	C3 vessels not otherwise designated in this table
Offshore Support/Drillship	Vessels that support offshore oil and gas platforms or perform exploratory offshore drilling
Oil Tanker	Liquid-cargo vessels that transport petroleum products in bulk
Other Service	Vessels that perform support services (e.g., oil spill cleanup)
Other Tanker	Liquid-cargo vessels that transport cargo not otherwise designated in this list
Refrigerated (Reefer)	Vessels that carry refrigerated cargo
Roll-on/Roll-off (RORO)	Vessels that handle cargo that is rolled on and off the ship, such as trucks and construction equipment

Ship Type	Description
Vehicle Carrier	Dry-cargo vessels that transport vehicles
Yacht (C2/C3)**	Private passenger vessels

* C3 in a ship type designates that emissions from vessels of the specified ship type should be estimated according to the methodologies presented in this section if they have C3 propulsion engine(s). If they have C1 or C2 propulsion engine(s), their emissions should be estimated according to the methodologies presented in Section 4.

** Emissions from yachts should be quantified using the methodologies presented in this section if they have C2 or C3 propulsion engines. If they have C1 or gasoline engines, their emissions should be quantified as described in Section 5. See Table 3.2 for how to distinguish between the different categories of marine engines.

In general, emissions for all OGV operating within the geographical domain for the inventory should be estimated. However, taking this approach may include innocent passage emissions, which are emissions from vessel activity not related to the port(s) for which the inventory is being calculated (i.e., vessels just passing through the geographical domain). Depending on the purpose of the inventory, it may be important to quantify emissions from innocent passage separately from vessels calling on the port. See Section 2 of this guidance for more discussion about inventory purpose, geographical domains, and temporal detail.

OGV typically have three kinds of emission sources:

- Propulsion engines, also referred to as main engines, which supply power to move the vessel
- Auxiliary engines, which supply power for non-propulsion (e.g., electrical) loads
- Boilers, which heat fuel and water

3.2 Emissions Estimation Overview

OGV base year emissions from each type of emission source can be estimated for each vessel using Equation 3.1:

$$E = P \times A \times EF \times LLAF \qquad \textbf{Equation 3.1}$$

Where E = per vessel emissions (g)
P = engine operating power (kW)
A = engine operating activity (h)
EF = emission factor (g/kWh)
$LLAF$ = low load adjustment factor, a unitless factor that reflects increasing propulsion emissions during low load operations (always 1 for auxiliary engines and boilers)

Each of the above parameters models a specific emissions source (propulsion engine, auxiliary engine, or boiler) and thus will change for each vessel or vessel population. Therefore, it is important to accurately account for vessel characteristics (discussed in Section 3.3) and activity (Section 3.4) to ensure the operating power and hours are calculated correctly and that the right emission factors (Section 3.5), auxiliary loads (Section 3.6) and low load adjustment factors (Section 3.7) are applied to this activity.

There are different methods that can be used for estimating OGV emissions for a base year emissions inventory depending on data and resource availability. The two methods described in this guidance are an Automatic Identification System (AIS) based approach (Section 3.8) and an alternative approach based on vessel trip records (Section 3.9):

- With the AIS based approach, emissions are calculated for each AIS record. Emission factors (EF) are assigned by engine type, fuel, and other characteristics; operating power (P), activity (A), and low load adjustment factor ($LLAF$) are derived from AIS data as described in Section 3.8.
- The vessel trip records approach relies on using the same vessel characteristics and emission factors as the AIS based approach; however, P, A, and $LLAF$ are derived by operating mode for each vessel trip rather than AIS record, as described in Section 3.9.

The AIS approach allows for a highly detailed OGV inventory, which may be desirable for inventories that need a fine level of temporal or geospatial resolution (e.g., for air quality analyses, looking at different types of activities, or analyzing emission reduction strategies). However, this approach can be resource intensive. Therefore, the vessel trip records approach can be used instead if the purpose of the inventory does not necessitate a fine level of detail. Either approach could be used for most regulatory or voluntary purposes. The chosen approach is usually determined by the purpose of the inventory and the availability of activity data and the resources to process them.

Projections of future year emission inventories are discussed in Section 3.10.

3.3 Vessel Characteristics

Both the AIS and the vessel trip records approach involve data related to the characteristics of the vessels operating in the geographical domain. This information may be available for purchase in the form of vessel registry databases. Port records, vessel surveys, federal databases,[a] and online searches can supplement and validate these data. The following subsections detail the various data fields that comprise vessel characteristic data:

- Fields used to identify vessels to cross-reference various data sets (Section 3.3.1)
- Fields used to characterize engines to determine appropriate emission factors (Section 3.3.2)
- Fields used to determine ship type and subtype to fill data gaps and to group similar activity patterns (Section 3.3.3)
- Fields used as part of the calculation to determine engine operating power (Section 3.3.4)

The final subsection, Section 3.3.5, discusses techniques to fill data gaps in vessel characteristic data sets.

3.3.1 Vessel Identification

All vessels have unique identifiers that can be used to match their activity data to vessel characteristic data. The following vessel identifiers are useful when matching OGV records in different data sets:

[a] The U.S. Coast Guard maintains the following databases which may contain useful vessel characteristic data for estimating emissions: *Merchant Vessels of the United States* (accessible by searching https://www.dco.uscg.mil) and *U.S. Coast Guard Port State Information Exchange* (accessible at https://cgmix.uscg.mil/PSIX/Default.aspx).

- International Maritime Organization (IMO) number
- Maritime Mobile Service Identity (MMSI)

The IMO number is generally the best field to use for vessel identification, as this number is uniquely assigned to each vessel under IMO resolutions[16] and does not change over its lifespan. However, if the IMO number is not available, the MMSI (which is uniquely assigned to each AIS transmitter) can also be used to match vessel records. However, care should be taken when doing so as MMSI is not a constant identifier and may change over the life of a vessel. If neither IMO number or MMSI are available, the vessel name and call sign can possibly be used to match local port records to local vessel survey data. However, vessel name and call sign are not unique identifiers and thus are not recommended for matching AIS records to national or global vessel characteristic data sets.

3.3.2 Engine Characteristics

Emission factors for each emission source depend on engine category and type. The following data fields can be used to determine the vessel's propulsion engine characteristics:

- Engine category (C1, C2, or C3)
- Engine bore (the diameter of each engine cylinder)
- Engine stroke (the stroke length of each engine cylinder)
- Engine type (typically slow- or medium-speed diesel, among others as described below)
- Engine speed (revolutions per minute [rpm])
- Keel-laid year (used to determine engine tier)

3.3.2.1 Engine Category

If the engine category field is missing from the vessel characteristic data, it can be determined by calculating cylinder displacement in liters using Equation 3.2, assuming the engine bore and stroke are measured in millimeters:

$$\text{Cylinder Displacement} = \frac{\pi}{4} \times \text{Bore}^2 \times \text{Stroke} \times 10^{-6} \qquad \textbf{Equation 3.2}$$

Propulsion engines with a per-cylinder displacement of 30 liters or greater are C3 engines. For other engines, Table 3.2 can be used to determine the engine category from the cylinder displacement and engine tier.[17] For engines with a per-cylinder displacement less than 30 liters and unknown engine tier, it can be determined using the information presented in Appendix B. If the fields used to calculate displacement are also missing, engine category can be assigned based on the defaults presented in Appendix C.

Table 3.2. Classifying Marine Propulsion Engines

Engine Category	Engine Tier	Per-cylinder Displacement
1	Uncontrolled, 1, 2	displacement < 5 L
	3, 4	displacement < 7 L
2	Uncontrolled, 1, 2	5 L ≤ displacement < 30 L
	3, 4	7 L ≤ displacement < 30 L
3	All	displacement ≥ 30 L

3.3.2.2 Engine Type

Emission factors for OGV depend not only on engine category, but also engine type. There are several different propulsion engine types seen on C3 vessels:

- Slow-speed diesel (SSD)
- Medium-speed diesel (MSD)
- High-speed diesel (HSD)
- Gas turbine (GT)
- Steam turbine (ST)
- Electric drive MSD or GT (identified as MSD-ED or GT-ED)
- Liquified natural gas (LNG)

If the engine type field is missing, it may be possible to identify it based on the descriptive propulsion type, engine speed, or engine stroke type fields in the vessel characteristic data. The descriptive propulsion type field often indicates if the engine is diesel, GT, ST, MSD-ED, or GT-ED. If the engine is diesel but it is unknown if it is SSD, MSD, or HSD, Table 3.3 can be used to assign engine type based on engine speed and/or stroke type.

Table 3.3. Marine Diesel Engine Speed Designations

Diesel Engine Type	Typical Engine Speed Range	Engine Stroke Type
SSD	< 500 rpm	2
MSD	500 – 1,400 rpm	4
HSD	> 1,400 rpm	4

While there is no definite rpm cutoff between SSD and MSD diesel engines, EPA assigns a C3 vessel that is missing engine type information to the SSD category if its engine speed is less than 500 rpm and MSD if otherwise.[18] If all fields used to determine the propulsion engine type are missing, C3 vessels can be assumed to have SSD propulsion engines. For vessels with missing data on auxiliary engine type, all auxiliary engines can be assumed to be MSD.

For C1/C2 propulsion engines, the engine speed is not necessary for assigning emission factors.

3.3.3 Ship Type and Subtype

Ship type and subtype information are used to group similar ships together to fill gaps in vessel characteristic data, as well as for assigning auxiliary engine and boiler loads by operating mode. The following vessel characteristic fields can be used to determine ship type and subtype:

- Ship type
- Gross tonnage
- Deadweight tonnage (DWT)
- Twenty-foot equivalent units (TEUs)

Depending on the source of the vessel characteristic data, the ship type field can have varying levels of detail. Ship type can generally be aggregated to the categories listed in Table 3.1.

Ship subtypes are assigned to each vessel according to its ship type and size class. If the default auxiliary and boiler loads are used (as discussed in Section 3.6 and presented in Appendix E), the subtypes listed in Table 3.4 are appropriate, which are primarily based on the *Third IMO Greenhouse Gas Study*.[19] However, if detailed local data on auxiliary and boiler loads are available, alternate and/or more detailed subtypes may be used. For example, cruise ships may be assigned to subtypes based on passenger capacity or container ship subtypes could be defined by 1,000 TEU increments if that is how information on auxiliary and boiler loads are available.

Table 3.4. Ship Subtype Mapping Based on Ship Type and Size

Ship Type	Size	Units	Subtype
Bulk Carrier	0–9,999	DWT	Small
	10,000–34,999		Handysize
	35,000–59,999		Handymax
	60,000–99,999		Panamax
	100,000–199,999		Capesize
	≥ 200,000		Capesize Largest
Chemical Tanker	0–4,999	DWT	Smallest
	5,000–9,999		Small
	10,000–19,999		Handysize
	≥ 20,000		Handymax
Container Ship	0–999	TEU	1,000 TEU
	1,000–1,999		2,000 TEU
	2,000–2,999		3,000 TEU
	3,000–4,999		5,000 TEU
	5,000–7,999		8,000 TEU
	8,000–11,999		12,000 TEU
	12,000–14,499		14,500 TEU
	≥ 14,500		Largest
Cruise	0–1,999	Gross Tonnage	2,000 Ton
	2,000–9,999		10,000 Ton
	10,000–59,999		60,000 Ton
	60,000–99,999		100,000 Ton
	≥ 100,000		Largest
Ferry/Passenger (C3)	0–1,999	Gross Tonnage	2,000 Ton
	≥ 2,000		Largest
Ferry/Roll-on/Passenger (C3)	0–1,999	Gross Tonnage	2,000 Ton
	≥ 2,000		Largest
Fishing (C3)	All	N/A	All C3 Fishing

Ship Type	Size	Units	Subtype
General Cargo	0–4,999	DWT	5,000 DWT
	5,000–9,999		10,000 DWT
	≥ 10,000		Largest
Liquified Gas Tanker	0–49,999	DWT	50,000 DWT
	50,000–99,999		100,000 DWT
	100,000–199,999		200,000 DWT
	≥ 200,000		Largest
Miscellaneous (C3)	All	N/A	All C3 Miscellaneous
Offshore Support/Drillship	All	N/A	All Offshore Support/Drillship
Oil Tanker	0–4,999	DWT	Smallest
	5,000–9,999		Small
	10,000–19,999		Handysize
	20,000–59,999		Handymax
	60,000–79,999		Panamax
	80,000–119,999		Aframax
	120,000–199,999		Suezmax
	≥ 200,000		VLCC
Other Service	All	N/A	All Other Service
Other Tanker	All	N/A	All Other Tanker
Reefer	All	N/A	All Reefer
RORO	0–4,999	Gross Tonnage	5,000 Ton
	≥ 5,000		Largest
Vehicle Carrier	0–3,999	Vehicles	4,000 Vehicles
	≥ 4,000		Largest
Yacht (C2/C3)	All	N/A	C2/C3 Yacht

3.3.4 Engine Operating Power

Engine operating power varies with different kinds of activity, and its calculation depends on the activity data source. The following vessel characteristics are needed to calculate propulsion engine operating power:

- Total installed propulsion power, also known as the vessel's maximum continuous rated engine power (kW)
- Service speed or maximum speed (kn)
- Maximum draft, also known as the vessel's summer load line (m)

Propulsion engine load is calculated from maximum vessel speed and other parameters when using the equations provided in this document. However, if only vessel service speed (also known as cruise speed) is known from the vessel characteristic data, maximum speed can be estimated by dividing the service speed by 0.94.[20]

Section 3.6 discusses auxiliary and boiler operating power and Sections 3.8.4 and 3.9.3 discuss how to calculate propulsion engine operating power.

3.3.5 Filling Gaps in Vessel Characteristic Data Sets

Missing data is a common occurrence in vessel characteristic data sets. The best practice for filling gaps in vessel characteristic data is to use information from vessels with known values operating in the geographical domain. For categorical fields, such as engine type, the most common values can be identified from the known vessels. For numerical values, such as installed propulsion power, the average of the known vessels can be used, weighted by time spent within the geographical boundary if known or weighted by number of vessels otherwise. The following lists general considerations for performing a gap-filling analysis:

- Size indicators in the vessel characteristic data are DWT and/or gross tonnage for most ship types, except TEUs are used for container ships and number of vehicles are used for vehicle carriers. Table 3.4 shows which size indicator is used for each ship type when assigning ship subtypes. In some cases, gross tonnage is known, but DWT, TEUs, or number of vehicles is missing and needs to be gap filled in order to assign ship subtype. In these cases, the missing DWT, TEUs, or number of vehicles can be regressed from gross tonnage by ship type from vessels that are not missing these data. However, predicted values based on a regression analysis should be used only if they fall within the expected range of that ship type. If gross tonnage is also missing or if the data are not robust enough to support a regression analysis, ships can be assigned the average DWT, TEUs, or number of vehicles by ship type, and then can be accordingly assigned a subtype.
- Keel-laid year is used when determining the correct emission factors to assign to a vessel. In some cases, keel-laid year is missing, but vessel build year is known. In these cases, keel-laid year can be estimated from vessel build year by calculating the average difference between these two fields by ship subtype from vessels that are not missing these data. If the amount of time a vessel spends within the geographical boundary is known, the average difference should be time weighted.
- Engine category and type are also used when determining the correct emission factors to assign to a vessel. To gap fill these fields, the most common values should be determined from vessels that are not missing these data. Specifically:
    - If just engine type is missing, the most common value should be determined by ship type, subtype, and engine category.
    - If both engine category and type are missing, the most common value should be determined by ship type and subtype.
- Any other missing numeric parameters (such as maximum speed or maximum draft) can be filled using average values, calculated from vessels that are not missing these data and weighted by time spent within the geographical boundary. The time weighted average at the most

detailed grouping should be prioritized in gap-filling these fields, after which averages determined by less detailed groupings can be applied.

While there may be uncertainty in vessel characteristics for individual vessels, the process described above provides aggregate results that are useful for port-wide inventories.[21] If the data are not robust enough to support the above gap-filling analysis, or if this kind of analysis is not practical for other purposes, national average values listed in Appendix C can be assigned to vessels with missing vessel characteristics.

3.4 Vessel Activity Data Sources

There are many different data sources available to estimate vessel activity at U.S. ports. This section describes the most useful data sources for calculating emission inventories. These data sources generally include vessel identifiers, such as IMO number, which can be used to match vessel activity data with vessel characteristic data, as described in Section 3.3. This is important to assign the correct emission factors and to estimate engine load appropriately.

3.4.1 Automatic Identification System

AIS equipment is used on vessels to aid navigation and to avoid collisions by broadcasting and receiving messages. These messages contain dynamic operational data, which are automatically updated with every message and include the following fields:

- Position
- Bearing
- Speed

AIS data also contain static fields, which may be manually entered by the vessel operator. The static fields include (among others):

- IMO number
- MMSI
- Draft

Most OGV use AIS to comply with the *International Convention for the Safety of Life at Sea,*[16] which requires AIS to be fitted aboard all passenger vessels as well as vessels with gross tonnage of 300 or more that are involved in international trips. Therefore, an AIS analysis often provides good coverage of all OGV activity in a port.[b]

Before starting an AIS analysis, it is important to note that AIS data are typically noisy with some random variation in the dynamic data, missing messages, and potential inaccuracies in manually entered static data. However, the datasets are large, with messages for most C3 vessels usually recorded every 2 to 10 seconds while underway. Therefore, with appropriate aggregation, data cleaning techniques, and quality control checks, AIS is a good, detailed data source for estimating vessel activity. Section 3.8 describes how AIS speed and position data can be used to estimate time-in-mode (e.g., hours spent hotelling) and propulsion engine load. See Section 3.8.2 for AIS data cleaning techniques and Section

[b] For more general information on AIS, see https://www.navcen.uscg.gov/?pageName=AISmain.

3.8.9 for quality control checks. Note that AIS data do not contain information on auxiliary engine or boiler loads, which should be estimated using other methods (see Section 3.6).

AIS messages are recorded by the U.S. Coast Guard (USCG) as well as by commercial vendors for various purposes. Marine Cadastre is a joint initiative of the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration that provides publicly available AIS data derived from USCG records.[c] Alternatively, U.S. federal, state, local, and Tribal government agencies can request historical data from the USCG Navigation Center.[d] Depending on the data source, individual AIS records may be provided at their raw collected rate (e.g., 2 to 10 second intervals) or averaged records may be provided at longer intervals (e.g., 5 minute intervals). While a shorter interval will provide higher resolution and more precise determination of operating modes, it will also increase the size and complexity of the data set. The purpose of the emissions inventory should determine the level of AIS record aggregation. For example, a detailed inventory supporting air quality analysis may benefit from a shorter AIS time interval than an annual, port-wide inventory. Similarly, the geographical boundary of the emissions inventory should determine the geographical extent of the AIS data acquisition.

Note that there are two kinds of AIS receivers: terrestrial- and satellite-based. Depending on the data source, some AIS data sets may contain one or both types. Terrestrial-based AIS data sets usually have good coverage in and around U.S. ports, and include AIS messages at a higher frequency than satellite-based AIS data sets. However, they can only receive messages within line-of-sight. In contrast, satellite-based AIS data sets include messages at farther distances from shore, which may be important for inventories that have a broad geographical domain. Occasionally, in high traffic areas, terrestrial-based receivers may be unable to handle the load of recording all messages received and some records may be dropped. Combining terrestrial- and satellite-based AIS data can improve the total coverage of a given area. In general, if a dataset includes both terrestrial- and satellite-based data, and if there are AIS messages for the same vessel and timestamp from both kinds of receivers, the message from the terrestrial receiver should be used instead of the satellite receiver.

3.4.2 Local Logs

The local port authority, marine exchange, board of trade, or other local organizations may have information on local vessel movements. These data sources (referred to as “local logs”) usually include vessel identification data (such as IMO number and/or vessel name), and date and time of vessel arrival and departure. They may also record ship type, pier/wharf/dock information, cargo type, cargo tonnage, vessel draft, and other information. Generally, one record of data corresponds to one vessel call, although some data sets will also include vessel shifts between berths within the area of interest. These records may be able to provide time-in-mode estimates (e.g., hours spent hotelling) and whether tug support was involved during maneuvering.

If the purpose of the emissions inventory is to focus on only vessels that visit a port, or to quantify the differences in emissions between innocent passage and vessels that call at a port, local logs can be a primary data source to identify the specific vessels to be included in the inventory.

A potential limitation of local logs is that they may not include all OGV activity in a port. For example, a port authority might not collect data on vessels that call at private terminals. Additionally, local logs do

[c] For more information, see https://marinecadastre.gov/ais.
[d] For more information, see https://www.navcen.uscg.gov.

not contain information on innocent passage, propulsion engine loads, or auxiliary engine and boiler loads. The availability and cost of local logs vary by source.

3.4.3 Survey Data

Interviews with harbor pilots and/or surveys of vessels operating within the geographical domain can provide useful data for estimating emissions. For example, interviews with harbor pilots can provide a quality control check on average vessel speeds. Surveys of vessels can provide information on auxiliary engine and boiler loads, which are typically not available from the other data sources described in this section.

If there are not resources available to collect data directly on auxiliary engine and boiler loads by ship type, size, and operating mode (as described in Section 3.6), surrogate data sources will be needed. If a similar port[e] has recently conducted an inventory and collected these kinds of data, those could be used instead. Alternatively, defaults are discussed in Section 3.6, although these data do not reflect local operating conditions, which may impact auxiliary engine and boiler loads.

3.4.4 Entrances and Clearances

The U.S. Army Corps of Engineers (USACE) maintains the Vessel Entrances and Clearances (E&C) data set, which is part of the Waterborne Foreign Cargo series.[22] Records in this publicly available data source include vessel identification data (such as IMO number), type of vessel, vessel draft, and origin/destination of goods.

While this data source includes vessels that call at both public and private terminals, it only includes foreign vessel movements; U.S. ships delivering cargo from one U.S. port to another U.S. port are not accounted for in this data source. Instead, these vessel trips will appear in the Waterborne Commerce data set, described below.

A limitation of E&C data is that they do not contain information on vessel speed, hours spent hotelling, propulsion engine loads, or auxiliary engine and boiler loads.

3.4.5 Waterborne Commerce

USACE maintains the Waterborne Commerce Statistics (WCS) data set of domestic vessel movements.[f] The WCS data provide vessel trips for individual vessels and include vessel identification data, type of vessel, vessel draft, and trip route. These detailed data are available to U.S. Federal government agencies but note that the data are confidential business information and not available for public release.

A limitation of WCS data is that they do not contain information on vessel speed, hours spent hotelling, propulsion engine loads, or auxiliary engine and boiler loads. Additionally, this data source may not have good coverage of vessel activity unrelated to cargo movement (e.g., ferries).

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[e] Ideally, a "similar port" would be a different port in the same region with similar kinds and levels of activity. However, any port with similar kinds and levels of activity could have useful surrogate data. For example, a port with a lot of cruise ship activity could find useful data on cruise ship auxiliary engine and boiler loads from inventory work done at a different port with similar levels of cruise ship activity.

[f] For more information, see https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center.

3.5 Emission Factors

Emission factors vary by engine category (C1, C2, or C3), group (propulsion, auxiliary, or boiler), fuel type, keel-laid year, and engine type (SSD, MSD, GT, ST, LNG, or boiler). For inventories of 2015 activity and later, all diesel C3 marine vessels operating within the North American Emissions Control Area (ECA)[23] can be assumed to be using distillate marine gas oil (MGO) or marine diesel oil (MDO) to comply with fuel sulfur regulations, unless local data indicate that specific vessels are using residual marine (RM) or heavy fuel oil (HFO) with exhaust scrubbers. For inventories of activity before 2015, OGV can be assumed to be using RM/HFO.

Note that electric drive engines are not assigned distinct emission factors. For example, MSD-ED engines are assigned the same emission factors as MSD engines.

Emission factors for vessels with C3 propulsion engines, which comprise the majority of OGV, are given below. The tables include emission factors for C3 propulsion engines, as well as smaller auxiliary engines and boilers operating on C3 vessels. These emission factors apply for all C3 vessels, regardless if they are considered to be OGV or harbor craft. They reflect the latest information available and reflect implementation of the applicable EPA regulations. For OGV that have C1 or C2 propulsion engines, see Section 4.5 for the appropriate propulsion and auxiliary engine emission factors.

Speciation profiles of additional hazardous air pollutants for all commercial marine vessels are presented in Appendix D. For methods to estimate energy consumption for this source sector, see Appendix A.

3.5.1 Nitrogen Oxides (NOx)

NOx emission factors vary by engine group, fuel type, engine tier (as determined by keel-laid year), and engine type. Emission factors for vessels with C3 propulsion engines are presented in Table 3.5.[20]

Table 3.5. Category 3 Vessel NOx Emission Factors (g/kWh)

Engine Group	Fuel Type	Keel-laid Year (NOx Tier, if applicable)	Engine Type	NOx Emission Factor (g/kWh)	Source
Propulsion	MGO/MDO	Any	ST	2.0	24
			GT	5.7	24
		1999 and earlier*	SSD	17.0	24
			MSD	13.2	24
		2000–2010 (Tier I)	SSD	16.0	25
			MSD	12.2	25
		2011–2015 (Tier II)	SSD	14.4	25
			MSD	10.5	25
		2016 and later (Tier III)**	SSD	3.4	25
			MSD	2.6	25
	RM/HFO	Any	ST	2.1	24
			GT	6.1	24

Engine Group	Fuel Type	Keel-laid Year (NOx Tier, if applicable)	Engine Type	NOx Emission Factor (g/kWh)	Source
		1999 and earlier*	SSD	18.1	24
			MSD	14.0	24
		2000–2010 (Tier I)	SSD	17.0	26
			MSD	13.0	26
		2011–2015 (Tier II)	SSD	15.3	26
			MSD	11.2	26
		2016 and later (Tier III)**	SSD	3.6	25
			MSD	2.8	25
	LNG	Any	LNG	1.3	27
Auxiliary	MGO/MDO	1999 and earlier	MSD	13.8	25
			HSD	10.9	25
		2000–2010 (Tier I)	MSD	12.2	25
			HSD	9.8	25
		2011–2015 (Tier II)	MSD	10.5	25
			HSD	7.7	25
		2016 and later (Tier III)	MSD	2.6	25
			HSD	2.0	25
	RM/HFO	1999 and earlier	MSD	14.7	19
			HSD	11.6	19
		2000–2010 (Tier I)	MSD	13.0	19
			HSD	10.4	19
		2011–2015 (Tier II)	MSD	11.2	19
			HSD	8.2	19
		2016 and later (Tier III)	MSD	2.8	25
			HSD	2.1	25
	LNG	Any	LNG	1.3	27
Boiler	MGO/MDO	Any	Boiler	2.0	24
	RM/HFO			2.1	24

* Marine diesel engines with a power output of more than 5,000 kW and a per-cylinder displacement at or above 90 liters installed on a ship constructed between 1990 through 1999 are required to be rebuilt using an approved method certified to the MARPOL Annex VI Regulation 13.3 (Tier I) standards if such a method is available (Regulation 13.7 of the Convention; see reference 28). If it is known that a vessel in this category has had an approved method applied to its propulsion engine, the corresponding Tier I emission factor instead of the uncontrolled emission factor should be used.

** Tier III propulsion engines operating below 25% load should be assigned the corresponding Tier II emission factor.

When a vessel with a Tier III propulsion engine is operating at less than 25% load, it is likely that the exhaust temperature is too low for the emissions control technologies to work as intended. Therefore, vessels with Tier III propulsion engines should be assigned the corresponding Tier II emission factors when the vessel's propulsion load is less than 25% of its total installed propulsion power.[25]

3.5.2 Brake Specific Fuel Consumption (BSFC)

BSFC rates vary by engine group, fuel type, and engine type. Note that particulate matter, carbon dioxide, and sulfur dioxide are calculated based on these values. BSFC rates for vessels with C3 propulsion engines are presented in Table 3.6.

Table 3.6. Category 3 Vessel BSFC Rates (g/kWh)

Engine Group	Fuel Type	Engine Type	BSFC (g/kWh)	Source
Propulsion	MGO/MDO	SSD	185	29
		MSD	205	29
		ST	300	29
		GT	300	29
	RM/HFO	SSD	195	29
		MSD	215	29
		ST	305	29
		GT	305	29
	LNG	LNG	166	30
Auxiliary	MGO/MDO	MSD	217	29
		HSD	217	29
	RM/HFO	MSD	227	29
		HSD	227	29
	LNG	LNG	166	30
Boiler	MGO/MDO	Boiler	300	29
	RM/HFO		305	29

3.5.3 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC)

PM_{10} C3 emission factors are calculated for SSD and MSD propulsion and auxiliary engines and boilers according to Equation 3.3:

$$EF_{PM_{10}} = PM_{base} + (S_{act} \times BSFC \times FSC \times MWR) \qquad \textbf{Equation 3.3}$$

Where $EF_{PM_{10}}$ = PM_{10} emission factor adjusted for fuel sulfur (g/kWh)
PM_{base} = Base emission factor assuming zero fuel sulfur
= 0.1545 g/kWh for distillate fuel (MGO and MDO)
= 0.5761 g/kWh for residual fuel (RM and HFO)
S_{act} = actual fuel sulfur level (weight ratio)
= 0.001 for most vessel activity within the ECA in 2015 and beyond

= 0.027 for all vessel activity outside the ECA before 2020
= 0.005 for all vessel activity outside the ECA in 2020 and beyond

$BSFC$ = brake specific fuel consumption (g/kWh) as calculated according to Section 3.5.2

FSC = fraction of sulfur in fuel that is converted to direct sulfate PM[20]
= 0.02247

MWR = molecular weight ratio of sulfate PM to sulfur
= 224/32 = 7

The base PM_{10} emission factor assuming zero fuel sulfur is from the 2017 NEI.[32] In the ECA, fuel is required to have a maximum sulfur content of 0.1%. If local port data indicate that diesel with a sulfur content less than 0.1% is being used, or if the inventory is being calculated for an earlier year than 2015, the actual fuel sulfur level should be used in the Equation 3.3. If the port has a low sulfur fuel program for OGV in the base year, the proportion of vessels using the lower sulfur fuel should be accounted for when determining the actual fuel sulfur level. Additionally, if there is a formal commitment to implement such a program in a future, projected future inventories should reflect the anticipated actual fuel sulfur level.

Equation 3.3 is not used for ST, GT, and LNG engines. Instead, the PM_{10} emission factors for these engines are presented in Table 3.7.

Table 3.7. PM_{10} Emission Factors (g/kWh) for ST, GT, and LNG Engines on OGV

Fuel Type	Engine Type	PM_{10} Emission Factor (g/kWh)	Source
MGO/MDO	ST	0.16	29
	GT	0.01	29
RM/HFO	ST	0.93	29
	GT	0.06	29
LNG	LNG	0.03	27

For all compression ignition engines, DPM_{10} emission factors are identical to PM_{10} emission factors. Note that DPM emission factors are not applicable to boilers, ST, GT, or LNG engines because they are not diesel engines.

For all C3 engines, $PM_{2.5}$ and $DPM_{2.5}$ emission factors should be calculated as 92% of the PM_{10} and DPM_{10} emission factors, respectively.[20] BC emission factors should be calculated as 3% of $PM_{2.5}$ emission factors for C3 engines.[33] [34]

3.5.4 Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Methane (CH_4)

Hydrocarbon (HC) and CO emission factors for vessels with C3 propulsion engines vary by engine group and type and these factors are presented in Table 3.8. VOC and CH_4 emission factors are derived from the HC emission factors, as described below.

Table 3.8. Category 3 Vessel HC and CO Emission Factors (g/kWh)

Engine Group	Engine Type	HC Emission Factor (g/kWh)	CO Emission Factor (g/kWh)	Source
Propulsion	SSD	0.6	1.4	20
	MSD	0.5	1.1	20
	ST	0.1	0.2	20
	GT	0.1	0.2	20
	LNG	0.0	1.3	27
Auxiliary	MSD	0.4	1.1	25
	HSD	0.4	0.9	25
	LNG	0.0	1.3	27
Boiler	Boiler	0.1	0.2	25

VOC emission factors should be calculated as 1.053 times the HC emission factors.[17] CH_4 emission factors should be calculated as 2% of HC emission factors.[29]

3.5.5 Nitrous Oxide (N_2O)

N_2O emission factors for vessels with C3 propulsion engines vary by engine group and type and these factors are presented in Table 3.9.

Table 3.9. Category 3 Vessel N_2O Emission Factors (g/kWh)

Engine Group	Fuel Type	Engine Type	N_2O Emission Factor (g/kWh)	Source
Propulsion	MGO/MDO	SSD	0.029	25
		MSD	0.029	25
		ST	0.075	25
		GT	0.075	25
	RM/HFO	SSD	0.031	29
		MSD	0.031	29
		ST	0.080	29
		GT	0.080	29
Auxiliary	MGO/MDO	MSD	0.029	25
		HSD	0.029	25
	RM/HFO	MSD	0.031	29
		HSD	0.031	29
Boiler	MGO/MDO	Boiler	0.075	25
	RM/HFO		0.080	29

Lacking better data on N_2O emissions from LNG engines, this emission factor can be assumed to be the same as that for SSD engines using MDO fuel: 0.029 g/kWh.

3.5.6 Carbon Dioxide (CO_2)

CO_2 emission factors depend on BSFC rates and fuel type and should be calculated for vessels with C3 propulsion engines according to Equation 3.4:

$$EF_{CO_2} = BSFC \times CCF \qquad \textbf{Equation 3.4}$$

Where EF_{CO_2} = CO_2 emission factor (g/kWh)
$BSFC$ = brake specific fuel consumption (g/kWh) as calculated according to Section 3.5.2
CCF = carbon content factor,[19] which varies by fuel type (g CO_2/g fuel)
= 3.206 for MGO/MDO
= 3.114 for RM/HFO
= 2.75 for LNG

3.5.7 Sulfur Dioxide (SO_2)

SO_2 emission factors should be calculated according to Equation 3.5:

$$EF_{SO_2} = BSFC \times S_{act} \times FSC \times MWR \qquad \textbf{Equation 3.5}$$

Where EF_{SO_2} = SO_2 emission factor (g/kWh)
$BSFC$ = brake specific fuel consumption (g/kWh) as calculated according to Section 3.5.2
S_{act} = actual fuel sulfur level (weight ratio)
= 0.001 for most vessel activity within the ECA in 2015 and beyond
= 0.027 for all vessel activity outside the ECA before 2020
= 0.005 for all vessel activity outside the ECA in 2020 and beyond
FSC = fraction of sulfur in fuel that is converted to SO_2[20]
= 0.97753
MWR = molecular weight ratio of SO_2 to sulfur
= 64/32 = 2

If local port data indicate that diesel with a sulfur content less than 0.1% is being used, or if the inventory is being calculated for an earlier year than 2015, the actual fuel sulfur level should be used in Equation 3.5. If the port has a low sulfur fuel program for OGV in the base year, the proportion of vessels using the lower sulfur fuel should be accounted for when determining the actual fuel sulfur level. Additionally, if there is a formal commitment to implement such a program in a future, projected future inventories should reflect the anticipated actual fuel sulfur level.

3.6 Auxiliary Engine and Boiler Loads by Operating Mode

Auxiliary engines support electrical generators for auxiliary vessel power, and boilers provide heat and steam on vessels for a variety of purposes.[g] Unlike propulsion engine loads (the calculation of which is

[g] Another group of engines that could be present on OGV are maneuvering thrusters, which provide transverse propulsive forces for vessels and are also known as bow or stern thrusters. While engines that provide power to maneuvering thrusters are regulated as propulsion engines, these loads are usually included in the auxiliary engine loads for modeling purposes.

discussed in Sections 3.8 and 3.9), auxiliary engine and boiler usage cannot be obtained from vessel activity data sets. In addition, these engines are generally not included in vessel characterization data sets.

If resources allow, data on auxiliary engine and boiler loads (in kW) can be directly collected from the vessels operating in the geographical domain via surveys, interviews, or other data collection methods. If a similar port has recently conducted an inventory and collected these kinds of data, those could be used instead. Alternatively, the default auxiliary engine and boiler loads presented in the *Third IMO Greenhouse Gas Study*[19] can be used, which are presented in Appendix E by operating mode. Note that auxiliary engine and boiler usage typically vary by operating mode, which are described below.

3.6.1 Transit

The transit operating mode covers vessels moving within the geographical domain, but outside the breakwater[h] or restricted speed zone. Auxiliary engine usage is generally low in this operating mode, and boilers are typically not running in this operating mode for most ship types. Instead, auxiliary power is pulled off of the main engine.

3.6.2 Maneuvering

The maneuvering operating mode covers vessels moving between the breakwater and the pier/wharf/dock or anchorage zone. OGV moving in this mode are frequently assisted by tugs or towboats. If a vessel shifts between different piers/wharfs/docks or anchorage zones, it is usually moving in this operating mode. Auxiliary and maneuvering thruster usage is expected to be high in this operating mode, and boilers are also often used in this mode as main engine power is reduced.

3.6.3 Restricted Speed Zone

The restricted speed zone operating mode generally covers vessels moving at speeds between those of transit and maneuvering. Some restricted speed zones have enforced speed limits, whereas others are voluntary. Not all ports have this operating mode (e.g., if the only area of the port with speed limits is within the maneuvering area, it has the maneuvering operating mode and not the restricted speed zone operating mode). Auxiliary engine and boiler usage in this operating mode is usually similar to the transit operating mode.

3.6.4 Hotelling

The hotelling operating mode covers vessels that are moored, berthed, or docked at a pier/wharf/dock. When hotelling, a vessel either uses its auxiliary engines and boilers, or it uses shore power if available and the ship is equipped to use it (this is also known as cold ironing[i]). Propulsion engines are not used in this mode. Auxiliary engine and boiler usage in this operating mode is expected to be high if not using shore power, particularly for self-unloading vessels. Note that auxiliary and boiler usage may be different for loading and unloading activity, so it is useful to make this distinction when collecting local data, if possible.

[h] The breakwater is a geographical marker for the change from open water to inland waterway. For ports that do not have a physical breakwater, the point at which ships enter the restricted speed zone or where ships slow down to start maneuvering operations should be used instead.

[i] Shore power is a strategy to reduce auxiliary engine emissions while a ship is dockside by "plugging in" to electrical power sources on shore. For more information, see reference 31.

3.6.5 Anchorage

This operating mode covers vessels that are at anchor. Many ports have specified anchorage zones. While at anchor, a vessel uses its auxiliary engines and boilers; propulsion engines are not used in this mode. Auxiliary engine and boiler usage in this operating mode varies by ship type and size.

3.7 Low Load Adjustment Factors

The propulsion engine emission factors presented in Section 3.5 assume that the vessel's propulsion load is more than 20% of its total installed propulsion power. Below that threshold, emissions per unit of energy tend to increase as the engine load decreases. This is because diesel engines are less efficient at low loads and BSFC tends to increase. To account for this, low load adjustment factors (LLAFs) should be applied in Equation 3.1 when the propulsion engines are operating at less than 20% load. Table 3.10 presents LLAF by propulsion engine load and pollutant.[20] Sections 3.8 and 3.9 discuss how these LLAFs should be incorporated in the inventory calculations in further detail.

The PM low load adjustment applies to PM_{10}, $PM_{2.5}$, DPM_{10}, $DPM_{2.5}$, and BC emissions. The NOx adjustment also applies to N_2O emissions, and the HC adjustment also applies to VOC and CH_4 emissions. Note that the SO_2 LLAF depends on the fuel sulfur content. If a fuel with a sulfur level other than 0.1% is used, use the equations in Appendix F to calculate the SO_2 LLAF. These equations were used to generate the factors in this table.

Auxiliary and electric drive (MSD-ED or GT-ED) engines do not need low load adjustment factors because of the way they are generally operated: when power needs are reduced, one or more engines are shut off and the remaining engines can then be operated at a more efficient level. Additionally, LLAFs are not applied to boilers.

If engine-specific load adjustment factors are available for vessels with known engine data, they may be used instead of the low load adjustment factors presented here. For example, load adjustment factors for MAN 2-stroke engines with slide valves (from 2004 and later) are available.[25] If vessels known to have this kind of engine are operating in the geographical domain, those specific vessels should use the corresponding load adjustment factors instead of the low load adjustment factors in Table 3.10.[j]

Table 3.10. C3 Propulsion Engine Low Load Adjustment Factors (unitless)

Propulsion Engine Load Factor	NOx	HC	CO	PM	CO_2*	SO_2 (0.1% fuel sulfur content)
≤ 2%	4.63	21.18	9.68	7.29	3.28	9.54
3%	2.92	11.68	6.46	4.33	2.44	6.38
4%	2.21	7.71	4.86	3.09	2.01	4.79
5%	1.83	5.61	3.89	2.44	1.76	3.85
6%	1.60	4.35	3.25	2.04	1.59	3.21
7%	1.45	3.52	2.79	1.79	1.47	2.76

[j] Note that the load adjustment factors may be applicable to a broader range of propulsion engine load factors than the low load condition (<20% load factor) discussed here. For example, the load adjustment factors presented in reference **Error! Reference source not found.** apply to all loads (0% to 100%).

Propulsion Engine Load Factor	NOx	HC	CO	PM	CO_2*	SO_2 (0.1% fuel sulfur content)
8%	1.35	2.95	2.45	1.61	1.38	2.42
9%	1.27	2.52	2.18	1.48	1.31	2.16
10%	1.22	2.20	1.96	1.38	1.25	1.95
11%	1.17	1.96	1.79	1.30	1.21	1.78
12%	1.14	1.76	1.64	1.24	1.17	1.63
13%	1.11	1.60	1.52	1.19	1.14	1.51
14%	1.08	1.47	1.41	1.15	1.11	1.41
15%	1.06	1.36	1.32	1.11	1.08	1.32
16%	1.05	1.26	1.24	1.08	1.06	1.24
17%	1.03	1.18	1.17	1.06	1.04	1.17
18%	1.02	1.11	1.11	1.04	1.03	1.11
19%	1.01	1.05	1.05	1.02	1.01	1.05
≥ 20%	1.00	1.00	1.00	1.00	1.00	1.00

* Note that there is no LLAF for fuel consumption. It is expected that BSFC increases at low loads, but because BSFC is used in the emission factor equations for different pollutants, LLAF should not be applied to the BSFC rates. Instead, LLAF should be applied separately for each pollutant using Equation 3.1.

3.8 AIS Inventory Calculations

A detailed emissions inventory can be calculated using AIS activity data from the base year. In general, the base year inventory calculation is done at the AIS record level through the following steps:

1. Link each AIS record to vessel characteristic data
2. Clean AIS data
3. Fill temporal gaps in AIS activity
4. Calculate propulsion engine operating power and load factor
5. Assign operating mode
6. Calculate propulsion engine emissions
7. Calculate auxiliary engine and boiler emissions
8. Aggregate emissions
9. Perform quality control checks

The subsections below explain each of these steps in further detail.

3.8.1 Link Each AIS Record to Vessel Characteristic Data

Each AIS record contains vessel identification fields that can be used to link the AIS activity data to vessel characteristic data. This is important not only for calculating emissions, but also for data cleaning and quality control steps as well. Section 3.3 describes how vessel identifiers can be used to determine the engine and vessel characteristics, and how to fill missing vessel characteristic data.

3.8.2 Clean AIS Data

It is not uncommon for AIS data to contain errors or extraneous data that need to be identified and addressed before emissions can be calculated. The source of the AIS data will affect the amount of data cleaning that will be involved. Some AIS vendors include data cleaning in their processes, while others supply raw data that need more cleaning. While this is not a comprehensive list of all AIS data cleaning procedures, the following list describes commonly performed cleaning steps:

- Remove records for vessels that are not identified as OGV operating within the geographical boundary. Note that these records may be useful for a harbor craft or recreational marine inventory, but not an OGV inventory.
- Remove records where the coordinates appear outside the inventory's geographical boundary.
- Remove duplicate records (records with identical timestamps and vessel identifiers).
- Examine records with the following AIS-reported speed issues:
    - Records with speeds above 1.5 times the maximum speed of the vessel should instead use the maximum speed.
    - Remove records with changes in speed, as compared to the previous record for the vessel, that exceed 10% of the maximum speed if the interval between records is 5 minutes or less.
    - Remove records with changes in speed, as compared to the previous record for the vessel, that exceed 20% of the maximum speed if the interval between is 10 minutes or less.

Depending on the purposes of the emissions inventory, additional data processing at this phase may be desired. For example, if an inventory needs to differentiate between vessels that call at the port and innocent passage, AIS records will need to be marked accordingly. This step can be processed in different ways:

- Matching AIS records to local logs, Entrances & Clearances data, or Waterborne Commerce data, or
- Identifying individual vessel trips in the AIS records, geofencing berths within the geographical boundary, and flagging every record in the trip if any of the records show the vessel entering them.

3.8.3 Fill Temporal Gaps in AIS Activity

Temporal gaps between AIS records may occur for a variety of reasons, including:

- The vessel left the geographical domain
- The vessel's AIS transponder malfunctioned or was turned off
- Records were removed as part of the cleaning process described above

A gap due to a vessel leaving the geographical domain can be identified by extrapolating vessel activity, assuming a constant speed and heading from the last record before the gap.[k] If the extrapolated position is outside the geographical domain, then the gap should not be filled, and emissions should not be calculated for it. However, gaps occuring for other reasons should be filled in by interpolating

[k] If the last record before the gap has unknown speed, average vessel speed by ship type based on other vessels operating in the same localized area can be used instead.

location, speed, and draft data at the expected frequency of the AIS records (e.g., if the AIS data has been aggregated to 5-minute intervals, the gaps should be filled in by interpolating the data at 5-minute intervals).

After filling the temporal gaps, each AIS record can be assumed to represent the same time interval (e.g., 5 minutes), which will be used when calculating the emissions of each record as described in the following sections.

3.8.4 Calculate Propulsion Engine Operating Power and Load Factor

Propulsion engine operating power and load factor should be calculated for each AIS record. There are several methods that can be used to estimate a vessel's propulsion engine operating power. One such method is the propeller law, which estimates that propulsion engine operating power varies with the cube of vessel speed.[35] While this does not account for vessel draft or hull resistance, which can significantly affect ship propulsion load, it relies on few vessel characteristics and is easy to calculate. The propeller law can be used to estimate a vessel's operating power for each AIS record as shown in Equation 3.6:

$$P_p = P_{ref} \times \left(\frac{V}{V_{ref}}\right)^3 \times SM \qquad \textbf{Equation 3.6}$$

Where P_p = propulsion engine operating power (kW)
P_{ref} = vessel's total installed propulsion power (kW)
V = AIS-reported speed before the record interval (kn)
V_{ref} = vessel's maximum speed (kn)
SM = sea margin, which accounts for average weather conditions, assumed to be 1.10 for coastal operations and 1.15 for at-sea operations (unitless)

An improvement on the propeller law is the admiralty formula,[19] which also includes terms for the impact of draft on propulsion power as shown in Equation 3.7:

$$P_p = P_{ref} \times \left(\frac{V}{V_{ref}}\right)^3 \times \left(\frac{D}{D_{ref}}\right)^{\frac{2}{3}} \times SM \qquad \textbf{Equation 3.7}$$

Where P_p = propulsion engine operating power (kW)
P_{ref} = vessel's total installed propulsion power (kW)
V = AIS-reported speed before the record interval (kn)
V_{ref} = vessel's maximum speed (kn)
D = AIS-reported draft before the record interval (m)
D_{ref} = vessel's maximum draft (m)
SM = sea margin, which accounts for average weather conditions, assumed to be 1.10 for coastal operations and 1.15 at-sea operations (unitless)

The admiralty formula is preferred over the propeller law when the vessel's draft is known.[l] If it is unavailable or if the data quality is highly uncertain, the vessel can be assumed to be operating at maximum draft, in which case the propeller law and admiralty formula yield the same result, as the propeller law is an upper bound for the admiralty formula.

Note that both the propeller law and admiralty formula include a sea margin (SM). Resistance from waves and wind puts additional load on the propeller, which increases the propulsion engine operating power. While the exact weather conditions associated with every AIS record would impact the value of this term, a simplified approach is recommended that uses annual average values of 1.10 for coastal operations and 1.15 for at-sea operations (representing a 10% and 15% increase in engine load, respectively).[19 35] At-sea operations have a higher average value, as they are expected to experience more extreme environmental conditions.

Regardless of which method is used to calculate the instantaneous power, the chosen method should be clearly indicated in the documentation for the resulting inventory. In addition, the maximum limit of the result should be set to the vessel's total installed propulsion power (P_{ref}), such that its load factor does not exceed 100%. Load factor describes how much power an engine is producing as a fraction of its maximum rated power. It is also used to determine the vessel's operating mode (see Section 3.8.5) and to determine if low load adjustment factors need to be applied when calculating propulsion engine emissions. The propulsion engine load factor should be calculated for each AIS record as shown Equation 3.8:

$$LF = \frac{P_p}{P_{ref}} \qquad \textbf{Equation 3.8}$$

Where LF = propulsion engine load factor (unitless)
P_p = propulsion engine operating power for each AIS record (kW), from Equation 3.6 or Equation 3.7
P_{ref} = vessel's total installed propulsion power (kW)

3.8.5 Assign Operating Mode

The ship's operating mode should be determined for each AIS record, as this information is used to determine if the propulsion engine is being used, as well as to calculate auxiliary engine and boiler emissions as described in Section 3.8.7. This is best done considering both geographical and speed data from each AIS record, because operating modes are generally associated with certain locations within the port. To help determine operating mode, each area of interest within the port where specific operating modes are observed (e.g., the maneuvering area between the breakwater and each pier/wharf/dock) can be defined as a polygon using geographic information system (GIS) software. Each AIS record can then be flagged according to the area of interest where it appears, so this information can be considered along with speed and load in determining operating mode. General considerations for determining a vessel's operating mode for each AIS record are listed in Table 3.11. Note that the determination of operating mode relies on port-specific characteristics, and not all ports have activity in

[l] There are other methods available to estimate propulsion engine load based on vessel hull resistances. However, the admiralty formula provides a reasonable estimate of engine load using few vessel parameters and is therefore the preferred approach for individual port inventories.

all of the operating modes presented in this table (e.g., some ports may not have a restricted speed zone, so they may not have activity in that operating mode).

Table 3.11. Considerations for Determining Operating Mode

Operating Mode	Geospatial Considerations	General Speed Considerations	General Propulsion Engine Load Factor Considerations
Transit	Outside the breakwater or restricted speed zone	> 1 kn	> 20%
Maneuvering	Between the breakwater and pier/wharf/dock or anchorage zone	> 1 kn	≤ 20%
Restricted Speed Zone	Varies by port	Varies by port	Varies by port
Hotelling	At a pier/wharf/dock	≤ 1 kn	N/A
Anchorage	In an anchorage zone	≤ 3 kn	N/A

3.8.6 Calculate Propulsion Engine Emissions

Propulsion engine emissions are calculated for each time interval between consecutive AIS records for each vessel using Equation 3.9:

$$E_p = P_p \times A \times EF \times LLAF \qquad \textbf{Equation 3.9}$$

Where E_p = propulsion engine emissions for each AIS record (g)
P_p = propulsion engine operating power for each AIS record (kW), from Equation 3.6 or Equation 3.7
A = time interval between consecutive AIS records (h)
EF = emission factor (g/kWh)
$LLAF$ = low load adjustment factor determined for each AIS record (unitless)

Propulsion engine emission factors (as described in Section 3.5) should be assigned to each vessel based on its engine characteristics and the actual sulfur level of the fuel used. If the load factor for an individual AIS record is less than 20%, the low load adjustment factors should be applied as described in Section 3.7.[m] Note that propulsion engine emissions should only be calculated for AIS records that are determined to be in the transit, maneuvering, or restricted speed zone operating modes (i.e., propulsion engines can be assumed to be off while hotelling or at anchor).

These emissions can be then aggregated at the most useful level for the purposes of the inventory. This process is discussed in further detail in Section 3.8.8.

[m] As described in Section 3.7, if engine-specific load adjustment factors are available for vessels with known engine data, they may be used instead of the low load adjustment factors provided in Table 3.10. Note that the load adjustment factors may be applicable to a broader range of propulsion engine load factors than the low load (<20% load factor) condition discussed here.

3.8.7 Calculate Auxiliary Engine and Boiler Emissions

Auxiliary engine and boiler emission factors should be assigned to each vessel based on the actual sulfur level used in the geographical domain as described in Section 3.5. Then, auxiliary engine and boiler loads should be estimated for each operating mode as described in Section 3.6. With this information, emissions for auxiliary engines should be calculated for each time interval between consecutive AIS records for each vessel using Equation 3.10:

$$E_a = P_a \times A \times EF \qquad \textbf{Equation 3.10}$$

Where E_a = auxiliary engine emissions for each AIS record (g)
P_a = auxiliary engine operating power for each AIS record based on operating mode (kW)
A = time interval between consecutive AIS records (h)
EF = emission factor (g/kWh)

Emissions for boilers should be calculated for each time interval between consecutive AIS records for each vessel using Equation 3.11:

$$E_b = P_b \times A \times EF \qquad \textbf{Equation 3.11}$$

Where E_b = boiler emissions for each AIS record (g)
P_b = boiler load for each AIS record based on operating mode (kW)
A = time interval between consecutive AIS records (h)
EF = emission factor (g/kWh)

3.8.8 Aggregate Emissions

Total emissions for each time interval between consecutive AIS records should be calculated using Equation 3.12:

$$E = E_p + E_a + E_b \qquad \textbf{Equation 3.12}$$

Where E = total emissions for each AIS record (g)
E_p = propulsion engine emissions for each AIS record (g) from Equation 3.9
E_a = auxiliary engine emissions for each AIS record (g) from Equation 3.10
E_b = boiler emissions for each AIS record (g) from Equation 3.11

The total emissions at the AIS record level can then be aggregated to the most useful level for the purposes of the inventory:

- For an annual inventory without a need for spatial considerations, all emissions of a particular pollutant can be summed together. Note that even for annual inventories, reporting more detailed emissions in addition to the annual results can be useful as described below in Section 3.8.9.
- If the inventory has a spatial component to it, the emissions calculated at the AIS record level should be allocated to the location of the record before the interval. These emissions can then be summed to the most useful spatial resolution for the purpose of the inventory (e.g., 100 m^2 grid cells for a detailed analysis or summed for the entire port for planning purposes).

- Similarly, if the inventory has a temporal component to it, the emissions calculated at the AIS record level should be allocated to the timestamp of the record before the interval. These emissions can then be summed to the most useful resolution for the purpose of the inventory (e.g., at the hourly level for a detailed analysis).

3.8.9 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of vessel activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by ship type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Distributions of vessel speed, vessel draft, and propulsion load factor: Examining these distributions allow for general checks to ensure that vessels are modeled to be operating within reasonable limits and with expected patterns of behavior. For example, tankers often have a bi-modal draft distribution, which reflects activity where a full vessel offloads its cargo and then departs empty.
- Vessel counts, number of trips, and total operating hours: Examining these values provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Installed power: Examining this helps to estimate the relative impact that a given ship type should have on the inventory. For example, container ships tend to have relatively large engines, and so may contribute more emissions than their activity might otherwise suggest.
- Hotelling hours and anchorage hours by ship subtype: Examining both totals and distributions provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Total energy consumption (kWh) for propulsion engines and for auxiliary engines: Examining energy consumption by ship type and engine group provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.

Other quality control checks include:

- Comparing the distribution of propulsion load factor with relative vessel speed (i.e., speed divided by maximum speed): This is a normalized map of engine load vs. vessel speed, with both axes ranging from 0 to 1, and it should show a roughly cubic relationship between these parameters.
- Examining geospatial heatmaps of energy consumption: This helps identify if there are gaps in the AIS data, or if there are anomalies in the data such as vessels being allocated to land or shallow regions where they should be unable to operate. This check also helps identify issues with the algorithms used for temporal gap-filling and can be used to fine-tune the gap-filling methods.

- For annual inventories, examining emissions per day by ship type over the course of the year: This helps identify anomalies in input data that significantly impact emissions over a short period of time. For example, if a ship is in harbor for an extended period (i.e., much longer than it normally takes to load/unload a ship of its size), its auxiliary engines are not likely running the entire time. If this case is not correctly handled when filling temporal gaps (as discussed in Section 3.8.3), examining emissions by ship type as a time series may show changes of several orders of magnitude that warrant a closer review. Similarly, if a local AIS receiver experiences data recording issues, no AIS messages may be logged, which could have a significant impact on emissions calculated for the duration.
- Searching for transitions between operating modes that are unlikely: This check at the AIS record level for transitions such as going from hotelling directly to transit can identify anomalies in the data that warrant a closer review.
- Searching for rapid toggling between modes: This check at the AIS record level for irregularities such as switching between hotelling and maneuvering too frequently can identify anomalies in the data that warrant a closer review.
- Searching for vessel positions outside the geographical domain: This check at the AIS record level can identify any AIS messages or gap filled records that should not be included in the inventory.
- Correcting for vessels whose drafts are deeper than the known channel limits: This check at the AIS record level for vessels with reported draft levels deeper than what is allowed in specific channels allows for those records to be corrected with a more reasonable draft estimate.

3.9 Alternative Inventory Calculations

An alternative method can be used to calculate a base year emissions inventory (e.g., if AIS data or the resources to process them are unavailable). This method relies on using the same vessel characteristics and emission factors as described above; however, the derivation of ship activity and propulsion power are different. In general, the emissions calculation is performed at the vessel trip level through the following steps:

1. Link each vessel call record to vessel characteristic data
2. Calculate activity by operating mode
3. Calculate propulsion engine operating power and emissions
4. Calculate auxiliary engine and boiler emissions
5. Aggregate emissions
6. Perform quality control checks

The subsections below explain each of these steps in further detail.

3.9.1 Link Each Vessel Call Record to Vessel Characteristic Data

In the alternative method, the primary data sources for vessel activity are local logs (vessel call records from the local port authority, marine exchange, board of trade, or other local organization); Entrances and Clearances data; and Waterborne Commerce data. These sources generally have vessel identification data that can be used to link the activity record to vessel characteristic data. Section 3.3 describes how the vessel identifiers can be used to determine the engine and vessel characteristics, and how to fill missing vessel characteristic data. If local logs are used in conjunction with Entrances and

Clearances and Waterborne Commerce, the data should be combined appropriately so that vessel calls are not double counted. For example, if an individual vessel call appears in more than one data set, emissions associated with this vessel call should still be counted only once.

Similarly, if alternative inventory calculations are performed to supplement an AIS analysis (e.g., if there is not full AIS data coverage), care will need to be taken to avoid vessel calls being double counted.

3.9.2 Calculate Activity by Operating Mode

Hours of engine operation need to be estimated for each vessel call by the various operating modes that a typical vessel call includes. The best source for this information is usually AIS data (see Section 3.8 for calculating inventories from AIS data). However, information from interviewing pilots and/or surveying vessels operating within the area of interest can also provide valuable data for these estimations.

Many variables affect one or more time-in-mode calculations. These variables cannot be accurately predicted for a ship type category over an entire year of calls. Traffic conditions, weather, vessel schedule, and current all affect how much time is spent in each operating mode. For example:

- Traffic conditions may make travel in the waterway slower because a wake is more damaging in a congested waterway, forcing vessels to be more careful and travel at slower speeds. In addition, docking at a pier/wharf/dock takes much longer on busy days, resulting in more time spent in the maneuvering operating mode.
- Bad weather in the form of high winds causes vessel maneuvering to be more difficult and less predictable. Rain and fog obscure visibility and can significantly reduce a vessel's maximum speed. Like congested conditions, bad weather increases the time it takes for vessels to dock, resulting in more time spent in the maneuvering operating mode.
- River or strait currents can also impact travel speeds, time-in-mode, and propulsion engine loads, depending on the direction of travel.
- Vessel schedule also affects time-in-mode. If a vessel is ahead of schedule, it may travel at slower speeds to conserve fuel and arrive closer to schedule. Conversely, if a vessel is behind schedule, it may travel at the maximum allowed speed to get back on schedule.

When calculating averages for time-in-mode by ship type, the effects of these types of issues should be included to ensure the averages are representative of annual activity. The following subsections provide additional information on how hours of operation can be estimated for each operating mode, which typically vary by ship type.

3.9.2.1 Transit

For each call, it can be assumed that each vessel is in the transit operating mode twice: once when it enters the area of interest and approaches the breakwater or restricted speed zone, and again when it leaves the breakwater or restricted speed zone. Local data sources may be able to provide transit speeds. If these are unavailable, average transit speeds derived by EPA from national 2017 AIS data can be used instead. Table 3.12 presents the most common transit speeds normalized by the vessel's maximum speed.

Table 3.12. Mode of National Transit Speed Ratios by Ship Type

Ship Type	Mode of Transit Speed Ratios
Bulk Carrier	0.76
Chemical Tanker	0.81
Container Ship	0.74
Cruise	0.75
Ferry/Passenger (C3)	0.93
Ferry/Roll-on/Passenger (C3)	0.93
Fishing (C3)	0.74
General Cargo	0.68
Liquified Gas Tanker	0.81
Miscellaneous (C3)	0.74
Offshore Support/Drillship	0.82
Oil Tanker	0.83
Other Tanker	0.78
Reefer	0.80
RORO	0.73
Yacht (C2/C3)	0.57

The typical distance traveled at this speed can be determined from typical shipping routes that are within the area of interest but outside the breakwater or restricted speed zone. Hours of operation in the transit operating mode per vessel call can then be calculated by dividing the distance traveled by the vessel speed.

3.9.2.2 Restricted Speed Zone

If a port has a restricted speed zone, it can be assumed that each vessel is in this operating mode twice: once on its way into the port, and once on its way out. Pilots can generally report the average vessel speed for restricted speed zones; however, lacking this data, a conservative estimate is to assume the vessels travel at the maximum speed allowed in the restricted speed zone. The typical distance traveled at this speed can be determined from typical shipping routes. Hours of operation in this operating mode per vessel call can then be calculated by dividing the distance traveled by the vessel speed.

If the restricted speed zone's speed limit is part of a voluntary program to reduce emissions, using AIS data and following the approach discussed in Section 3.8 would allow for more precision and result in a more valuable analysis of emissions in the restricted speed zone.

3.9.2.3 Maneuvering

For each call, it can be assumed that each vessel is in the maneuvering operating mode at least twice: once on its way into the port, and once on its way out. Average maneuvering speeds vary depending on direction and ship type (generally, outbound speeds are greater because the vessel does not need to dock). The speeds also depend on the location and the approach to the destination terminal and the

turning requirements of the vessel. Because of the expected variance in maneuvering speeds by ship type and size, these speeds should be estimated based on conversations with pilots. The typical distance traveled in this operating mode can be estimated as the average distance from the breakwater to each pier/wharf/dock. Hours of operation in this operating mode per vessel call can then be calculated by dividing the distance traveled by the vessel speed.

If the local logs also include information on vessel shifts (when a vessel moves from one pier/wharf/dock to another, typically at a different terminal), this can be used to determine additional maneuvering time.

3.9.2.4 Hotelling

The hours of operation in the hotelling operating mode can usually be determined from the local logs. They can be determined directly if the logs include timestamps when a vessel entered and left its berth. Other logs keep track of when a vessel enters and exits the breakwater. In this case, hours of hotelling can be calculated by determining the total time a vessel spent in port and subtracting time spent in the maneuvering operating mode. Lacking these data sources, hotelling times can also be determined from pilot records of vessel arrival and departure times. Hotelling times should be calculated separately for ships that are using shore power or other methods of reducing hotelling emissions and those that are not.

3.9.2.5 Anchorage

If possible, anchorage time (where a vessel is at anchor, but not at a pier/wharf/dock) should be determined separately from the hotelling operating mode. If these data are not available in the local logs, these may possibly be determined from pilot interviews.

3.9.3 Calculate Propulsion Engine Operating Power and Emissions

First, propulsion engine emission factors should be assigned to each vessel based on its engine characteristics and the actual sulfur level of the fuel used, as described in Section 3.5. Then, the propulsion engine operating power should be calculated for each vessel call and for each of the transit, reduced speed zone, and maneuvering operating modes. Finally, a low load adjustment factor should be assigned if necessary.

3.9.3.1 Propulsion Engine Operating Power

Several methods can be used to estimate a vessel's propulsion engine operating power. One method is the propeller law, which estimates that propulsion engine load varies with the cube of vessel speed.[35] While this does not account for vessel draft or hull resistance, which can significantly affect ship propulsion power, it relies on few vessel characteristics and is easy to calculate. The propeller law can be used to estimate a vessel's operating power for each of the transit, reduced speed zone, and maneuvering operating modes as shown in Equation 3.13:

$$P_{p,i} = P_{ref} \times \left(\frac{V_i}{V_{ref}}\right)^3 \times SM \qquad \textbf{Equation 3.13}$$

Where $P_{p,i}$ = propulsion engine operating power for operating mode i (kW)
P_{ref} = vessel's total installed propulsion power (kW)
V_i = average speed in operating mode i (kn)
V_{ref} = vessel's maximum speed (kn)

SM = sea margin, which accounts for average weather conditions, assumed to be 1.10 for coastal operations and 1.15 for at-sea operations (unitless)

If either V_i or V_{ref} are unknown, the transit speed ratios presented in Table 3.12 can be used in place of the V_i/V_{ref} term in Equation 3.13 (i.e., the values in the table should be cubed and multiplied by the vessel's total installed propulsion power to determine the vessel's operating power for the transit operating mode). If a vessel's draft is known, EPA recommends using the admiralty formula instead, as described in Section 3.8.4. Regardless of which method is used to calculate the propulsion engine operating power, the maximum limit of the result should be set to the vessel's total installed propulsion power.

Note that the propeller law includes a sea margin (SM). Resistance from waves and wind puts additional load on the propeller, which increases the propulsion engine operating power. The accepted annual average value for this term is 1.10 for coastal operations and 1.15 for at-sea operations (representing a 10% and 15% increase in engine load, respectively).[19] [35] At-sea operations have a higher average value, as they are expected to experience more extreme environmental conditions.

3.9.3.2 Calculating Load Factor and Determining Low Load Adjustment Factor

To determine if low load adjustment factors need to be applied, the propulsion engine load factor should be calculated at each operating mode as shown in Equation 3.14:

$$LF_i = \frac{P_{p,i}}{P_{ref}} \qquad \textbf{Equation 3.14}$$

Where LF_i = propulsion engine load factor for operating mode i (unitless)
$P_{p,i}$ = propulsion engine operating power for operating mode i (kW)
P_{ref} = vessel's total installed operating power (kW)

If the load factor is less than 20%, the low load adjustment factors should be applied as described in Section 3.7.

3.9.3.3 Calculating Propulsion Engine Emissions

Propulsion engine emissions are calculated for each vessel call and for each of the applicable operating modes using Equation 3.15:

$$E_{p,i} = P_{p,i} \times A_i \times EF \times LLAF_i \qquad \textbf{Equation 3.15}$$

Where $E_{p,i}$ = propulsion engine emissions for operating mode i (g)
$P_{p,i}$ = propulsion engine operating power for operating mode i (kW)
A_i = time spent in operating mode i (h)
EF = emission factor (g/kWh)
$LLAF$ = low load adjustment factor for operating mode i (unitless)

These emissions can be then aggregated at the most useful level for the purposes of the inventory. This process is discussed in further detail in Section 3.9.5.

3.9.4 Calculate Auxiliary and Boiler Emissions

First, auxiliary engine and boiler emission factors (as described in Section 3.5) should be assigned to each vessel based on its engine characteristics and the actual sulfur level of the fuel used. Then, auxiliary engine and boiler loads should be estimated for each operating mode as described in Section 3.6. Emissions for auxiliary engines should be calculated for each vessel call and for each operating mode using Equation 3.16:

$$E_{a,i} = P_{a,i} \times A_i \times EF \qquad \textbf{Equation 3.16}$$

Where $E_{a,i}$ = auxiliary emissions for operating mode i (g)
$P_{a,i}$ = auxiliary engine operating power for operating mode i (kW)
A_i = time spent in operating mode i (h)
EF = emission factor (g/kWh)

Emissions for boilers should be calculated for each vessel call and for each operating mode using Equation 3.17:

$$E_{b,i} = P_{b,i} \times A_i \times EF \qquad \textbf{Equation 3.17}$$

Where $E_{b,i}$ = boiler emissions for operating mode i (g)
$P_{b,i}$ = boiler load for operating mode i (kW)
A_i = time spent in operating mode i (h)
EF = emission factor (g/kWh)

3.9.5 Aggregate Emissions

Total emissions for each vessel should be calculated by operating mode using Equation 3.18:

$$E_i = E_{p,i} + E_{a,i} + E_{b,i} \qquad \textbf{Equation 3.18}$$

Where E_i = total emissions by vessel for operating mode i (g)
$E_{p,i}$ = propulsion engine emissions for operating mode i (g)
$E_{a,i}$ = auxiliary engine emissions for operating mode i (g)
$E_{b,i}$ = boiler emissions for operating mode i (g)

The total emissions for each vessel can then be aggregated to the most useful level for the purposes of the inventory:

- For an annual inventory without a need for spatial considerations, all emissions of a particular pollutant can be summed together. Note that even for annual inventories, reporting more detailed emissions in addition to the annual results can be useful as described below in Section 3.9.6.
- If the inventory has a spatial component to it, emissions by operating mode should be assigned as appropriate to shipping lanes or specific berths. Transit, restricted speed zone, and maneuvering emissions should be assigned to the typical path that vessels take entering and exiting port; hotelling and anchorage emissions should be assigned to the appropriate pier/wharf/dock or anchorage zone, respectively.

- If the inventory has a temporal component to it, the purpose of the inventory will direct the resolution needed. Because the vessel activity data used in the alternative inventory calculations are not as finely detailed as AIS, additional assumptions may need to be made to allocate emissions to a finer level of detail. In general, the temporal dimension of emissions by operating mode should be based on the timestamp of the vessel call offset by the time spent in the other operating modes.

3.9.6 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of vessel activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by ship type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Vessel speeds and operating hours by operating mode: Examining these values allow for general checks to ensure that vessels are modeled to be operating within reasonable limits and with expected patterns of behavior.
- Vessel counts and number of trips: Examining these values provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Installed power: Examining this helps to estimate the relative impact that a given ship type should have on the inventory. For example, container ships tend to have relatively large engines, and so may contribute more emissions than their activity might otherwise suggest.
- Total energy consumption: Examining energy consumption provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Outliers in hotelling times: Checking for vessels with abnormally long hotelling times is useful, because it may not be appropriate to include these when calculating averages as they may represent ships at a pier/wharf/dock that may not be running auxiliary engines for the entire time.

3.10 Projecting Future Emission Inventories

Future OGV emissions should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Activity growth rates are applied to the base year activity to estimate future activity
2. Vessel keel-laid dates are adjusted to account for fleet turnover to newer, cleaner engines and emission factors are reassigned
3. Projected emissions are calculated using the estimated future activity
4. Projected emissions are aggregated to the same level of detail as the base year inventory, as determined by the purpose of the inventory

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Projected changes in activity should be determined for each ship type. Local port projections or other regional forecasts are usually by commodity type and/or business sector; growth can be grouped by the ship types that carry the various commodities. Local port projections may also have information regarding expected future changes in vessel sizes or fleet composition.

If local port projections or other regional forecasts are unavailable, the Freight Analysis Framework (FAF)[15] can be used to forecast growth instead. If this is used, the commodity flows in the FAF assigned to the water transportation mode should be grouped by the appropriate ship type. For example, all commodity types that can be containerized should be included when determining the container vessel growth rates.[n]

The growth rates should be applied to the base year activity. If the original base year inventory was developed using AIS data, the growth rate for the appropriate ship type should be applied to the activity (kilowatt-hours) calculation for each AIS record. If the original inventory was developed using alternate sources of vessel activity, the growth rate should be applied to the hours of activity for each vessel in each operating mode.

To reflect fleet turnover, the vessel keel-laid dates used in the base year inventory should be adjusted for use in the future year inventory. If the port or local fleet operator has already identified an expected future age distribution, that should be used in determining how to adjust the keel-laid dates. If the future age distribution is unknown, it can be assumed to be the same as the base year age distribution. That is, it can be assumed that in the future, the percentages of vessels that are brand new, one year old, two years old, etc. are the same as those percentages in the base year inventory. Functionally, this can be implemented by adding the difference between the future and base years to each keel-laid date used in the base year inventory, to get a new set of keel-laid dates for the future year inventory. For example, if the base year inventory is for 2020 and the projected inventory is for 2030, the difference of 10 years is added to each keel-laid year. In this example, a keel-laid year 2005 vessel in the base year inventory would be a keel-laid year 2015 vessel in the 2030 inventory. Emission factors should be reassigned to all vessels using the adjusted keel-laid dates.[o] Similarly, to reflect changes in future vessel sizes, the distribution of vessel subtypes used in the base year inventory should be adjusted to account for the expected vessel sizes in the future year inventory.

Additionally, any planned action or emission reduction strategies that have been committed to that would affect future emissions should be included according to the actual expected implementation of such commitments. For example, if a port has committed to encouraging the use of LNG through authorization of funds for such a program, the target percentage of vessels using LNG should be used when assigning emission factors. Note that if the future year inventory is for a regulatory purpose,

[n] See Table K.1 in Appendix K for a description of common conveyance types by commodity type.

[o] Note that there is uncertainty regarding the implementation of Tier III, which reduces NOx emissions from engines on ocean-going vessels, both domestic and foreign. EPA may revise this document in the future to improve the modeling of NOx emissions from these engines when more is known about the implementation of Tier III.

planned future actions should be included only if written commitments have been made by the agency or operator with the power to implement them.

Once the base year activity has been scaled and appropriate emission factors are assigned to each vessel, the projected future emissions can be calculated using the same methodology at the same level of detail as the base year inventory.

4 HARBOR CRAFT

4.1 SOURCE DESCRIPTION

The harbor craft source sector covers all commercial marine vessels that are not ocean-going vessels (OGV). Unlike OGV, harbor craft typically spend most of their operating time in or near a single port or region. These vessels typically have Category 1 (C1) or Category 2 (C2) engines[a] and use distillate diesel fuel. While the methodologies listed in this section are generally similar to those described in the OGV section, this source sector focuses on commercial vessels that have different travel patterns than OGV. This distinction is important because harbor craft are frequently part of captive fleets owned by the port or a company operating them within the port or regional area, and their data sources and strategies for reducing their emissions can be different from the other source sectors. Table 4.1 lists the various ship types that comprise the harbor craft source sector. Note that there may be specialized types of harbor craft that do not appear on this list. The harbor craft source sector includes barges and other vessels that are not self-propelled. However, it does not include any vessels with gasoline engines or recreational diesel vessels; these are discussed in Section 5.[b]

In general, emissions from all harbor craft operating within the geographical domain for the inventory should be estimated. However, taking this approach may include innocent passage emissions, which are emissions that occur from vessel activity not related to the port(s) for which the inventory is being calculated (i.e., vessels just passing through the geographical domain). For the harbor craft source sector, innocent passage emissions are generally limited to barges moving through the geographical domain. Depending on the purpose of the inventory, it may be important to quantify emissions from innocent passage separately from all other harbor craft. See Section 2 of this guidance for more discussion about inventory purpose, geographical domains, and temporal detail.

Harbor craft typically have two kinds of emission sources:

- Propulsion engines, also referred to as main engines, which supply power to move the vessel
- Auxiliary engines, which supply power for non-propulsion loads

Table 4.1. Harbor Craft Ship Types

Ship Type	Description
Barge	Flat-bottomed vessels used to transport goods; typically not self-propelled, but may have auxiliary engines
Crew and Supply	Passenger vessels used to carry personnel and supplies to and from offshore and in-harbor locations
Dredging	Vessels that perform or assist in performing dredging activities
Excursion	Passenger vessels typically engaged in partial- or single-day specialty cruises

[a] Category 1 and 2 engines are marine engines with less than 30 liters displacement per cylinder (approximately 8 gallons).

[b] Note, some diesel vessels may appear to be recreational but are considered commercial for the purposes of the national marine diesel engine regulatory program. As explained in Section 5, the decision on whether to include these vessels with the commercial inventory may depend on local usage patterns.

Ship Type	Description
Fishing (C1/C2)*	C1 or C2 vessels used in commercial fishing operations
Government	Coast Guard, police, fire, or other government-owned vessels
Harbor Ferry (C1/C2)	Commercial C1 or C2 vessels used for passenger transport
Miscellaneous (C1/C2)	Commercial C1 or C2 vessels not otherwise designated in this list
Pilot	Vessels used to transport pilots to or from OGV
Towboat/Pushboat	Vessels used to push barges and pontoons; typically used in harbors and inland waterways
Tugboat	Vessels that assist maneuvering other vessels; can be used in open sea, inland waterways, and harbors
Work Boat	Vessels used for utility, inspection, survey, spill response, research, mining, training, and construction

* C1/C2 in a ship type designates that emissions from vessels of the specified ship type should be estimated according to the methodologies presented in this section if they have C1 or C2 propulsion engine(s). If they have C3 propulsion engine(s), their emissions should be estimated according to the methodologies presented in Section 3.

4.2 Emissions Estimation Overview

Harbor craft base year emissions from both propulsion and auxiliary engines can be determined for each vessel using Equation 4.1:

$$E = P \times LF \times A \times EF \qquad \textbf{Equation 4.1}$$

Where E = per vessel emissions (g)
P = engine power (kW)
LF = engine load factor (unitless)
A = engine operating activity (h)
EF = emission factor (g/kWh)

Each of the above parameters models a specific emissions source (propulsion or auxiliary engine) and thus will change for each vessel or vessel population. Therefore, it is important to accurately account for vessel characteristics (discussed in Section 4.3) and activity (Section 4.4) to ensure the operating power and hours are calculated correctly and that the right emission factors (Section 4.5) are applied to this activity.

There are different modeling methods that can be used to estimate harbor craft emissions for a base year emissions inventory depending on data and resource availability. The two methods described in this guidance are an Automatic Identification System (AIS) based approach (Section 4.7) and an alternative approach based on estimated annual operating hours (Section 4.8):

- With the AIS based approach, emissions are calculated for each vessel. Engine power (P) and load factor (LF) are assigned according to vessel characteristics; emission factors (EF) are assigned by engine category, model year, and other engine characteristics; and engine operating activity (A) is derived from AIS data as described in Section 4.7.

- The alternative approach relies on using the same vessel characteristics and emission factors as the AIS based approach; however, vessel activity (A) is derived from alternative sources, as described in Section 4.8.

The AIS approach allows for a highly detailed harbor craft inventory, which may be desirable for inventories that need a fine level of temporal or geospatial resolution (e.g., for air quality analyses or when analyzing the effectiveness of operational strategies to reduce emissions for harbor craft, where more detailed activity information would be important to consider). However, the alternative approach could be used (e.g., if the purpose of the inventory does not necessitate a fine level of detail, or if the AIS data do not fully cover harbor craft activity). Additionally, harbor craft activity may not be fully represented in AIS data for some ship types, therefore, harbor craft inventories may be calculated using the AIS approach for some ship types and using the alternative approach for others. If this dual approach is used, care should be taken to not double count emissions for the same vessel in both approaches.

Projections of future year emission inventories are discussed in Section 4.9.

4.3 Vessel Characteristics

Both the AIS and the alternative approach for estimating emissions involve data related to the characteristics of the vessels operating in the geographical domain. This information may be available for purchase in the form of vessel registry databases; however, local data sources such as port records and vessel surveys are the best source for harbor craft vessel characteristics. Federal databases[c] and online searches can supplement and validate these data. The following subsections detail the various data fields that comprise vessel characteristic data:

- Fields used to identify vessels to cross-reference various data sets (Section 4.3.1)
- Fields used to characterize engines to determine appropriate emission factors (Section 4.3.2)
- Fields used to determine ship type to fill data gaps and to group similar activity patterns (Section 4.3.3)

The final subsection (Section 4.3.4) discusses techniques to fill data gaps in vessel characteristic data sets.

4.3.1 Vessel Identification

All vessels have unique identifiers that can be used to match vessel activity data to vessel characteristic data. The following vessel identifiers are useful when matching harbor craft records in different data sets:

- International Maritime Organization (IMO) number
- Maritime Mobile Service Identity (MMSI)
- Vessel name
- Vessel call sign

[c] The U.S. Coast Guard maintains the following databases which may contain useful vessel characteristic data for estimating emissions: *Merchant Vessels of the United States* (accessible by searching https://www.dco.uscg.mil) and *U.S. Coast Guard Port State Information Exchange* (accessible at https://cgmix.uscg.mil/PSIX/Default.aspx).

The IMO number is generally the best field to use for vessel identification, as this number is uniquely assigned to each vessel under IMO resolutions[16] and does not change over its lifespan. However, if the IMO number is not available, the MMSI (which is uniquely assigned to each AIS transmitter) can also be used to match vessel records. However, care should be taken when doing so as MMSI is not a constant identifier and may change over the life of a vessel. If neither IMO number or MMSI are available, the vessel name or call sign can possibly be used to match vessel characteristics for harbor craft; however, this should be done with care as vessel names and call signs can change and are not necessarily unique identifiers.

4.3.2 Engine Characteristics

Emission factors for each emission source depend on engine category and tier, among other factors. The following data fields can be used to determine the vessel's propulsion engine characteristics:

- Engine category (C1, C2, or C3)
- Engine bore (the diameter of each engine cylinder)
- Engine stroke (the stroke length of each engine cylinder)
- Rated engine size (kW)
- Total installed propulsion power (kW)
- Engine model year
- Remanufacture year, if applicable

If the engine category field is missing from the vessel characteristic data, it can be determined by calculating cylinder displacement in liters using Equation 4.2, assuming the engine bore and stroke are measured in millimeters:

$$\text{Cylinder Displacement} = \frac{\pi}{4} \times \text{Bore}^2 \times \text{Stroke} \times 10^{-6} \qquad \textbf{Equation 4.2}$$

Table 4.2 lists how to determine if a vessel's propulsion engine is C1 or C2 from the cylinder displacement.[17 d] If engine tier is unknown, it can be determined using the information presented in Appendix B.

Table 4.2. Classifying C1 and C2 Engines

Engine Category	Engine Tier	Per-cylinder Displacement
1	Uncontrolled, 1, 2	displacement < 5 L
	3, 4	displacement < 7 L
2	Uncontrolled, 1, 2	5 L ≤ displacement < 30 L
	3, 4	7 L ≤ displacement < 30 L

Emission factors for most pollutants are assigned based on engine category, cylinder displacement, rated engine size, and engine model year (see Section 4.5 for more information). Engine model year can

[d] Some harbor craft, such as large tugs, may have C3 engines, as determined by having a per-cylinder displacement of 30 liters or more. Emissions from these vessels should be calculated as described in this section, with the exception that the appropriate emission factors for these vessels are presented in Section 3.5.

generally be assumed to be the same as the vessel model year if this detail is not explicitly included in the vessel characteristic data. The emissions inventory calculations (detailed in Sections 4.7 and 4.8) use the total installed propulsion power and not rated engine size. The total installed propulsion power is the sum of the rated engine sizes for all propulsion engines installed on the vessel. If the vessel only has one propulsion engine, the total installed propulsion power is the same as the rated engine size. If the vessel characteristic data only indicate total installed propulsion power and number of engines, the rated engine size can be estimated for all installed propulsion engines by dividing the total installed propulsion power by the number of engines.

4.3.3 Ship Type

Ship type information is used to group similar vessels together to fill gaps in vessel characteristic and activity data. It is also used to assign load factors. Depending on the source of the vessel characteristic data, the ship type field can have varying levels of detail. Ship type can generally be aggregated to the categories listed in Table 4.1.

4.3.4 Filling Gaps in Vessel Characteristic Data Sets

Missing data is a common occurrence for harbor craft in vessel characteristic data sets. If resources are available, data such as number, displacement, rated size, and model year of propulsion and auxiliary engines can be collected through interviewing pilots and/or surveying vessels operating in the geographical domain, and averages by ship type can be applied to any remaining data gaps. Otherwise, default assumptions on propulsion and auxiliary engine sizes as presented in Appendix G can be applied by ship type, although these data have the limitation in that they do not reflect local conditions that would affect vessel operation and thus emissions. Appendix G presents defaults by ship type and engine group (propulsion or auxiliary) for the following data fields:

- Average rated engine size (kW)
- Average installed power (kW)
- Average engine operating hours (hours)

4.4 Vessel Activity Data Sources

There are many different data sources available to estimate vessel activity at U.S. ports. This section describes the most useful data sources for calculating emission inventories. These data sources generally include vessel identifiers, which can be used to match vessel activity data with vessel characteristic data, as described in Section 4.3. This is important to assign the correct emission factors and to estimate engine load appropriately.

4.4.1 Survey Data

Interviews with harbor pilots and/or surveys of vessels operating within the geographical domain can provide useful data for estimating emissions. For example, interviews with harbor pilots can provide average vessel speeds. Surveys of vessels can provide information on engine model year, size, and annual hours of use for both propulsion and auxiliary engines.

Interviews and surveys should be used when available, and EPA encourages this type of information to be collected for developing port-related inventories when possible. However, surrogate survey data

could be used instead, if a similar port[e] has recently conducted an inventory and collected these kinds of data. However, these data would have the limitation that they do not reflect local operating conditions.

4.4.2 Automatic Identification System

AIS equipment is used on vessels to aid navigation and to avoid collisions by broadcasting and receiving messages. These messages contain dynamic operational data, which are automatically updated with every message and include the following fields:

- Position
- Bearing
- Speed

AIS messages also contain static data, which may be manually entered by the vessel operator. The relevant static fields for harbor craft include (among others):

- IMO number
- MMSI

While AIS coverage of C1 and C2 vessels is not as complete as it is for C3, many harbor craft are outfitted with AIS transponders, making it a suitable source of activity data for some C1 and C2 vessel types such as ferries and tugboats.[f]

Before starting an AIS analysis, it is important to note that AIS data are typically noisy with some random variation in the dynamic data, missing messages, and potential inaccuracies in manually entered static data. However, the datasets are large, with messages for most C1 and C2 vessels usually recorded every 2 seconds to 5 minutes or longer. Therefore, with appropriate aggregation, data cleaning techniques, and quality control checks, AIS is a good, detailed data source for estimating vessel activity. Section 4.7 describes how AIS data can be analyzed to estimate hours of operation. See Section 4.7.2 for AIS data cleaning techniques and Section 4.7.6 for quality control checks. Note that AIS data do not contain information on auxiliary engine loads, which should be estimated using other methods. Additionally, it is difficult to accurately estimate propulsion engine load for some harbor craft ship types using AIS data (e.g., tugs that are assisting OGV have higher propulsion engine loads than what would be indicated by only analyzing their speed); see Section 4.6 for a discussion on how to estimate propulsion and auxiliary engine loads.

AIS messages are recorded by the U.S. Coast Guard (USCG) as well as by commercial vendors for various purposes. Marine Cadastre is a joint initiative of the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration that provides publicly available AIS data derived from USCG records.[g] Alternatively, U.S. federal, state, local, and Tribal government agencies can request historical data from the USCG Navigation Center.[h] Depending on the data source, individual AIS records may be provided at their raw collected rate (potentially as fast as 2 to 10 second intervals) or averaged records may be provided at longer intervals (e.g., 5 minute intervals). While a shorter interval will

[e] Ideally, a "similar port" would be a different port in the same region with similar kinds and levels of activity. However, any port with similar kinds and levels of activity could have useful surrogate data.

[f] For more general information on AIS, see https://www.navcen.uscg.gov/?pageName=AISmain.

[g] For more information, see https://marinecadastre.gov/ais.

[h] For more information, see https://www.navcen.uscg.gov.

provide higher resolution and more precise determination of operating modes, it will also increase the size and complexity of the data set. The purpose of the emissions inventory should determine the level of AIS record aggregation. For example, a detailed inventory supporting air quality analysis may benefit from a shorter AIS time interval than an annual, port-wide inventory. Similarly, the geographical boundary of the emissions inventory should determine the geographical extent of the AIS data acquisition.

Note that there are two kinds of AIS receivers: terrestrial- and satellite-based. Depending on the data source, some AIS data sets may contain one or both types. Terrestrial-based AIS data sets usually have good coverage in and around U.S. ports, and include AIS messages at a higher frequency than satellite-based AIS data sets. While they can only receive messages within line-of-sight, this is unlikely to be an issue for most harbor craft. Occasionally, in high traffic areas, terrestrial-based receivers may be unable to handle the load of recording all messages received and some records may be dropped. Therefore, combining terrestrial- and satellite-based AIS data can improve the total coverage of a given area. In general, if a dataset includes both terrestrial- and satellite-based data, and if there are AIS messages for the same vessel and timestamp from both kinds of receivers, the message from the terrestrial receiver should be used instead of the satellite receiver.

4.4.3 Other Vessel Activity Data Sources

In addition to the sources discussed above, there are other data sources that may be used to estimate harbor craft activity.

Information on tug, barge, and other harbor craft activity may be available in the U.S. Army Corps of Engineers (USACE) Vessel Entrances and Clearances (E&C) data set, which is part of the Waterborne Foreign Cargo series,[22] as well as the Waterborne Commerce Statistics (WCS) data set of domestic vessel movements.[i] USACE also has information on dredging activity.[j]

In addition, the local port authority, marine exchange, board of trade, or other local organizations may have information on vessel movements. While these data sources typically focus on OGV activity, they can be used to estimate tugboat activity, as most C3 vessels can be assumed to need the support of tugboats. Additionally, these sources may contain information on excursion vessels and other harbor craft ship types.

Alternatively, Appendix G provides average annual propulsion and auxiliary engine hours by ship type that can be used instead. However, these data do not reflect local conditions, which likely impact vessel operation.

4.5 Emission Factors

Emission factors vary by engine category (C1, C2, or C3), group (propulsion or auxiliary), cylinder displacement, engine power, model year, and fuel sulfur level. For inventories of 2012 activity and later, all C1 and C2 marine vessels can be assumed to be using ultra low sulfur diesel (ULSD) to comply with

[i] For more information, see https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center.

[j] For more information, see https://publibrary.planusace.us/#/series/Dredging%20Information.

domestic fuel sulfur regulations.[36] If the inventory is being calculated for a year prior to 2012, different emission factors should be used as described in the subsections below.

Emission factors for U.S. flagged vessels with diesel C1 and C2 propulsion engine(s), which comprise most harbor craft, are discussed below and are presented in Appendix H. These apply to all vessels with C1 or C2 propulsion engine(s), regardless of whether the vessels are considered to be OGV or harbor craft. Emission factors for vessels with C3 propulsion engines are presented in Section 3.5, and emissions for recreational marine and marine engines fueled by gasoline are discussed in Section 5.

Speciation profiles of additional hazardous air pollutants for all commercial marine vessels are presented in Appendix D.

For methods to estimate energy consumption for this source sector, see Appendix A.

4.5.1 Nitrogen Oxides (NOx)

NOx emission factors vary by engine category, group (propulsion or auxiliary), cylinder displacement, engine power, and model year. Emission factors for C1 and C2 NOx are presented in Appendix H.1.

4.5.2 Brake Specific Fuel Consumption (BSFC)

BSFC rates vary by engine power range. Note that particulate matter, carbon dioxide, nitrous oxide, and sulfur dioxide are calculated based on these values. BSFC rates for C1 and C2 engines are presented in Table 4.3.[17]

Table 4.3. Category 1 and 2 BSFC Rates (g/kWh)

Power Range	BSFC (g/kWh)
kW < 37	248
kW ≥ 37	213

4.5.3 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC)

PM_{10} emission factors vary by engine category, group (propulsion or auxiliary), cylinder displacement, engine power, and model year. Emission factors for engines using ULSD are presented in Appendix H.2.1

If the port emissions inventory is being calculated for engines not using ULSD (e.g., activity occuring prior to 2012), emission factors for PM_{10} will need to be adjusted to reflect the actual sulfur content used by harbor craft vessels during the time period of the inventory. This adjustment is described in Appendix H.2.2.

$PM_{2.5}$ emission factors are estimated to be 97% of the PM_{10} emission factors.[17] For all vessels using ULSD, the DPM_{10} and $DPM_{2.5}$ emission factors are equal to the PM_{10} and $PM_{2.5}$ emission factors, respectively. BC emission factors are 77% of $PM_{2.5}$ emission factors for marine C1 and C2 engines.[33]

For C1 and C2 marine engines that have been remanufactured using a certified remanufacture system, all PM emission factors (including PM_{10}, $PM_{2.5}$, DPM_{10}, $DPM_{2.5}$, and BC) should be multiplied by 0.75, which represents a 25% reduction in PM emissions.[37] [k]

4.5.4 Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Methane (CH_4)

Hydrocarbon (HC) and CO emission factors vary by engine category, group (propulsion or auxiliary), cylinder displacement, engine power, and model year. VOC and CH_4 emission factors are derived from the HC emission factors. HC emission factors for C1 and C2 are presented in Appendix H.3 and CO emission factors for C1 and C2 are presented in Appendix H.4.

VOC emission factors are 1.053 times the HC emission factors.[17] CH_4 emission factors are 2% of HC emission factors.[29]

4.5.5 Nitrous Oxide (N_2O)

N_2O emission factors can be estimated from BSFC using Equation 4.3:

$$EF_{N_2O} = BSFC \times NCF \qquad \textbf{Equation 4.3}$$

Where EF_{N_2O} = N_2O emission factor (g/kWh)
$BSFC$ = brake specific fuel consumption (g/kWh) as determined according to Section 4.5.2
NCF = N_2O conversion factor (g N_2O/g fuel)
= 0.000156 for C1 and C2 engines[38]

4.5.6 Carbon Dioxide (CO_2)

CO_2 is directly proportional to fuel consumption. Therefore, the CO_2 emission factor is determined according to Equation 4.4:

$$EF_{CO_2} = BSFC \times CCF \qquad \textbf{Equation 4.4}$$

Where EF_{CO_2} = CO_2 emission factor (g/kWh)
$BSFC$ = brake specific fuel consumption (g/kWh) as determined according to Section 4.5.2
CCF = carbon content factor (g CO_2/g fuel)
= 3.19 for diesel[39]

4.5.7 Sulfur Dioxide (SO_2)

SO_2 should be calculated according to Equation 4.5:

$$EF_{SO2} = BSFC \times S_{act} \times FSC \times MWR \qquad \textbf{Equation 4.5}$$

Where EF_{SO_2} = SO_2 emission factor (g/kWh)
$BSFC$ = brake specific fuel consumption (g/kWh) as determined according to Section 4.5.2
S_{act} = actual fuel sulfur level (weight ratio)
= 15×10^{-6} for vessels using ULSD
FSC = percentage of sulfur in fuel that is converted to SO_2[17]
= 0.97753

[k] For more information, see https://www.epa.gov/vehicle-and-engine-certification/remanufacture-systems-category-1-and-2-marine-diesel-engines.

MWR = molecular weight ratio of SO_2 to sulfur
= 64/32 = 2

If the port emissions inventory is being calculated for a year prior to 2012, or if a fuel with a different sulfur level was used by harbor craft, then the actual fuel sulfur level should be used in Equation 4.5.

4.6 Load Factors

Load factor describes how much power an engine is producing as a fraction of its maximum rated power. These values vary by ship type as different kinds of vessels perform different kinds of work (e.g., a harbor ferry compared to a tugboat), and load factors are inherently linked to duty cycle. Average annual load factors are useful when modeling emissions as they capture average engine power usage. Local propulsion engine average annual load factors can be estimated using the methodology developed by California Air Resources Board (ARB),[40] which is summarized here.

Average annual load factors for propulsion engines by ship type can be determined using average fuel consumption, rated engine size, and annual hours of use by ship type using Equation 4.6:

$$LF_p = \frac{FC_p}{BSFC \times P_p \times A} \qquad \textbf{Equation 4.6}$$

Where LF_p = average annual propulsion engine load factor (unitless)
FC_p = average annual propulsion engine fuel consumption (g)
$BSFC$ = brake specific fuel consumption (g/kWh) as determined according to Section 4.5.2
P_p = average total installed propulsion power (kW)
A = average total annual activity (h)

If fuel consumption data are measured in gallons, they can be converted to grams using a conversion factor of 3,200 g/gal for diesel.[39]

However, if estimating local load factors is not feasible, default propulsion engine load factors from ARB, as presented in Table 4.4, can be used instead.[40] An auxiliary engine load factor of 0.43 can be assumed for all ship types unless detailed local data indicate otherwise.[l] Note that barges do not have a propulsion engine load factor because they are typically not self-propelled. However, if they have auxiliary engines, those emissions should be included in the inventory. Additionally, note that if local load factors are not available for dredging vessels, an average value of 0.66 can be used for all engines present on a dredging vessel.[m]

Table 4.4. Default Harbor Craft Propulsion and Auxiliary Engine Load Factors

Ship Type	Propulsion Engine Load Factor	Auxiliary Engine Load Factor
Barge	--	0.43
Crew and Supply	0.45	0.43

[l] The 0.43 value is based on the estimated load factor for nonroad diesel generators from reference 41.
[m] The 0.66 value is an activity weighted average load factor based on data presented in reference 42. For additional information about estimating emissions from dredging vessels, see Appendix G.

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

4.7 AIS Inventory Calculations

A detailed emissions inventory can be calculated using AIS activity data from the base year. In general, the base year inventory calculation is done at the individual vessel level through the following steps:

1. Link each AIS record to vessel characteristic data
2. Clean AIS data
3. Fill temporal gaps in AIS activity
4. Assign operating mode and calculate emissions
5. Aggregate and/or allocate emissions
6. Perform quality control checks

The subsections below explain these steps in further detail.

4.7.1 Link Each AIS Record to Vessel Characteristic Data

Each AIS record contains vessel identification fields that can be used to link the AIS activity data to vessel characteristic data. This is important not only for calculating emissions, but also for data cleaning and quality control steps as well. Section 4.3 describes how vessel identifiers can be used to determine the engine and vessel characteristics, and how to fill missing vessel characteristic data.

4.7.2 Clean AIS Data

It is not uncommon for AIS data to contain errors or extraneous data that need to be identified and addressed before emissions can be calculated. The source of the AIS data will affect the amount of data cleaning that will be involved. Some AIS vendors include data cleaning in their processes, while others supply raw data that need more cleaning. While this is not a comprehensive list of all AIS data cleaning procedures, the following list describes commonly performed cleaning steps:

- Remove records for vessels that are not identified as harbor craft vessels operating within the geographical boundary. Note that these records may be useful for an OGV or recreational marine inventory, but not a harbor craft inventory.
- Remove records where the coordinates appear outside the inventory's geographical boundary.

- Remove duplicate records (records with identical timestamps and vessel identifiers).
- Examine records with the following AIS-reported speed issues:
    - Records with speeds above 1.5 times the maximum speed of the vessel should instead use the maximum speed.
    - Remove records with changes in speed, as compared to the previous record for the vessel, that exceed 10% of the maximum speed if the interval between records is 5 minutes or less.
    - Remove records with changes in speed, as compared to the previous record for the vessel, that exceed 20% of the maximum speed if the interval between is 10 minutes or less.

Depending on the purposes of the emissions inventory, additional data processing at this phase may be desired. For example, if an inventory needs to differentiate between vessels that call at the port and innocent passage, AIS records will need to be marked accordingly. This step can be processed in different ways:

- Matching AIS records to local logs, Entrances & Clearances data, or Waterborne Commerce Statistics data, or
- Identifying individual vessel trips in the AIS records, geofencing harbor craft berths within the geographical boundary, and flagging every record in the trip if any of the records show the vessel entering them.

4.7.3 Fill Temporal Gaps in AIS Activity

Temporal gaps between AIS records may occur for a variety of reasons, including:

- The vessel left the geographical domain
- The vessel's AIS transponder malfunctioned or was turned off
- Records were removed as part of the cleaning process described above

A gap due to a vessel leaving the geographical domain can be identified by extrapolating vessel activity, assuming a constant speed and heading from the last record before the gap.[n] If the extrapolated position is outside the geographical domain, then the gap should not be filled, and emissions should not be calculated for it. Similarly, if the vessel is at berth and is not transmitting AIS messages, it may be assumed that the vessel's engines are not operating, and therefore this gap should not filled. However, gaps occuring for other reasons should be filled in by interpolating location, speed, and draft data at the expected frequency of the AIS records (e.g., if the AIS data has been aggregated to 5-minute intervals, the gaps should be filled in by interpolating the data at 5-minute intervals).

After filling the temporal gaps, each AIS record can be assumed to represent the same time interval (e.g., 5 minutes), which will be used when calculating the emissions of each vessel trip as described in the following sections.

[n] If the last record before the gap has unknown speed, average vessel speed by ship type based on other vessels operating in the same localized area can be used instead.

4.7.4 Assign Operating Mode and Calculate Emissions

When estimating emissions for harbor craft using AIS data, there are two important operating modes to consider: hotelling and non-hotelling. When a harbor craft vessel is hotelling, it should be assumed that its auxiliary engine is running, but not its propulsion engines. When not hotelling, it should be assumed that both auxiliary and propulsion engines are running.

Operating mode can be determined by geofencing the harbor craft berthing areas (e.g., defining polygons using geographic information system (GIS) software for the berthing areas used exclusively by harbor craft). If the vessel is transmitting AIS messages from within these areas, those records should be assigned to the hotelling operating mode; otherwise, harbor craft AIS records should be assigned to the non-hotelling operating mode. Total activity in hours should then be calculated for each vessel by operating mode by counting the number of AIS records in each operating mode and multiplying by the time interval between each record, (e.g., 30 records in the hotelling operating mode × 5-minute time interval = 150 minutes, or 2.5 hours hotelling).

Propulsion and auxiliary engine emission factors and load factors should be assigned to each vessel as described in Sections 4.5 and 4.6, respectively. Then, emissions for each vessel can be estimated for each operating mode. Non-hotelling emissions for each harbor craft vessel can be calculated using Equation 4.7:

$$E_{nh} = \left(P_p \times LF_p \times EF_p + P_a \times LF_a \times EF_a\right) \times A_{nh} \qquad \textbf{Equation 4.7}$$

Where E_{nh} = non-hotelling emissions for each vessel (g)
P_p = total installed propulsion engine power (kW)
LF_p = propulsion engine load factor (unitless)
EF_p = propulsion engine emission factor (g/kWh)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
EF_a = auxiliary engine emission factor (g/kWh)
A_{nh} = non-hotelling activity (h)

Hotelling emissions for each harbor craft vessel can be calculated using Equation 4.8:

$$E_h = P_a \times LF_a \times EF_a \times A_h \qquad \textbf{Equation 4.8}$$

Where E_h = hotelling emissions for each vessel (g)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
EF_a = auxiliary engine emission factor (g/kWh)
A_h = hotelling activity (h)

4.7.5 Aggregate and/or Allocate Emissions

Total emissions should be calculated using Equation 4.9:

$$E = E_{nh} + E_h \qquad \textbf{Equation 4.9}$$

Where E = total harbor craft emissions (g)

E_{nh} = propulsion engine emissions for each AIS record (g)
E_h = hotelling emissions for each vessel (g)

The total emissions can then be aggregated or allocated to the most useful level for the purposes of the inventory:

- For an annual inventory without a need for spatial considerations, all emissions for a particular pollutant can be summed together. Note that even for annual inventories, reporting more detailed emissions in addition to the annual results can be useful as described below in Section 4.7.6.
- If the inventory has a spatial component to it, the hotelling emissions should be allocated to the berthing area where they occur, and the non-hotelling emissions should be allocated equally across the vessel tracking paths derived from the AIS data. These emissions can then be summed across all vessels to the most useful spatial resolution for the purpose of the inventory (e.g., 100 m^2 grid cells for a detailed analysis or summed for the entire port for planning purposes).
- Similarly, if the inventory has a temporal component to it, the emissions can be allocated according to the temporal distribution of AIS records. These emissions can then be summed to the most useful resolution for the purpose of the inventory (e.g., at the hourly level for a detailed analysis or yearly for an annual inventory).

4.7.6 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of vessel activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by ship type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Distributions of vessel speed: Examining these distributions allow for general checks to ensure that vessels are modeled to be operating within reasonable limits and with expected patterns of behavior.
- Vessel counts and total operating hours and hotelling hours: Examining both totals and distributions provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Installed power: Examining this helps to estimate the relative impact that a given ship type should have on the inventory. For example, harbor ferries tend to have relatively large engines, and so may contribute more emissions than their activity might otherwise suggest.
- Total energy consumption (kWh): Examining energy consumption by ship type and engine group provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.

Other quality control checks include:

- Examining geospatial heatmaps of energy consumption: This helps identify if there are gaps in the AIS data, or if there are anomalies in the data such as vessels being allocated to land or shallow regions where they should be unable to operate. This check also helps identify issues with the algorithms used for temporal gap-filling and can be used to fine-tune the gap-filling methods.
- Reviewing vessel characteristics: This ensures values are consistent with ship types (e.g., pilot boats likely do not have very high-power engines).
- Searching for rapid toggling between modes: This check at the AIS record level for irregularities such as switching between hotelling and non-hotelling too frequently can identify anomalies in the data that warrant a closer review.
- Searching for vessel positions outside the geographical domain: This check at the AIS record level can identify any AIS messages or gap filled records that should not be included in the inventory.

4.8 Alternative Inventory Calculations

An alternative method can be used to calculate a base year emission inventory (e.g., if AIS data are incomplete for some harbor craft ship types or if the resources to process them are unavailable). This alternative method can also be used in combination with AIS, with the alternative method used for some ship types and AIS data used for others. This method relies on using the same vessel characteristics, installed power, load factors, and emission factors as described above; however, the derivation of ship activity is different. In general, the alternative emissions calculation is performed at the annual scale for each vessel through the following steps:

1. Link each vessel to vessel characteristic data
2. Assign load factors, emission factors, and operating hours
3. Calculate vessel emissions
4. Aggregate and/or allocate emissions as needed for the purposes of the inventory
5. Perform quality control checks

4.8.1 Link Each Vessel to Vessel Characteristic Data

Each harbor craft vessel identified in the local logs or other vessel activity data source as described in Section 4.4 should be linked to corresponding vessel characteristic data. This step may be accomplished implicitly depending on the data source (e.g., if the data source is vessel surveys, the surveys should be designed to collect both vessel activity [propulsion engine operating hours and auxiliary engine operating hours] as well as vessel characteristics [model year, installed propulsion power, and installed auxiliary power]). Alternatively, it may be accomplished by linking data sets using vessel identifiers as described in Section 4.3, which describes how vessel identifiers can be used to determine the engine and vessel characteristics, and how to fill missing vessel characteristic data.

4.8.2 Assign Load Factors, Emission Factors, and Operating Hours

Propulsion and auxiliary engine emission factors and load factors should be assigned to each vessel as described in Sections 4.5 and 4.6, respectively. If operating hours for each vessel are known (e.g., from surveying the vessel operators), total emissions for each vessel should be calculated using the annual operating hours for each vessel. For vessels with unknown operating hours, average annual hours by ship type should be used. Lacking that information, average annual hours by ship type from a similar

port or the defaults provided in Appendix G can be used, although these options do not reflect local conditions, which likely impact vessel operation.

4.8.3 Calculate Vessel Emissions

Total emissions for each harbor craft vessel can be calculated using Equation 4.10:

$$E = P_p \times LF_p \times A_p \times EF_p + P_a \times LF_a \times A_a \times EF_a \quad \textbf{Equation 4.10}$$

Where E = emissions for each vessel (g)
P_p = total installed propulsion engine power (kW)
LF_p = propulsion engine load factor (unitless)
A_p = propulsion engine activity (h)
EF_p = propulsion engine emission factor (g/kWh)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
EF_a = auxiliary engine emission factor (g/kWh)
A_a = auxiliary engine activity (h)

4.8.4 Aggregate and/or Allocate Emissions

The total emissions can then be aggregated or allocated to the most useful level for the purposes of the inventory:

- For an annual inventory without a need for spatial considerations, all emissions of a particular pollutant can be summed together. Note that even for annual inventories, reporting more detailed emissions in addition to the annual results can be useful as described below in Section 4.8.5.
- If the inventory has a spatial component to it but detailed activity data (such as AIS) are unavailable, emissions should be allocated as appropriate to shipping lanes or specific berths.
- If the inventory has a temporal component to it but detailed activity data are lacking, the emissions can be allocated using the OGV temporal allocations as a surrogate data source. These emissions can then be summed to the most useful resolution for the purpose of the inventory (e.g., at the hourly level).

4.8.5 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of vessel activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by ship type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Vessel counts: Examining these values provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.

- Installed power: Examining this helps to estimate the relative impact that a given ship type should have on the inventory. For example, harbor ferries tend to have relatively large engines, and so may contribute more emissions than their activity might otherwise suggest.
- Total energy consumption: Examining energy consumption provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Outliers in hotelling times: Checking for vessels with abnormally long hotelling times is useful, because it may not be appropriate to include these when calculating averages as they may represent ships at a pier/wharf/dock that may not be running auxiliary engines for the entire time.

4.9 Projecting Future Emission Inventories

Future harbor craft emissions should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Activity growth rates are applied to the base year activity to estimate future activity
2. Model years are adjusted to account for fleet turnover to newer, cleaner engines and emission factors are reassigned
3. Projected emissions are calculated using the estimated future activity
4. Projected emissions are aggregated to the same level of detail as the base year inventory, as determined by the purpose of the inventory

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Projected changes in activity should be determined for each ship type. Local port projections or other regional forecasts are usually by commodity type and/or business sector; growth can be grouped by the ship types associated with the various business sectors. For example, all commodity types can be grouped together to determine growth in tug and pilot boat activity.

If local port projections or other regional forecasts are unavailable, the Freight Analysis Framework (FAF)[15] can be used to forecast growth instead. If this is used, the growth in total commodity flows in the FAF assigned to the water transportation mode can be applied to all ship types. Note that this method may not reflect possible differences in the growth of activity by ship type.

The growth rates should be applied to the base year activity. If the original base year inventory was developed using AIS data, this growth rate is applied to the hours of operation in each operating mode calculation for each vessel trip. If the original inventory was developed using alternate sources of vessel activity, the growth rate should be applied to the total hours of activity for each vessel.

To reflect fleet turnover, the vessel model years used in the base year inventory should be adjusted for use in the future year inventory. If the port or local fleet operator has already identified an expected future vessel age distribution (e.g., if written commitments have been made to replace older vessels), that should be used in determining how to adjust the model years. If the future age distribution is unknown, it can be assumed to be the same as the base year age distribution. That is, it can be assumed that in the future, the percentages of vessels that are brand new, one year old, two years old, etc. are

the same as those percentages in the base year inventory. Functionally, this can be implemented by adding the difference between the future and base years to each model year used in the base year inventory, to get a new set of model years for the future year inventory. For example, if the base year inventory is for 2020 and the projected inventory is for 2030, the difference of 10 years is added to each model year. In this example, a model year 2005 vessel in the base year inventory would be a model year 2015 vessel in the 2030 inventory. Emission factors should be reassigned to all vessels using the adjusted model years.

Additionally, any planned action or emission reduction strategies that have been committed to that would affect future emissions should be included according to the actual expected implementation of such commitments. For example, if a port has committed to replacing or repowering its oldest tugs through authorization of funds for such purchases, the effects of such a program should be reflected in the projected age distribution. Note that if the future year inventory is for a regulatory purpose, planned future actions should be included only if written commitments have been made by the agency or operator with the power to implement them.

Once the base year activity has been scaled and appropriate emission factors are assigned to each vessel, the projected future emissions can be calculated using the same methodology at the same level of detail as the base year inventory.

5 RECREATIONAL MARINE

5.1 SOURCE DESCRIPTION

Recreational marine vessels are boats that are operated primarily for pleasure or are leased, rented, or chartered to another for the latter's pleasure. This category includes motorboats, cruisers, yachts, personal water craft, and other types of motorized pleasure craft.[a] It also includes all gasoline-powered vessels. Recreational marine vessels typically are operated only a small number of hours per year. However, some seemingly recreational vessels are more similar to commercial vessels in that they are operated continuously during the year or a boating season, and these additional hours of use may have an impact on the local emission inventory. Therefore, EPA's regulatory definition of "recreational vessel" excludes vessels below 100 gross tons that carry more than 6 passengers, or vessels at or above 100 gross tons that carry one or more passengers.[b] This means that some sport fishing vessels and excursion boats may be commercial vessels, which should be included in harbor craft inventory. Additionally, vessels used solely for competition are not considered to be recreational.

When planning the scope of an inventory, it is important to determine whether the recreational marine sector should be included. For example, not all ports have marina facilities for recreational marine vessels or have significant recreational marine activity within the geographical domain of the inventory. In these cases, it may not be important to include this sector in a port emissions inventory. However, ports that do have significant recreational marine activity, or ports that expect significant increases or decreases in future recreational marine activity may find it important to include emissions from this sector at the level of detail consistent with the purpose of the inventory and the expected contributions of this sector to the overall port-related emissions inventory.

If this sector is included in a detailed analysis, recreational marine emissions should be calculated at the marina level, and both public and private marinas should be represented. Note that data may be less readily accessible for private terminals. Regardless of whether a detailed or alternative approach is employed, the scope of the inventory should be determined in advance of any calculations and in accordance with the overall inventory purposes. Additionally, the inventory should be calculated at the temporal level of detail necessitated by the purpose of the inventory (e.g., at the year level for an annual inventory). See Section 2 of this guidance for more discussion about inventory purpose, geographical domains, and temporal detail.

5.2 EMISSIONS ESTIMATION OVERVIEW

This section describes recreational marine data sources and general approaches that are relevant for any port, regardless of location. Other than in California, the nonroad module of EPA's MOVES model (referred to here as MOVES-Nonroad) is the primary tool for estimating emissions from recreational

[a] Sailboats also typically have auxiliary installed onboard, but those engines tend to be low power and not continuously operated.

[b] A passenger is someone who provides payment as a condition of boarding a vessel. See EPA's definitions of recreational vessel and passenger at 40 CFR 1042.901.

marine vessels in the U.S.[c] When using MOVES to develop a recreational marine emissions inventory, the most recent version should be used. The information in this section is applicable to all versions of MOVES3 as well as future versions of the MOVES model, unless EPA notes otherwise when approving the model for state implementation plan (SIP) and conformity purposes.[d] Inventories of recreational marine emissions for ports in California should use California Air Resources Board's resources for pleasure craft and outboard marine tank emissions instead of the guidance here for using MOVES-Nonroad.[e]

The MOVES Technical Guidance[43] provides detailed information on how to generate emission inventories using MOVES-Nonroad. However, the general equation for calculating per vessel emissions based on MOVES-Nonroad output is as shown in Equation 5.1:

$$E = N_e \times P \times LF \times A \times EF \qquad \textbf{Equation 5.1}$$

Where E = per unit emissions (g)
N_e = number of engines on the vessel
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)
EF = emission factor (g/hp·h)

Each of the above parameters may vary by vessel. Therefore, it is important to accurately account for vessel characteristics (Section 5.3) and activity (Section 5.4) to ensure the operating power and hours are calculated correctly and that the right emission factors (Section 5.5) are applied to this activity.

There are different methods that can be used for estimating base year emissions from recreational marine vessels, depending on data and resource availability:

- The primary method used to calculate a detailed emissions inventory is based on Automatic Identification System (AIS) data and is described in Section 5.6, where emissions are calculated for each vessel. Rated engine power (P), load factor (LF), and emission factors (EF) are assigned according to vessel characteristics, and engine operating activity (A) is derived from AIS data.
- Alternative methodologies can be used where port-specific data on vessel activity, engine power, and/or model year are not available. These methodologies rely on surrogate sources of data that may not be specific to the port and are presented in Section 5.7.

Section 5.8 describes how to project future year emission inventories for recreational marine vessels.

If the port-related emissions inventory is to be combined with a larger regional emissions inventory (e.g., for SIP purposes), including a detailed analysis of recreational marine emissions within the geographical domain could possibly result in double-counting when the results are combined with

[c] In addition to U.S. states, this includes the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. For more information about MOVES, see https://www.epa.gov/moves.
[d] Note the information in this section also applies to all versions of MOVES2014.
[e] For more information, see https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-offroad.

county-wide inventories using the default activity estimates in MOVES-Nonroad. Since it is difficult to apportion default activity estimates in MOVES-Nonroad to a specific area within the county, EPA recommends using only MOVES-Nonroad default activity for the larger regional emission inventory. However, there could be cases where a more detailed analysis using the methods described in this document would be appropriate. If the purpose of the inventory is related to an overall inventory for a SIP, the interagency consultation process should be used to determine the methodology of calculating the port-related recreational marine emissions inventory.

5.3 Vessel Characteristics

To inform inputs for Equation 5.1 above, characteristic data for each recreational vessel should be collected if possible. The best sources of detailed data on recreational vessels are surveys of and/or interviews with marina operators. The following data for each vessel are useful when calculating a recreational vessel emissions inventory:

- Vessel type
- Fuel type
- Engine model year
- Rated engine power
- Number of engines

These data may be difficult to collect, particularly from private marinas. Therefore, default assumptions can be made for some of these characteristics. Each of these data fields are discussed in more detail in the remainder of this section.

5.3.1 Vessel Type and Fuel Type

MOVES-Nonroad categorizes various types of recreational marine vessels into source classification codes (SCCs). A list of the recreational marine vessel SCCs in MOVES-Nonroad is presented in Table 5.1. Each recreational vessel in the geographical domain should be assigned an appropriate SCC.

Table 5.1. Recreational Vessel SCCs in MOVES-Nonroad

MOVES-Nonroad Recreational Vessel Type	Source Classification Code (SCC)
Gasoline (2-Stroke) Outboard	2282005010
Gasoline (2-Stroke) Personal Water Craft	2282005015
Gasoline (4-Stroke) Inboard/Sterndrive	2282010005
Diesel Inboard/Sterndrive	2282020005
Diesel Outboard	2282020010

In general, the default fuel characteristics in MOVES can be used as-is, which will be automatically applied in a MOVES-Nonroad run for the county containing the port. MOVES users should review the default fuel supply and fuel formulation information provided in MOVES, and make changes only where precise local volumetric fuel property information is available or where local fuel requirements have changed.

One exception to this guidance is in the case of Reid Vapor Pressure (RVP); the MOVES user should change this value to reflect any specific local regulatory requirements and differences between ethanol- and non-ethanol blended gasoline not reflected in the default database (e.g., the default database may not reflect a recent regulatory action to change an RVP requirement). Any changes to RVP (or to any other gasoline fuel formulation parameters) should be made using the "Fuels Wizard" tool in the Fuel Tab of the Nonroad Data Importer. This process is described in more detail in Section 5.2.2 of the MOVES Technical Guidance. Note that the Fuels Wizard only applies to gasoline fuels. If any diesel fuel properties (such as the diesel sulfur content) need to be changed, MOVES users should modify the property in the fuel formulation table for the modeled county using the Nonroad Data Importer.

5.3.2 Engine Model Year

Engine model year is an important vessel characteristic, as newer recreational marine engines and vessels meet more stringent EPA emission standards. The MOVES-Nonroad model internally associates an emission standard tier based on an engine's model year and power rating, and accounts for other factors that vary by model year and/or age, including tier phase-in, specific technology penetration rates, and deterioration. Therefore, it is not necessary to collect data on tier distributions or different technology types, as these are accounted for by the model year parameter.

Note that due to assumptions made in MOVES-Nonroad regarding median life,[41] a single model run may not be sufficient to generate emission factors for all recreational vessel model years present during the timespan of the analysis. That is, there may be recreational vessels at the port that are older than the oldest vessels assumed in the model. Therefore, it may be necessary to run MOVES-Nonroad for multiple calendar years to ensure emission factors for all model years are calculated. This is discussed in further detail in Section 5.5.

If a representative sample of recreational marine vessels have model year data, vessels with missing model years can be assumed to have the average value. However, in the likely scenario that there are insufficient model year data for this kind of analysis, default assumptions can be made as described in Section 5.7.1.

5.3.3 Rated Engine Power

In addition to vessel type, fuel type, and model year, emission factors from MOVES-Nonroad vary by rated engine power bin. Therefore, each vessel should be assigned to the appropriate bin. Table 5.2 lists the definitions of the engine power bins in MOVES-Nonroad.

Table 5.2. MOVES-Nonroad Engine Power Bins

Bin ID*	Rated Engine Power (hp)	Rated Engine Power (kW)
1	0 < hp ≤ 1	0 < kW ≤ 0.7
3	1 < hp ≤ 3	0.7 < kW ≤ 2.2
6	3 < hp ≤ 6	2.2 < kW ≤ 4.5
11	6 < hp ≤ 11	4.5 < kW ≤ 8.2
16	11 < hp ≤ 16	8.2 < kW ≤ 12
25	16 < hp ≤ 25	12 < kW ≤ 19
40	25 < hp ≤ 40	19 < kW ≤ 30

Bin ID*	Rated Engine Power (hp)	Rated Engine Power (kW)
50	40 < hp ≤ 50	30 < kW ≤ 37
75	50 < hp ≤ 75	37 < kW ≤ 56
100	75 < hp ≤ 100	56 < kW ≤ 75
175	100 < hp ≤ 175	75 < kW ≤ 130
300	175 < hp ≤ 300	130 < kW ≤ 224
600	300 < hp ≤ 600	224 < kW ≤ 447
750	600 < hp ≤ 750	447 < kW ≤ 559
1000	750 < hp ≤ 1,000	559 < kW ≤ 746
1200	1,000 < hp ≤ 1,200	746 < kW ≤ 895
2000	1,200 < hp ≤ 2,000	895 < kW ≤ 1,491
3000	2,000 < hp ≤ 3,000	1,491 < kW ≤ 2,237

* Corresponds to values in the *hpID* column of MOVES-Nonroad output tables.

Engine power ratings can in most cases be obtained from the vessel's physical engine tag.[44] If the engine tag does not provide this information, rated power can be determined from the specification guide or owner's manual for the engine model.

If a power value cannot be determined for a vessel (e.g., because engine manufacturer and/or model is not known), the average of known power values from similar recreational vessels at the port can be used instead. However, in the likely scenario that there are insufficient data for this kind of analysis, default assumptions can be made as described in Section 5.7.2.

5.4 Vessel Activity

Activity profiles should be developed for each type of recreational vessel; these include information on hours of use (specifically, hours of engine operation during the analysis time period) and load factor (fraction of full engine power used, on average, over a given period).

The best data source for hours of operation is Automatic Identification System (AIS) data. AIS equipment is used on vessels to aid navigation and to avoid collisions by broadcasting and receiving messages. These messages contain dynamic operational data, which are automatically updated with every message and include the following fields:

- Position
- Bearing
- Speed

AIS messages also contain static data, which may be manually entered by the vessel operator. The relevant static fields for recreational marine include vessel identifiers and other information.

While AIS coverage of recreational vessels is not as complete as it is for harbor craft, many recreational vessels are outfitted with AIS transponders, making it a suitable source of activity data for some recreational marine vessels.[f]

Before starting an AIS analysis, it is important to note that AIS data are typically noisy with some random variation in the dynamic data, missing messages, and potential inaccuracies in manually entered static data. However, the datasets are large, with recreational marine messages usually recorded every 2 seconds to 5 minutes or longer. Therefore, with appropriate aggregation, data cleaning techniques, and quality control checks, AIS is a good, detailed data source for estimating vessel activity. Section 5.6 describes how AIS data can be analyzed to estimate hours of operation for these vessels. See Section 5.6.2 for AIS data cleaning techniques and Section 5.6.6 for quality control checks.

AIS messages are recorded by the U.S. Coast Guard (USCG) as well as by commercial vendors for various purposes. Marine Cadastre is a joint initiative of the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration that provides publicly available AIS data derived from USCG records.[g] Alternatively, U.S. federal, state, local, and Tribal government agencies can request historical data from the USCG Navigation Center.[h] Depending on the data source, individual AIS records may be provided at their raw collected rate (potentially as fast as 2 to 10 second intervals) or averaged records may be provided at longer intervals (e.g., 5 minute intervals). While a shorter interval will provide higher resolution and more precise determination of operating modes, it will also increase the size and complexity of the data set. The purpose of the emissions inventory should determine the level of AIS record aggregation. For example, a detailed inventory supporting air quality analysis may benefit from a shorter AIS time interval than an annual, port-wide inventory. Similarly, the geographical boundary of the emissions inventory should determine the geographical extent of the AIS data acquisition.

Note that there are two kinds of AIS receivers: terrestrial- and satellite-based. Depending on the data source, some AIS data sets may contain one or both types. Terrestrial-based AIS data sets usually have good coverage in and around U.S. ports, and include AIS messages at a higher frequency than satellite-based AIS data sets. While they can only receive messages within line-of-sight, this is unlikely to be an issue for most recreational vessels. Occasionally, in very high traffic areas, terrestrial-based receivers may be unable to handle the load of recording all messages received and some records may be dropped. Therefore, combining terrestrial- and satellite-based AIS data can improve the total coverage of a given area. In general, if a dataset includes both terrestrial- and satellite-based data, and if there are AIS messages for the same vessel and timestamp from both kinds of receivers, the message from the terrestrial receiver should be used instead of the satellite receiver.

If a representative sample of recreational marine vessels have AIS data, vessels without such data can be assumed to have the average hours of use. Alternatively, hours of use can be estimated through surveys of and/or interviews with marina operators. If resources are not available or the data sources are not robust enough, default assumptions can be made as described in Section 5.7.2.

[f] For more general information on AIS, see https://www.navcen.uscg.gov/?pageName=AISmain.
[g] For more information, see https://marinecadastre.gov/ais.
[h] For more information, see https://www.navcen.uscg.gov.

As for load factors, the default values from MOVES-Nonroad can be used unless vessel operators have reason to believe their engines are operating with significantly different load factors. Gasoline and diesel recreational marine engines can be assumed to have load factors of 0.21 and 0.35, respectively.[41]

5.5 Emission Factors

Recreational marine emission factors for most pollutants come from post-processing MOVES-Nonroad output. However, MOVES-Nonroad cannot estimate emissions for nitrous oxide (N_2O) or black carbon (BC), so if these pollutants are included in the inventory, they will need additional post-processing as described below.

For methods to estimate energy consumption for this source sector, see Appendix A.

5.5.1 Running MOVES-Nonroad

MOVES-Nonroad calculates emissions based on model inputs for vessel activity, age distributions, meteorological conditions, fuel characteristics, and other variables. In some cases, the default inputs are specific to the region or county being modeled. The recommended approach for incorporating local port activity data in a MOVES-Nonroad analysis is to first run MOVES-Nonroad for the geographical domain and time period of the inventory with default inputs, and then post-process the output using scripts included in MOVES to calculate emission factors. These emission factors can then be applied to local activity data to generate an emissions inventory. Note that the latest version of MOVES-Nonroad should be used, and the latest MOVES Technical Guidance and the MOVES training[45] contain background information on how to use MOVES-Nonroad.

When setting up a Run Specification (RunSpec) using the MOVES Graphical User Interface (GUI), the following selections should be made:

1. Time Spans Panel: Select the calendar year of analysis and all months/day types (weekday/weekend).
2. Geographic Bounds Panel: Select the county containing the port.[i]
3. Nonroad Vehicle Equipment Panel: Select gasoline and marine diesel Pleasure Craft.
4. Pollutants and Processes Panel: Select all processes for the pollutants of interest (refer to Section 2):
5. Output Emissions Detail Panel: Select model year, SCC, and hp class (i.e., engine power bin).

If user supplied fuel data needs to be included (see Section 5.3.1), this input should be configured using the Nonroad Data Importer after setting up the RunSpec as described in Section 5.2.2 of the MOVES Technical Guidance.

The run will produce inventory output for the months and day types selected in the Time Spans Panel by the selected level of detail in the General Output Panel. After the run has finished, the MOVES-Nonroad post-processing menu should be used to run the *EmissionFactors_per_hphr_by_SCC_and_ModelYear.sql* script on the output database. This step will generate emission factors in grams per horsepower-hour by SCC, engine power bin, and model year (for each month and day type) for each pollutant selected

[i] If the geographical domain spans multiple counties, the county containing most of the geographical domain should be selected.

based on the model run output. Section 5.3 of the MOVES Technical Guidance provides more details on how to run MOVES-Nonroad post-processing scripts.

After the script finishes, the MOVES user should inspect the results. If there are older vessels at the port than the earliest model year appearing in the MOVES-Nonroad results, an additional MOVES run is needed. The same steps outlined above should be taken, except the MOVES user should select the previous calendar year (e.g., if the base year is 2020, calendar year 2019 would be selected for the additional run). Note that the default fuel sulfur level for both gasoline and diesel should be inspected before running earlier calendar years; it should be set to the same value that was used in the base year run because this run is simulating emissions from the older model years operating in the base year. Results for only the oldest model year should be used from this additional run. This step will need to be repeated (incrementing back one calendar year while maintaining the base year's fuel sulfur level) until emission factors are obtained for all recreational vessels operating at the port.

If the temporal scale of the analysis is daily, the appropriate emission factor for the time domain should be used. However, if the temporal scale of the analysis is annual or seasonal, weighted average emission factors for each SCC, engine power bin, and model year can be estimated from the month-day type specific emission factors:

- Emission factors should be weighted by seasonal or weekday/weekend activity information, if those data are available.
- Otherwise, the emission factors could be weighted by the number of times a given month-day type occurs in the analysis year.

Note, if model year information is not available in the activity data, see Section 5.7.1 for a modified methodology for generating fleet average emission factors using MOVES-Nonroad.

5.5.2 Nitrous Oxide (N_2O)

N_2O emission factors can be estimated from brake specific fuel consumption (BSFC) using Equation 5.2:

$$EF_{N_2O} = BSFC \times NCF \qquad \textbf{Equation 5.2}$$

Where EF_{N_2O} = N_2O emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 5.5.1
NCF = N_2O conversion factor (g N_2O/g fuel) as presented in Table 5.3[38]

Table 5.3. Recreational Marine N_2O Conversion Factors

Fuel Type	N_2O Conversion Factor (g N_2O/g fuel)
Gasoline (2 Stroke)	0.000023
Gasoline (4 Stroke)	0.000083
Diesel	0.000156

5.5.3 Black Carbon (BC)

BC emission factors can be estimated from particulate matter less than or equal to 2.5 microns ($PM_{2.5}$) emission factors using Equation 5.3:

$$EF_{BC} = EF_{PM_{2.5}} \times BCF$$ **Equation 5.3**

Where EF_{BC} = BC emission factor (g/hp·h)
$EF_{PM_{2.5}}$ = $PM_{2.5}$ emission factor (g/hp·h) as determined according to Section 5.5.1
BCF = black carbon fraction[33] (g BC/g $PM_{2.5}$)
= 0.77 for diesel engines
= 0.10 for gasoline engines

5.6 AIS Inventory Calculations

A detailed emissions inventory can be calculated using AIS activity data from the base year. In general, the base year inventory calculation is done at the individual vessel level through the following steps, which are explained further below:

1. Assign each vessel the appropriate vessel characteristics and emission factors
2. Clean AIS data
3. Fill temporal gaps in AIS activity
4. Calculate vessel activity and emissions
5. Aggregate and/or allocate emissions
6. Perform quality control checks

The subsections below explain these steps in further detail.

5.6.1 Assign Each Vessel the Appropriate Vessel Characteristics and Emission Factors

This includes the following steps:

1. Assign each vessel to the appropriate MOVES-Nonroad SCC as described in Section 5.3.1, and a MOVES-Nonroad engine power bin as described in Section 5.3.3.
2. Assign each vessel an appropriate load factor as described in Section 5.4.
3. Run MOVES-Nonroad and the post-processing script as described in Section 5.5. If needed, calculate a weighted emission factor for all months and day types (e.g., if the activity data is on an annual basis), also as described in Section 5.5.
4. Assign each vessel the appropriate emission factor (or sets of emission factors by month and day type, e.g. if the activity data has that level of detail) for each pollutant, based on SCC, engine power bin (labeled as hpID in MOVES output), and model year.

5.6.2 Clean AIS Data

It is not uncommon for AIS data to contain errors or extraneous data that need to be identified and addressed before emissions can be calculated. The source of the AIS data will affect the amount of data cleaning that will be involved. Some AIS vendors include data cleaning in their processes, while others supply raw data that need more cleaning. While this is not a comprehensive list of all AIS data cleaning procedures, the following list describes commonly performed cleaning steps:

- Remove records for vessels that are not identified as recreational marine operating within the geographical boundary. Note that these records may be useful for an OGV or harbor craft inventory, but not a recreational marine inventory.
- Remove records where the coordinates appear outside the inventory's geographical boundary.

- Remove duplicate records (records with identical timestamps and vessel identifiers).

Depending on the purposes of the emissions inventory, additional data processing at this phase may be desired. For example, if an inventory needs to differentiate between vessels that call at the port and innocent passage, AIS records will need to be marked accordingly. This step can be processed in different ways:

- Matching AIS records to marina logs, or
- Identifying individual vessel trips in the AIS records, geofencing the marina(s) within the geographical boundary, and flagging every record in the trip if any of the records show the vessel entering them.

5.6.3 Fill Temporal Gaps in AIS Activity

Temporal gaps between AIS records may occur for a variety of reasons, including:

- The vessel left the geographical domain
- The vessel's AIS transponder malfunctioned or was turned off
- Records were removed as part of the cleaning process described above

A gap due to a vessel leaving the geographical domain can be identified by extrapolating vessel activity, assuming a constant speed and heading from the last record before the gap. If the extrapolated position is outside the geographical domain, then the gap should not be filled, and emissions should not be calculated for it. Similarly, if the vessel is at moored or at berth and is not transmitting AIS messages, it may be assumed that the vessel's engines are not operating, and therefore this gap should not filled. However, gaps occuring for other reasons should be filled in by interpolating location and speed data at the expected frequency of the AIS records (e.g., if the AIS data has been aggregated to 5-minute intervals, the gaps should be filled in by interpolating the data at 5-minute intervals).

After filling the temporal gaps, each AIS record can be assumed to represent the same time interval (e.g., 5 minutes), which will be used when calculating the emissions of each vessel as described in the following sections.

5.6.4 Calculate Vessel Activity and Emissions

Calculate hours of activity by counting the number of AIS records for each vessel and multiplying the time interval between each record, (e.g., 5 minutes). For vessels that do not have any AIS records associated with them, assign them the average number of hours of activity by vessel type.

Emissions can then be calculated for each vessel using Equation 5.4:

$$E = N_e \times P \times LF \times A \times EF \qquad \textbf{Equation 5.4}$$

Where E = per unit emissions (g)
N_e = number of engines on the vessel
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)
EF = emission factor (g/hp·h)

5.6.5 Aggregate and/or Allocate Emissions

Total recreational marine emissions can be aggregated or allocated to the most useful level for the purposes of the inventory:

- For an annual inventory without a need for spatial considerations, all emissions for a particular pollutant can be summed together. Note that even for annual inventories, reporting more detailed emissions in addition to the annual results can be useful as described below in Section 5.6.6.
- If the inventory has a spatial component to it, emissions should be allocated equally across the vessel tracking paths derived from the AIS data. These emissions can then be summed across all vessels to the most useful spatial resolution for the purpose of the inventory (e.g., 100 m^2 grid cells for a detailed analysis or summed for the entire port for aggregate emissions data).
- Similarly, if the inventory has a temporal component to it, the emissions can be allocated according to the temporal distribution of AIS records. These emissions can then be summed to the most useful resolution for the purpose of the inventory (e.g., at the hourly level for a detailed analysis or yearly for an annual inventory).

5.6.6 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of vessel activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by vessel type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Distributions of vessel speed: Examining these distributions allow for general checks to ensure that vessels are modeled to be operating within reasonable limits and with expected patterns of behavior.
- Vessel counts and total operating hours: Examining both totals and distributions provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Average engine power: Examining this helps to estimate the relative impact that a given vessel type should have on the inventory.
- Fuel consumption: Comparing fuel consumption with the total fuel sold for recreational vessels is a good check to see if there is substantial missing vessel activity. Note that the calculated fuel consumption based on AIS data should be lower than the fuel sales estimates if the geographical domain of the inventory does not span the entire area where the recreational vessels operate.
- Total energy consumption (kWh): Examining energy consumption provides an estimate of the scale of vessel activity contributing to the inventory and for enabling cross-comparisons with other inventories.

Other quality control checks include:

- Examining geospatial heatmaps of energy consumption: This helps identify if there are gaps in the AIS data, or if there are anomalies in the data such as vessels being allocated to land or shallow regions where they should be unable to operate. This can also identify any AIS messages or gap filled records that should not be included in the inventory.
- Comparing CO_2 emissions with fuel consumption: CO_2 emissions and fuel consumption should have a linear relationship for recreational marine vessels.

5.7 Alternative Inventory Calculations

This section describes alternative methodologies for developing a base year recreational marine emissions inventory (e.g., when port-specific data on vessel activity, engine power, and/or model year are not available). These methodologies rely on surrogate sources of data that are not specific to the port; therefore, the resulting inventory may not be as useful for decision making purposes compared to an inventory produced following the detailed methodology described in Section 5.6. However, such inventories may be useful to estimate the order of magnitude of recreational marine emissions in comparison with other port sectors, which could be useful in determining which sector or sectors should be the focus of additional data gathering efforts.

In general, when using the surrogate data sources discussed in this section, total emissions can be calculated for each vessel type using Equation 5.5 with fleet average values:

$$E = N_v \times P \times LF \times A \times EF \qquad \textbf{Equation 5.5}$$

Where E = fleet emissions for each vessel type (g)
N_v = number of recreational vessels
P = average engine power (hp)
LF = average load factor (unitless)
A = average operating activity (h)
EF = emission factor (g/hp·h)

When using Equation 5.5, the average operating activity in hours should account for the number of engines per vessel (e.g., by multiplying the average number of operating hours per vessel by the average number of engines per vessel). These emissions can be then aggregated to the most useful level for the purposes of the inventory.

5.7.1 Missing Model Year Data

If a representative sample of recreational marine vessels have model year data, vessels with missing model years can be assumed to have the average value. However, if there are not enough model year data for this kind of analysis, a weighted emission factor that does not vary by model year can be used in the inventory calculation instead. This method relies on the median life and scrappage assumptions used by MOVES-Nonroad.[41] The same steps outlined in Section 5.5 should be used to produce recreational marine emission factors with the following modifications:

1. In the General Output Panel, only select SCC (do not select model year or hp class).
2. After the run has finished, the MOVES-Nonroad post-processing menu should be used to run the *EmissionFactors_per_hphr_by_SCC.sql* script on the output database. This step will generate

emission factors in grams per horsepower-hour by SCC (for each month and day type) for each pollutant selected based on the model run output.

These emission factors should then be applied in Equation 5.5 as described above. Alternatively, an AIS-based emissions inventory could be calculated following the same steps in Section 5.6, except the emission factors are assigned only by SCC instead of by SCC, model year, and engine power bin.

5.7.2 Missing Hours of Use and/or Engine Power Data

If a representative sample of recreational marine vessels have hours of use and/or engine power data, vessels missing these data can be assumed to have the average value(s). However, if there are insufficient data for this kind of analysis, the national average values used in MOVES-Nonroad may be used instead (see Table 5.4), but the resulting inventory would not reflect local conditions, which could have a significant impact on the resulting emissions inventory.

Table 5.4. Average Hours of Use and Engine Size of Recreational Vessels in MOVES-Nonroad

MOVES-Nonroad Recreational Vessel Type	Average Annual Hours of Operation	Average Engine Size (hp)
Gasoline (2-Stroke) Outboard	34.8	83
Gasoline (2-Stroke) Personal Water Craft	77.3	121
Gasoline (4-Stroke) Inboard/Sterndrive	47.6	242
Diesel Inboard/Sterndrive	200	250
Diesel Outboard	150	32

When using this surrogate data, recreational marine emissions should be calculated at the fleet level using the methodology described above. Note that when using these defaults, it can be assumed that the average annual hours of operation accounts for the average number of engines on each vessel.

5.7.3 Missing Vessel Count Data

If an accurate count of recreational vessels that operate in the geographical domain is unavailable, the number of slips (berthing or mooring locations) in the geographical domain can be used as a surrogate number. The number of slips may not exactly correspond to the number of recreational vessels operating in a port area, as some slips may be unoccupied, or multiple vessels may share a slip. If necessary, the number of slips in a geographical domain can usually be determined using satellite imagery. These vessels should be assigned the most common vessel type observed at the port.

When using this surrogate data, recreational marine emissions should be calculated at the sector level using the methodology described above.

5.8 Projecting Future Emission Inventories

Future recreational marine emissions should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Determine projected activity, using local port projections or activity growth factors from MOVES-Nonroad, applied to the base year
2. Determine future emission factors using MOVES-Nonroad

3. Calculate the future inventory with the projected activity and future emission factors, using the same methodology used to calculate the base year inventory
4. Aggregate the future inventory to the same level of detail as the base year inventory

The remainder of this section describes these steps in further detail.

5.8.1 Determine Projected Activity

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Local port projections or other regional forecasts are usually by commodity type and/or business sector; if expected growth in recreational boating is known, this should be used to estimate future activity.

If local port projections are unavailable, regional growth factors employed by MOVES-Nonroad can be used instead. These can be calculated by performing a run as described here. When setting up the RunSpec, the following selections should be made:

1. Time Spans Panel: Select base year of the analysis and the projected year. Select July for the month and Weekdays for the days selection.[j]
2. Geographic Bounds Panel: Select the county containing the port.[k]
3. Nonroad Vehicle Equipment Panel: Select gasoline and diesel Pleasure Craft.
4. Pollutants and Processes Panel: Select Brake Specific Fuel Consumption (BSFC).
5. Output Emissions Panel: Do not make any selections.

After the run has finished, locate the MOVES-Nonroad population output, specifically rows in the *movesactivityoutput* table with activityTypeID 6. Dividing the population of the projection year by the population for the base year results in the regional growth factor. This growth factor can then be applied to the base year activity to estimate the projection year activity:

- If the base year inventory was calculated using the AIS methodology, this growth factor should be applied to the engine operating activity term of Equation 5.4 in Section 5.6.4.
- If the base year inventory was calculated using the alternative methodologies, this growth factor should be applied to the average operating activity term of Equation 5.5 in Section 5.7.

5.8.2 Determine Projected Emission Factors

Due to the complexity of projecting future age distributions for recreational marine vessels, the median life and scrappage assumptions used by MOVES-Nonroad can be used instead of attempting to project a local age distribution for this sector. The same steps outlined in Section 5.5 should be used to produce future recreational marine emission factors with the following modifications:

1. In the General Output Panel, only select SCC (do not select model year or hp class).

[j] MOVES-Nonroad only models equipment and vessel populations on an annual basis; that is, it does not model different populations for different months or day types. Because the runs described here will only be used to extract population growth, the month and day selections are arbitrary. Only one month and one day type are selected for performance purposes, as well as to simplify the post-processing.

[k] If the geographical domain spans multiple counties, the county containing most of the geographical domain should be selected.

2. After the run has finished, the MOVES-Nonroad post-processing menu should be used to run the *EmissionFactors_per_hphr_by_SCC.sql* script on the output database. This step will generate emission factors in grams per horsepower-hour by SCC (for each month and day type) for each pollutant selected based on the model run output.

5.8.3 Calculate the Future Inventory

The future inventory should be calculated using the same equation as the base year inventory. If the base year inventory was calculated using the AIS methodology, Equation 5.4 should be used with the grown engine operating activity term and the future emission factors as described above. If the base year inventory was calculated using the alternative methodologies, Equation 5.5 should be used with the grown average operating activity term and the future emission factors as described above. Finally, the resulting emissions inventory should be aggregated to the same level of detail as the base year inventory.

6 CARGO HANDLING EQUIPMENT

6.1 SOURCE DESCRIPTION

The cargo handling equipment (CHE) sector encompasses equipment used for moving cargo, products, and supplies around a port or other freight terminal, and on and off marine vessels, railcars, and onroad trucks. This section could be used to quantify CHE emission inventories at ports or at other locations where cargo is moved, such as off-port cargo distribution centers or intermodal freight terminals where freight is transferred between rail and trucks. CHE are typically classified as "nonroad equipment," i.e., mobile equipment that do not operate on roadways.

Equipment types to be considered in an emissions inventory for a port's CHE sector may include (but are not limited to):

- Aerial lifts
- Compressors
- Cranes
- Empty container handlers
- Excavators
- Forklifts
- Generators/power packs
- Light towers
- Manlifts
- Off-highway trucks
- Rail pushers
- Reach stackers
- Rollers
- Rubber-tired gantry (RTG) cranes
- Side handlers
- Skid steer loaders
- Sweepers
- Top handlers
- Tractors/loaders/backhoes
- Welders
- Yard tractors

The scope of the inventory should be determined in advance of any calculations and in accordance with the overall inventory purposes, as discussed in Section 2. For example, while a port may have many different types of cargo handling equipment, it may be decided that it is most important to include equipment types that are most in use or the oldest, i.e., the equipment types that make up the largest contribution to emissions or those that would be the focus of replacement. Alternatively, it may be decided that every type of CHE present at the facility will be included, but the effort to gather detailed information would be focused on the most important equipment types. Information needed for a CHE inventory will likely come from the CHE owners or operators, which could include the port authority or

port operator, port tenants, terminal operators, or other agencies, which highlights the importance of cooperation in the process of developing an inventory. Additionally, the inventory should be calculated at the temporal level of detail necessitated by the purpose of the inventory (e.g., at the year level for an annual inventory). See Section 2 of this guidance for more discussion about inventory purpose and time period covered.

6.2 Emissions Estimation Overview

This section provides guidance regarding CHE data sources and general approaches that are relevant for any port or freight terminal inventory, regardless of location. Other than in California, the nonroad module of EPA's MOVES model (referred to here as MOVES-Nonroad) is the primary tool for estimating emissions from CHE in the U.S.[a] When using MOVES to develop a CHE emissions inventory, the most recent version should be used. The information in this section is applicable to all versions of MOVES3 as well as future versions of the MOVES model, unless EPA notes otherwise when approving the model for state implementation plan (SIP) and conformity purposes.[b] Inventories of CHE emissions in California should reference guidance for the latest version of California Air Resources Board's CHE emissions model instead of the specific guidance here for using MOVES-Nonroad.[c]

Information on all CHE present at the port should be gathered from terminal operators, and both public and private terminals should be represented. Based on this information, MOVES-Nonroad can be used to produce emission factors that can be multiplied by port-specific activity data to generate a base year inventory. The MOVES Technical Guidance[43] provides detailed information on how to generate emission inventories using MOVES-Nonroad. However, the general equation for calculating per unit CHE emissions based on MOVES-Nonroad output is as shown in Equation 6.1:

$$E = P \times LF \times A \times EF \qquad \textbf{Equation 6.1}$$

Where E = per unit emissions (g)
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)
EF = emission factor (g/hp·h)

Each of the above parameters may vary by equipment type and per unit. Therefore, it is important to account for equipment characteristics (Section 6.3) and activity (Section 6.4) accurately to ensure that operating power and hours are calculated correctly and that the right emission factors (Section 6.5) are applied to this activity.

There are different methods that can be used for estimating base year emissions from CHE, depending on data and resource availability:

- The primary method used to calculate a detailed emissions inventory is based on detailed CHE activity data and is described in Section 6.6, where emissions are calculated for each unit of CHE.

[a] In addition to U.S. states, this includes the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. For more information about MOVES, see https://www.epa.gov/moves.
[b] Note that the information in this section also applies to all versions of MOVES2014.
[c] For more information, see https://ww2.arb.ca.gov/msei-documentation-offroad-diesel-equipment.

Rated engine power (P), load factor (LF), and emission factors (EF) are assigned according to equipment characteristics, and engine operating activity (A) is determined from local CHE activity data.

- Alternative methodologies can be used where port-specific data on CHE activity, engine power, and/or model year are not available. These methodologies rely on surrogate sources of data and are presented in Section 6.7.

Section 6.8 describes how to project future year emission inventories for CHE.

If the port-related emissions inventory is to be combined with a larger regional emissions inventory (e.g., for SIP purposes), including a detailed analysis of CHE emissions within the geographical domain could possibly result in double-counting when the results are combined with county-wide inventories using the default activity estimates in MOVES-Nonroad. Since it is difficult to apportion default activity estimates in MOVES-Nonroad to a specific area within the county, EPA recommends using only MOVES-Nonroad default activity for the larger regional emission inventory. However, there could be cases where a more detailed analysis using the methods described in this document would be appropriate. If the purpose of the inventory is related to an overall inventory for a SIP, the interagency consultation process should be used to determine the methodology of calculating the port-related CHE emissions inventory.

6.3 Equipment Characteristics

To inform inputs for Equation 6.1 above, equipment characteristic data for each unit of CHE should be collected. The best sources of detailed data on equipment characteristics are surveys of and/or interviews with terminal operators. While default assumptions can be made for various characteristics, the more detailed the data that are collected, the more representative the resulting emissions inventory will be, and the more useful it will be for decision-making purposes. Specifically, the following data for each unit of CHE are useful when calculating a CHE emissions inventory:

- Equipment type
- Fuel type (e.g., diesel, gasoline, electric)
- Engine model year
- Rated engine power
- Retrofit devices or other emission mitigation measures employed (if applicable)

Each of these data fields are discussed in more detail in the remainder of this section. In addition to the equipment characteristics listed above, activity data (such as hours of operation and engine load factor) should be collected for each unit of CHE; these are discussed in detail in Section 6.4.

6.3.1 Equipment Type and Fuel Type

The majority of CHE can be classified based on existing MOVES-Nonroad source classification codes (SCCs), which categorize nonroad engines by equipment type and fuel type. Note that MOVES-Nonroad does not include electricity as a fuel type. If there is electric CHE at a port, their tailpipe emissions would be zero. For methods to estimate energy consumption for this source sector, including electric equipment, see Appendix A.

A mapping of common CHE types to MOVES-Nonroad equipment types is presented in Table 6.1. This table does not include every type of CHE that could be operating at an individual port. In practice, CHE can include any equipment operating at a port that does not belong to one of the other source sectors. Emissions from CHE types not listed in the table can be estimated using the "Other General Industrial Equipment" type.

Table 6.1. Mapping CHE Types to MOVES-Nonroad Equipment Types

CHE Type	MOVES-Nonroad Equipment Type	MOVES-Nonroad Sector
Aerial Lifts	Aerial Lifts	Industrial
Compressors	Air Compressors	Commercial
Cranes	Cranes	Construction
Empty Container Handlers	Other General Industrial Equipment	Industrial
Excavators	Excavators	Construction
Forklifts	Forklifts	Industrial
Generators/Power Packs	Generator Sets	Commercial
Light Towers	Signal Boards/Light Plants	Construction
Manlifts	Aerial Lifts	Industrial
Off-highway Trucks	Off-highway Trucks	Construction
Pumps	Pumps	Commercial
Rail Pushers	Other General Industrial Equipment	Industrial
Reach Stackers	Other General Industrial Equipment	Industrial
Rollers	Rollers	Construction
RTG Cranes	Other General Industrial Equipment	Industrial
Side Handlers	Other General Industrial Equipment	Industrial
Skid Steer Loaders	Skid Steer Loaders	Construction
Sweepers	Sweepers/Scrubbers	Industrial
Top Handlers	Other General Industrial Equipment	Industrial
Tractor/Loader/Backhoes	Tractors/Loaders/Backhoes	Construction
Welders	Welders	Commercial
Yard/Jockey/Mule Tractors	Terminal Tractors	Industrial

A mapping of MOVES-Nonroad equipment types and fuel types to SCC is presented in Table 6.2. For each unit of CHE, the appropriate MOVES-Nonroad equipment type should be determined using Table 6.1, and then it should be assigned an SCC using Table 6.2.

Table 6.2. Mapping MOVES-Nonroad Equipment Types and Fuel Types to SCC

MOVES-Nonroad Equipment Type	Source Classification Code (SCC) by Fuel Type				
	Diesel	2-Stroke Gasoline	4-Stroke Gasoline	LPG*	CNG
Aerial Lifts	2270003010	N/A**	2265003010	2267003010	N/A
Air Compressors	2270006015	2260006015	2265006015	2267006015	2268006015
Cranes	2270002045	N/A	2265002045	2267002045	N/A
Excavators	2270002036	N/A	N/A	N/A	N/A
Forklifts	2270003020	N/A	2265003020	2267003020	2268003020
Generator Sets	2270006005	2260006005	2265006005	2267006005	2268006005
Off-highway Trucks	2270002051	N/A	N/A	N/A	N/A
Other General Industrial Equipment	2270003040	2260003040	2265003040	2267003040	2268003040
Pumps	2270006010	2260006010	2265006010	2267006010	2268006010
Rollers	2270002015	N/A	2265002015	2267002015	N/A
Signal Boards/Light Plants	2270002027	2260002027	2265002027	N/A	N/A
Skid Steer Loaders	2270002072	N/A	2265002072	2267002072	N/A
Sweepers/Scrubbers	2270003030	2260003030	2265003030	2267003030	2268003030
Terminal Tractors	2270003070	N/A	2265003070	2267003070	2268003070
Tractors/Loaders/Backhoes	2270002066	N/A	2265002066	2267002066	N/A
Welders	2270006025	N/A	2265006025	2267006025	N/A

* CHE using propane should be matched to an appropriate LPG SCC.

** N/A indicates that MOVES-Nonroad cannot model this combination of equipment type and fuel type. If such a combination is present, emissions can be estimated using the "Other General Industrial Equipment" type.

In general, the default fuel characteristics in MOVES can be used as-is, which will be automatically applied in a MOVES-Nonroad run for the county containing the port. MOVES users should review the default fuel supply and fuel formulation information provided in MOVES, and make changes only where precise local volumetric fuel property information is available or where local fuel requirements have changed.

One exception to this guidance is in the case of Reid Vapor Pressure (RVP); the MOVES user should change this value to reflect any specific state or local regulatory requirements and differences between ethanol- and non-ethanol blended gasoline not reflected in the default database (e.g., the default database may not reflect a recent regulatory action to change an RVP requirement). Any changes to RVP (or to any other gasoline fuel formulation parameters) should be done using the "Fuels Wizard" tool in the Fuel Tab of the Nonroad Data Importer. This process is described in more detail in Section 5.2.2 of the MOVES Technical Guidance. Note that the Fuels Wizard only applies to gasoline fuels. If any diesel fuel properties (such as the diesel sulfur content) need to be changed, MOVES users should modify the property in the fuel formulation table for the modeled county using the Nonroad Data Importer.

6.3.2 Engine Model Year

Engine model year is important for an emissions inventory, as newer CHE meet more stringent EPA emission standards. The MOVES-Nonroad model internally associates an emission standard tier based on an engine's model year and power rating, and accounts for other factors that vary by model year and/or age, including tier phase-in, specific technology penetration rates, and deterioration. Therefore, it is not necessary to collect data on tier distributions or different technology types, as these are accounted for by the model year parameter.

Note that due to assumptions made in MOVES-Nonroad regarding median life,[41] a single model run may not be sufficient to generate emission factors for all CHE model years present during the timespan of analysis. That is, there may be CHE at the port that are older than the oldest equipment assumed in the model. Therefore, it may be necessary to run MOVES-Nonroad for multiple calendar years to ensure emission factors for all model years are calculated. This is discussed in further detail in Section 6.5.

If a representative sample of CHE have model year data, equipment of the same type with missing model years can be assumed to have the average value. If there are insufficient model year data for this kind of analysis, default assumptions can be made as described in Section 6.7.1. However, using default data would not reflect local conditions, which could have a significant impact on the resulting emissions inventory.

6.3.3 Rated Engine Power

In addition to equipment type, fuel type, and model year, emission factors from MOVES-Nonroad vary by rated engine power bin. Therefore, each unit of equipment should be assigned to the appropriate bin. Table 6.3 lists the definitions of the engine power bins in MOVES-Nonroad. Each CHE type is generally represented in a subset of the listed power ranges (e.g., diesel aerial lifts span the range 6 < hp ≤ 175).

Table 6.3. MOVES-Nonroad Engine Power Bins

Bin ID*	Rated Engine Power (hp)	Rated Engine Power (kW)
1	0 < hp ≤ 1	0 < kW ≤ 0.7
3	1 < hp ≤ 3	0.7 < kW ≤ 2.2
6	3 < hp ≤ 6	2.2 < kW ≤ 4.5
11	6 < hp ≤ 11	4.5 < kW ≤ 8.2
16	11 < hp ≤ 16	8.2 < kW ≤ 12
25	16 < hp ≤ 25	12 < kW ≤ 19
40	25 < hp ≤ 40	19 < kW ≤ 30
50	40 < hp ≤ 50	30 < kW ≤ 37
75	50 < hp ≤ 75	37 < kW ≤ 56
100	75 < hp ≤ 100	56 < kW ≤ 75
175	100 < hp ≤ 175	75 < kW ≤ 130
300	175 < hp ≤ 300	130 < kW ≤ 224
600	300 < hp ≤ 600	224 < kW ≤ 447

Bin ID*	Rated Engine Power (hp)	Rated Engine Power (kW)
750	600 < hp ≤ 750	447 < kW ≤ 559
1000	750 < hp ≤ 1,000	559 < kW ≤ 746
1200	1,000 < hp ≤ 1,200	746 < kW ≤ 895
2000	1,200 < hp ≤ 2,000	895 < kW ≤ 1,491
3000	2,000 < hp ≤ 3,000	1,491 < kW ≤ 2,237

* Corresponds to values in the hpID column of MOVES-Nonroad output tables.

Engine power ratings can in most cases be obtained from the equipment's physical engine tag.[44] If the engine tag does not provide this information, rated power can be determined from the specification guide or owner's manual for the equipment model.

If an equipment-specific power value cannot be determined for a CHE unit (e.g., because equipment manufacturer and/or model is not known), the average of known power values from similar equipment in the CHE fleet can be used instead. If there are insufficient data for this kind of analysis, alternative assumptions can be made as described in Section 6.7.2. However, using alternative data would not reflect local conditions, which could have a significant impact on the resulting emissions inventory.

6.3.4 Equipment Retrofit and Replacement Projects

MOVES-Nonroad does not account for state or local projects to retrofit emission reduction technologies on nonroad diesel equipment or to replace older engines or equipment with newer, cleaner ones. If the port has such a program, it should be accounted for using MOVES-Nonroad. EPA has a separate guidance document, *Diesel Retrofit and Replacement Projects: Quantifying and Using Their Emission Benefits in SIPs and Conformity*, which addresses the quantification of diesel retrofit and replacement projects in detail.[46] Section 2.7 of that document describes how to quantify emission reductions from nonroad retrofit projects and Section 2.8 describes how to quantify emission reductions from nonroad equipment or engine replacement projects. EPA also provides a "Nonroad Retrofit Tool" to simplify the creation of a nonroad retrofit input file for use in MOVES, which applies when retrofitting an existing diesel engine with new technology or devices.[d]

6.4 Equipment Activity

As described in Section 6.2, emissions are directly related to activity. To create a detailed CHE emissions inventory, activity profiles should be developed for each unit of CHE; this includes information on hours of use (specifically, hours of engine operation during the analysis time period) and load factor (fraction of full engine power used, on average, over a given period). This information may be available from the CHE owners or operators, which could include the port authority or port operator, the port tenants, terminal operators, or other agencies.

The best source of data for hours of use is hour-meter readings. When hour-meter information is unavailable, estimates of hours of use can be derived from interviews or surveys with terminal operators. Note that equipment usage patterns likely differ by equipment type. If hour usage information is not available for individual equipment units in the fleet, averages by equipment type

[d] Available at https://www.epa.gov/moves/tools-develop-or-convert-moves-inputs.

operating at the same terminal (if available) or port can be used. If there are insufficient data for this kind of analysis, alternative assumptions can be made as described in Section 6.7.2. However, using alternative data would not reflect local conditions, which could have a significant impact on the resulting emissions inventory.

In general, the default load factors from MOVES-Nonroad can be used.[41 e f] Default load factors for MOVES-Nonroad equipment types are presented in Table 6.4.

Table 6.4. Default Load Factors by Fuel Type

MOVES-Nonroad Equipment Type	Diesel	2-Stroke Gasoline	4-Stroke Gasoline	LPG	CNG
Aerial Lifts	0.21	N/A*	0.46	0.46	N/A
Air Compressors	0.43	0.56	0.56	0.56	0.56
Cranes	0.43	N/A	0.47	0.47	N/A
Excavators	0.59	N/A	N/A	N/A	N/A
Forklifts	0.59	N/A	0.30	0.30	0.30
Generator Sets	0.43	0.68	0.68	0.68	0.68
Off-highway Trucks	0.59	N/A	N/A	N/A	N/A
Other General Industrial Equipment	0.43	0.54	0.54	0.54	0.54
Pumps	0.43	0.69	0.69	0.69	0.69
Rollers	0.59	N/A	0.62	0.62	N/A
Signal Boards/Light Plants	0.43	0.72	0.72	N/A	N/A
Skid Steer Loaders	0.21	N/A	0.58	0.58	N/A
Sweepers/Scrubbers	0.43	0.71	0.71	0.71	0.71
Terminal Tractors	0.39	N/A	0.78	0.78	0.78
Tractors/Loaders/Backhoes	0.21	N/A	0.48	0.48	N/A
Welders	0.21	N/A	0.68	0.68	N/A

* N/A indicates that MOVES-Nonroad cannot model this combination of equipment type and fuel type. If such a combination is present, use the load factor associated with the "Other General Industrial Equipment" type.

6.5 Emission Factors

CHE emission factors for most pollutants come from post-processing MOVES-Nonroad output. However, MOVES-Nonroad cannot estimate emissions for nitrous oxide (N_2O) or black carbon (BC), so if

[e] While it is possible to determine port-specific load factors by installing portable activity measurement systems (PAMS) on CHE, this is likely to be useful only for very detailed CHE emission inventories and when terminal operators have reason to believe their equipment are operating with significantly different load factors than the defaults.

[f] The default load factor given for the Terminal Tractors equipment type is based on a study conducted by the ports of Long Beach and Los Angeles in consultation with California Air Resources Board. See reference **Error! Reference source not found.** for more information.

these pollutants are included in the inventory, they will need additional post-processing as described below.

For methods to estimate energy consumption for this source sector, see Appendix A.

6.5.1 Running MOVES-Nonroad

MOVES-Nonroad calculates emissions based on model inputs for equipment activity, age distributions, meteorological conditions, fuel characteristics, and other variables. In some cases, the default inputs are specific to the region or county being modeled. The recommended approach for incorporating local port activity data in a MOVES-Nonroad analysis is to first run MOVES-Nonroad for the geographical domain and time period of the inventory with default inputs, and then post-process the output using scripts included in MOVES to calculate emission factors. These emission factors can then be applied to local activity data to generate an emissions inventory. Note that the latest version of MOVES-Nonroad should be used, and the latest MOVES Technical Guidance and the MOVES Training[45] contain background information on how to use MOVES-Nonroad.

When setting up a Run Specification (RunSpec) using the MOVES Graphical User Interface (GUI), the following selections should be made:

1. Time Spans Panel: Select the calendar year of analysis and all months/day types (weekday/weekend).
2. Geographic Bounds Panel: Select the county containing the port.[g]
3. Nonroad Vehicle Equipment Panel: Add the fuel type/source sector combinations represented at the port, based on the mapping of port CHE types to SCCs (as described in Section 6.3.1).
4. Pollutants and Processes Panel: Select all processes for the pollutants of interest (refer to Section 2).
5. Output Emissions Detail Panel: Select model year, SCC, and hp class (i.e., engine power bin).

If user supplied fuel data (see Section 6.3.1) or a retrofit or replacement program (see Section 6.3.4) needs to be included, those inputs should be configured using the Nonroad Data Importer after setting up the RunSpec as described in Section 5.2.2 of the MOVES Technical Guidance.

The MOVES-Nonroad run will produce inventory output for the months and day types selected in the Time Spans Panel by the selected level of detail in the General Output Panel. After the run has finished, the MOVES-Nonroad post-processing menu should be used to run the *EmissionFactors_per_hphr_by_SCC_and_ModelYear.sql* script on the output database. This step will generate emission factors in grams per horsepower-hour by SCC, engine power bin, and model year (for each month and day type) for each pollutant selected based on the model run output. Section 5.3 of the MOVES Technical Guidance provides more details on how to run MOVES-Nonroad post-processing scripts.

After the script finishes, the MOVES user should inspect the results. If there are older equipment at the port than the earliest model year appearing in the MOVES-Nonroad results, an additional MOVES run is needed. The same steps outlined above should be taken, except the MOVES user should select the previous calendar year (e.g., if the base year is 2020, calendar year 2019 would be selected for the

[g] If the geographical domain spans multiple counties, the county containing most of the geographical domain should be selected.

additional run). Note that the default fuel sulfur level for both gasoline and diesel should be inspected before running earlier calendar years; it should be set to the same value that was used in the base year run because this run is simulating emissions from the older model year equipment operating in the base year. Results for only the oldest model year should be used from this additional run. This step will need to be repeated (incrementing back one calendar year while maintaining the base year's fuel sulfur level) until emission factors are obtained for all equipment operating at the port.

If the temporal scale of the analysis is daily, the appropriate emission factor for the time domain should be used. However, if the temporal scale of the analysis is annual or seasonal, weighted average emission factors for each SCC, engine power bin, and model year can be estimated from the month-day type specific emission factors:

- Emission factors should be weighted by seasonal or weekday/weekend cargo throughput if those data are available.
- Otherwise, the emission factors could be weighted by the number of times a given month-day type occurs in the analysis year.

Note, if model year information is not available in the activity data, see Section 6.7.1 for an alternative method for generating fleet average emission factors using MOVES-Nonroad.

6.5.2 Nitrous Oxide (N_2O)

N_2O emission factors can be estimated from brake specific fuel consumption (BSFC) using Equation 6.2:

$$EF_{N_2O} = BSFC \times NCF \qquad \textbf{Equation 6.2}$$

Where EF_{N_2O} = N_2O emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 6.5.1
NCF = N_2O conversion factor (g N_2O/g fuel) as presented in Table 6.5[38]

Table 6.5. CHE N_2O Conversion Factors

Fuel Type	N_2O Conversion Factor (g N_2O/g fuel)
Gasoline (2 Stroke)	0.000020
Gasoline (4 Stroke)	0.000071
Diesel	0.000147
CNG	0.000201
LPG	0.000201

6.5.3 Black Carbon (BC)

BC emission factors can be estimated from particulate matter less than or equal to 2.5 microns ($PM_{2.5}$) emission factors using Equation 6.3:

$$EF_{BC} = EF_{PM_{2.5}} \times BCF \qquad \textbf{Equation 6.3}$$

Where EF_{BC} = BC emission factor (g/hp·h)

$EF_{PM_{2.5}}$ = $PM_{2.5}$ emission factor (g/hp·h) as determined according to Section 6.5.1
BCF = black carbon fraction[33] (g BC/g $PM_{2.5}$)
= 0.77 for diesel equipment
= 0.10 for other equipment

6.6 Detailed Inventory Calculations

A detailed emissions inventory is first calculated at the per unit level as described in Section 6.6.1 and then aggregated across all equipment to the most useful level for the purposes of the inventory (Section 6.6.2). The final step is to perform quality control checks, as described in Section 6.6.3.

6.6.1 Calculating an Emissions Inventory Per Unit

A detailed base year emissions inventory can be calculated for CHE on a per unit basis through the following steps:

1. Assign each CHE unit to the appropriate MOVES-Nonroad equipment type and SCC as described in Section 6.3.1, and a MOVES-Nonroad engine power bin as described in Section 6.3.3.
2. Assign each CHE unit an appropriate load factor as described in Section 6.4.
3. Run MOVES-Nonroad and the post-processing script as described in Section 6.5. If needed, calculate a weighted emission factor for all months and day types (e.g., if the activity data is on an annual basis), also as described in Section 6.5.
4. Assign each CHE unit the appropriate emission factor (or sets of emission factors by month and day type, e.g. if the activity data has that level of detail) for each pollutant, based on SCC, engine power bin (labeled as hpID in MOVES output), and model year.
5. Calculate emissions for each CHE unit using Equation 6.4:

$$E = P \times LF \times A \times EF \qquad \textbf{Equation 6.4}$$

Where E = per unit emissions (g)
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)
EF = emission factor (g/hp·h)

6.6.2 Aggregating Per Unit Emissions

These emissions can be then aggregated across all equipment to the most useful level for the purposes of the inventory.

- If the inventory has a spatial component to it, CHE emissions should be allocated to the terminal area where they occur. For example, the location of emissions is important if the purpose of estimating emissions is for use in air quality modeling or if different types of CHE activity occur in different parts of the port.
- If the inventory has a temporal component to it and the activity data are at a finer level of detail, the CHE emissions should be aggregated to the level of detail necessitated by the purpose of the inventory. For example, if the port has significant seasonal variation in activity or if the purpose of the inventory is to support air quality modeling, how emissions change over time is a key input. If activity data are available to estimate emissions for specific times of day

and/or seasons of the year, these data can be applied to other hours as appropriate in the air quality model.

However, if the activity data are at a coarser level of temporal detail than what is necessitated by the purpose of the inventory, the emissions will need to be allocated temporally using surrogate data. This surrogate data can come from other sectors in the port inventory, if those have sufficient detail (e.g., CHE activity could be temporally allocated based on AIS-derived OGV hotelling activity, if available).

6.6.3 Perform Quality Control Checks

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of equipment activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in several checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by equipment type and fuel type. The following distributions and metrics are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Equipment counts: Examining both totals and distributions provides an estimate of the scale of equipment activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Engine power and operating hours: Examining both totals and distributions helps to estimate the relative impact that a given equipment type should have on the inventory.
- Model year range and engine tier distribution: Examining the minimum and maximum observed values and average age, along with the distribution of engine tiers, provides an indication of how old the equipment are and can help in determining which equipment contribute substantially to the inventory.
- Total energy consumption (in horsepower-hours): Examining energy consumption by equipment type provides an estimate of the scale of equipment activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Comparing CO_2 emissions with fuel consumption: CO_2 emissions and fuel consumption should have a linear relationship.

6.7 Alternative Inventory Calculations

This section describes alternative methodologies for developing a base year CHE emissions inventory (e.g., when port-specific data on equipment activity, engine power, and/or model year are not available). As these methodologies rely on surrogate sources of data that are not specific to the port, the resulting inventory may not be as useful for decision making purposes as an inventory calculated with the detailed methodology described above. For example, an inventory that relies on surrogate sources would not necessarily help determine which specific types of CHE should be targeted for future replacements. However, at a minimum, such inventories may be useful to estimate the order of magnitude of CHE emissions in comparison with other port sectors, which could be useful in determining which sector or sectors should be the focus of additional data gathering efforts.

6.7.1 Missing Model Year Data

If a representative sample of an equipment type has model year data, units with missing model years can be assumed to have the average value. However, if there are not enough model year data for this kind of analysis, a weighted emission factor that does not vary by model year can be used in the inventory calculation instead. This method relies on the median life and scrappage assumptions used by MOVES-Nonroad.[41] The same steps outlined in Section 6.5 should be used to produce CHE emission factors with the following modifications:

1. In the General Output Panel, only select SCC (do not select model year or hp class).
2. After the run has finished, the MOVES-Nonroad post-processing menu should be used to run the *EmissionFactors_per_hphr_by_SCC.sql* script on the output database. This step will generate emission factors in grams per horsepower-hour by SCC (for each month and day type) for each pollutant selected based on the model run output.

The emissions inventory can then be calculated following the same five steps in Section 6.6, except the emission factors are assigned only by SCC instead of SCC, model year, and engine power bin.

6.7.2 Missing Equipment Hours of Use and/or Engine Power Data

If a representative sample of units of an equipment type have hours of use and/or engine power data, units missing these data can be assumed to have the average value(s). However, if there are insufficient data for this kind of analysis, surrogate averages from an existing detailed port inventory may be used instead, but the resulting inventory would be less precise than using local data. This method assumes that the surrogate port's CHE activity is similar in scope as the port in question. Therefore, care should be taken in reviewing recent port inventories; a surrogate port should have the same order of magnitude of cargo throughput and similar operational profiles. If a suitable match is found, the emissions inventory can be calculated following the same steps in Section 6.6, just using the average values by equipment type for CHE hours of use and/or engine power data from the surrogate port's detailed emissions inventory.

6.8 Projecting Future Emission Inventories

Future CHE emissions should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Activity growth rates are applied to the base year activity to estimate future activity
2. Equipment model years are adjusted to account for fleet turnover to newer, cleaner engines and emission factors are reassigned
3. Projected emissions are calculated using the estimated future activity
4. Projected emissions are aggregated to the same level of detail as the base year inventory, as determined by the purpose of the inventory

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Projected changes in activity should be determined for each CHE type. Local port projections or other regional forecasts are usually by commodity type and/or business sector; these projections by commodity type can be applied to the CHE types that handle the various commodities (i.e., containerized, dry bulk, liquid bulk, and break bulk).

If local port projections or other regional forecasts are unavailable, the Freight Analysis Framework (FAF)[15] can be used to forecast growth instead. If this is used, the commodity flows in the FAF assigned to all transportation modes should be grouped by the appropriate CHE types when calculating growth. For example, all commodity types that can be containerized should be included when determining the growth rates for CHE types that move containers. If detailed growth by commodity type and/or business sector is not available, or for CHE types that are involved in moving different kinds of cargo, total port growth can be used instead of commodity-specific growth.

The growth rates should then be applied to the base year hours of operation for each CHE unit.

To reflect fleet turnover, the equipment model years that were used in the base year inventory should be adjusted for use in the future year inventory. If the port or region has already identified an expected future age distribution (or if a fleet manager has identified their expected fleet retirements and replacements), that information should be used in determining how to adjust the model years. If the future age distribution is unknown, it can be assumed to be the same as the base year age distribution. That is, it can be assumed that in the future, the percentages of CHE that are brand new, one year old, two years old, etc. are the same as those percentages in the base year inventory. Functionally, this can be implemented by adding the difference between the future and base years to each model year used in the base year inventory, to get a new set of model years for the future year inventory. For example, if the base year inventory is for 2020 and the projected inventory is for 2030, the difference of 10 years is added to each model year. In this example, a model year 2005 CHE in the base year inventory would be model year 2015 CHE in the 2030 inventory.

Additionally, any planned action or emission reduction strategies that have been committed to that would affect future emissions should be included according to the actual expected implementation of such commitments. For example, if a port has committed to replacing or repowering its oldest ship-to-shore cranes through authorization of funds for such purchases, the effects of such a program should be reflected in the projected age distribution. Note that if the future year inventory is for a regulatory purpose, planned future actions should be included only if written commitments have been made by the agency or operator with the power to implement them.

The emission factors for the projection year should be determined using the same method as the base year (as described in Section 6.5), except the MOVES user should select the projection year on the Time Spans Panel instead of the base year. The resulting emission factors should be assigned to each CHE unit using the adjusted model years.

Once the base year activity has been scaled and appropriate emission factors are assigned to each unit, the projected future emissions can be calculated using the same methodology at the same level of detail as the base year inventory, and the resulting emissions inventory should be aggregated to the same level of detail as the base year inventory.

7 ONROAD VEHICLES

7.1 SOURCE DESCRIPTION

The onroad vehicles sector includes cars, buses, trucks, and other motor vehicles that operate on roads. This section could be used to quantify emissions for onroad vehicle activity occurring on the grounds of a port and also on nearby transportation corridors outside the port boundary that are determined to be appropriate to include, based on the purpose of the inventory. For convenience, the term "port-related" in this section refers to the onroad emissions being included, whether just at the port or also outside the port's boundary. Section 7.2.2 discusses geographical scope in further detail.

While this section is focused on estimating emissions that are port-related, it could also be used to estimate emissions at other locations where cargo is moved, such as off-port cargo distribution centers or intermodal freight terminals where freight is transferred between rail and trucks.

The types of onroad vehicles and their activity included in a port-related inventory will depend on the main function(s) of a given port. For example, a facility focused on freight will likely be serviced by an onroad vehicle fleet consisting of heavy-duty diesel trucks, whereas a cruise port may include large numbers of gasoline-fueled passenger vehicles and shuttle buses as well as diesel vehicles that service cruise ships with fuel and other supplies. Vehicle types to be considered in a port-related emissions inventory may include (but are not limited to):

Heavy-Duty Vehicles

- Drayage Trucks
- Long-Haul Trucks
- Shuttle Buses
- Refueling Trucks

Light-Duty Vehicles

- Passenger Cars and Trucks
- Passenger Vans
- Import/Export Vehicles
- Maintenance Vehicles

While this guidance does not specifically include methodologies for all onroad vehicle activity cases, it seeks to provide some conceptual approaches to address a range of activities. For example, a port that includes vehicle imports or exports via roll-on/roll-off vessels (i.e., where vehicles are driven off a ship) may want to include the emissions from those vehicle movements and storage. The methods and approaches in this guidance can be applied or adapted to most onroad vehicle activity.

7.2 OVERVIEW OF APPROACHES AND CONSIDERATIONS FOR DEVELOPING AN ONROAD VEHICLE EMISSIONS INVENTORY

This section provides guidance regarding data sources and general approaches that could be relevant for any port or freight terminal inventory, regardless of location. Other than in California, EPA's MOVES model is the primary tool for estimating emissions from onroad vehicles in the U.S.[a] When using MOVES to develop an onroad emissions inventory, the most recent version should be used. The information in this section is applicable to all versions of MOVES3 as well as future versions of the MOVES model,

[a] In addition to U.S. states, this includes the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. For more information about MOVES, see https://www.epa.gov/moves.

unless EPA notes otherwise when approving the model for state implementation plan (SIP) and conformity purposes. Inventories of onroad vehicle emissions in California should reference guidance for the latest EPA-approved version of California Air Resources Board's onroad emissions model, EMFAC, instead of the specific guidance here for using MOVES.[b] Note, neither MOVES nor EMFAC can estimate road dust emissions. EPA has methods for calculating road dust detailed in Section 13.2 of AP-42[47] and Section 6 of EPA's PM Hot-spot Guidance.[48]

MOVES includes the ability to model onroad emissions at different analysis "scales" and with different calculation types, which are discussed further in Section 7.3. MOVES also allows users to make choices that reflect the conditions in their local area. The two scales discussed in this guidance are:

- County Scale: This scale uses local data on the number and types of vehicles, how many miles they travel within the geographical domain, and various fleet characteristics, such as age distributions. When using this scale to estimate port-related onroad emissions, the geographical domain of the inventory is modeled as a "county" that includes only the activity occurring in that area (i.e., the activity that is port-related), and MOVES produces a total onroad vehicle emissions inventory that does not need further post-processing. The approach in this guidance that uses County Scale is detailed in Section 7.5.
- Project Scale: This scale uses more detailed data than County Scale. In addition to the local data described above, Project Scale allows the MOVES user to model a series of links that represent different types of vehicle activity that is port-related. Using this scale, activity-based emission factors for each onroad vehicle type operating in the area of interest are developed, and the port-related onroad emissions inventory is calculated by post-processing the MOVES results. Then, link emissions rates are scaled up and summed to develop an inventory for a specific period of time, such as a day or a year. The approaches in this guidance that use Project Scale are detailed in Section 7.6 and Appendix I.

These scales are discussed in more detail below in Section 7.3.1. Additionally, the MOVES Technical Guidance[43] and MOVES training[45] contain background information on how to use MOVES. Note that EPA has issued other guidance for developing inventories for onroad sources. Rather than duplicating existing guidance, this section describes the general approaches for developing an onroad vehicle inventory but refers the reader to EPA's existing guidance as appropriate.

7.2.1 Inventory Purpose and Other Considerations

The choice of modeling approach and the geographical scope covered by the inventory will depend on the purpose or end use of the inventory. If the purpose of the inventory is regulatory, please consult the appropriate EPA guidance document. The following discussion highlights some potential inventory purposes and associated analysis considerations.

- Regulatory Application – SIP: If the purpose of the emissions inventory is for use in a SIP, the analysis should follow the MOVES Technical Guidance to ensure that the applicable SIP requirements are met.
- Regulatory Application – Hot-spot Analysis: If the purpose of the analysis is to develop emissions for use in a PM hot-spot analysis, emissions must be geographically allocated.[49]

[b] For more information, see https://ww3.arb.ca.gov/msei/msei.htm.

Guidance on the use of the Project Scale in MOVES for quantitative hot-spot analysis in nonattainment and maintenance areas is described in the PM Hot-spot Guidance.[c] See Appendix I for more information.

- Non-Regulatory Application – Air Quality Analysis: If the inventory is for an air quality analysis not related to transportation conformity, such as corridor level analysis, MOVES at the Project Scale should be used with the project scale refined approach (see Appendix I for more information). However, since the purpose in this case is non-regulatory, there could be more discretion regarding the number of runs needed to capture variations in activity levels and the overall geographical scope to be included in the analysis.

Another consideration is whether emissions of volatile organic compounds (VOCs) or air toxics are to be included in the analysis for the onroad vehicle inventory. Evaporative processes that occur when gasoline vehicles are parked can account for a significant portion of gaseous hydrocarbon emissions from gasoline vehicles. Because the MOVES at the Project Scale estimates emissions for one hour at a time, it does not capture evaporative process emissions associated with soak activity. If VOCs or air toxics need to be included in the inventory, these can be estimated with the County Scale. Either the County Scale approach can be used for the entire inventory, or a Project Scale approach can be supplemented with a County Scale run for just these emissions.

Additionally, an inventory with a finer level of detail may provide greater value for port authorities and terminal operators for identifying potentially efficient mitigation strategies or control measures or other areas for operational changes.

7.2.2 Geographical Scope

The geographical scope of the inventory is a key consideration for the onroad vehicle sector, and part of this consideration is to determine what near-port transportation corridors and associated road types to include in the inventory. For example, the boundary of the inventory may include areas under jurisdiction of the local port authority only and exclude transportation corridors servicing the port. Alternatively, boundaries may be chosen to characterize all port-related emissions in an air basin and would thus include activity on nearby transportation corridors such as drayage movements to off-port rail facilities, short-haul truck movements to cross-docking facilities and local customers, or passenger car trips and long-haul truck movements to and from the boundary of the defined geographical scope. Regardless of which approach is employed, the scope of the inventory should be decided in advance of any calculations and remain consistent and in accordance with the inventory's purpose.

If the port-related emissions inventory is to be combined with a larger regional emissions inventory (e.g., for SIP purposes), including roads outside of the port could possibly result in double-counting the emissions from activity on these roads. However, there could be cases where roads outside the port boundary should be included in the port onroad inventory. For example, if the port has a long access road that is not a public road and therefore not included in the regional transportation network model, activity on that access road would be appropriate to include in the port inventory. If the purpose of the

[c] A PM hot-spot analysis is an estimation of likely future localized pollutant concentrations and a comparison of those concentrations to the relevant NAAQS. It is required only for certain kinds of transportation projects in PM_{10} and $PM_{2.5}$ nonattainment and maintenance areas. See 40 CFR 93.101, *Hot-spot analysis* definition, and 40 CFR 93.123(b).

inventory is related to an overall inventory for a SIP, the interagency consultation process should be used to determine the geographical scope of the port-related inventory.

7.3 Overview of MOVES

MOVES can be used to estimate emissions from port-related onroad vehicles directly or to develop emission factors that can then be used to create an inventory outside of the model. This section summarizes the different ways that MOVES can be run, including basic inputs, advantages, and limitations of each approach.

7.3.1 Scale and Calculation Type

A key feature of MOVES is the ability to estimate emissions at different analysis scales and calculation types. MOVES can analyze mobile emissions at different scales: Default , County, and Project. For the purposes of port-related onroad vehicle inventory development, EPA recommends using either the County or Project scales.[d] For more information on MOVES scales, see Section 3.2.2 of the MOVES Technical Guidance for more information.

The County Scale can be used to create onroad vehicle emissions inventories for an individual or multi-county area, a metropolitan area, a region of a state, an entire state, or a multi-state area or region. The County Scale can also be used to model a smaller geographical area, such as the area covered by the port-related inventory.

The Project Scale allows the modelling of a set of individual roadway links and/or parking area(s) where driving activity occurs or where vehicle parking and starts occur, and links can be defined to represent the port-related activity.[e] At the Project Scale, each MOVES run represents one specific hour of a single day of a single year. Therefore, if the Project Scale approach is selected for generating a port related onroad vehicle inventory, the MOVES user would need to consider the number of runs needed to represent the port conditions at the temporal scale of the inventory, such as a day or a year (discussed further in section 7.6.1.2).

MOVES can also be configured between two calculation types: Inventory or Emission Rates. Selecting Inventory produces an output of total emissions in a specified unit of mass. Selecting Emission Rates will provide emission factors in terms of units of mass per unit of activity, which can then be multiplied by

[d] At the Default Scale, MOVES uses a default national database that allocates emissions to the state and county level based on a mix of national data, allocation factors, and some preloaded local data. As the default data in the national database may not be the most current or best available information for any specific area, it is not recommended to use the Default Scale option when developing port-related emission inventories.

[e] Note that hotelling activity is usually not included in port-related onroad inventories. In this context, hotelling refers to the activity of long-haul trucks when the vehicle is parked, often overnight, during driver rest periods while heating/cooling equipment or appliances are in use. This activity places a load on the engine, auxiliary power unit, or electrical hookup. This activity is characterized separately from idling during "workday" truck operation such as queuing at a distribution center, loading freight, etc. Hotelling is assumed not to occur directly on ports, however, may occur within the broader region. For more details on hotelling activity, refer to Section 4.11 of the MOVES Technical Guidance or Module 3 of the MOVES Training (see reference **Error! Reference source not found.**).

different units of activity for inventory development.[f] Both the County Scale Approach (Section 7.5) and the Project Scale Generic Link Approach (Section 7.6.2) use the Inventory calculation type.

7.3.2 Pollutants and Processes

MOVES can provide onroad vehicle emissions for many pollutants including criteria air pollutants, greenhouse gases, and air toxics. Those selected when running MOVES would be based on the purpose of the inventory, as discussed in Section 2.

In MOVES, "Pollutant" refers to particular types of pollutants or pollutant precursors, such as nitrogen oxides (NOx), while "Process" refers to the mechanism by which emissions are created, such as running exhaust or start exhaust. Processes in MOVES are mutually exclusive types of emissions, and users need to select all processes associated with a specific pollutant to account for all emissions of that pollutant. Typically, it is recommended to select all processes for each pollutant selected. However, some processes may not be applicable for a given port-related inventory. For example, if no onroad vehicle refueling occurs within the scope of the inventory, "Refueling Displacement Vapor Loss and Refueling Spillage Loss" could be excluded; likewise, assuming the port has no hotelling activity (i.e., a truck driver runs the engine overnight while sleeping in the cab), the "Extended Idle and Auxiliary Power Unit" processes would not be included in the MOVES runs. Note, some pollutants in MOVES need the selection of other prerequisite pollutants and processes. For example, selecting the prerequisites for "Primary Exhaust PM2.5 – Total" will select elemental carbon, which is an indicator for black carbon (BC).

In general, pollutant and process selections should be consistent with the specific purpose and scope of the emissions inventory. If there is the possibility that a pollutant would be needed in the emissions inventory, it may be desirable to include it. It is easier to request MOVES results for pollutants that are ultimately not used than to decide after MOVES is run that another pollutant is needed. In such a case, another MOVES run would be necessary.

For methods to estimate energy consumption for this source sector, see Appendix A.

7.4 Port-Related Onroad Vehicle Inventory Data Needs

This section describes the data needs and possible sources for developing a port-related onroad vehicle emissions inventory. Gathering accurate data on vehicle characteristics (vehicle types, counts, age, etc.) and activities (vehicle travel speeds, idling time, etc.) is paramount for developing a robust onroad vehicle inventory. Likewise, better vehicle data improves the potential for identifying specific operational improvements.

Generally, vehicle data can be gathered from a variety of sources. In many cases, conducting site-specific manual counts and surveys can yield the most complete data set for use in inventory development. Additionally, port authorities or port operators could partner with their state's transportation or air quality agency to conduct traffic studies and collect vehicle activity and fleet characteristic information. These types of partnerships encourage information sharing and can improve the data used to develop an inventory.

[f] A port-related inventory could be developed using the Emission Rates calculation type, but this method is not covered in this document.

7.4.1 Fleet Characteristics

An onroad emissions inventory should account for the type, number, and the ages of vehicles in a fleet operating at a port and on nearby onroad transportation corridors if within the scope. To conduct a MOVES run, the following information is needed to describe the onroad vehicle population:

- Vehicle types (called "source types" in MOVES)
- Vehicle counts (by source type)
- Vehicle age (model years of vehicles are used to determine an age distribution by source type), and
- Diesel retrofit devices and replacements or other emission mitigation measures in use.[g]

7.4.1.1 Vehicle Types

An onroad vehicle emissions inventory should include all the vehicle types used within the inventory scope. Vehicle counts should be aggregated by vehicle type. In MOVES, vehicles are classified into source types, which are groups of vehicles with similar activity and usage patterns. MOVES source types and the associated Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) vehicle classes are listed in Table 7.1, and the various source type and fuel type combinations that MOVES can model are listed in Table 7.2 below.[50]

Table 7.1. MOVES Onroad Vehicle Source Types

SourceTypeID	Source Type	HPMSTypeID	HPMS Description
11	Motorcycle	10	Motorcycles
21	Passenger Car	25	Light Duty Vehicles
31	Passenger Truck		
32	Light Commercial Truck		
41	Other Bus[h]	40	Buses
42	Transit Bus		
43	School Bus		
51	Refuse Truck	50	Single Unit Trucks
52	Single Unit Short-haul Truck		
53	Single Unit Long-haul Truck		
54	Motor Home		
61	Combination Short-haul Truck	60	Combination Trucks
62	Combination Long-haul Truck		

[g] For onroad vehicles such as drayage vehicles, retiring older trucks and engines and replacing them with new equipment plays a major role in reducing emissions. In general, vehicle replacement, rather than retrofit, is a more effective option for port-related heavy-duty vehicles.

[h] Other buses include all buses that are not either "transit buses," which are those owned by a public transit organization for the primary purpose of transporting passengers on fixed routes and schedules, or "school buses," which are those used to transport K-12 students between their home and school carrying more than 10 passengers.

Table 7.2. Allowable Source Type and Fuel Type Combinations in MOVES (Allowable combinations are marked with X)

SourceTypeID	Source Type	Gasoline	Diesel	CNG	E-85 Capable	Electricity
11	Motorcycle	X				
21	Passenger Car	X	X		X	X
31	Passenger Truck	X	X		X	X
32	Light Commercial Truck	X	X		X	X
41	Other Bus	X	X	X		
42	Transit Bus	X	X	X		
43	School Bus	X	X	X		
51	Refuse Truck	X	X	X		
52	Single Unit Short-haul Truck	X	X	X		
53	Single Unit Long-haul Truck	X	X	X		
54	Motor Home	X	X	X		
61	Combination Short-haul Truck	X	X	X		
62	Combination Long-haul Truck		X			

A port-related onroad vehicle fleet may include vehicles such as drayage trucks, shuttle buses, service vehicles, and different varieties of passenger cars and trucks. Generally, the types of vehicles serving a port could include the following, and should be modeled as the MOVES source types noted:

- Drayage trucks and other local delivery tractor-trailer trucks: Drayage trucks are generally diesel-fueled, heavy duty (Class 8) trucks that transport containers and bulk freight between the port and intermodal railyards, distribution centers, and other near-port locations. A common practice is to use older trucks that are near the end of their useful life to serve as drayage trucks because of the lower annual mileage accumulation and proximity to repair facilities. In MOVES, drayage trucks and other local delivery tractor-trailer trucks should be modeled as Combination Short-haul Trucks (sourceTypeID 61).
- Tractor-trailers operating on long-distance routes: These vehicles are generally diesel-fueled, heavy-duty (Class 8) trucks that transport containers and bulk freight long distances (i.e., 200 miles or more from the port). In MOVES, these vehicles should be modeled as Combination Long-haul Trucks (sourceTypeID 62).
- Passenger vehicles: These vehicles are light-duty cars and trucks used for passenger transport. In MOVES, these vehicles should be modeled as Passenger Cars and Passenger Trucks, (sourceTypeIDs 21 and 31, respectively).
- Light-duty service vehicles: These vehicles include may include gasoline or diesel-fueled maintenance trucks and shuttle vans. In MOVES, these vehicles should be modeled as Light Commercial Trucks (sourceTypeID 32).
- Transit buses, shuttle buses and motor coaches: These vehicles are used to bring passengers to or from the site or transport passengers on-site. In MOVES, these vehicles should be modeled

as Transit Buses (sourceTypeID 42) if they are owned and operated by a transit authority and/or operate on regular, fixed schedules; otherwise, they should be modeled as Other Buses (sourceTypeID 41).

- Other heavy-duty trucks: These vehicles are generally large, heavy-duty service vehicles, such as refueling trucks and other support vehicles. In MOVES, these vehicles should be modeled as Single Unit Short-haul Truck (sourceTypeID 52) or as Long-haul Truck (sourceTypeID 53) if used on long distance routes (i.e., routes that extend 200 miles or more from the port).

7.4.1.2 Vehicle Counts

Capturing the number of vehicles by source type is another key aspect of developing an onroad vehicle emission inventory. Vehicle counts can be gathered from a variety of sources. Many state Departments of Transportation (DOTs) have permanent highway sensors in place that can separate heavy-duty truck counts from passenger cars and trucks, and other vehicles. However, these sensors are typically located on highway segments, which means the raw traffic volume numbers do not account for traffic entering and exiting via highway ramps. These counts are generally available through FHWA HPMS data sets, state DOTs, or local transportation planning agencies. These counts could serve as a basis of port-related vehicle counts, but further refinement may be necessary.

There are numerous other technologies that could assist with vehicle counts. Automatic vehicle classification counters co-located with manual survey locations may best provide an overall estimate of the traffic volume, vehicle type, and vehicle speeds. Automatic counters provide continuous counts for a longer period than is practical with manual surveys. Vehicle classification counters that identify the type of trucks can only be deployed across a single lane of traffic, while the more commonly used total vehicle counters can be used over multiple lanes. FHWA has identified other equipment for traffic data collection in the *Highway Performance Monitoring System Traffic Data for High-Volume Routes: Best Practices and Guidelines* report.[51]

In addition to the vehicle count sources above, depending on the type of port activity, vehicle gate counts, parking receipts, and passenger counts could also be sources of information to determine the number of vehicles arriving at and operating on port.

7.4.1.3 Age Distribution

Age is an important factor in calculating onroad vehicle emission inventories because older vehicles tend to produce higher emissions. A vehicle's age is the difference between its model year and the inventory year. Age distributions in MOVES vary by source type and range from zero to 30+ years, so that all vehicles 30 years and older are modeled together. As such, an age distribution is comprised of 31 fractions, where each fraction represents the number of vehicles present at a certain age divided by the vehicle population for all ages.

To build a MOVES-compatible age distribution table, there are three options depending on data availability that are presented in order of specificity. For each vehicle type, inventory preparers should use the best option for age distribution that is supported by the data available. Age distribution can have a considerable impact on emission estimates, so the most specific information available should be used:

1. For fleets that operate locally, such as drayage trucks, the MOVES user should provide specific fleet age distribution data. For these locally-based fleets, an exact age distribution could be obtained from on-terminal truck registrations or license plates studies.
2. If a port-specific age distribution is not available, MOVES users should use the latest state or local age distribution assumptions from their SIP or transportation conformity regional emissions analysis, which would be available from the state air quality agency or the local metropolitan planning organization if the port is located in or near an ozone, PM, or other nonattainment or maintenance area.
3. If no state or local age distribution is available, the MOVES default age distribution could be used.[i] The MOVES user can select the analysis year(s) and find the corresponding age distribution. These fractions are national defaults and could be significantly different than the local age distribution. Default data should be used only if more representative data set (e.g., reflecting port-related vehicles or a state or local information) cannot be obtained.

Short-distance, drayage transportation of freight tends to be performed by older trucks, while long-distance movements generally rely on newer and more fuel-efficient equipment. The age distributions used for combination short-haul and combination long-haul trucks should reflect differences in the ages of these different source types.

Truck license plate sampling is a direct way to collect and determine truck age distributions and other fleet characteristics. For example, at the Port of Oakland, researchers developed and implemented a truck-traffic survey in West Oakland, California. During the manual truck counts, the license plates of at least 10 trucks that entered the survey intersection per hour were recorded. License plate information was cross-refenced with a California's Department of Motor Vehicles database to gather information on the model year, fuel type, manufacturer's maximum gross vehicle weight ratings (GVWR), the number of axles, the city of registration, and zip code of registration.[52]

7.4.1.4 Vehicle Retrofits and Replacements

The MOVES model does not incorporate assumptions on the existence of any local projects to retrofit emission reduction technologies on onroad diesel vehicles or to replace older vehicles with newer, cleaner ones. If such a program is in place, MOVES users should account for it in a port-related inventory. For more information, see EPA's Diesel Retrofit and Replacement Guidance which addresses retrofit and replacement projects in detail.[46] Section 2.5 of the Diesel Retrofit and Replacement Guidance describes how to quantify emission reductions from diesel emission reduction strategies, such as a drayage truck replacement program; Section 2.6 describes how to quantify emission reductions from onroad vehicle or engine replacement projects.

7.4.2 Vehicle Activity

Characterizing vehicle activity for on-port terminals and on near-port corridors is critical for calculating emission inventories. Vehicle activity in this context includes running, parking, and starting activity.

[i] For more information, see www.epa.gov/otaq/models/moves/tools.htm.

7.4.2.1 Running Activity

Generally, port-related running activity can be broken down into three stages: activity on near-port transportation corridors (if within the inventory's scope), queuing activities such as creep and idling occurring at gates, and activity within the port.

If within the inventory scope, port-related vehicle activity on transportation corridors such as highways and access roads to the port should be included in the onroad vehicle emissions inventory. This activity captures vehicle travel to and from the port facilities such as truck trips to nearby freight facilities or warehouses and passenger travel. To characterize this activity, MOVES users would define the route lengths, in miles, and estimate the number of port-related trips by vehicle type and vehicle speeds in miles per hour.

Gate queuing, which includes creep and idling, should be characterized separately from activity on near-port transportation corridors because it has a substantially different driving cycle. Users should consider where gate queuing activity occurs. Gate queuing by drayage vehicles or passenger vehicles may occur in different areas as vehicles approach different terminals. The length of the queuing area may vary depending on the level of activity at a given terminal but should generally reflect the distance from where gate queuing starts to the terminal entrance gate. Gate queuing activity should also be characterized by distance traveled (in miles) within the queuing area, number of trips by source type, and vehicle speeds (in miles per hour) within the queuing area. Truck queuing data may be limited if the terminal operators do not capture queue times; however, surveying drivers may be a helpful source of information.[53] Alternatively, if hours of wait time by source type is known, this information can be used in the Project Scale approach described in Section 7.6 without the other information (distance traveled, number of trips by source type, or vehicle speeds).

Running activity within the port may include driving along drayage routes and driveways. This activity is likely dominated by low speed driving with frequent stops and short periods of acceleration.

Running activity types described above are quantified as vehicle miles traveled (VMT) by source type and allocated by road type. Most or all running travel activity in a port-related onroad vehicle emissions inventory would most likely correspond to the urban unrestricted road type in MOVES (roadTypeID 5). However, if the inventory includes other road types, such as restricted access highways (i.e., highways with entrance and exit ramps), the MOVES user will need to estimate this activity by source type, and distribute travel activity by source type to other road types as appropriate. If the emissions inventory will support regulatory purposes, the interagency consultation process should be used to determine the geographical boundaries, including which roads to include, and how to address and minimize double-counting or missing emissions.

Estimating a vehicle speed distribution can be a complex process. For a county-wide inventory, a typical approach for estimating average speeds is to post-process the output from a travel demand network model. However, travel demand models are unlikely to cover the details of traffic within a port. A detailed approach is to process on-vehicle Global Positioning System (GPS) data. GPS dataloggers could be used to collect speed data from a sample of vehicles traveling within the port. This data could then be used to construct an average speed distribution for use in the County Scale approach, calculate a link-level average speeds for the Project Scale approach, or develop a second-by-second link drive schedule for use in the Project Scale approach.

7.4.2.2 Vehicles Parked and Starts

Depending on the port's business activities, the port may store large numbers of vehicles on site for some duration. For example, at a cruise terminal, cruise passengers may park their vehicles during the duration of their trip at a terminal parking facility. Similarly, a terminal that handles a high number of new passenger import/export vehicles may store these vehicles in onsite lots at some stage during their shipment. While stored, vehicles can still produce emissions through evaporative processes. To estimate this activity, the number of vehicles and duration of time parked by source type should be captured. As noted earlier, emissions associated with evaporative processes would be estimated at the County Scale.

Vehicle start emissions are closely associated with parking activity. Start emissions are determined based on the time a vehicle has been parked prior to the engine starting ("soak"). Vehicle start emissions can be estimated with either the County Scale or the Project Scale approach. At the County Scale, MOVES applies an average default operating mode distribution that will apply to the parking activity. For the Project Scale approach, users can define parking activity with the operating mode IDs (opModeID) in Table 7.3 to describe the amount of time a vehicle is parked.

Table 7.3. MOVES Parking-Related Operating Modes

OpModeID	Operating Mode
101	Soak Time < 6 minutes
102	6 minutes ≤ Soak Time < 30 minutes
103	30 minutes ≤ Soak Time < 60 minutes
104	60 minutes ≤ Soak Time < 90 minutes
105	90 minutes ≤ Soak Time < 120 minutes
106	120 minutes ≤ Soak Time < 360 minutes
107	360 minutes ≤ Soak Time < 720 minutes
108	720 minutes ≤ Soak Time

All start and parking activity would be modeled using the off-network road type in MOVES (roadTypeID 1).

Parking and start activity information can be gathered from a variety of sources. For passenger vehicles, parking receipts may be a source of information detailing parking duration (soak time) and starts can be approximated as one start per park. For service vehicles, starts and parking activity should be collected for a "typical" work day. For vehicles such as drayage trucks, some local governments and port authorities have instituted policies and programs that require truck drivers to turn off engines if idling is expected to exceed a certain duration such as during queuing, loading, and unloading activities. These programs may generate additional start activity that should be included in the onroad vehicle emissions inventory.

7.5 County Scale Approach for Developing an Onroad Vehicle Inventory

Running MOVES at County Scale takes advantage of features built into MOVES that simplify the process of developing a base year inventory. In this approach, the MOVES user treats the area included in the

inventory as if it were a county, using inputs that describe the total fleet and activity within the area rather than the total fleet and activity in the whole county.

Table 7.4. Overview of Developing Onroad Vehicle Emission Inventories Using MOVES at the County Scale

Data Needs	Advantages	Considerations
Local information for: • VMT • Vehicle population • Fleet age distribution • Average speed distribution • Road type distribution • Fuel characteristics	• Access to MOVES default database for some inputs • Includes output for all evaporative emission processes • Can produce an annual inventory without post-processing	• Does not provide the detailed spatial distribution of emissions provided by a Project Scale approach, which may be useful depending on the inventory purpose (see Section 7.2.1)

7.5.1 Setting up a County Scale RunSpec for a Port

To produce an onroad vehicle emissions inventory using the County Scale, a MOVES Run Specification (RunSpec) is created to define elements such as time period(s), geographical area, source types, etc. to be included in the modeling. These elements are defined in a series of panels in the MOVES Graphical User Interface (GUI). When setting up a County Scale RunSpec for a port-related and/or goods movement onroad vehicle emissions inventory, the following selection should be made:

1. Scale Panel: Select "Onroad" model and "County" for domain/scale. Calculation type should be specified as "Inventory."
2. Time Spans Panel: Select the inventory year (e.g., 2020 for a 2020 base year inventory), all months, both day types (weekday/weekend), and all hours to ensure the inventory includes the entire year. Note, only a single year can be selected in a County Scale run.
3. Geographic Bounds Panel: Select the county containing the port in the Geographic Bounds panel. Note, if the port spans multiple counties, the county containing most of the port should be selected.
4. Onroad Vehicle Equipment Panel: Add source types operated within the boundaries of the port-related inventory (as described in Section 7.4.1).
5. Road Type Panel: Select the road types that are to be included in the inventory scope. The driving behavior of vehicles traveling within the port itself is likely to be most like the Urban Unrestricted category, which includes urban arterials, collectors, and local streets. If the area of analysis includes other road types, such as a restricted access highway with ramps that provide access to the port, include the Urban Restricted category as well. Always select Off-Network to include calculation of emissions from engine starts and evaporative emissions from parked gasoline vehicles.
6. Pollutants and Processes Panel: Select all processes of the pollutants of concern. Note, running MOVES at the County Scale can estimate emissions associated with the fuel vapor venting process; these emissions cannot be estimated using MOVES at the Project Scale (see Section 7.2.1).

7. General Output Panel: Choose units for emissions and distance if different from "grams" and "miles" (recommended). EPA also recommends selecting "Distance Travelled" and "Population" under the "Activity" heading. These results can be used as a quality assurance check when reviewing the run's output. Provide a name for the output database. EPA recommends output database names end with "_out"; see Section 3.8 of the MOVES Technical Guidance for additional information.
8. Output Emissions Detail Panel: Select the level of detail needed in the model output. Selecting more detail results in larger output files but provides more flexibility for further review and analysis of the MOVES results. For example, choosing "Year" for the time period will result in a simple annual inventory. Choosing "Month" produces results for each month, which may allow the analysis of how emissions vary throughout the year. The inventory purpose will inform the level of detail needed for the time period selections in this panel. Of the other choices, "Source Use Type" might be a useful option to select, as it allows the user to distinguish the relative contributions of different source types to the total inventory.
9. Create Input Database Panel: Provide a name for the input database name. EPA recommends input database names end with "_in"; see Section 4.1 of the MOVES Technical Guidance for additional information. Provide a brief description for the input database.
10. Advanced Performance Features Panel: This panel is not needed and should be skipped (clicking on the panel converts the icon to a green check).

7.5.2 Using the County Data Manager to Enter Port-Specific Data

Once the RunSpec is completed, the County Data Manager (CDM) is used to enter activity and fleet information specific to the area of analysis. For a typical county-level inventory, the MOVES user would enter information that applies to the entire county. In this case, the MOVES user will enter the applicable port-related information.

7.5.2.1 Meteorology Data

The meteorology input allows the MOVES user to enter an average 24-hour temperature and humidity profile for each month of the year. The MOVES default database includes average monthly meteorology data for every county in the country based on 10 years of data from the National Climatic Data Center. For non-regulatory purposes (e.g., will not be used as part of a SIP or conformity analysis), the default data in MOVES for the county containing the port can be used. When the port-related inventory will be incorporated into a larger inventory to be used for a SIP or conformity analysis, the meteorology inputs should be the same as those used for the rest of the inventory.

7.5.2.2 Source Type Population

At County Scale, vehicle populations by source type are used to calculate evaporative emissions and can also be used to calculate start emissions. It is a necessary input at this scale and should represent the average number of vehicles in a typical day, by source type, that are present within the boundaries of the geographical area addressed by the inventory. See section 7.4.1.2 for more information on sources of vehicle counts for source type population inputs.

7.5.2.3 Age Distribution

As discussed in Section 7.4.1.3, the age distribution of the vehicles in the analysis is an important input in MOVES and having accurate vehicle data improves the potential for identifying specific operational

improvements. The age distribution by source type should be representative of the vehicles in use at the port.

7.5.2.4 Vehicle Type VMT

Vehicle miles traveled is a necessary input and should be based on estimates of vehicle activity within the boundaries of the inventory. MOVES can accept VMT information provided in terms of HPMS vehicles types or MOVES sources types and provides two options for the time period of VMT information as either an annual or daily value. Any of these combinations can be used, depending on data availability. Choices include entering VMT by:

Input by:	**VMT value:**
• HPMS vehicle types; or • MOVES source types	• Annual; or • Daily

7.5.2.5 Hotelling

In the onroad context, hotelling refers to the activity of long-haul trucks when the vehicle is parked, often overnight, during driver rest periods while heating/cooling equipment or appliances are in use. Hotelling is assumed not to occur directly on ports; however, MOVES includes default hotelling activity for county scale runs. Default activity is based on VMT assigned to the rural restricted road type (roadTypeID 5). If the rural restricted road type is included within the geographical scope of the analysis, it is necessary to enter zeros for all rows in the hotelling hours column in the *HotellingHours* table for the Hotelling tab input. If this is not done, the county scale run will calculate extended idling emissions if the rural restricted road type is included.

7.5.2.6 Fuel

Onroad vehicle emissions also depend on what fuels and fuel mixes are used. MOVES includes default fuel information by county, month, and year. MOVES users should review the default fuel supply and fuel formulation information provided in MOVES and make changes only where precise local volumetric fuel property information is available or where local fuel requirements have changed.

One exception to this guidance is in the case of Reid Vapor Pressure (RVP); the MOVES user should change this value to reflect any specific local or state regulatory requirements and differences between ethanol- and non-ethanol blended gasoline not reflected in the default database. Any changes to RVP (or to any other gasoline fuel formulation parameters) should be made using the "Fuels Wizard" tool in the Fuel Tab of the CDM. This process is described in more detail in Section 4.8.1 of the MOVES Technical Guidance. Note that the Fuels Wizard only applies to gasoline fuels. If any diesel fuel properties (such as the diesel sulfur content) need to be changed, MOVES users should modify the property in the fuel formulation table for the modeled county using the CDM.

Additionally, the Alternative Vehicle and Fuels Technology (AVFT) table defines the fractional mix of vehicles capable of using different fuels for each model year. In most cases, the default AVFT table should be used. However, in some cases the fleet of vehicles that operate in the port may have a unique mix of fuel types that is different from the national average used to create the default table. For example, a cruise ship port might have a fleet of passenger shuttle buses that operates only on

compressed natural gas (CNG). In this case, the AVFT table should be adjusted to reflect that the local fleet of shuttle buses (sourceTypeID 42) does not include any diesel or gasoline buses.[j]

For more information on Fuels in MOVES, including the primary fuels tables, see Section 4.8 of the MOVES Technical Guidance.

7.5.2.7 I/M Programs

Some counties have local inspection and maintenance (I/M) programs to reduce emissions from the passenger car and light duty truck fleet. If the local county containing the port has an I/M program, coordinate with the state or local air agency administering the I/M program to verify that the default inputs in MOVES are consistent with the local program. Refer to Section 4.9 of the MOVES Technical Guidance for more information.

7.5.2.8 Retrofit Data

This tab allows users to enter retrofit and replacement program data that apply adjustments to vehicle emission rates.[k] There is no default retrofit/replacement data in MOVES and users do not have to input data into MOVES unless they have a retrofit or replacement program that they wish to model. Users should consult the Diesel Retrofit and Replacement Guidance[46] for more information.

7.5.2.9 Road Type Distribution

As noted in Section 7.4.2, most or all travel activity in a port-related area would most likely correspond to the Urban Unrestricted Road Type or Off-network Road Type in MOVES. However, if any other road type activity, such as urban restricted activity (i.e., driving on highways with entrance and exit ramps for access) occurs within the port area, the user will need to distribute travel activity, by source type, across the road types included in the analysis. See section 4.7 of the MOVES Technical Guidance for more information on this input.

7.5.2.10 Average Speed Distribution

MOVES needs an average speed distribution for each source type, road type, and hour of day included in the analysis. The MOVES user would distribute vehicle hours traveled (VHT, rather than vehicle miles traveled) into 16 speed bins; these fractions should sum to 1 across source type, road type, and hour of day.[l] For sourceTypeIDs 61 and 62, which represent short- and long-haul combination trucks, there may be a substantial amount of activity in the lower speed bins because of their queuing activity.

7.5.2.11 Starts

At County Scale, start information is an optional input. By default, MOVES uses vehicle population to estimate start emissions. However, for a port-related onroad vehicle emission inventory, using the starts input is a more precise way to estimate start emissions. The starts input contains multiple tables, which allow the user to:

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[j] In this specific example, the CNG-fueled shuttle buses could be modeled either as Transit Buses (sourceTypeID 42) or Other Buses (sourceTypeID 41), depending if their activity resembles regular, fixed schedule service or not.

[k] For onroad vehicles, retiring older vehicles and engines and replacing them with new equipment plays a major role in reducing emissions. In general, vehicle replacement, rather than retrofit, is a more effective option for port-related heavy-duty vehicles.

[l] More information about how this input is developed can be found in Section 4.6 of the MOVES Technical Guidance.

- enter the total number of starts for all source types in the inventory area for a typical weekday and weekend day,
- distribute the total number of starts by source type and by hour of the day, and/or
- enter monthly adjustment factors to account for cases where number of starts varies by month.

There is also the option to use the operating mode distribution table to change the default distribution of vehicle soak times (the length of time between key-off and key-on) represented by opModeID 101 through 108, as discussed in Section 7.4.2.2. Ports are likely to have soak time distributions that are different from national defaults. For example, a cargo port might have a high percentage of short soak times, while a port with a cruise terminal that includes a long-term parking structure might have a higher percentage of long soak times.

7.5.2.12 Idle

This user input is also optional and is used to import off-network idle (ONI) activity that is not related to combination truck hotelling activity. ONI is defined in MOVES as time during which a vehicle engine is running idle and the vehicle is somewhere other than on the road, such as in a parking lot or driveway. For further explanation, see Section 4.12 of the MOVES3 Technical Guidance. Ports where cruise ships berth may have ONI activity related to passenger vehicles and shuttle vans that should be included in this tab. Likewise, ports that have drayage or other trucks idling while queueing or waiting should also include data in this tab.

7.5.2.13 Running MOVES

Once the input database is complete, MOVES can be run. The results will be the port-related emissions inventory at the level of detail chosen in the Output Emissions Detail Panel of the RunSpec, which may need additional aggregation. For example, if source type was chosen in the output emissions detail panel, emissions from each of the source types would need to be summed to get total port emissions inventory for the onroad sector.

7.6 Project Scale Approach for Developing an Onroad Vehicle Emissions Inventory

Using MOVES at the Project Scale can provide a greater level of detail for developing a base year onroad vehicle emission inventory. Additionally, as discussed in Section 7.2, using MOVES at the Project Scale can provide emissions at enough geographical resolution to conduct air quality modeling if setup correctly following the methods described in the PM Hot-spot Guidance. As noted in the introduction of this section, this guidance does not provide step-by-step instructions on how to run MOVES, but discusses an overview of the process of using MOVES at the Project Scale.

There are several ways that MOVES at the Project Scale could be used to create an inventory of port-related onroad emissions, and this guidance focuses on two of them:

1. Generic Link Approach: Using MOVES at the Project Scale to model a series of generic links that represent different types of activity at the port. This section primarily focuses on the Generic Link Approach.
2. Refined Approach: Using MOVES at the Project Scale to model a series of specific links that represent specific locations at the port. This is a more detailed approach applicable for areas conducting refined air quality modeling requiring geographically allocated emissions. Refer to Appendix I for more information about this approach.

Table 7.5. Overview of Developing Onroad Vehicle Emission Inventories Using MOVES at the Project Scale

Data Needs	Advantages	Considerations
• Link level characterization of port activity • VMT • Fleet age distributions • Fuel characteristics	• Can provide a detailed link-based spatial distribution of emissions • Allows for a detailed analysis of different kinds of activity (e.g., queuing)	• Post-processing is needed to produce an inventory for the time period needed (e.g., daily or annual emissions) • No MOVES default database information available • Does not includes output for all evaporative emission processes

7.6.1 Major Considerations for the Project Scale Approach

The following items should be carefully considered when developing a modeling plan for a project scale approach, which are discussed in further detail below:

1. Number of links
2. Number of runs
3. Pollutants and processes to include

7.6.1.1 Number of Links

A link represents a segment of road or driveway or other location where a certain type of vehicle activity occurs. A link should be a segment with similar traffic/activity conditions and characteristics. Where vehicle volumes or vehicle activity changes, a new link should be defined.

There are two primary types of links: running and off-network.

- Running links are used to describe driving activity (e.g. free-flow cruising, deceleration, idle, and acceleration activity). Near-port onroad transportation corridors, on terminal drayage routes, driveways, loading and unloading zones, and queuing areas would be characterized by running links.
- An off-network link is used to describe areas of start and hotelling activity (e.g. parking areas truck or transit terminals). Generally, long term hotelling activity does not occur on ports and therefore is not included in this guidance; however, if hotelling occurs within the overall project geographical scope of the analysis, refer to Section 4 of the PM Hot-spot Guidance for more information on how to characterize this activity in MOVES.

As indicated in Section 7.4, near-port corridor and on-port vehicle activity may include different running, queuing, and parking activity. There is no limit on the number of running links in a run, but only one off-network link can be defined per run.

7.6.1.2 Number of Runs

At the Project Scale, each MOVES run covers one specific hour of a single day of a single year. Therefore, determining the number of Project Scale runs depends on the inventory purpose, how activity levels, meteorological conditions, and fuels vary over the course of the time period of the inventory.

The inventory purpose, whether it be an annual emissions inventory or an inventory for a specific national ambient air quality standard (NAAQS), determines the number of runs needed. For example, for the annual $PM_{2.5}$ NAAQS, an annual SIP inventory is necessary, whereas ozone SIPs are developed for a typical summer day, and the 24-hour $PM_{2.5}$ and PM_{10} NAAQS need daily inventories. For more information on the number of runs for a specific pollutant, please consult the appropriate EPA guidance. For $PM_{2.5}$ and PM_{10}, please see Section 4.3 of EPA's PM Hot-spot Guidance.[48] For CO, please see Section 2.2 of EPA's CO Hot-spot Guidance.[54]

One advantage to the Project Scale Generic Link Approach, discussed in 7.6.2, is that one MOVES run may be all that is needed to generate emission rates for the entire year for non-regulatory purposes. However, more than one run may be necessary to account for variation in fuel type and possibly temperature across seasons. If multiple runs are necessary, the resulting rates would need to be multiplied by the appropriate fraction of the yearly activity, and the products aggregated as discussed further in Section 7.6.5.

7.6.1.3 Pollutants and Processes to Include

MOVES cannot estimate emissions from fuel vapor venting at the Project Scale. Fuel vapor venting is the emission process in MOVES that accounts for evaporative emissions from parked gasoline vehicles. (See Section 7.2.1 for more information). If the ports inventory needs to include these emissions, the user can either supplement this Project Scale method with an additional run using the County Scale that only includes the "evap fuel vapor venting" process, or create the whole inventory using the County Scale Approach described in Section 7.5.

7.6.2 Project Scale Generic Link Approach

A simplified Project Scale approach could be used if the inventory is not done for regulatory purposes and is not needed for air dispersion modeling. In this approach, a set of generic links can be created for each different type of activity: one link for each type of activity and for each source type engaged in that activity. Given this set up, these generic links result in emission rates (even though the Inventory calculation type is used) that can then be multiplied by the appropriate activity for each of those source types (e.g., VMT, hours idling, or starts).

The number of generic links used should sufficiently capture the different types of activity occuring in the scope of the inventory. The links defined in this approach would include a set of running links and one off-network link.

- Each running link would include just one vehicle, and all running links would be defined as a length of one mile.
- The off-network link should include one of each source type with start activity for the geographical area.

With this approach, multiple areas within the port where similar activity occurs can be represented by the same link. For example, if within the port there are different areas where trucks and other vehicles are queuing, these different areas of queuing can be represented with one link for each source type. Table 7.6 provides a simple example of this approach representing links for one source type.

Table 7.6. Generic Link Approach Sample Link Characterization

Activity Type	Generic Link Description	Output Emission Rate	MOVES Link Example
Driving to and from port	Running link with representative average speed of near-port onroad transportation corridors	mass per mile (e.g. g/mi)	Running link with 30 mph average speed
Queuing (including idling and creeping) at gates or terminals	Running link with low average speed	mass per mile converted to mass per hour (e.g. g/mi to g/hr)	Running link with 1.8 mph average speed
Driving activities on-port	Running link with representative average speeds of driving on-port to capture all drayage routes and driveways	mass per mile (e.g. g/mi)	Running link with 10 mph average speed
Vehicle Parking and Starts	Off-network link to represent all parking areas to capture number of vehicles parked and starting*	mass per start (e.g. g/start)	Off-network Link

* MOVES at the Project Scale does not capture evaporative process emissions associated with soak activity from parked vehicles. If VOCs or air toxics need to be included in the inventory, these can be estimated with an additional County Scale run for just these emissions.

This example includes four links for this source type; similar links would be defined for other source types. The resulting MOVES output, which represent emission rates for a given pollutant, can then be multiplied by the number of vehicles of that source type and activity amount, and then aggregated to create a total onroad vehicle emissions inventory.

7.6.3 Creating a Run Specification for the Generic Link Approach

To produce emission factors for use in the calculation of an onroad vehicle inventory, the user would run MOVES for the representative time periods of interest for the analysis. As discussed in Section 7.6.1.2, the MOVES user should consider whether more than one run is necessary to account for variation in fuel type and temperature. If more than one run is needed, separate RunSpecs should be developed for each run.

When setting up a RunSpec for a Project Scale Generic Link run, the following selections should be made:

1. Scale Panel: Select "Onroad" model and "Project" scale. Calculation type should be specified as "Inventory." Because running links will be defined with one vehicle with a length of one mile, selecting "Inventory" results in a set of emission rates for these links, e.g., grams/vehicle-mile.
2. Time Spans Panel: Select the calendar year, a month, a day type (weekday/weekend), and an hour of analysis. The selection of month will affect the fuel MOVES uses, but otherwise, the selections for month, day type, and hour do not matter for this approach.

3. Geographic Bounds Panel: Select the county containing the port in the Geographic Bounds Panel. Note, if the port spans multiple counties, users should select the county containing most of the port.
4. Onroad Vehicle Equipment Panel: Add the fuel type/source type combinations represented at the port (as described in Section 7.4.1.1).
5. Road Type Panel: Select the road types that are to be included in the project scope. Always select "Off-Network" to include calculation of emissions from engine starts and evaporative emissions from parked gasoline vehicles.
6. Pollutants and Processes Panel: Select all processes of the pollutants of concern. Note, VOC and air toxics emissions from the fuel vapor venting process cannot be estimated using MOVES at the Project Scale and would necessitate a supplemental County Scale run.
7. General Output Panel: Choose units for emissions and distance. EPA recommends choosing "grams" and "miles" for these units. EPA also recommends selecting "Distance Travelled" and "Population" under the "Activity" heading. This can be used as a check for the output, since distance travelled should be 1 mile, and population should be 1 vehicle for each link, based on input database choices described below.
8. Output Emissions Detail Panel: Select check the box for "Source Use Type" to obtain start emission rates by source type.
9. Create Input Database Panel: Provide a name for the input database name. EPA recommends input database names end with "_in". Provide a brief description for the input database.
10. Advanced Performance Features Panel: This panel is not needed and should be skipped (clicking on the panel converts the icon to a green check).

Before executing this run, the user will need to create an input database to describe the activity by link for the inventory, as described in the next section.

7.6.4 Using the Project Data Manager for the Generic Link Approach

The Project Data Manager (PDM) in MOVES is used to import tables containing the information needed to populate a Project Scale input database. This section assumes familiarity with creating a MOVES input database by exporting the spreadsheet templates (or in the case of fuel, default data) for each of the inputs, and importing completed templates into the input database. A simple, hypothetical example is provided in Appendix I to illustrate some of the PDM tab inputs for the Project Scale Generic Link Approach.

The following subsections provide information on how to populate the PDM tabs for the Generic Links Approach.

7.6.4.1 Meteorology Data

Enter the average monthly temperature and humidity for the month selected in the RunSpec.

7.6.4.2 Age Distribution

As discussed in Section 7.4.1.3, the age distribution of the vehicles in the analysis is an important input in how MOVES calculates emission rates. In the Generic Link Approach, each running link consists of one vehicle and the off-network link has only one vehicle of each type. The age distribution for each source type should be representative of the fleet of those vehicles at the port. This fleet age distribution is

then assigned as a composite age for the single vehicle included in the link. If available, use the specific fleet age distribution from the port.

7.6.4.3 Fuel

Onroad vehicle emissions also depend on what fuels and fuel mixes are used. MOVES includes default fuel information by county, month, and year. MOVES users should review the default fuel supply and fuel formulation information provided in MOVES and make changes only where precise local volumetric fuel property information is available or where local fuel requirements have changed.

One exception to this guidance is in the case of Reid Vapor Pressure (RVP); the MOVES user should change this value to reflect any specific local or state regulatory requirements and differences between ethanol- and non-ethanol blended gasoline not reflected in the default database. Any changes to RVP (or to any other gasoline fuel formulation parameters) should be made using the "Fuels Wizard" tool in the Fuel Tab of the CDM. This process is described in more detail in Section 4.9.1 of the MOVES Technical Guidance. Note that the Fuels Wizard only applies to gasoline fuels. If any diesel fuel properties (such as the diesel sulfur content) need to be changed, MOVES users should modify the property in the fuel formulation table for the modeled county using the CDM.

Additionally, the Alternative Vehicle and Fuels Technology (AVFT) table defines the fractional mix of vehicles capable of using different fuels for each model year. In most cases, the default AVFT table should be used. However, in some cases the fleet of vehicles that operate in the port may have a unique mix of fuel types that is different from the national average used to create the default table. For example, a cruise ship port might have a fleet of passenger shuttle buses that operates only on compressed natural gas (CNG). In this case, the AVFT table should be adjusted to reflect that the local fleet of shuttle buses (sourceTypeID 42) does not include any diesel or gasoline buses.[m]

For more information on Fuels in MOVES, including the primary fuels tables, see Section 4.8 of the MOVES Technical Guidance.

7.6.4.4 I/M Programs

Some counties have local inspection and maintenance (I/M) programs to reduce emissions from the passenger car and light duty truck fleet. If the local county containing the port has an I/M program, coordinate with the state or local air agency program administrator to verify that the default inputs in MOVES are consistent with the local program. For ports that do not serve cruise ships (i.e., those ports that do not have large numbers of passenger vehicles), this panel may potentially be skipped. Ports that serve cruise ships will have more light-duty vehicle activity; in such a case, enter the details of the I/M program in the county selected in the RunSpec panel. Refer to Section 4.9 of the MOVES Technical Guidance for more information.

[m] In this specific example, the CNG-fueled shuttle buses should be modeled as Transit Buses (sourceTypeID 42) in MOVES, because that is the only source type that can be modeled with CNG in MOVES2014.

7.6.4.5 Retrofit Data

This tab allows users to enter retrofit and/or replacement program data that apply adjustments to vehicle emission rates.[n] There is no default retrofit data in MOVES and users do not need to input retrofit data into MOVES unless they have a retrofit/replacement program that they wish to model. Users should consult the Diesel Retrofit and Replacement Guidance for more information.

7.6.4.6 Links

The *Link* input table is where the MOVES user defines the links. For the Generic Link Approach, each running link includes just one vehicle, and all running links are defined as a length of one mile. Table 7.7 describes the columns in the *Link* input table.

Table 7.7. Project Scale *Link* Input Table Description

Column Name	Entry
linkID	Each link should have a unique linkID made up of letters, numbers, and underscores. For running links, use a unique link for each source type present at each average speed of interest. Only one off-network link can be defined.
countyID	The first row for this column will be pre-populated based on selections in the RunSpec. Copy the first-row entry into the other rows of the column.
zoneID	The first row for this column will be pre-populated based on selections in the RunSpec. Copy the first-row entry into the other rows of the column.
roadTypeID	Running links: specify the appropriate road type (e.g., roadTypeID 5). Off-network link: specify road type 1.
linkLength	Running links: link length of 1 (in miles). Off-network link: link length of 0.
linkVolume	Running links: link volume of 1. Off-network link: link volume equal to the number of source types with start activity (e.g. For 4 source types parking and starting, the link volume for the off-network link would be 4).
linkAvgSpeed	Running links: use average speeds to reflect the vehicle activity. Examples in Table 7.6 includes running links for three different speeds, representing driving to and from the port (30 mph), driving on the port (10 mph), and queuing activity (1.8 mph). Off-network link: use an average speed of 0 mph.
linkDescription	Text can be entered in this field to keep track of which link corresponds to which source type and activity.
linkAvgGrade	This can be left blank or 0 can be entered for each link, unless there are roads in the geographical domain with significant grade (most links in or near ports likely have 0 grade).

[n] For onroad vehicles, retiring older vehicles and engines and replacing them with new equipment plays a major role in reducing emissions. In general, vehicle replacement, rather than retrofit, is a more effective option for port-related heavy-duty vehicles.

7.6.4.7 Link Source Types

This input describes which source types operate on each running link. In the generic link approach, there is only one source type per link, so this input will only include one sourceTypeID per link with a sourceTypeHourFraction of 1. Table 7.8 describes the columns in the *LinksSourceTypeHour* input table.

Table 7.8. Project Scale *LinksSourceTypeHour* Input Table Description

Column Name	Entry
linkID	Include all roadway linkIDs defined in the *Links* input table.
sourceTypeID	Include one source type per link.
sourceTypeHourFraction	This fraction needs to sum to one for each link. As there is only one source type per link, enter 1 in this column.

7.6.4.8 Off-Network

The off-network link should include all source types with start or soak activity. Table 7.9 describes the columns in the *OffNetworkLink* input table.

Table 7.9. Project Scale *OffNetworkLink* Input Table Description

Column Name	Entry
zoneID	This will be pre-populated based on the RunSpec; copy the zoneID from the first cell for the rows in the column.
sourceTypeID	Include all source types present in the off-network link, one source type in each row.
vehiclePopulation	Enter 1 for each source type.
startFraction	Enter 1 for each source type. (100% of the vehicles are starting during the hour.)
extendedIdleFraction	This column represents hotelling activity of long-haul combination trucks. This column can be left blank because it is assumed that that long-term truck hotelling activity does not occur at ports.
parkedVehicleFraction	Leave blank

7.6.4.9 Operating Mode Distribution

This input is needed for the off-network link to describe how long vehicles have been soaking before they are started. Table 7.10 describes the columns in the *OpModeDistribution* input table.

Table 7.10. Project Scale *OpModeDistribution* Input Table Description

Column Name	Entry
sourceTypeID	Add rows for each of the source types present.
hourDayID	This is a combination of the hourID (1–24) and dayID (weekday, 5, or weekend day, 2). For example, if the hour chosen in the RunSpec was 10:00–10:59 (hourID 11), and the day type chosen was weekday (dayID 5), then 115 would be entered in this column.

Column Name	Entry
linkID	Include the linkID used for the off-network link in the *Links* input table.
pollutantProcessID	This is a combination of the pollutantID and the processID. While any number of pollutants may be of interest, for the purposes of this method, the only relevant processID is 02, "Start Exhaust." All other processIDs can be deleted from this table.
opModeID	Select appropriate opModeIDs from Table 7.3. A simplifying assumption is that all light-duty vehicle starts at a port have the opModeID 108, because most light-duty starts will be either from vehicles being driven on or off a vehicle carrier, or from vehicles being driven after their owners have returned from a cruise. Similarly, a simplifying assumption is that all heavy-duty vehicle starts have the opModeID 102, because these vehicles will not stop for long periods of time on port. Note, opModeIDs 0-99 describe onroad activity and are not necessary; they can be deleted when using the generic link approach.
opModeFraction	The fraction of the vehicle population that is in each operating mode; these fractions needs to sum to 1 for each source type and pollutant process. Assuming one opModeID is chosen for each source type (i.e., 108 for light-duty source types, and 102 for all heavy-duty source types), enter 1 for each cell in this column.

7.6.4.10 Link Drive Schedules

The Link Drive Schedules is an optional input and is not needed when using the generic link approach.

7.6.5 Post-Processing Project Scale Output for Inventory Development

After executing a generic link run, MOVES will produce a link-by-link emission mass for each pollutant, for the hour specified within the RunSpec. The result of such a run would be a set of emission rates, for each source type as follows:

- Running activity: emissions per mile
- Creeping/idling activity (e.g., trucks waiting at the gate): MOVES results of emissions per mile can be converted to emissions per hour
- Off-network activity: emissions per start

As discussed in Section 7.6.1, each MOVES Project Scale run covers a single hour, and that hour may represent a longer span of time for the purposes of inventory development. The resultant output emission factors can then be multiplied by the corresponding amount and type of annual activity (e.g., VMT, hours of wait time, and number of starts) and the products aggregated to produce an annual emissions inventory for each pollutant.

For the Project Scale Generic Link Approach, the output is an emission rate by source type per mile or per start. To produce a total annual inventory for a given pollutant, each of these rates would then be multiplied by the corresponding activity occuring in the time span in which the MOVES run represents (e.g., if the hourly run represents annual activity at the port, the emission rates by source type should be multiplied by annual activity values by source type). This calculation should be performed for each

source type and summed to produce a total emission value. A hypothetical example is provided in Appendix I to illustrate the post-processing of emission rates produced from a Project Scale Generic Link run.

7.7 Projecting Future Emission Inventories

Future onroad emissions should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Activity growth rates are applied to the base year activity to estimate future activity (described below)
2. Age distributions are adjusted to account for fleet turnover to newer, cleaner engines
3. MOVES is run for the future analysis year to estimate emissions
4. Projected emissions are aggregated to the same level of detail as the base year inventory, as determined by the purpose of the inventory

Onroad activity rates (VMT, starts, etc.) should be adjusted based on anticipated future port growth. Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations. Local port projections, if available, are usually by commodity type and/or business sector; growth can be grouped by the vehicle types that are associated with the various business sectors (i.e., projected cargo throughput for truck activity or projected increases in cruise activity for passenger travel). Annual activity for port-related onroad vehicles should be adjusted in proportion to the anticipated growth rate for a given business activity between the base year and future year inventories. For example, if the projection year is 2030 and the port's total projected growth in cargo throughput between the base year and 2030 is 15%; then drayage activity would be projected to increase by 15%. If the Freight Analysis Framework (FAF)[15] is used to forecast growth, the commodity flows assigned to the truck mode should be used when calculating growth. The growth rates should then be applied to the base year activity estimates.

Based on the future year specified in the RunSpec, MOVES accounts for changes in emissions rates from expected improvements in powertrain and emissions technology, however, some MOVES inputs should be projected. If available, a port-specific age distribution can be applied to the projection year. EPA has developed the *Age Distribution Projection Tool*,[55] which projects a base year age distribution by source type to a future distribution using a similar algorithm to what was used to generate the national projected age distributions. Additionally, any planned action or emission reduction strategies that have been committed to that would affect future emissions should be included according to the actual expected implementation of such commitments. For example, a port may implement a future vehicle electrification program for certain port-related vehicles, therefore the AVFT table should reflect the program components. Note that if the future year inventory is for a regulatory purpose, planned future actions should be included only if written commitments have been made by the agency or operator with the power to implement them.

The emissions inventory for the projection year should be determined using the same method as the base year, except the MOVES user should select the projection year on the Time Spans Panel instead of the base year and ensure that all inputs entered through the County Data Manager or Project Data

Manager correctly reflect the chosen analysis year. Finally, the resulting emissions inventory should be aggregated to the same level of detail as the base year inventory.

8 RAIL

8.1 SOURCE DESCRIPTION

The rail sector covers emissions from locomotives. Port-related rail operations are typically characterized into two categories: line-haul and switching activity. Line-haul operations in a port setting refer to the movement of cargo at the beginning or end of a line-haul trip, where cargo is either picked up or delivered for transport to off-port locations via land or water. Switching activities involve the assembling and disassembling of trains, the sorting of rail cars, and the delivery of empty rail cars to terminals.

Compared to line-haul operations, switching operations generally include more idling activity and involve older locomotives; it is not unusual for older line-haul locomotives to be converted to switcher locomotives as newer, higher-powered line-haul models are produced. At some ports, cargo handling equipment (CHE) perform the assembling and disassembling of trains, and switcher locomotives are not used. In these cases, the rail sector includes only line-haul activity; emissions from CHE are calculated as described in Section 6. Note, this section can be used to quantify emissions related to locomotives at ports, or also at other locations of locomotive activity, such as intermodal freight terminals where freight is transferred between rail and trucks.

The Surface Transportation Board (STB) divides railroad companies into three classes based on annual operating revenues.[a] Class I carriers are the largest operators, Class II carriers operate regional railroads, and Class III carriers operate shortline railroads. Class I railroads are required to report locomotive counts and fuel use for switching and line-haul operations to the STB; Class II and III carriers are not subject to these requirements. Due in part to this fact, default assumptions regarding locomotive duty cycles and other characteristics by class are generally not available for use in the development of a rail emissions inventory. Thus, with a few exceptions, the methodologies presented in this section are not distinguished by carrier class.

For a detailed inventory, locomotive emissions should be calculated for each locomotive type (line-haul and switcher) and each rail terminal/railyard. The scope of the inventory should be determined in advance of any calculations and in accordance with the overall inventory purposes. For example, the boundary of the rail inventory may potentially include only areas under the jurisdiction of the local port authority and exclude rail corridors servicing the port. Alternatively, if the inventory considers port-related emissions over a broader area, the inventory may include emissions from rail corridors beyond the port's boundary. Additionally, the inventory should be calculated at the temporal level of detail necessitated by the purpose of the inventory (e.g., at the year level for an annual inventory). If the purpose of the inventory needs to quantify locomotive idle emissions separately from other locomotive operations, see EPA's Guidance for Quantifying Yard Locomotive Idling Emission Reductions.[56] See Section 2 of this guidance for more discussion about inventory purpose, geographical domains, and temporal detail.

[a] The Surface Transportation Board is a U.S. federal government entity created in 1995, charged with the fundamental missions of resolving railroad rate and service disputes and reviewing proposed railroad mergers. For more information, see https://www.stb.gov/stb/faqs.html.

8.2 Emissions Estimation Overview

In general, base year locomotive emissions can be calculated as shown in Equation 8.1:

$$E = A \times EF \qquad \textbf{Equation 8.1}$$

Where E = emissions (g)
A = activity (hp·h)
EF = emission factor (g/hp·h)

As the data available for locomotives vary from port to port and vary by type of locomotive (i.e., switcher vs. line-haul locomotive), multiple strategies for developing inputs for this calculation are described in the following sections. Locomotive characteristics, activity, and emission factors are described in Sections 8.3, 8.4, and 8.5, respectively. These inputs can be used to calculate a detailed base year rail inventory, as described in Section 8.6. Alternative methodologies are presented in Section 8.7, and Section 8.8 explains how to project port rail emission inventories for future years.

When developing a rail inventory, rail technologies currently in place at the port (e.g., automatic engine stop/start systems, auxiliary power units, and air compressor systems) should be included in the base year inventory.

8.3 Locomotive Characteristics

Locomotives serving ports generally include both line-haul and switcher locomotives. Data needed for estimating a base year emissions inventory will depend on the methodology used to estimate fleet equipment activity (see Section 8.4) and may include the following characteristics:

- Number of locomotives per train: For line-haul operations, the average number of locomotives used in each train.
- Rated engine size: Measured in hp.
- In-use locomotive load factor: The percent of maximum available power used by the locomotive engine over the course of its duty cycle.
- Engine model year/tier (age) distribution: The emission tier level information should reflect the current tier level of the locomotive engine (i.e., reflect the latest repower/replacement of the engine, if applicable), rather than the emission tier level of the engine when the locomotive was first manufactured.
- Use of emission reduction technologies: Technologies such as automatic engine stop/start systems, auxiliary power units, and air compressor systems should be accounted for if present.

This information, if available, could be obtained in consultation with the local port authority and/or the railroad company servicing the port. This will be most feasible for switcher locomotives, which are typically a captive fleet. Because line-haul locomotives transport commodities over long-distances, it is often the case that no identifiable fleet of line-haul locomotives that calls exclusively at a specific port. As a result, characteristics of nationwide fleets of line-haul locomotives, published in the Surface Transportation Board's annual R-1 reports, can be considered in lieu of port-specific data. These reports are available for each Class I railroad. However, if information on line-haul activity within the geographical domain of the inventory is available in consultation with the local port authority and/or the railroad company servicing a port, it should be used, as it will result in higher quality rail activity data.

The Association of American Railroads maintains a directory of contact information for representatives of rail companies operating within each state.[57]

8.4 Locomotive Activity

Activity rates for locomotives, measured in horsepower-hours, can be estimated based on:

- Fuel consumption (preferred methodology for switcher locomotives);
- Gross ton-miles (preferred methodology for line-haul locomotives); or
- Number of trains.

These approaches are discussed in detail in Sections 8.4.1, 8.4.2, and 8.4.3 respectively. The method that relies on fuel consumption is preferred for switchers because it relies on a robust source of data. The gross ton-miles method is preferred for line-haul because it produces a reliable estimate of fuel consumption for that type of locomotive. Although the first two methods are preferred, all three approaches can be used to estimate both switching and line-haul activity within the geographical domain, and the choice of method may depend on data availability.

If the purpose of the inventory is for a refined analysis involving air quality modeling, see Appendix I of EPA's PM Hot-spot Guidance[48] for a detailed rail inventory methodology.

8.4.1 Activity Based on Fuel Consumption

The fuel consumption approach for calculating locomotive activity combines data on fuel consumption and a conversion factor to estimate work done by the locomotive.

As fuel consumption information for locomotives servicing a specific port is likely to be more readily available (in consultation with the local port authority and/or the railroad company servicing the port) for a captive fleet, this method is likely more feasible for characterizing switching operations than for long-haul operations. Fuel consumption information may not be available for line-haul locomotives, because it is often the case that no identifiable fleet of line-haul locomotives that calls exclusively on any specific port.

EPA has estimated conversion factors for different locomotive types, as shown in Table 8.1.[39] These conversion factors relate fuel consumption to the usable power of the locomotive engine. Older locomotives and locomotives used in lower powered applications, such as switching, tend to be less fuel efficient. If fleet-specific conversion factors are available, those should be used instead of the factors in Table 8.1.

Table 8.1. Locomotive Fuel Consumption to Horsepower-Hour Conversion Factors

Locomotive Type	Conversion Factor (hp·h/gal)
Line-haul (Class I)	20.8
Line-haul (Class II/III)	18.2
Switcher	15.2

Activity for a locomotive fleet based on fuel consumption and a conversion factor can be determined using Equation 8.2:

$$A = FC \times CF$$ **Equation 8.2**

Where A = locomotive activity (hp·h)
FC = fuel consumption (gal)
CF = conversion factor (hp·h/gal)

8.4.2 Activity Based on Gross Ton-miles

When fuel consumption information is not directly available, it can be estimated from gross ton-miles. This is calculated as the product of total train weight, distance moved, and the fleet average fuel consumption factor, as described in Equation 8.3 below. This estimated fuel consumption value can, in turn, be used with Equation 8.2 in Section 8.4.1 to estimate annual activity. This approach is most applicable to line-haul locomotives for which port-specific fleet characteristics are unknown.

Equation 8.3 can be applied to estimate fuel consumption based on gross ton-miles:

$$FC = GTM \times FCF$$ **Equation 8.3**

Where FC = fuel consumption (gal)
GTM = gross ton-miles (ton-mi)
FCF = fleet average fuel consumption factor (gal/ton-mi)

The fuel consumption factor (FCF) is a measure of fuel efficiency that relates fuel consumption to work performed. For Class I fleets, a national average value can be derived from information in the railroad's latest R-1 report, published annually by the STB.[58] Specifically, the railroad's fleet average FCF can be calculated by dividing national fuel consumption (reported in R-1, Schedule 750, Line 4) by national gross ton-miles (reported in R-1, Schedule 755, Line 104; note that this number is reported in thousands, and therefore needs to be multiplied by 1,000 to get it in units of ton-miles).[59]

8.4.3 Activity Based on Number of Trains

A third approach for determining locomotive activity uses the number of trains visiting the port combined with fleet characteristics to estimate locomotive activity. This strategy is likely more applicable to line-haul locomotives operating within the geographical domain of the inventory. To implement this approach, the following data are needed:

- Number of trains visiting the port, over the time period chosen for the inventory
- Average number of locomotives per train
- Average time spent on port per train trip
- Average locomotive rated power
- Average in-use locomotive load factor

These data, if available, could be obtained in consultation with the local port authority and/or the railroad company servicing the port. The equation that can be applied for estimating activity based on these fleet characteristics is shown in Equation 8.4:

$$A = N_t \times N_l \times H \times P \times LF$$ **Equation 8.4**

Where A = fleet activity (hp·h)

N_t = number of trains visiting the port
N_l = average number of locomotives per train
H = average time spent on port per train trip (h)
P = average rated power of locomotives (hp)
LF = average in-use load factor (unitless)

The load factor here is defined as the percent of maximum available power used by the locomotive engine over the course of its duty cycle. Most locomotives employ a diesel engine coupled to an electrical drive system, which operates in a series of discrete steady-state power settings called "notches." Notch positions typically range from one to eight (from least to most powerful), idle, and dynamic braking, which allows for speed reduction using the locomotive's drive system. As line-haul and switcher locomotives have different duty cycles, they are expected to have different load factors. A port-specific load factor could be calculated for each type of locomotive if the percent of maximum power used by the engine in each notch setting is known, as well as the time spent in each notch setting (i.e., the duty cycle). Appendix I of EPA's PM Hot-spot Guidance provides detailed instructions on applying this methodology.

If detailed information to inform the calculation of fleet-specific load factors is not available, a national average load factor of 28% for line-haul and 10% for switcher locomotives can be assumed.[17]

In Equation 8.4, the product of trains visiting the port, locomotives per train, and time spent on port per train trip represents the aggregate activity of the locomotive fleet. To more precisely determine locomotive activity using this methodology, activity data loggers could be installed on the locomotives or other telematics data could be used.

8.5 Emission Factors

Emission factors for locomotives vary by emissions tier and fuel type consistent with EPA's regulations, as described below. For methods to estimate energy consumption for this source sector, see Appendix A.

8.5.1 Diesel

The diesel emission factors given below are from EPA's *Emission Factors for Locomotives*,[39] unless otherwise noted. Speciation profiles of additional hazardous air pollutants for locomotive engines are presented in Appendix J.

8.5.1.1 Nitrogen Oxides (NOx), Particulate Matter (PM), Black Carbon (BC), Volatile Organic Compounds (VOC), and Carbon Monoxide (CO)

Emission factors for NOx, PM, and CO are provided in Table 8.2 and Table 8.3 for Class I line-haul and switcher locomotives, respectively. The plus ("+") in the tables below reflect the emission factors that should be used if a locomotive engine has been rebuilt to meet the revised standards in 40 CFR Part 1033. For example, if a locomotive was initially Tier 0 but has been rebuilt to meet the Tier 1 standards, use the emission factors in the "Tier 1+" row. Emission factors for hydrocarbons (HC) are also included in the tables below, which are the basis for the VOC emission factors, as described later.

Table 8.2. Line-Haul Emission Factors for NOx, PM_{10}, HC, and CO (g/hp·h)

Tier Level	NOx	PM_{10}	HC	CO
Uncontrolled	13.00	0.32	0.48	1.28
Tier 0	8.60	0.32	0.48	1.28
Tier 0+	7.20	0.20	0.30	1.28
Tier 1	6.70	0.32	0.47	1.28
Tier 1+	6.70	0.20	0.29	1.28
Tier 2	4.95	0.18	0.26	1.28
Tier 2+	4.95	0.08	0.13	1.28
Tier 3	4.95	0.08	0.13	1.28
Tier 4	1.00	0.015	0.04	1.28

+ Indicates that these are the revised standards in 40 CFR Part 1033.

Table 8.3. Switcher Emission Factors for NOx, PM_{10}, HC, and CO (g/hp·h)

Tier Level	NOx	PM_{10}	HC	CO
Uncontrolled	17.40	0.44	1.01	1.83
Tier 0	12.60	0.44	1.01	1.83
Tier 0+	10.60	0.23	0.57	1.83
Tier 1	9.90	0.43	1.01	1.83
Tier 1+	9.90	0.23	0.57	1.83
Tier 2	7.30	0.19	0.51	1.83
Tier 2+	7.30	0.11	0.26	1.83
Tier 3	4.50	0.08	0.26	1.83
Tier 4	1.00	0.015	0.08	1.83

+ Indicates that these are the revised standards in 40 CFR Part 1033.

$PM_{2.5}$ emission factors are calculated as 97% of the PM_{10} emission factors. As these are emission factors for diesel fuel, the DPM_{10} and $DPM_{2.5}$ emission factors are equal to the PM_{10} and $PM_{2.5}$ emission factors, respectively. BC emission factors are 73% of $PM_{2.5}$ emission factors.[33]

VOC emission factors are 1.053 times the HC emission factors.[17]

For Class II/III line-haul locomotives, the Tier 0 line-haul emission factors should be used.

8.5.1.2 Brake Specific Fuel Consumption (BSFC)

BSFC rates vary by locomotive type. Note that carbon dioxide, methane, nitrous oxide, and sulfur dioxide are calculated based on these values. BSFC rates by locomotive type are presented in Table 8.4.

Table 8.4. Locomotive BSFC Rates (g/hp·h)

Locomotive Type	BSFC Rate (g/hp·h)
Line-haul (Class I)	154
Line-haul (Class II/III)	176
Switcher	211

8.5.1.3 Carbon Dioxide (CO_2)

CO_2 is directly proportional to fuel consumption. Therefore, the CO_2 emission factor is determined according to Equation 8.5:

$$EF_{CO_2} = BSFC \times CCF \quad \textbf{Equation 8.5}$$

Where EF_{CO_2} = CO_2 emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 8.5.1.2
CCF = carbon content factor (g CO_2/g fuel)
= 3.19 for diesel[39]

8.5.1.4 Methane (CH_4)

CH_4 emission factors can be estimated from BSFC using Equation 8.6:

$$EF_{CH_4} = BSFC \times MCF \quad \textbf{Equation 8.6}$$

Where EF_{CH_4} = CH_4 emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 8.5.1.2
MCF = methane conversion factor (g CH_4/g fuel)
= 0.00025 for diesel locomotive engines[38]

8.5.1.5 Nitrous Oxide (N_2O)

N_2O emission factors can be estimated from BSFC using Equation 8.7:

$$EF_{N_2O} = BSFC \times NCF \quad \textbf{Equation 8.7}$$

Where EF_{N_2O} = N_2O emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 8.5.1.2
NCF = N_2O conversion factor (g N_2O/g fuel)
= 0.00008 for diesel locomotive engines[38]

8.5.1.6 Sulfur Dioxide (SO_2)

SO_2 should be calculated according to Equation 8.8:

$$EF_{SO2} = BSFC \times S_{act} \times FSC \times MWR \quad \textbf{Equation 8.8}$$

Where EF_{SO2} = SO_2 emission factor (g/hp·h)
$BSFC$ = brake specific fuel consumption (g/hp·h) as determined according to Section 8.5.1.2
S_{act} = actual fuel sulfur level (weight ratio)

= 15×10^{-6} for locomotives using ULSD

FSC = percentage of sulfur in fuel that is converted to SO_2[17]
= 0.97753

MWR = molecular weight ratio of SO_2 to sulfur
= 64/32 = 2

If the port emissions inventory is being calculated for a year prior to 2012, or if a fuel with a different sulfur level was used by locomotives, then the actual fuel sulfur level should be used.[36]

8.5.2 LNG and LNG/Diesel Dual Fuel

For alternative fuel locomotive fleets, emission factors from the engine manufacturer should be used, if available. However, if manufacturer data are unavailable, the following resources could be used instead:

- LNG-fueled locomotives: See the emission factors presented in *An Evaluation of Natural Gas-fueled Locomotives*,[60] a joint publication from the BNSF Railway and Union Pacific Railroad companies, the Association of American Railroads, and California Environmental Associates.
- LNG/diesel dual fueled locomotives: See the emission factors published in Argonne National Laboratory's *Future Restrictions on Diesel Fuel Combustion in California: Energy and Emissions Implications of Four Scenarios* report.[61]

8.6 Inventory Calculations

The base year locomotive emissions are calculated as the product of the locomotive activity estimate and a pollutant-specific (and in some cases tier-specific) emission factor, where the activity has been determined based on locomotive fuel consumption, number of trains, or gross ton-miles (as described in Section 8.4), for both line-haul and switcher locomotives. If both the emission standard tier and the activity estimate are known for each locomotive (more likely for captive switcher fleets), emissions should be quantified on a per-locomotive basis.

If the emission standard tier is not known for individual locomotives, but the fleet average distribution is known (which is more likely for line-haul fleets), a fleet average emission factor should be calculated, weighted by the percentage of total fleet activity or population in each tier. If the fleet average tier distribution is unknown, EPA's default fleet average emission factors for PM, HC, NOx, and CO can be used instead (see Section 8.7.2 for more details). In these cases, the emissions should be quantified separately for the fleet of line-haul and switcher locomotives.

These emissions can be then aggregated across all locomotives to the most useful level for the purposes of the inventory. If the inventory has a spatial component to it, switcher emissions should be allocated to the railyard where they occur, and line-haul emissions should be allocated to the rail lines where they occur.

If the inventory has a temporal component to it and the activity data are at a finer level of detail, the locomotive emissions should be aggregated to the level of detail for the purpose of the inventory. However, if the activity data are at a coarser level of temporal detail than what is necessitated by the purpose of the inventory, the emissions will need to be allocated to smaller units of time using surrogate data. This surrogate data can come from other sectors in the port inventory, if those have enough

detail. For example, locomotive activity could be temporally allocated based on AIS-derived OGV container ship calls.

Performing quality control checks and including them in the supporting documentation for an inventory are useful steps that support the results of the inventory, help stakeholders understand the results, and facilitate comparisons between different inventories. The various checks listed below should provide a consistent view of rail activity and emissions for an inventory. An inconsistency in one check that is not reflected in others is indicative that additional scrutiny of input data sets and calculations may reveal useful insights. Likewise, an anomaly that shows up in multiple checks may suggest an issue with input data or methodology implementation. Note that unless otherwise specified, the analytical calculations listed below should be aggregated by locomotive type and fuel type. The following distributions and metrics (if available) are useful to examine as quality control checks and to facilitate comparisons between different inventories:

- Engine power and operating hours: Examining both totals and distributions helps to estimate the relative impact that a given locomotive type should have on the inventory.
- Model year range and engine tier distribution: Examining the minimum and maximum observed values and average age, along with the distribution of engine tiers, provides an indication of how old the locomotives are and can help in determining which locomotives contribute substantially to the inventory.
- Total energy consumption (in horsepower-hours): Examining energy consumption provides an estimate of the scale of locomotive activity contributing to the inventory and for enabling cross-comparisons with other inventories.
- Comparing CO_2 emissions with fuel consumption: CO_2 emissions and fuel consumption should have a linear relationship.

8.7 Alternative Methodologies

Alternative methodologies described in this section can be used to calculate a base year emission inventory (e.g., if there is not enough local information to fully implement the detailed methodologies described above). National data or default activity assumptions do not necessarily reflect local conditions, and their use may have a significant effect on the resulting emissions inventory.

8.7.1 Activity Calculations

The following sections contain alternative methodologies that make use of national data or default assumptions that can be used to calculate locomotive activity.

8.7.1.1 Switcher Locomotive Hours

If fuel consumption data are not available from the rail company to estimate the activity for switcher locomotives, the following alternative methodologies can be used to fill any gaps as necessary:

- Number of switcher locomotive hours: Estimated by multiplying the number of rail cars visiting the port by the average number of switching hours per rail car.
- Number of rail cars: Estimated using the methodology presented in Appendix K.
- Number of switching hours per rail car: An average value of 0.182 hours can be assumed, based on an analysis of data from the Federal Railroad Administration.[62]

The switcher activity in horsepower-hours can then be estimated by multiplying the switcher locomotive hours by the average switcher rated power times 10% (i.e., the average switcher load factor).

8.7.1.2 Activity Based on Gross Ton-miles

If precise values are not available from the rail company for use in Equation 8.3 in Section 8.4.2, the following alternative methodologies can be used to fill any gaps as necessary:

- Gross ton-miles: Estimated by multiplying the average weight of each train (including the weight of the locomotives, rail cars, and cargo), the distance traveled by each train within the geographical domain, and the number of train visits. Gross ton-miles should be summed for all train routes and directions. This aggregate value can then be used in Equation 8.3 to calculate annual fuel consumption based on fleet gross ton-miles.
- Number of rail cars: Estimated using the methodology presented in Appendix K.

8.7.1.3 Activity Based on Number of Trains

If precise values are not available from the rail company for use in Equation 8.4 in Section 8.4.3, the alternative methodologies presented in this section can be used to fill any gaps as necessary.

Average locomotive engine power for Class I locomotives of a railroad can be determined based on information from the STB's annual R-1 reports. Specifically, average locomotive engine power can be calculated by dividing the aggregate capacity (hp) of units by total number of units in service (columns k and j, respectively, of R-1 Schedule 710; line-hauls are reported on line 1, switchers on line 4).

The total number of trains visiting the port can be estimated by determining the number of trains needed to move the rail modal share of port throughput of containerized and non-containerized cargo separately. While trains can be comprised of both containerized and non-containerized cargo, these cargo types can be modeled separately for simplicity.

The number of container trains visiting the port can be estimated using Equation 8.9:

$$T_c = \frac{TEU_p}{TEU_m \times UR} \times (1 + RER) \qquad \textbf{Equation 8.9}$$

Where T_c = Number of container trains
TEU_p = Port throughput of TEUs moved by rail
TEU_m = Maximum train capacity (TEUs per train)
UR = Utilization ratio
RER = Return empty ratio

The number of TEUs at the port can be found in the U.S. Army Corps of Engineers *Waterborne Container Traffic* statistics,[63] published annually. If the fraction of TEUs that enter or exit a port via the rail mode is unknown, it can be approximated using a region-specific fraction of cargo throughput by mode from the Freight Analysis Framework (FAF).[15]

If the other factors of Equation 8.9 are unknown, the following general assumptions can be used:

- For TEU_m, the maximum train capacity: assume 500 TEUs per train.

- For UR, the utilization ratio (an estimation of how many platforms are filled or how many double stack platforms are totally utilized): assume 80%.
- For RER, the return empty ratio (share of loaded railcars that return empty): assume 0.5.

Note that the above assumptions do not reflect local conditions, which likely impact rail activity. Also, Equation 8.9 can be adapted for other forms of cargo (such as bulk) as necessary. If the number of rail cars moved by the port for other forms of cargo is unknown, it can be estimated using the methodology presented in Appendix K.

8.7.2 Fleet Average Emission Factors

If the tier level of locomotives visiting the port is not known, national average fleet emission factors for PM_{10}, HC, NOx, and CO can be used instead (presented in Table 8.5 and Table 8.6), which are not specific to engine tier.[39] The other pollutants should be calculated as described in Section 8.5.

Table 8.5. Fleet Average Line-Haul Emission Factors for NOx, PM_{10}, HC, and CO (g/hp·h)

Calendar Year	NOx	PM_{10}	HC	CO
2006	8.65	0.31	0.46	1.28
2007	8.41	0.30	0.45	1.28
2008	8.13	0.25	0.43	1.28
2009	7.93	0.24	0.42	1.28
2010	7.55	0.23	0.40	1.28
2011	7.16	0.21	0.37	1.28
2012	6.92	0.20	0.34	1.28
2013	6.68	0.18	0.31	1.28
2014	6.49	0.17	0.29	1.28
2015	6.20	0.16	0.27	1.28
2016	5.82	0.15	0.25	1.28
2017	5.48	0.14	0.22	1.28
2018	5.19	0.13	0.20	1.28
2019	4.95	0.12	0.19	1.28
2020	4.76	0.11	0.17	1.28
2021	4.52	0.11	0.16	1.28
2022	4.28	0.10	0.15	1.28
2023	4.04	0.09	0.14	1.28
2024	3.80	0.08	0.13	1.28
2025	3.56	0.08	0.13	1.28
2026	3.32	0.07	0.12	1.28
2027	3.13	0.07	0.11	1.28
2028	2.93	0.06	0.10	1.28

Calendar Year	NOx	PM_{10}	HC	CO
2029	2.74	0.05	0.10	1.28
2030	2.55	0.05	0.09	1.28
2031	2.36	0.05	0.08	1.28
2032	2.21	0.04	0.08	1.28
2033	2.07	0.04	0.07	1.28
2034	1.92	0.03	0.07	1.28
2035	1.78	0.03	0.06	1.28
2036	1.68	0.03	0.06	1.28
2037	1.59	0.03	0.06	1.28
2038	1.49	0.02	0.05	1.28
2039	1.39	0.02	0.05	1.28
2040	1.35	0.02	0.05	1.28

Table 8.6. Fleet Average Switcher Emission Factors for NOx, PM_{10}, HC, and CO (g/hp·h)

Calendar Year	NOx	PM_{10}	HC	CO
2006	16.45	0.43	0.99	1.83
2007	16.38	0.43	0.99	1.83
2008	15.99	0.36	0.95	1.83
2009	15.86	0.36	0.95	1.83
2010	15.53	0.36	0.93	1.83
2011	15.46	0.35	0.92	1.83
2012	14.93	0.34	0.88	1.83
2013	14.80	0.33	0.88	1.83
2014	14.28	0.32	0.84	1.83
2015	14.14	0.32	0.83	1.83
2016	13.68	0.30	0.79	1.83
2017	13.55	0.30	0.78	1.83
2018	13.29	0.29	0.76	1.83
2019	13.16	0.29	0.75	1.83
2020	12.30	0.27	0.69	1.83
2021	12.17	0.26	0.68	1.83
2022	11.64	0.26	0.64	1.83
2023	11.32	0.24	0.63	1.83
2024	10.66	0.23	0.59	1.83

Calendar Year	NOx	PM_{10}	HC	CO
2025	9.87	0.21	0.53	1.83
2026	9.47	0.20	0.50	1.83
2027	9.08	0.20	0.48	1.83
2028	8.68	0.18	0.45	1.83
2029	8.29	0.18	0.43	1.83
2030	7.83	0.16	0.41	1.83
2031	7.37	0.16	0.38	1.83
2032	6.91	0.14	0.36	1.83
2033	6.45	0.14	0.34	1.83
2034	5.99	0.13	0.31	1.83
2035	5.53	0.11	0.29	1.83
2036	5.07	0.11	0.26	1.83
2037	4.67	0.10	0.24	1.83
2038	4.41	0.09	0.24	1.83
2039	4.14	0.09	0.22	1.83
2040	3.95	0.08	0.21	1.83

8.8 Projecting Future Emission Inventories

Future locomotive emission inventories should be projected from a base year inventory, developed as described in the sections above. In general, the projection process follows these steps:

1. Activity growth rates are applied to the base year activity to estimate future activity
2. Locomotive tier distributions are adjusted to account for fleet turnover to newer, cleaner engines and emission factors are reassigned
3. Projected emissions are calculated using the estimated future activity
4. Projected emissions are aggregated to the same level of detail as the base year inventory, as determined by the purpose of the inventory

Activity growth rates should be derived from local port growth projections or regional economic forecasts, if available, which could be obtained in consultation with the local port authority, marine exchange, board of trade, or other local and/or state organizations.

If local port projections or other regional forecasts are unavailable, the FAF[15] can be used to forecast growth instead. If this is used, the commodity flows in the FAF assigned to the rail transportation mode should be used when calculating growth. The growth rates should then be applied to the base year horsepower-hours activity estimate for both locomotive types.

If the age distribution of a port locomotive fleet in the future analysis year can be anticipated (e.g., for a captive fleet), this age distribution should inform the assignment of future emission factors for the future fleet. If this information is not available, the emission factors presented in Section 8.7.2 can be

used instead. These fleet-average emission factors are not specific to engine tier and are available for future years through 2040. For other pollutants of concern that are not included in Section 8.7.2, the emission factor estimation methodologies from Section 8.5 should be applied.

Additionally, any planned action or emission reduction strategies that have been committed to that would affect future emissions should be included according to the actual expected implementation of such commitments. For example, if a port has committed to replacing or repowering its oldest switcher locomotives through authorization of funds for such purchases, the effects of such a program should be reflected in the projected age distribution. Note that if the future year inventory is for a regulatory purpose, planned future actions should be included only if written commitments have been made by the agency or operator with the power to implement them.

Once the base year activity has been scaled and appropriate emission factors are assigned to each unit, the projected future emissions can be calculated using the same methodology at the same level of detail as the base year inventory. Finally, the resulting emissions inventory should be aggregated to the same level of detail as the base year inventory.

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Appendix A ESTIMATING PORT-RELATED ENERGY CONSUMPTION

This appendix can be used to estimate energy consumption for each of the port-related mobile source sectors covered in this guidance. As discussed in Section 2, energy consumption is an important measure of port activity. The following subsections discuss how to estimate energy consumption for each source sector in the context of estimating an emissions inventory.

Note that some of the sectors use kilowatt hours (kWh) as the unit for energy consumption, whereas others use horsepower-hours (hp·h) for historical purposes. The following conversion factor can be used to convert hp·h into kWh:

1 hp·h = 0.7457 kWh

A.1 OCEAN-GOING VESSELS

Energy in kWh is a measure of activity for the ocean-going vessels (OGV) sector and is calculated as part of the inventory development process. Section A.1.1 describes how to calculate energy using the Automatic Identification System (AIS) methodology corresponding to Section 3.8; Section A.1.2 describes how to calculate energy using the alternative methodology corresponding to Section 3.9.

A.1.1 AIS Inventory Methodology

When calculating an emissions inventory for OGV using AIS data, propulsion engine emissions are calculated at the AIS record level by multiplying engine load by hours of operation, an emission factor, and a low load adjustment factor (LLAF), as described in Section 3.8.6. Propulsion engine energy consumption is calculated using these components without the emission factor, as shown in Equation A.1:

$$Energy_p = P_p \times A \times LLAF \qquad \textbf{Equation A.1}$$

Where $Energy_p$ = propulsion engine energy consumption for each AIS record (kWh)
P_p = propulsion engine operating power for each AIS record (kW), from Equation 3.6 or Equation 3.7
A = time interval between consecutive AIS records (h)
$LLAF$ = low load adjustment factor determined for each AIS record (unitless)

If the load factor for an individual AIS record is less than 20% (as calculated using Equation 3.8), the LLAF for CO_2 should be applied (see Section 3.7). If the load factor is 20% or greater, no LLAF is needed. Note that propulsion engine energy consumption should only be calculated for AIS records that are determined to be in the transit, maneuvering, or restricted speed zone operating modes (i.e., propulsion engines can be assumed to be off while hotelling or at anchor).

As for auxiliary engines and boilers, their emissions are calculated at the AIS record level by multiplying engine load by hours of operation and an emission factor, as described in Section 3.8.7 (note, auxiliary engine and boiler loads are estimated for each operating mode as described in Section 3.6). Energy consumption for these sources is calculated using these components without the emission factor, as shown in Equation A.2 and Equation A.3:

$$Energy_a = P_a \times A$$ **Equation A.2**

Where $Energy_a$ = auxiliary engine energy consumption for each AIS record (kWh)
P_a = auxiliary engine operating power for each AIS record based on operating mode (kW)
A = time interval between consecutive AIS records (h)

$$Energy_b = P_b \times A$$ **Equation A.3**

Where $Energy_b$ = boiler energy consumption for each AIS record (kWh)
P_b = boiler load for each AIS record based on operating mode (kW)
A = time interval between consecutive AIS records (h)

Total energy consumption for each time interval between consecutive AIS records should be calculated using Equation A.4:

$$Energy = Energy_p + Energy_a + Energy_b$$ **Equation A.4**

Where $Energy$ = total energy consumption for each AIS record (kWh)
$Energy_p$ = propulsion engine energy consumption for each AIS record (kWh) from Equation A.1
$Energy_a$ = auxiliary engine energy consumption for each AIS record (kWh) from Equation A.2
$Energy_b$ = boiler energy consumption for each AIS record (kWh) from Equation A.3

The total energy consumption at the AIS record level can then be aggregated to the same levels as the OGV emissions inventory, as described in Section 3.8.8.

A.1.2 Alternative Inventory Methodology

When calculating an emissions inventory for OGV using the alternative inventory methodology, propulsion engine emissions are calculated for each vessel call and for each of the transit, reduced speed zone, and maneuvering operating modes. Specifically, the emissions are calculated by multiplying engine load by hours of operation, an emission factor, and a low load adjustment factor (LLAF), as described in Section 3.9.3. Propulsion engine energy consumption is calculated using these components without the emission factor, as shown in Equation A.5:

$$Energy_{p,i} = P_{p,i} \times A_i \times LLAF_i$$ **Equation A.5**

Where $Energy_{p,i}$ = propulsion engine energy consumption for operating mode i (kWh)
$P_{p,i}$ = propulsion engine operating power for operating mode i (kW), from Equation 3.13
A_i = time spent in operating mode i (h)
$LLAF_i$ = low load adjustment factor for operating mode i (unitless)

If the load factor for an operating mode is less than 20% (as calculated using Equation 3.14), the LLAF for CO_2 should be applied (see Section 3.7). If the load factor is 20% or greater, no LLAF is needed.

As for auxiliary engines and boilers, their emissions are calculated for all operating modes by multiplying engine load by hours of operation and an emission factor, as described in Section 3.9.4 (note, auxiliary

engine and boiler loads are estimated for each operating mode as described in Section 3.6). Energy consumption for these sources is calculated using these components without the emission factor, as shown in Equation A.6 and Equation A.7:

$$Energy_{a,i} = P_{a,i} \times A_i \quad \textbf{Equation A.6}$$

Where $Energy_{a,i}$ = auxiliary engine energy consumption for operating mode i (kWh)
$P_{a,i}$ = auxiliary engine operating power for operating mode i (kW)
A_i = time spent in operating mode i (h)

$$Energy_{b,i} = P_{b,i} \times A_i \quad \textbf{Equation A.7}$$

Where $Energy_{b,i}$ = boiler energy consumption for operating mode i (kWh)
$P_{b,i}$ = boiler load for operating mode i (kW)
A_i = time spent in operating mode i (h)

Total energy consumption for each vessel should be calculated using Equation A.8:

$$Energy_i = Energy_{p,i} + Energy_{a,i} + Energy_{b,i} \quad \textbf{Equation A.8}$$

Where $Energy_i$ = total energy consumption for operating mode i (kWh)
$Energy_{p,i}$ = propulsion engine energy consumption for operating mode i (kWh) from Equation A.6
$Energy_{a,i}$ = auxiliary engine energy consumption for operating mode i (kWh) from Equation A.7
$Energy_{b,i}$ = boiler energy consumption for operating mode i (kWh) from Equation A.8

The total energy consumption for each vessel can then be aggregated to the same levels as the OGV emissions inventory, as described in Section 3.9.5.

A.2 Harbor Craft

Energy in kWh is a measure of activity for the harbor craft sector and is calculated as part of the inventory development process. Section A.2.1 describes how to calculate energy using the AIS methodology corresponding to Section 4.7; Section A.2.2 describes how to calculate energy using the alternative methodology corresponding to Section 4.8.

A.2.1 AIS Inventory Methodology

When calculating an emissions inventory for harbor craft using AIS data, two operating modes are considered: hotelling and non-hotelling. Emissions are calculated at the vessel level by multiplying the installed power by a load factor, an emission factor, and hours of operation for each operating mode, as described in Section 4.7.4. Energy consumption is calculated using these components without the emission factor. Equation A.9 describes how non-hotelling energy consumption is calculated, and Equation A.10 describes the calculation for hotelling energy consumption.

$$Energy_{nh} = \left(P_p \times LF_p + P_a \times LF_a\right) \times A_{nh} \quad \textbf{Equation A.9}$$

Where $Energy_{nh}$ = non-hotelling energy consumption for each vessel (kWh)
P_p = total installed propulsion engine power (kW)
LF_p = propulsion engine load factor (unitless)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
A_{nh} = non-hotelling activity (h)

$$Energy_h = P_a \times LF_a \times A_h$$ **Equation A.10**

Where $Energy_h$ = hotelling energy consumption for each vessel (kWh)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
A_h = hotelling activity (h)

Total energy consumption for the harbor craft sector should be calculated using Equation A.11.

$$Energy = Energy_{nh} + Energy_h$$ **Equation A.11**

Where $Energy$ = total energy consumption for each vessel (kWh)
$Energy_{nh}$ = non-hotelling energy consumption for each vessel (kWh)
$Energy_h$ = hotelling energy consumption for each vessel (kWh)

The total energy consumption can then be aggregated or allocated to the same levels as the harbor craft emissions inventory, as described in Section 4.7.5.

A.2.2 Alternative Inventory Methodology

When calculating an emissions inventory for harbor craft using the alternative inventory methodology, emissions are calculated at the vessel level by multiplying the installed power by a load factor, an emission factor, and hours of operation for both propulsion and auxiliary engines, as described in Section 4.8.3. Energy consumption is calculated using these components without the emission factor. Equation A.12 describes how energy consumption is calculated using this methodology:

$$Energy = P_p \times LF_p \times A_p + P_a \times LF_a \times A_a$$ **Equation A.12**

Where $Energy$ = energy consumption for each vessel (kWh)
P_p = total installed propulsion engine power (kW)
LF_p = propulsion engine load factor (unitless)
A_p = propulsion engine activity (h)
P_a = total installed auxiliary engine power (kW)
LF_a = auxiliary engine load factor (unitless)
A_a = auxiliary engine activity (h)

The total energy consumption can then be aggregated or allocated to the same levels as the harbor craft emissions inventory, as described in Section 4.8.4.

A.3 Recreational Marine

Energy in hp·h is a measure of activity for the recreational marine sector and is calculated as part of the inventory development process. Section A.3.1 describes how to calculate energy using the AIS methodology corresponding to Section 5.6; Section A.3.2 describes how to calculate energy using the alternative methodology corresponding to Section 5.7.

A.3.1 AIS Inventory Methodology

When calculating an emissions inventory for recreational marine using AIS data, emissions are calculated at the vessel level by multiplying the number of engines on the vessel by the rated engine power, load factor, operating activity, and an emission factor, as described in Section 5.6.4. Energy consumption is calculated using these components without the emission factor. Note that because this does not include the emission factor, it is not necessary to run MOVES-Nonroad to estimate energy consumption from recreational marine vessels. Equation A.13 describes how energy consumption is calculated using this methodology:

$$Energy = N_e \times P \times LF \times A$$ **Equation A.13**

Where $Energy$ = energy consumption for each vessel (hp·h)
N_e = number of engines on the vessel
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)

The total energy consumption can then be aggregated or allocated to the same levels as the recreational marine emissions inventory, as described in Section 5.6.5.

A.3.2 Alternative Inventory Methodology

When calculating an emissions inventory for recreational marine using the alternative inventory methodology, emissions are calculated at the fleet level by multiplying the number of recreational vessels by the average engine power, average load factor, average operating activity, and an emission factor, as described in Section 5.7. Energy consumption is calculated using these components without the emission factor. Note that because this does not include the emission factor, it is not necessary to run MOVES-Nonroad to estimate energy consumption from recreational marine vessels. Equation A.14 describes how energy consumption is calculated using this methodology for each vessel type with fleet average values:

$$Energy = N_v \times P \times LF \times A$$ **Equation A.14**

Where $Energy$ = fleet energy consumption for each vessel type (hp·h)
N_v = number of recreational vessels
P = average engine power (hp)
LF = average load factor (unitless)
A = average operating activity (h)

The total energy consumption can then be aggregated or allocated to the same levels as the recreational marine emissions inventory, as described in Section 5.7.

A.4 Cargo Handling Equipment

Energy in hp·h is a measure of activity for the cargo handling equipment (CHE) sector and is calculated as part of the inventory development process. Emissions are calculated in this sector for each unit of CHE by multiplying the unit's rated engine power by a load factor, operating activity, and an emission factor, as described in Section 6.6.1. Energy consumption is calculated using these components without the emission factor. Note that because this does not include the emission factor, it is not necessary to run MOVES-Nonroad to estimate energy consumption from CHE. Equation A.15 describes how energy consumption is calculated using this methodology:

$$Energy = P \times LF \times A \qquad \textbf{Equation A.15}$$

Where $Energy$ = per unit energy consumption (hp·h)
P = rated engine power (hp)
LF = engine load factor (unitless)
A = engine operating activity (h)

The total energy consumption can then be aggregated or allocated to the same levels as the CHE emissions inventory, as described in Section 6.6.2.

A.5 Onroad Vehicles

Energy consumption for onroad vehicles can be estimated in the same manner as any pollutant selected for this sector. Regardless if the County Scale (Section 7.5) or Project Scale (Section 7.6) approach is used, the model setup and post-processing for energy consumption is identical to those steps taken for the rest of the onroad inventory development process. The MOVES user simply needs to select "Total Energy Consumption" in the Pollutants and Processes Panel when setting up the run specification (RunSpec). Note that the unit of energy consumption for the onroad sector can be joules (J), kilojoules (kJ), or million British thermal units (BTU), as selected by the user when setting up the RunSpec.

The following conversion factors can be used to convert these units into kWh:

- Divide energy consumption in joules by 3,600,000 to get energy consumption in kWh
- Divide energy consumption in kilojoules by 3,600 to get energy consumption in kWh
- Multiply energy consumption in million BTU by 293.07107 to get energy consumption in kWh

A.6 Rail

Energy in hp·h is the primary measurement of activity for the rail sector and it is directly and specifically calculated as part of the inventory development process. It is either calculated based on fuel consumption (Section 8.4.1), gross ton-miles (Section 8.4.2), or number of trains (Section 8.4.3). See Section 8.4 for more information.

Appendix B DETERMINING C1 AND C2 ENGINE TIERS

This appendix can be used to determine the applicable engine tier of Category 1 and 2 (C1 and C2, respectively) propulsion engines on U.S. flagged ships based on cylinder displacement range, power range, and engine model year. As described in Sections 3.3.2 and 4.3.2, this is a necessary step if the C1 and C2 vessel characteristic data do not include engine tier information, but do include cylinder displacement, engine power rating, and engine model year data. The information in this table is consistent with the C1 and C2 emission factors presented in Appendix H. If the cylinder displacement information is unavailable, average emission factors by model year, power range, and engine group (propulsion or auxiliary) can be used instead (see Section H.5).

C1 and C2 engine tiers vary by cylinder displacement, engine power, and model year, and are presented in Table B.1.[17] Note that if the per-cylinder displacement is 30 liters or greater, it is a C3 engine, and those tiers are discussed in Section 3.5.1.

Table B.1. Category 1 and 2 Engine Tiers

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

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

Appendix C FILLING GAPS IN VESSEL CHARACTERISTICS FOR OGV

Missing data is a common occurrence in vessel characteristic data sets. The best practice for filling gaps in vessel characteristic data is to use information from vessels with known values operating in the geographical domain, as described in Section 3.3.5. However, if the data are not robust enough to support such analysis, or if the analysis is not practical for other purposes, national average values presented here can be used instead. Section C.1 presents the national averages for installed propulsion power, maximum speed, and maximum draft, which are all used to calculate propulsion engine operating power. Section C.2 presents average differences between keel-laid year and build year, which is used to estimate engine tier if only build year is known.

C.1 AVERAGE INSTALLED PROPULSION POWER, MAXIMUM SPEED, AND MAXIMUM DRAFT

National average values for installed propulsion power, maximum speed, and maximum draft are presented in the following tables with diminishing levels of detail. At the lowest levels of detail, national average values for propulsion engine category and engine type are also presented. This appendix contains the following tables:

- Table C.1. Average OGV Installed Power, Maximum Speed, and Maximum Draft by Ship Type, Subtype, Engine Category, and Engine Type
- Table C.2. Average OGV Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type, Subtype, and Engine Category
- Table C.3. Average OGV Engine Category, Engine Type, Installed Power, Max Speed, and Maximum Draft by Ship Type and Subtype
- Table C.4. Average OGV Engine Category, Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type

When using defaults presented in these tables, values should be assigned at the most detailed grouping available. That is, values should be assigned from the first table if possible, then the second, and so forth. The average vessel characteristics presented in this appendix were used to fill gaps for the 2017 NEI CMV analysis.[32] In the tables below, italicized text indicates the look up values. For example, Table C.1 can be used to look up average installed propulsion power, maximum speed, and maximum draft by the following italicized values: ship type, subtype, engine category, and engine type. In contrast, Table C.2 can be used to look up the most common engine type and average installed propulsion power, maximum speed, and maximum draft by the following italicized values: ship type, subtype, and engine category.

Table C.1. Average OGV Installed Power, Maximum Speed, and Maximum Draft by Ship Type, Subtype, Engine Category, and Engine Type

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Bulk Carrier	*Small*	*1*	*MSD*	3,400	16.0	3.1
Bulk Carrier	*Small*	*2*	*MSD*	3,500	14.9	5.7
Bulk Carrier	*Small*	*2*	*SSD*	4,400	17.0	7.8
Bulk Carrier	*Small*	*3*	*MSD*	1,700	14.0	6.2
Bulk Carrier	*Small*	*3*	*SSD*	3,300	13.3	6.9
Bulk Carrier	*Handysize*	*2*	*MSD*	3,500	14.6	7.8
Bulk Carrier	*Handysize*	*2*	*SSD*	5,100	14.9	8.6
Bulk Carrier	*Handysize*	*2*	*ST*	2,900	12.8	7.6
Bulk Carrier	*Handysize*	*3*	*MSD*	6,200	15.1	8.7
Bulk Carrier	*Handysize*	*3*	*MSD-ED*	22,500	21.3	9.1
Bulk Carrier	*Handysize*	*3*	*SSD*	6,900	15.2	9.8
Bulk Carrier	*Handysize*	*3*	*ST*	5,100	15.2	8.1
Bulk Carrier	*Handymax*	*2*	*SSD*	5,700	14.8	9.2
Bulk Carrier	*Handymax*	*3*	*MSD*	8,700	15.3	9.8
Bulk Carrier	*Handymax*	*3*	*SSD*	8,500	15.3	11.5
Bulk Carrier	*Panamax*	*2*	*SSD*	10,500	16.0	10.1
Bulk Carrier	*Panamax*	*3*	*MSD*	12,000	15.7	9.2
Bulk Carrier	*Panamax*	*3*	*SSD*	10,200	15.4	13.9
Bulk Carrier	*Capesize*	*3*	*SSD*	16,400	15.7	17.2
Bulk Carrier	*Capesize Largest*	*3*	*SSD*	17,400	16.5	18.2
Chemical Tanker	*Smallest*	*2*	*MSD*	2,200	11.3	5.0
Chemical Tanker	*Smallest*	*3*	*MSD*	3,000	14.4	6.2
Chemical Tanker	*Small*	*2*	*MSD*	2,800	15.3	7.1
Chemical Tanker	*Small*	*3*	*MSD*	3,700	15.1	6.9
Chemical Tanker	*Small*	*3*	*SSD*	3,300	14.1	7.5
Chemical Tanker	*Handysize*	*2*	*MSD*	3,700	13.5	7.6
Chemical Tanker	*Handysize*	*3*	*MSD*	5,500	15.4	8.6
Chemical Tanker	*Handysize*	*3*	*SSD*	5,300	15.1	9.1
Chemical Tanker	*Handymax*	*2*	*MSD-ED*	9,700	17.1	11.4
Chemical Tanker	*Handymax*	*3*	*MSD*	7,700	15.6	11.7
Chemical Tanker	*Handymax*	*3*	*MSD-ED*	9,000	15.4	12.2

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Chemical Tanker	*Handymax*	*3*	*SSD*	9,000	15.6	12.3
Chemical Tanker	*Handymax*	*3*	*ST*	12,900	16.0	10.8
Container Ship	*1,000 TEU*	*2*	*MSD*	2,700	16.1	5.6
Container Ship	*1,000 TEU*	*3*	*MSD*	7,600	18.5	7.3
Container Ship	*1,000 TEU*	*3*	*SSD*	13,100	20.0	8.8
Container Ship	*2,000 TEU*	*3*	*MSD*	10,600	20.9	9.0
Container Ship	*2,000 TEU*	*3*	*SSD*	15,600	21.3	9.9
Container Ship	*2,000 TEU*	*3*	*ST*	23,500	23.4	10.4
Container Ship	*3,000 TEU*	*3*	*MSD*	20,800	23.2	9.5
Container Ship	*3,000 TEU*	*3*	*SSD*	21,800	23.0	11.4
Container Ship	*3,000 TEU*	*3*	*ST*	22,200	22.4	11.3
Container Ship	*5,000 TEU*	*3*	*SSD*	37,000	25.1	12.4
Container Ship	*8,000 TEU*	*3*	*SSD*	55,800	26.5	13.9
Container Ship	*12,000 TEU*	*3*	*SSD*	61,000	25.9	14.4
Container Ship	*14,500 TEU*	*3*	*SSD*	65,000	25.6	15.2
Container Ship	*Largest*	*3*	*SSD*	49,000	25.6	14.0
Cruise	*2,000 Ton*	*3*	*MSD*	2,300	12.8	4.5
Cruise	*10,000 Ton*	*1*	*MSD*	3,800	14.5	3.6
Cruise	*10,000 Ton*	*2*	*MSD*	5,800	17.9	4.6
Cruise	*10,000 Ton*	*3*	*MSD*	7,100	19.1	5.0
Cruise	*10,000 Ton*	*3*	*SSD*	2,500	17.0	4.6
Cruise	*60,000 Ton*	*2*	*MSD*	14,700	20.4	6.6
Cruise	*60,000 Ton*	*3*	*MSD*	16,200	20.4	6.4
Cruise	*60,000 Ton*	*3*	*MSD-ED*	20,700	21.0	7.0
Cruise	*60,000 Ton*	*3*	*SSD*	23,400	20.4	7.5
Cruise	*100,000 Ton*	*1*	*GT-ED*	40,200	25.5	8.1
Cruise	*100,000 Ton*	*3*	*GT-ED*	37,900	24.3	8.2
Cruise	*100,000 Ton*	*3*	*MSD*	23,100	21.4	7.6
Cruise	*100,000 Ton*	*3*	*MSD-ED*	34,000	23.3	8.0
Cruise	*Largest*	*3*	*GT-ED*	86,000	25.5	10.3
Cruise	*Largest*	*3*	*MSD*	41,700	22.3	8.6
Cruise	*Largest*	*3*	*MSD-ED*	41,700	23.5	8.6
Cruise	*Largest*	*3*	*SSD*	60,000	24.0	9.3

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*1*	*SSD*	2,200	20.2	2.2
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*2*	*SSD*	2,700	15.1	3.2
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*3*	*SSD*	900	15.1	3.1
Ferry/Roll-on/Passenger (C3)	*Largest*	*1*	*MSD*	3,900	16.9	4.7
Ferry/Roll-on/Passenger (C3)	*Largest*	*1*	*MSD-ED*	3,700	14.9	3.8
Ferry/Roll-on/Passenger (C3)	*Largest*	*2*	*MSD*	10,000	21.2	4.3
Ferry/Roll-on/Passenger (C3)	*Largest*	*2*	*MSD-ED*	5,400	14.9	3.7
Ferry/Roll-on/Passenger (C3)	*Largest*	*2*	*ST*	1,100	10.6	2.6
Ferry/Roll-on/Passenger (C3)	*Largest*	*3*	*MSD*	10,800	20.9	5.1
Ferry/Roll-on/Passenger (C3)	*Largest*	*3*	*MSD-ED*	11,000	22.3	5.8
Ferry/Roll-on/Passenger (C3)	*Largest*	*3*	*ST*	6,000	14.9	5.7
Fishing (C3)	*All C3 Fishing*	*1*	*MSD*	700	12.0	3.6
Fishing (C3)	*All C3 Fishing*	*1*	*SSD*	1,000	12.1	3.1
Fishing (C3)	*All C3 Fishing*	*2*	*MSD*	2,600	13.6	5.6
Fishing (C3)	*All C3 Fishing*	*2*	*SSD*	2,200	13.3	4.4
Fishing (C3)	*All C3 Fishing*	*3*	*MSD*	3,200	13.8	5.4
Fishing (C3)	*All C3 Fishing*	*3*	*SSD*	4,000	18.0	5.7
General Cargo	*5,000 DWT*	*1*	*MSD*	1,500	11.5	3.0
General Cargo	*5,000 DWT*	*2*	*MSD*	1,300	12.6	4.4
General Cargo	*5,000 DWT*	*3*	*MSD*	1,100	12.7	4.1
General Cargo	*10,000 DWT*	*2*	*MSD*	2,500	13.3	6.7
General Cargo	*10,000 DWT*	*3*	*MSD*	3,500	13.8	7.2
General Cargo	*10,000 DWT*	*3*	*SSD*	3,300	16.5	6.9
General Cargo	*Largest*	*3*	*MSD*	14,400	18.0	8.3
General Cargo	*Largest*	*3*	*SSD*	15,900	18.4	8.4

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
General Cargo	*Largest*	*3*	*ST*	14,200	22.3	8.4
Liquified Gas Tanker	*50,000 DWT*	*2*	*MSD*	2,900	14.5	6.2
Liquified Gas Tanker	*50,000 DWT*	*3*	*MSD*	2,700	15.2	6.1
Liquified Gas Tanker	*50,000 DWT*	*3*	*SSD*	2,600	15.9	5.5
Liquified Gas Tanker	*100,000 DWT*	*2*	*SSD*	3,500	15.7	6.8
Liquified Gas Tanker	*100,000 DWT*	*3*	*MSD*	4,100	16.0	7.3
Liquified Gas Tanker	*100,000 DWT*	*3*	*SSD*	4,900	16.3	7.4
Liquified Gas Tanker	*200,000 DWT*	*2*	*MSD*	5,000	14.4	8.0
Liquified Gas Tanker	*200,000 DWT*	*3*	*MSD*	7,000	17.1	9.3
Liquified Gas Tanker	*200,000 DWT*	*3*	*SSD*	7,000	17.9	9.2
Liquified Gas Tanker	*Largest*	*3*	*MSD*	22,900	13.8	12.5
Liquified Gas Tanker	*Largest*	*3*	*MSD-ED*	25,600	20.1	11.9
Liquified Gas Tanker	*Largest*	*3*	*SSD*	12,400	17.4	11.5
Liquified Gas Tanker	*Largest*	*3*	*ST*	27,400	20.7	12.0
Miscellaneous (C3)	*All C3 Misc.*	*1*	*MSD*	2,200	12.7	4.2
Miscellaneous (C3)	*All C3 Misc.*	*1*	*MSD-ED*	3,300	13.8	5.4
Miscellaneous (C3)	*All C3 Misc.*	*1*	*SSD*	1,300	11.3	2.8
Miscellaneous (C3)	*All C3 Misc.*	*2*	*MSD*	6,300	17.4	5.2
Miscellaneous (C3)	*All C3 Misc.*	*2*	*MSD-ED*	6,400	15.2	5.4
Miscellaneous (C3)	*All C3 Misc.*	*2*	*SSD*	3,700	14.9	4.3
Miscellaneous (C3)	*All C3 Misc.*	*3*	*MSD*	6,000	16.1	8.0
Miscellaneous (C3)	*All C3 Misc.*	*3*	*MSD-ED*	16,300	15.4	11.3
Miscellaneous (C3)	*All C3 Misc.*	*3*	*SSD*	8,900	17.0	9.5
Miscellaneous (C3)	*All C3 Misc.*	*3*	*ST*	21,200	20.4	9.8
Offshore Support/Drillship	*All Offshore Support / Drillship*	*1*	*MSD*	3,100	16.2	3.6
Offshore Support/Drillship	*All Offshore Support / Drillship*	*1*	*MSD-ED*	5,400	13.7	5.7
Offshore Support/Drillship	*All Offshore Support / Drillship*	*1*	*SSD*	1,400	13.4	3.2
Offshore Support/Drillship	*All Offshore Support / Drillship*	*2*	*MSD*	5,300	14.1	5.6
Offshore Support/Drillship	*All Offshore Support / Drillship*	*2*	*MSD-ED*	13,000	13.3	9.6

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Offshore Support/Drillship	*All Offshore Support / Drillship*	*2*	*SSD*	4,700	13.8	4.6
Offshore Support/Drillship	*All Offshore Support / Drillship*	*3*	*MSD*	9,200	14.5	6.9
Offshore Support/Drillship	*All Offshore Support / Drillship*	*3*	*MSD-ED*	26,300	13.3	10.9
Offshore Support/Drillship	*All Offshore Support / Drillship*	*3*	*SSD*	11,300	15.7	13.4
Oil Tanker	*Handymax*	*3*	*SSD*	8,700	15.5	12.1
Oil Tanker	*Aframax*	*3*	*SSD*	12,200	15.7	14.6
Oil Tanker	*Suezmax*	*3*	*SSD*	16,900	15.6	16.9
Other Tanker	*All Other Tanker*	*1*	*MSD*	1,600	8.7	3.2
Other Tanker	*All Other Tanker*	*1*	*MSD-ED*	2,300	6.4	3.0
Other Tanker	*All Other Tanker*	*1*	*SSD*	1,200	8.4	2.2
Other Tanker	*All Other Tanker*	*2*	*MSD*	3,300	13.6	4.5
Other Tanker	*All Other Tanker*	*2*	*MSD-ED*	14,000	19.1	9.0
Other Tanker	*All Other Tanker*	*2*	*SSD*	3,400	13.3	4.6
Other Tanker	*All Other Tanker*	*3*	*GT*	78,300	27.7	11.9
Other Tanker	*All Other Tanker*	*3*	*MSD*	4,700	14.4	8.0
Other Tanker	*All Other Tanker*	*3*	*MSD-ED*	20,000	16.3	18.8
Other Tanker	*All Other Tanker*	*3*	*SSD*	15,700	16.2	15.5
Other Tanker	*All Other Tanker*	*3*	*ST*	21,600	18.0	16.6
Reefer	*All Reefer*	*1*	*MSD*	1,300	10.6	0.0
Reefer	*All Reefer*	*2*	*MSD*	2,200	13.3	5.9
Reefer	*All Reefer*	*2*	*SSD*	2,200	12.8	5.5
Reefer	*All Reefer*	*3*	*MSD*	9,200	21.7	8.6
Reefer	*All Reefer*	*3*	*SSD*	9,800	20.4	8.6
RORO	*5000 Ton*	*1*	*MSD*	1,700	12.6	3.1
RORO	*5000 Ton*	*2*	*MSD*	1,300	11.8	3.4
RORO	*5000 Ton*	*2*	*SSD*	2,400	14.9	4.5
RORO	*5000 Ton*	*3*	*MSD*	3,200	16.4	4.7
RORO	*5000 Ton*	*3*	*SSD*	2,300	16.6	4.5
RORO	*Largest*	*1*	*MSD-ED*	7,000	19.7	9.3
RORO	*Largest*	*2*	*MSD*	3,500	15.1	5.9

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
RORO	*Largest*	*2*	*SSD*	5,900	16.0	3.7
RORO	*Largest*	*3*	*GT*	45,100	26.8	10.2
RORO	*Largest*	*3*	*MSD*	18,500	19.6	8.2
RORO	*Largest*	*3*	*MSD-ED*	39,500	25.5	9.0
RORO	*Largest*	*3*	*SSD*	15,600	21.3	10.0
RORO	*Largest*	*3*	*ST*	49,400	26.1	10.0
Yacht (C2/C3)	*C2/C3 Yacht*	*1*	*MSD*	3,000	18.7	2.7
Yacht (C2/C3)	*C2/C3 Yacht*	*2*	*MSD*	5,400	16.8	3.7
Yacht (C2/C3)	*C2/C3 Yacht*	*3*	*MSD*	3,900	17.0	4.7
Yacht (C2/C3)	*C2/C3 Yacht*	*3*	*SSD*	5,000	18.4	6.0

Table C.2. Average OGV Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type, Subtype, and Engine Category

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Bulk Carrier	*Small*	*1*	MSD-ED	3,400	16.0	3.1
Bulk Carrier	*Small*	*2*	SSD	4,400	17.0	7.8
Bulk Carrier	*Small*	*3*	MSD	1,800	13.9	6.3
Bulk Carrier	*Handysize*	*2*	SSD	4,300	14.6	8.2
Bulk Carrier	*Handysize*	*3*	SSD	7,100	15.3	9.6
Bulk Carrier	*Handymax*	*2*	SSD	5,700	14.8	9.2
Bulk Carrier	*Handymax*	*3*	SSD	8,500	15.3	11.5
Bulk Carrier	*Panamax*	*2*	SSD	10,500	16.0	10.1
Bulk Carrier	*Panamax*	*3*	SSD	10,300	15.4	13.8
Bulk Carrier	*Capesize*	*3*	SSD	16,400	15.7	17.2
Bulk Carrier	*Capesize Largest*	*3*	SSD	17,400	16.5	18.2
Chemical Tanker	*Smallest*	*2*	MSD	2,200	11.3	5.0
Chemical Tanker	*Smallest*	*3*	MSD	3,000	14.4	6.2
Chemical Tanker	*Small*	*2*	MSD	2,800	15.3	7.1
Chemical Tanker	*Small*	*3*	SSD	3,400	14.4	7.3
Chemical Tanker	*Handysize*	*2*	MSD	3,700	13.5	7.6
Chemical Tanker	*Handysize*	*3*	SSD	5,400	15.2	8.9
Chemical Tanker	*Handymax*	*2*	MSD-ED	9,700	17.1	11.4
Chemical Tanker	*Handymax*	*3*	SSD	9,100	15.6	12.3
Container Ship	*1,000 TEU*	*2*	MSD	2,700	16.1	5.6
Container Ship	*1,000 TEU*	*3*	MSD	8,600	18.8	7.6
Container Ship	*2,000 TEU*	*3*	SSD	14,700	21.3	9.7
Container Ship	*3,000 TEU*	*3*	SSD	21,800	22.9	11.3
Container Ship	*5,000 TEU*	*3*	SSD	37,000	25.1	12.4
Container Ship	*8,000 TEU*	*3*	SSD	55,800	26.5	13.9
Container Ship	*12,000 TEU*	*3*	SSD	61,000	25.9	14.4
Container Ship	*14,500 TEU*	*3*	SSD	65,000	25.6	15.2
Container Ship	*Largest*	*3*	SSD	49,000	25.6	14.0
Cruise	*2,000 Ton*	*1*	MSD	2,300	12.8	4.5
Cruise	*2,000 Ton*	*3*	MSD	2,300	12.8	4.5
Cruise	*10,000 Ton*	*1*	MSD	3,800	14.5	3.6

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Cruise	*10,000 Ton*	*2*	MSD	5,800	17.9	4.6
Cruise	*10,000 Ton*	*3*	MSD	6,300	18.8	4.9
Cruise	*60,000 Ton*	*2*	MSD	14,700	20.4	6.6
Cruise	*60,000 Ton*	*3*	MSD-ED	19,600	20.7	6.9
Cruise	*100,000 Ton*	*1*	GT-ED	40,200	25.5	8.1
Cruise	*100,000 Ton*	*3*	MSD-ED	34,300	23.4	8.0
Cruise	*Largest*	*3*	MSD-ED	42,900	23.5	8.6
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*1*	MSD	2,200	20.2	2.2
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*2*	SSD	2,700	15.1	3.2
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	*3*	SSD	900	15.1	3.1
Ferry/Roll-on/Passenger (C3)	*Largest*	*1*	MSD	3,900	16.5	4.5
Ferry/Roll-on/Passenger (C3)	*Largest*	*2*	SSD	8,500	19.4	4.1
Ferry/Roll-on/Passenger (C3)	*Largest*	*3*	MSD	10,700	21.0	5.2
Fishing (C3)	*All C3 Fishing*	*1*	MSD	700	12.0	3.5
Fishing (C3)	*All C3 Fishing*	*2*	MSD	2,400	13.4	5.1
Fishing (C3)	*All C3 Fishing*	*3*	MSD	3,200	14.0	5.4
General Cargo	*5,000 DWT*	*1*	MSD	1,500	11.5	3.0
General Cargo	*5,000 DWT*	*2*	MSD	1,300	12.6	4.4
General Cargo	*5,000 DWT*	*3*	MSD	1,100	12.7	4.1
General Cargo	*10,000 DWT*	*2*	MSD	2,500	13.3	6.7
General Cargo	*10,000 DWT*	*3*	MSD	3,400	15.1	7.1
General Cargo	*Largest*	*3*	MSD	14,900	18.5	8.4
Liquified Gas Tanker	*50,000 DWT*	*2*	MSD	2,900	14.5	6.2
Liquified Gas Tanker	*50,000 DWT*	*3*	SSD	2,600	15.7	5.6
Liquified Gas Tanker	*100,000 DWT*	*2*	MSD	3,500	15.7	6.8
Liquified Gas Tanker	*100,000 DWT*	*3*	SSD	4,800	16.2	7.4
Liquified Gas Tanker	*200,000 DWT*	*2*	MSD	5,000	14.4	8.0
Liquified Gas Tanker	*200,000 DWT*	*3*	SSD	7,000	17.9	9.2
Liquified Gas Tanker	*Largest*	*3*	SSD	14,800	17.9	11.5

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Miscellaneous (C3)	*All C3 Misc.*	*1*	MSD	2,100	12.6	4.0
Miscellaneous (C3)	*All C3 Misc.*	*2*	MSD	6,100	17.1	5.1
Miscellaneous (C3)	*All C3 Misc.*	*3*	MSD	7,500	16.5	8.5
Offshore Support/Drillship	*All Offshore Support / Drillship*	*1*	MSD	3,300	15.5	3.9
Offshore Support/Drillship	*All Offshore Support / Drillship*	*2*	MSD	6,200	13.9	5.8
Offshore Support/Drillship	*All Offshore Support / Drillship*	*3*	SSD	14,200	15.0	12.0
Oil Tanker	*Handymax*	*3*	SSD	8,700	15.5	12.1
Oil Tanker	*Aframax*	*3*	SSD	12,200	15.7	14.6
Oil Tanker	*Suezmax*	*3*	SSD	16,900	15.6	16.9
Other Tanker	*All Other Tanker*	*1*	MSD	1,600	8.5	3.0
Other Tanker	*All Other Tanker*	*2*	SSD	3,300	13.4	4.6
Other Tanker	*All Other Tanker*	*3*	SSD	15,800	16.2	15.4
Reefer	*All Reefer*	*1*	MSD	1,300	10.6	5.7
Reefer	*All Reefer*	*2*	SSD	2,200	13.0	5.7
Reefer	*All Reefer*	*3*	SSD	9,700	20.5	8.6
RORO	*5000 Ton*	*1*	MSD	1,700	12.6	3.1
RORO	*5000 Ton*	*2*	SSD	2,200	14.1	4.2
RORO	*5000 Ton*	*3*	MSD	2,900	16.5	4.6
RORO	*Largest*	*1*	MSD-ED	7,000	19.7	9.3
RORO	*Largest*	*2*	MSD	4,500	15.4	5.0
RORO	*Largest*	*3*	SSD	19,900	21.6	9.7
Yacht (C2/C3)	*C2/C3 Yacht*	*1*	MSD	3,000	18.7	2.7
Yacht (C2/C3)	*C2/C3 Yacht*	*2*	MSD	5,400	16.8	3.7
Yacht (C2/C3)	*C2/C3 Yacht*	*3*	MSD	3,900	17.0	4.7

Table C.3. Average OGV Engine Category, Engine Type, Installed Power, Max Speed, and Maximum Draft by Ship Type and Subtype

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Bulk Carrier	*Small*	3	MSD	2,500	14.8	6.7
Bulk Carrier	*Handysize*	3	SSD	6,900	15.3	9.5
Bulk Carrier	*Handymax*	3	SSD	8,500	15.3	11.4
Bulk Carrier	*Panamax*	3	SSD	10,300	15.4	13.7
Bulk Carrier	*Capesize*	3	SSD	16,400	15.7	17.2
Bulk Carrier	*Capesize Largest*	3	SSD	17,400	16.5	18.2
Chemical Tanker	*Smallest*	2	MSD	2,300	11.4	5.1
Chemical Tanker	*Small*	3	SSD	3,200	14.7	7.2
Chemical Tanker	*Handysize*	3	SSD	5,300	15.2	8.9
Chemical Tanker	*Handymax*	3	SSD	9,100	15.6	12.3
Container Ship	*1,000 TEU*	3	MSD	8,200	18.6	7.4
Container Ship	*2,000 TEU*	3	SSD	14,700	21.3	9.7
Container Ship	*3,000 TEU*	3	SSD	21,800	22.9	11.3
Container Ship	*5,000 TEU*	3	SSD	37,000	25.1	12.4
Container Ship	*8,000 TEU*	3	SSD	55,800	26.5	13.9
Container Ship	*12,000 TEU*	3	SSD	61,000	25.9	14.4
Container Ship	*14,500 TEU*	3	SSD	65,000	25.6	15.2
Container Ship	*Largest*	3	SSD	49,000	25.6	14.0
Cruise	*2,000 Ton*	1	MSD	2,300	12.8	4.5
Cruise	*10,000 Ton*	1	MSD	4,500	15.5	3.9
Cruise	*60,000 Ton*	3	MSD-ED	19,100	20.7	6.9
Cruise	*100,000 Ton*	3	MSD-ED	34,500	23.5	8.0
Cruise	*Largest*	3	MSD-ED	42,900	23.5	8.6
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	1	MSD	2,400	17.7	2.7
Ferry/Roll-on/Passenger (C3)	*Largest*	2	MSD	8,800	19.7	4.7
Fishing (C3)	*All C3 Fishing*	1	MSD	1,000	12.3	3.8
General Cargo	*5,000 DWT*	1	MSD	1,400	12.0	3.6
General Cargo	*10,000 DWT*	3	MSD	3,400	15.1	7.1
General Cargo	*Largest*	3	MSD	14,900	18.5	8.4
Liquified Gas Tanker	*50,000 DWT*	3	SSD	2,700	15.3	5.8

Ship Type	Subtype	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Liquified Gas Tanker	*100,000 DWT*	3	SSD	4,700	16.2	7.3
Liquified Gas Tanker	*200,000 DWT*	3	SSD	7,000	17.8	9.2
Liquified Gas Tanker	*Largest*	3	SSD	14,800	17.9	11.5
Miscellaneous (C3)	*All C3 Misc.*	3	MSD	5,800	15.5	6.7
Offshore Support/Drillship	*All Offshore Support / Drillship*	1	MSD	6,300	15.1	6.1
Oil Tanker	*Handymax*	3	SSD	8,700	15.5	12.1
Oil Tanker	*Aframax*	3	SSD	12,200	15.7	14.6
Oil Tanker	*Suezmax*	3	SSD	16,900	15.6	16.9
Other Tanker	*All Other Tanker*	3	SSD	11,800	14.6	11.9
Reefer	*All Reefer*	3	SSD	9,200	20.0	8.4
RORO	*5000 Ton*	2	MSD	2,100	13.9	3.9
RORO	*Largest*	3	SSD	19,600	21.5	9.6
Yacht (C2/C3)	*C2/C3 Yacht*	1	MSD	3,100	18.7	2.7

Table C.4. Average OGV Engine Category, Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type

Ship Type	Engine Category	Engine Type	Installed Propulsion Power (kW)	Max Speed (kn)	Max Draft (m)
Bulk Carrier	3	SSD	8,800	15.3	11.8
Chemical Tanker	3	SSD	8,200	15.5	11.5
Container Ship	3	SSD	35,300	23.7	11.8
Cruise	3	SSD	34,800	22.9	8.0
Ferry/Roll-on/Passenger (C3)	1	MSD	6,500	18.9	4.0
Fishing (C3)	1	MSD	1,000	12.3	3.8
General Cargo	3	SSD	4,800	14.1	5.5
Liquified Gas Tanker	3	SSD	12,000	17.6	10.5
Miscellaneous (C3)	3	SSD	5,800	15.5	6.7
Offshore Support/Drillship	1	MSD	6,300	15.1	6.1
Oil Tanker	3	SSD	10,100	15.6	13.1
Other Tanker	3	SSD	11,800	14.6	11.9
Reefer	3	SSD	9,200	20.0	8.4
RORO	3	SSD	16,800	20.3	8.7
Yacht (C2/C3)	1	MSD	3,100	18.7	2.7

C.2 Average Differences Between Keel-laid Year and Build Year

The activity time-weighted national average differences between keel-laid year and build year by ship type and subtype, based on the 2017 NEI C3 AIS data set, are presented in Table C.5. This difference is important for assigning emission factors to C3 vessels because the C3 emission standards are based on keel-laid year. If the vessel build year is known, but the keel-laid year is not, the average build time can be subtracted from the build year to estimate the keel-laid year.

Table C.5. Average OGV Difference Between Keel-laid Year and Build Year by Ship Type and Subtype

Ship Type	Subtype	Average Build Time (Years)
Bulk Carrier	*Small*	0
Bulk Carrier	*Handysize*	1
Bulk Carrier	*Handymax*	1
Bulk Carrier	*Panamax*	1
Bulk Carrier	*Capesize*	1
Bulk Carrier	*Capesize Largest*	2
Chemical Tanker	*Smallest*	2
Chemical Tanker	*Small*	2
Chemical Tanker	*Handysize*	1
Chemical Tanker	*Handymax*	1
Container Ship	*1,000 TEU*	1
Container Ship	*2,000 TEU*	1
Container Ship	*3,000 TEU*	1
Container Ship	*5,000 TEU*	1
Container Ship	*8,000 TEU*	1
Container Ship	*12,000 TEU*	1
Container Ship	*14,500 TEU*	1
Container Ship	*Largest*	2
Cruise	*2,000 Ton*	1
Cruise	*10,000 Ton*	2
Cruise	*60,000 Ton*	2
Cruise	*100,000 Ton*	2
Cruise	*Largest*	2
Ferry/Roll-on/Passenger (C3)	*2,000 Ton*	1
Ferry/Roll-on/Passenger (C3)	*Largest*	1
Fishing (C3)	*All C3 Fishing*	1

Ship Type	Subtype	Average Build Time (Years)
General Cargo	*5,000 DWT*	1
General Cargo	*10,000 DWT*	2
General Cargo	*Largest*	2
Liquified Gas Tanker	*50,000 DWT*	2
Liquified Gas Tanker	*100,000 DWT*	1
Liquified Gas Tanker	*200,000 DWT*	1
Liquified Gas Tanker	*Largest*	1
Miscellaneous (C3)	*All C3 Miscellaneous*	2
Offshore Support/Drillship	*All Offshore Support/Drillship*	1
Oil Tanker	*Smallest*	1
Oil Tanker	*Small*	2
Oil Tanker	*Handysize*	1
Oil Tanker	*Handymax*	1
Oil Tanker	*Panamax*	2
Oil Tanker	*Aframax*	1
Oil Tanker	*Suezmax*	1
Other Tanker	*All Other Tanker*	1
Reefer	*All Reefer*	1
RORO	*5000 Ton*	1
RORO	*Largest*	1
Yacht (C2/C3)	*C2/C3 Yacht*	3

Appendix D HAP SPECIATION PROFILES FOR COMMERCIAL MARINE ENGINES

Hazardous air pollutants (HAPs) are calculated from various basis pollutants. The basis emission factors for Category 3 (C3) engines are given in Section 3.5. The basis emission factors for Category 1 and 2 (C1 and C2) engines are described in Section 4.5 and are presented in Appendix H. Emission factors for HAPs are calculated by multiplying the appropriate basis emission factor by the fraction listed in Table D.1.[32]

Table D.1. HAP Speciation Profiles for Commercial Marine Engines

Pollutant	Pollutant Code	Basis	Fraction	Source
1,3-Butadiene*	106990	VOC	0.001013	64
2,2,4-Trimethylpentane	540841	VOC	0.00712	65
Acenaphthene*	83329	VOC	0.0000509	64
Acenaphthylene*	208968	VOC	0.000118	64
Acetaldehyde*	75070	VOC	0.009783	64
Acrolein*	107028	VOC	0.001848	64
Ammonia	NH_3	$PM_{2.5}$	0.019247	29
Anthracene*	120127	VOC	0.000344	64
Antimony*	7440360	$PM_{2.5}$	0.000615	64
Arsenic	7440382	$PM_{2.5}$	0.0000259	29
Benz[a]Anthracene*	56553	$PM_{2.5}$	0.00000882	64
Benzene*	71432	VOC	0.004739	64
Benzo[a]Pyrene	50328	$PM_{2.5}$	0.00000418	29
Benzo[b]Fluoranthene	205992	$PM_{2.5}$	0.00000835	29
Benzo[k]Fluoranthene	207089	$PM_{2.5}$	0.00000418	29
Benzo(g,h,i)Fluoranthene*	203123	$PM_{2.5}$	0.000132	64
Cadmium*	7440439	$PM_{2.5}$	0.000236	64
Chrysene*	218019	$PM_{2.5}$	0.0000163	64
Chromium (VI)	18540299	$PM_{2.5}$	0.00000000724	65
Dibenzo[a,h]anthracene*	53703	$PM_{2.5}$	0.00000865	64
Ethyl Benzene*	100414	VOC	0.000439	64
Fluoranthene*	206440	$PM_{2.5}$	0.0000897	64
Fluorene*	86737	VOC	0.000164	64
Formaldehyde*	50000	VOC	0.042696	64
Indeno[1,2,3-c,d]Pyrene	193395	$PM_{2.5}$	0.00000835	29
Lead	7439921	$PM_{2.5}$	0.000125	29

Pollutant	Pollutant Code	Basis	Fraction	Source
Manganese	7439965	$PM_{2.5}$	0.00000322	65
Mercury	7439976	$PM_{2.5}$	0.0000000418	29
Naphthalene*	91203	VOC	0.031304	64
Hexane	110543	VOC	0.00279	65
Nickel	7440020	$PM_{2.5}$	0.000687	29
Polychlorinated Biphenyls	1336363	$PM_{2.5}$	0.000000418	29
Phenanthrene*	85018	VOC	0.001356	64
Propionaldehyde*	123386	VOC	0.001517	64
Pyrene*	129000	$PM_{2.5}$	0.0000337	64
Selenium	7782492	$PM_{2.5}$	0.0000000438	29
Toluene*	108883	VOC	0.002035	64
Xylenes (Mixed Isomers)*	1330207	VOC	0.001422	64
o-Xylene*	95476	VOC	0.000513	64

* Used data for auxiliary engine which burned marine gas oil with 0.06 wt% sulfur and 0.001 wt% ash content.

Appendix E DEFAULT OGV AUXILIARY ENGINE AND BOILER LOADS

If resources allow, data on auxiliary engine and boiler usage can be directly collected from the ocean-going vessels (OGV) operating in the geographical domain via surveys, interviews, or other data collection methods. If a similar port has recently conducted an inventory and collected these kinds of data, those could be used instead. Alternatively, the auxiliary engine and boiler loads used in the *Third IMO Greenhouse Gas Study*[19] can be used. These data are primarily based on Starcrest's Vessel Boarding Program in the Port of Los Angeles, the Port of Long Beach, the Port Authority of New York & New Jersey, the Port of Houston Authority, the Port of Seattle, and the Port of Tacoma, along with data collected by the Finnish Metrological Institute. Table E.1 presents default auxiliary engine loads and Table E.2 presents default boiler loads. Note that the default loads account for engine size and load factor. The operating modes listed in these tables are described in detail in Section 3.6. If the geographical domain includes vessel activity in a restricted speed zone, the transit operating loads should be used for that activity because auxiliary engine and boiler usage in this operating mode is usually similar to the transit operating mode.

Table E.1. Default OGV Auxiliary Engine Operating Loads by Mode

Ship Type	Subtype	Transit (kW)	Maneuvering (kW)	Hotelling (kW)	Anchorage (kW)
Bulk Carrier	Small	190	310	280	190
	Handysize	190	310	280	190
	Handymax	260	420	370	260
	Panamax	420	680	600	420
	Capesize	420	680	600	420
	Capesize Largest	420	680	600	420
Chemical Tanker	Smallest	80	110	160	80
	Small	230	330	490	230
	Handysize	230	330	490	230
	Handymax	550	780	1,170	550
Container Ship	1,000 TEU	300	550	340	300
	2,000 TEU	820	1,320	600	820
	3,000 TEU	1,230	1,800	700	1,230
	5,000 TEU	1,390	2,470	940	1,390
	8,000 TEU	1,420	2,600	970	1,420
	12,000 TEU	1,630	2,780	1,000	1,630
	14,500 TEU	1,960	3,330	1,200	1,960
	Largest	2,160	3,670	1,320	2,160
Cruise	2,000 Ton	450	580	450	450
	10,000 Ton	450	580	450	450

Ship Type	Subtype	Transit (kW)	Maneuvering (kW)	Hotelling (kW)	Anchorage (kW)
	60,000 Ton	3500	5,460	3,500	3,500
	100,000 Ton	11,480	14,900	11,480	11,480
	Largest	11,480	14,900	11,480	11,480
Ferry/Passenger (C3)	2,000 Ton	186	186	186	186
	Largest	524	524	524	524
Ferry/Roll-on/Passenger (C3)	2,000 Ton	105	105	105	105
	Largest	710	710	710	710
Fishing (C3)	All C3 Fishing	200	200	200	200
General Cargo	5,000 DWT	60	90	120	60
	10,000 DWT	170	250	330	170
	Largest	490	730	970	490
Liquified Gas Tanker	50,000 DWT	240	360	240	240
	100,000 DWT	240	360	240	240
	200,000 DWT	1,710	2,565	1,710	1,710
	Largest	1,710	2,565	1,710	1,710
Miscellaneous (C3)	All C3 Misc.	190	190	190	190
Offshore Support/Drillship	All Offshore Support/Drillship	320	320	320	320
Oil Tanker	Smallest	250	375	250	250
	Small	375	563	375	375
	Handysize	625	938	625	625
	Handymax	750	1,125	750	750
	Panamax	750	1,125	750	750
	Aframax	1,000	1,500	1,000	1,000
	Suezmax	1,250	1,875	1,250	1,250
	VLCC	1,500	2,250	1,500	1,500
Other Service	All Other Service	220	220	220	220
Other Tanker	All Other Tanker	500	750	500	500
Reefer	All Reefer	1,170	1,150	1,080	1,170
RORO	5,000 Ton	600	1,700	800	600
	Largest	950	2,720	1,200	950
Vehicle Carrier	4,000 Vehicles	500	1,125	800	500
	Largest	500	1,125	800	500
Yacht	C2/C3 Yacht	130	130	130	130

Table E.2. Default OGV Boiler Loads by Operating Mode

Ship Type	Subtype	Transit (kW)	Maneuvering (kW)	Hotelling (kW)	Anchorage (kW)
Bulk Carrier	Small	0	50	50	50
	Handysize	0	50	50	50
	Handymax	0	100	100	100
	Panamax	0	200	200	200
	Capesize	0	200	200	200
	Capesize Largest	0	200	200	200
Chemical Tanker	Smallest	0	125	125	125
	Small	0	250	250	250
	Handysize	0	250	250	250
	Handymax	0	250	250	250
Container Ship	1,000 TEU	0	120	120	120
	2,000 TEU	0	290	290	290
	3,000 TEU	0	350	350	350
	5,000 TEU	0	450	450	450
	8,000 TEU	0	450	450	450
	12,000 TEU	0	520	520	520
	14,500 TEU	0	630	630	630
	Largest	0	700	700	700
Cruise	2,000 Ton	0	250	250	250
	10,000 Ton	0	250	250	250
	60,000 Ton	0	1,000	1,000	1,000
	100,000 Ton	0	500	500	500
	Largest	0	500	500	500
Ferry/Passenger (C3)	2,000 Ton	0	0	0	0
	Largest	0	0	0	0
Ferry/Roll-on/Passenger (C3)	2,000 Ton	0	0	0	0
	Largest	0	0	0	0
Fishing (C3)	All C3 Fishing	0	0	0	0
General Cargo	5,000 DWT	0	0	0	0
	10,000 DWT	0	75	75	75
	Largest	0	100	100	100
Liquified Gas Tanker	50,000 DWT	100	200	1,000	200
	100,000 DWT	150	300	1,500	300

Ship Type	Subtype	Transit (kW)	Maneuvering (kW)	Hotelling (kW)	Anchorage (kW)
	200,000 DWT	300	600	3,000	600
	Largest	300	600	3,000	600
Miscellaneous (C3)	All C3 Misc.	0	0	0	0
Offshore Support/Drillship	All Offshore Support/Drillship	0	0	0	0
Oil Tanker	Smallest	0	100	500	100
	Small	0	150	750	150
	Handysize	0	250	1,250	250
	Handymax	150	300	1,500	300
	Panamax	150	300	1,500	300
	Aframax	200	400	2,000	400
	Suezmax	250	500	2,500	500
	VLCC	300	600	3,000	600
Other Service	All Other Service	0	0	0	0
Other Tanker	All Other Tanker	100	200	1,000	200
Reefer	All Reefer	0	270	270	270
RORO	5,000 Ton	0	200	200	200
	Largest	0	300	300	300
Vehicle Carrier	4,000 Vehicles	0	268	268	268
	Largest	0	268	268	268
Yacht	C2/C3 Yacht	0	0	0	0

Appendix F OGV SULFUR DIOXIDE LOW LOAD ADJUSTMENT FACTORS

As discussed in Section 3.7, diesel engines are generally less efficient at low loads, and so propulsion engine emissions per unit of energy tend to increase as engine load decreases. To account for this, low load adjustment factors (LLAFs) should be applied when the propulsion engines are operating at less than 20% load. Table 3.10 in Section 3.7 presents LLAFs by engine load and pollutant for 0.1% sulfur fuel. However, the sulfur dioxide (SO_2) LLAFs are dependent on the fuel sulfur level. If a fuel with a sulfur level other than 0.1% is used, this appendix can be used to calculate the appropriate SO_2 LLAFs.

Based on the Regulatory Impact Analysis for EPA's C3 rulemaking,[20] LLAFs for SO_2 can be calculated by normalizing load- and sulfur-dependent SO_2 emission factors to 20% load using Equation F.1:

$$LLAF_{SO_2} = \frac{2.3735 \times \left(\frac{14.1205}{LF} + 205.7169\right) \times S_{act} - 0.4792}{2.3735 \times \left(\frac{14.1205}{0.2} + 205.7169\right) \times S_{act} - 0.4792} \qquad \textbf{Equation F.1}$$

A simplified version of the above equation is shown in Equation F.2:

$$LLAF_{SO_2} = \frac{2.3735 \times \left(\frac{14.1205}{LF} + 205.7169\right) \times S_{act} - 0.4792}{655.8441 \times S_{act} - 0.4792} \qquad \textbf{Equation F.2}$$

Where $LLAF_{SO_2}$ = low load adjustment factor for SO_2 (unitless)
LF = fractional engine load, ranging from 0.02–0.20 (unitless)
S_{act} = actual fuel sulfur level (weight ratio)

The underlying data used to calculate the coefficients in the above equations rely on tests performed on engines rated below 10,000 kW using diesel fuel. This introduces uncertainty regarding the use of these coefficients for Category 3 engines; however, these are the best estimates evaluated by EPA. Equation F.2 was used to calculate the SO_2 LLAF for 0.1% sulfur fuel as presented in Table 3.10. To determine the effect of low load on SO_2 emissions of C3 engines using fuel with a different sulfur level, Equation F.2 should be used with the actual fuel sulfur level for fractional engine loads between 0.02 and 0.2.

Appendix G DEFAULT HARBOR CRAFT VESSEL CHARACTERISTICS AND ACTIVITY

Engine size, installed power, and operating hours are important data when calculating vessel activity. Sections 4.3 and 4.4 discuss harbor craft vessel characteristics (which include engine size and installed power) and activity (which includes operating hours), respectively. If these vessel characteristics and activity data are unavailable from local data sources, per vessel defaults by ship type and engine group (propulsion or auxiliary) for the following data fields can be used instead:

- Average rated engine size (kW)
- Average installed power (kW)
- Average engine operating hours (hours)

These defaults are based on averages of data collected by Starcrest for harbor craft operating within the geographical domain for the emission inventories for Port of Los Angeles,[66] Port of Long Beach,[67] Puget Sound,[68] and Port Everglades.[69] While these defaults can be used if local data are unavailable, they have the limitation that they do not reflect local conditions, which likely impact vessel operation.

Table G.1. Default Harbor Craft Engine Sizes and Annual Activity

Ship Type	Average Propulsion Engine Size (kW)	Average Installed Propulsion Power (kW)	Average Annual Propulsion Engine Hours	Average Auxiliary Engine Size (kW)	Average Installed Auxiliary Power (kW)	Average Annual Auxiliary Engine Hours
Barge	--	--	--	171	622	581
Crew and Supply	427	1,037	747	42	50	766
Excursion	283	513	1,038	30	24	1,268
Fishing (C1/C2)	520	909	170	224	186	139
Government	724	1,343	423	502	389	251
Harbor Ferry (C1/C2)	1,516	3,658	3,329	201	419	1,865
Misc. (C1/C2)	735	1,309	799	168	205	802
Pilot	606	1,211	1,344	14	28	137
Towboat / Pushboat	846	1,559	864	68	97	1,137
Tugboat	1,720	3,512	1,683	126	285	1,404
Work Boat	283	464	753	46	36	732

The above references do not include estimates for dredging vessels. As with the other vessel types, if local data on engine type, size, and hours of operation are available for dredging vessels, these data

should be used in conjunction with the appropriate emission factors for the engines present. That is, propulsion and auxiliary engines should be assigned the appropriate Category 1 or Category 2 emission factors (see Appendix H), and the dredging equipment should be assigned the appropriate emission factors from MOVES-Nonroad (see Section 6). If local load factors are not available for the engines present on dredging vessels, an average value of 0.66 can be used for all engines (propulsion, auxiliary, and dredging).[42]

If local data on engine type and size for dredging vessels are unavailable, average total power ratings by dredging vessel type can be used, as listed in Table G.2.[70]

Table G.2. Power Rating for Dredging Vessels by Dredging Type

Dredging Type	Total Power Rating (kW)
Bucket or mechanical	1,600
Hopper	7,272
Non-conventional (Specialty)	2,093
Pipeline (Cutterhead)	7,161
Pipeline and Hopper Combination	4,080
Undefined (Average)	5,028

Note that the power ratings in Table G.2 are sum totals of all engines on dredging vessels, including propulsion engine(s) if present and dredging equipment engines. Since these defaults are for a combination of different engines, the average emission factors for this sector should be used, as presented in Appendix H, specifically Table H.7.

If hours of operation for dredging vessels are unknown, they can be estimated from the length of the project (measured in days) and assuming that the vessels are operating 21.6 hours per day (i.e., operating 90% of the time).[70]

Appendix H TABLES OF C1 AND C2 EMISSION FACTORS

This appendix contains tables of Category 1 and 2 (C1 and C2, respectively) emission factors for U.S. flagged ships, which are from EPA's 2008 C1/C2 Regulatory Impact Analysis (RIA),[17] unless otherwise noted. These emission factors are further discussed in Section 4.5. Note that these emission factors apply to engines on vessels with C1 and C2 propulsion engines, regardless if the vessel is considered to be an OGV or harbor craft. Emission factors for vessels with C3 propulsion engines are presented in Section 3.5, and emissions for recreational marine and marine engines fueled by gasoline are discussed in Section 5.

These emission factors for each pollutant of concern should be multiplied by the corresponding relevant activity measurement in kilowatt-hours. This appendix contains the following tables that present emission factors by engine category, group, cylinder displacement, engine power, and model year:

- Table H.1. Category 1 and 2 NOx Emission Factors (g/kWh)
- Table H.2. Category 1 and 2 PM ULSD Emission Factors (g/kWh)
- Table H.3. Category 1 and 2 Base PM_{10} Emission Factors for Other Diesel Fuels (g/kWh)
- Table H.4. Category 1 and 2 HC, VOC, and CH_4 Emission Factors (g/kWh)
- Table H.5. Category 1 and 2 CO Emission Factors (g/kWh)

If cylinder displacement is unknown, average emission factors by model year, power range, and engine group are presented in Table H.6. If engine tier is the only information available for a particular vessel, average emission factors by engine tier are presented in Table H.7.

H.1 NITROGEN OXIDES (NOX)

NOx emission factors vary by engine category, group, cylinder displacement, engine power, and model year. Emission factors for C1 and C2 NOx are presented in Table H.1.

Table H.1. Category 1 and 2 NOx Emission Factors (g/kWh)

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	NOx (g/kWh)
Uncontrolled					
C1	All	All	0 < kW ≤ 8	Pre-2000	13.41
			8 < kW ≤ 19	Pre-2000	11.40
			19 < kW ≤ 37	Pre-1999	9.25
	Propulsion	Disp < 0.9	kW > 37	Pre-2004	10.00
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	10.00
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	10.00
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	10.00
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	11.00
	Auxiliary	Disp < 0.9	kW > 37	Pre-2004	11.00

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	NOx (g/kWh)
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	10.00
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	10.00
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	10.00
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	11.00
C2	All	5 ≤ Disp < 30	All	Pre-2004	13.36
Tier 1					
C1	All	All	0 < kW ≤ 8	2000–2004	7.01
			8 < kW ≤ 19	2000–2004	5.95
			19 < kW ≤ 37	1999–2003	6.34
	Propulsion	Disp < 0.9	kW > 37	2004	9.80
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	9.10
		3.5 ≤ Disp < 5	kW > 37	2004–2006	9.20
	Auxiliary	Disp < 0.9	kW > 37	2004	9.80
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	9.10
		3.5 ≤ Disp < 5	kW > 37	2004–2006	9.20
C2	All	5 ≤ Disp < 30	All	2004–2006	10.55
Tier 2					
C1	All	All	0 < kW ≤ 8	2005–2008	5.89
			8 < kW ≤ 19	2005–2008	4.87
			19 < kW ≤ 37	2004–2008	4.98
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2005–2008	5.70
			75 < kW ≤ 600	2005–2011	5.70
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	6.10
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	6.00
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	6.00
		3.5 ≤ Disp < 5	kW > 37	2007–2011	6.00
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2005–2008	5.70
			75 < kW ≤ 600	2005–2011	5.70
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	5.40
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	6.10
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	6.10
		3.5 ≤ Disp < 5	kW > 37	2007–2011	6.10
C2	All	5 ≤ Disp < 15	All	2007–2012	8.33

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	NOx (g/kWh)
			2000 < kW ≤ 3700	2013	8.33
			kW > 3700	2013	8.33
		15 ≤ Disp < 30	All	2007–2013	8.33
Tier 3					
C1	All	All	0 < kW ≤ 8	2009+	4.39
			8 < kW ≤ 19	2009–2013	3.63
			8 < kW ≤ 19	2014+	2.32
			19 < kW ≤ 37	2009–2013	3.71
			19 < kW ≤ 37	2014+	2.32
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2009–2013	5.7
			37 < kW ≤ 75	2014+	3.56
			75 < kW ≤ 600	2012+	4.08
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	4.54
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	4.69
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	4.69
		3.5 ≤ Disp < 7	kW ≤ 600	2012+	4.81
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	4.69
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	4.69
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	4.81
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2014–2016	4.69
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	4.69
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	4.81
			kW > 1400	2012–2015	4.81
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2009–2013	5.70
			37 < kW ≤ 75	2014+	3.56
			75 < kW ≤ 600	2012+	4.08
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	4.02
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	4.77
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	4.77
		3.5 ≤ Disp < 7	kW ≤ 600	2012+	4.89
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	4.77
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	4.77
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	4.89

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	NOx (g/kWh)
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	4.77
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	4.89
			kW > 1400	2012–2015	4.89
C2	All	7 ≤ Disp < 15	kW ≤ 600	2013+	5.97
			600 < kW ≤ 1000	2013–2017	5.97
			1000 < kW ≤ 1400	2013–2016	5.97
			1400 < kW ≤ 2000	2013–2015	5.97
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2014–2015	6.77
Tier 4					
C1	Propulsion	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	1.30
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	1.30
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	1.30
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2017+	1.30
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	1.30
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	1.30
			kW > 1400	2016+	1.30
	Auxiliary	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	1.30
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	1.30
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	1.30
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	1.30
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	1.30
			kW > 1400	2016+	1.30
C2	All	7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	1.30
			1000 < kW ≤ 1400	2017+	1.30
			1400 < kW ≤ 2000	2016+	1.30
			2000 < kW ≤ 3700	2014+	1.30
			kW > 3700	2014–2016	1.30
			kW > 3700	2017+	1.30
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	1.30
			2000 < kW ≤ 3700	2014+	1.30
			kW > 3700	2014–2016	1.30
			kW > 3700	2017+	1.30

H.2 Particulate Matter (PM), Diesel Particulate Matter (DPM), and Black Carbon (BC)

PM emission factors vary by engine category, group, cylinder displacement, engine power, and model year. They also vary by fuel sulfur content. For inventories of 2012 activity and later, all C1 and C2 marine engines can be assumed to be using ultra low sulfur diesel (ULSD), and the corresponding emission factors are presented in Section H.2.1. Emission factors for engines using other fuels are presented in Section H.2.2.

H.2.1 ULSD

PM emission factors for engines using ULSD are presented in Table H.2. The PM_{10} and $PM_{2.5}$ values were derived from the 2008 C1/C2 RIA; however, the emission factors for uncontrolled engines as well as Tier 1 and 2 engines were adjusted to reflect the use of ULSD.[a] [b]

Table H.2. Category 1 and 2 PM ULSD Emission Factors (g/kWh)

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	PM_{10} & DPM_{10} (g/kWh)	$PM_{2.5}$ & $DPM_{2.5}$ (g/kWh)	BC (g/kWh)
Uncontrolled							
C1	All	All	0 < kW ≤ 8	Pre-2000	1.213	1.1764	0.9058
			8 < kW ≤ 19	Pre-2000	1.079	1.0463	0.8057
			19 < kW ≤ 37	Pre-1999	0.945	0.9162	0.7055
	Propulsion	Disp < 0.9	kW > 37	Pre-2004	0.430	0.4170	0.3211
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.360	0.3491	0.2688
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.230	0.2230	0.1717
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.190	0.1842	0.1419
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.190	0.1842	0.1419
	Auxiliary	Disp < 0.9	kW > 37	Pre-2004	0.730	0.7080	0.5452
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.420	0.4073	0.3137
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.230	0.2230	0.1717
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.210	0.2036	0.1568
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.190	0.1842	0.1419
C2	All	5 ≤ Disp < 30	All	Pre-2004	0.210	0.2036	0.1568

[a] Base PM_{10} emission factors were calculated from the PM_{10} emission factors in the 2008 C1/C2 RIA to reflect theoretical emissions from using sulfur-free fuel (presented in Table H.3), using the methodology described in reference 32. Adjusted PM_{10} emission factors for 15 ppm sulfur fuel were then calculated according to Equation H.1 in Section H.2.2.

[b] BC emission factors are estimated to be 77% of $PM_{2.5}$ emission factors, based on reference 33.

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	PM_{10} & DPM_{10} (g/kWh)	$PM_{2.5}$ & $DPM_{2.5}$ (g/kWh)	BC (g/kWh)
Tier 1							
C1	All	All	0 < kW ≤ 8	2000–2004	0.475	0.4610	0.3549
			8 < kW ≤ 19	2000–2004	0.234	0.2268	0.1747
			19 < kW ≤ 37	1999–2003	0.328	0.3179	0.2448
	Propulsion	Disp < 0.9	kW > 37	2004	0.430	0.4170	0.3211
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	0.190	0.1842	0.1419
		3.5 ≤ Disp < 5	kW > 37	2004–2006	0.190	0.1842	0.1419
	Auxiliary	Disp < 0.9	kW > 37	2004	0.730	0.7080	0.5452
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	0.210	0.2036	0.1568
		3.5 ≤ Disp < 5	kW > 37	2004–2006	0.190	0.1842	0.1419
C2	All	5 ≤ Disp < 30	All	2004–2006	0.210	0.2036	0.1568
Tier 2							
C1	All	All	0 < kW ≤ 8	2005–2008	0.497	0.4816	0.3708
			8 < kW ≤ 19	2005–2008	0.242	0.2345	0.1805
			19 < kW ≤ 37	2004–2008	0.295	0.2865	0.2206
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.219	0.2122	0.1634
			75 < kW ≤ 600	2005–2011	0.219	0.2122	0.1634
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.109	0.1055	0.0812
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.119	0.1152	0.0887
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.119	0.1152	0.0887
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.119	0.1152	0.0887
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.219	0.2122	0.1634
			75 < kW ≤ 600	2005–2011	0.219	0.2122	0.1634
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.199	0.1928	0.1485
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.139	0.1346	0.1037
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.139	0.1346	0.1037
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.139	0.1346	0.1037
C2	All	5 ≤ Disp < 15	All	2007–2012	0.309	0.2995	0.2306
			kW > 3700	2013	0.309	0.2995	0.2306
		15 ≤ Disp < 30	All	2007–2013	c	0.2995	0.2306

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	PM_{10} & DPM_{10} (g/kWh)	$PM_{2.5}$ & $DPM_{2.5}$ (g/kWh)	BC (g/kWh)
Tier 3							
C1	All	All	0 < kW ≤ 8	2009+	0.240	0.2328	0.1793
			8 < kW ≤ 19	2009+	0.190	0.1843	0.1419
			19 < kW ≤ 37	2009+	0.180	0.1746	0.1344
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2009+	0.170	0.1649	0.1270
			75 < kW ≤ 600	2012+	0.080	0.0776	0.0598
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	0.050	0.0485	0.0373
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014–2017	0.070	0.0679	0.0523
			kW ≤ 600	2018+	0.061	0.0592	0.0456
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013–2017	0.070	0.0679	0.0523
			kW ≤ 600	2018+	0.061	0.0592	0.0456
		3.5 ≤ Disp < 7	kW ≤ 600	2012–2017	0.070	0.0679	0.0523
			kW ≤ 600	2018+	0.061	0.0592	0.0456
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	0.070	0.0679	0.0523
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	0.070	0.0679	0.0523
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	0.070	0.0679	0.0523
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2014–2016	0.070	0.0679	0.0523
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	0.070	0.0679	0.0523
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	0.070	0.0679	0.0523
			kW > 1400	2012–2015	0.070	0.0679	0.0523
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2009+	0.170	0.1649	0.1270
			75 < kW ≤ 600	2012+	0.080	0.0776	0.0598
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	0.080	0.0776	0.0598
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014–2017	0.080	0.0776	0.0598
			kW ≤ 600	2018+	0.070	0.0679	0.0523
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013–2017	0.080	0.0776	0.0598
			kW ≤ 600	2018+	0.070	0.0679	0.0523
		3.5 ≤ Disp < 7	kW ≤ 600	2012–2017	0.080	0.0776	0.0598

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	PM_{10} & DPM_{10} (g/kWh)	$PM_{2.5}$ & $DPM_{2.5}$ (g/kWh)	BC (g/kWh)
			kW ≤ 600	2018+	0.070	0.0679	0.0523
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	0.080	0.0776	0.0598
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	0.080	0.0776	0.0598
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	0.080	0.0776	0.0598
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	0.080	0.0776	0.0598
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	0.080	0.0776	0.0598
			kW > 1400	2012–2015	0.080	0.0776	0.0598
C2	All	7 ≤ Disp < 15	kW ≤ 600	2013+	0.110	0.1067	0.0822
			600 < kW ≤ 1000	2013–2017	0.110	0.1067	0.0822
			1000 < kW ≤ 1400	2013–2016	0.110	0.1067	0.0822
			1400 < kW ≤ 2000	2013–2015	0.110	0.1067	0.0822
			2000 < kW ≤ 3700	2013–2015	0.110	0.1067	0.0822
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2014–2015	0.300	0.2910	0.2241
			2000 < kW ≤ 3700	2014–2015	0.300	0.2910	0.2241
Tier 4							
C1	Propulsion	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	PM_{10} & DPM_{10} (g/kWh)	$PM_{2.5}$ & $DPM_{2.5}$ (g/kWh)	BC (g/kWh)
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224
			kW > 1400	2016+	0.030	0.0291	0.0224
	Auxiliary	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224
			kW > 1400	2016+	0.030	0.0291	0.0224
C2	All	7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	0.030	0.0291	0.0224
			1000 < kW ≤ 1400	2017+	0.030	0.0291	0.0224
			1400 < kW ≤ 2000	2016+	0.030	0.0291	0.0224
			2000 < kW ≤ 3700	2016+	0.030	0.0291	0.0224
			kW > 3700	2014–2016	0.100	0.0970	0.0747
			kW > 3700	2017+	0.040	0.0388	0.0299
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	0.040	0.0388	0.0299
			2000 < kW ≤ 3700	2016+	0.040	0.0388	0.0299
			kW > 3700	2014–2016	0.230	0.2231	0.1718
			kW > 3700	2017+	0.050	0.0485	0.0373

H.2.2 Other Diesel Fuels

For engines using diesel fuel with a different sulfur level than ULSD, PM_{10} and DPM_{10} emission factors for uncontrolled engines and Tiers 1 and 2 should be calculated according to Equation H.1:[32] [c]

$$EF_{PM_{10}} = PM_{base} + (S_{act} \times BSFC \times FSC \times MWR) \qquad \textbf{Equation H.1}$$

Where $EF_{PM_{10}}$ = PM_{10} and DPM_{10} emission factor adjusted for fuel sulfur (g/kWh)
PM_{base} = Base emission factor assuming zero fuel sulfur as listed in Table H.3 (g/kWh)
S_{act} = actual fuel sulfur level (weight ratio)
= e.g., 0.0005 for 500 ppm sulfur fuel
$BSFC$ = brake specific fuel consumption[17]
= 248 g/kWh for vessels with power range less than 37 kW
= 213 g/kWh for vessels with power range of 37 kW or more
FSC = fraction of sulfur in fuel that is converted to direct sulfate PM[17]
= 0.02247
MWR = molecular weight ratio of sulfate PM to sulfur
= 224/32 = 7

Similar to the analysis performed for the 2017 NEI for C3 PM emissions, base PM_{10} emission factors were calculated from the PM_{10} emission factors in the 2008 C1/C2 RIA to reflect theoretical emissions from using sulfur-free fuel. These base PM_{10} emission factors are presented in Table H.3.

$PM_{2.5}$ emission factors are estimated to be 97% of the PM_{10} emission factors.[17] For all engines using ULSD, DPM_{10} and $DPM_{2.5}$ emission factors are equal to the PM_{10} and $PM_{2.5}$ emission factors, respectively. BC emission factors for C1 and C2 engines are 77% of $PM_{2.5}$ emission factors.[33]

Table H.3. Category 1 and 2 Base PM_{10} Emission Factors for Other Diesel Fuels (g/kWh)

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	Base PM_{10} (g/kWh)
Uncontrolled					
C1	All	All	0 < kW ≤ 8	Pre-2000	1.2122
			8 < kW ≤ 19	Pre-2000	1.0781
			19 < kW ≤ 37	Pre-1999	0.9440
	Propulsion	Disp < 0.9	kW > 37	Pre-2004	0.4294
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.3594
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.2294
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.1894
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.1894
	Auxiliary	Disp < 0.9	kW > 37	Pre-2004	0.7294
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.4194
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.2294

[c] Emission factors for Tiers 3 and 4 are provided in Section H.2.1, as these vessels cannot use fuels with higher sulfur levels than ULSD.

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	Base PM_{10} (g/kWh)
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.2094
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.1894
C2	All	5 ≤ Disp < 30	All	Pre-2004	0.2094
Tier 1					
C1	All	All	0 < kW ≤ 8	2000–2004	0.4746
			8 < kW ≤ 19	2000–2004	0.2333
			19 < kW ≤ 37	1999–2003	0.3271
	Propulsion	Disp < 0.9	kW > 37	2004	0.4294
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	0.1894
		3.5 ≤ Disp < 5	kW > 37	2004–2006	0.1894
	Auxiliary	Disp < 0.9	kW > 37	2004	0.7294
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	0.2094
		3.5 ≤ Disp < 5	kW > 37	2004–2006	0.1894
C2	All	5 ≤ Disp < 30	All	2004–2006	0.2094
Tier 2					
C1	All	All	0 < kW ≤ 8	2005–2008	0.4959
			8 < kW ≤ 19	2005–2008	0.2411
			19 < kW ≤ 37	2004–2008	0.2948
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.2183
			75 < kW ≤ 600	2005–2011	0.2183
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.1083
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.1183
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.1183
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.1183
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.2183
			75 < kW ≤ 600	2005–2011	0.2183
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.1983
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.1383
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.1383
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.1383
C2	All	5 ≤ Disp < 15	All	2007–2012	0.3083
		15 ≤ Disp < 30	All	2007–2013	0.3083

H.3 Volatile Organic Compounds (VOC) and Methane (CH_4)

Emission factors for VOC and CH_4 vary by engine category, group, cylinder displacement, engine power, and model year. Emission factors for C1 and C2 hydrocarbons (HC), VOC, and CH_4 are presented in Table H.4.

Table H.4. Category 1 and 2 HC, VOC, and CH_4 Emission Factors (g/kWh)

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	HC (g/kWh)	VOC (g/kWh)	CH_4 (g/kWh)
Uncontrolled							
C1	All	All	0 < kW ≤ 8	Pre-2000	2.012	2.1181	0.0402
			8 < kW ≤ 19	Pre-2000	2.280	2.4006	0.0456
			19 < kW ≤ 37	Pre-1999	2.414	2.5418	0.0483
	Propulsion	Disp < 0.9	kW > 37	Pre-2004	0.410	0.4317	0.0082
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.320	0.3370	0.0064
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.270	0.2843	0.0054
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.270	0.2843	0.0054
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.270	0.2843	0.0054
	Auxiliary	Disp < 0.9	kW > 37	Pre-2004	0.410	0.4317	0.0082
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	0.320	0.3370	0.0064
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	0.270	0.2843	0.0054
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	0.270	0.2843	0.0054
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	0.270	0.2843	0.0054
C2	All	5 ≤ Disp < 30	All	Pre-2004	0.134	0.1411	0.0027
Tier 1							
C1	All	All	0 < kW ≤ 8	2000–2004	1.019	1.0732	0.0204
			8 < kW ≤ 19	2000–2004	0.590	0.6213	0.0118
			19 < kW ≤ 37	1999–2003	0.375	0.3954	0.0075
	Propulsion	Disp < 0.9	kW > 37	2004	0.410	0.4317	0.0082
		2.5 ≤ Disp < 3.5	kW > 37	2000–2006	0.270	0.2843	0.0054
		3.5 ≤ Disp < 5	kW > 37	2000–2006	0.270	0.2843	0.0054
	Auxiliary	Disp < 0.9	kW > 37	2004	0.410	0.4317	0.0082
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	0.270	0.2843	0.0054
		3.5 ≤ Disp < 5	kW > 37	2004–2006	0.270	0.2843	0.0054
C2	All	5 ≤ Disp < 30	All	2004–2006	0.134	0.1411	0.0027
Tier 2							
C1	All	All	0 < kW ≤ 8	2005–2008	0.912	0.9602	0.0182

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	HC (g/kWh)	VOC (g/kWh)	CH_4 (g/kWh)
			8 < kW ≤ 19	2005–2008	0.282	0.2965	0.0056
			19 < kW ≤ 37	2004–2008	0.724	0.7625	0.0145
	Propulsion	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.410	0.4317	0.0082
			75 < kW ≤ 600	2005–2011	0.410	0.4317	0.0082
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.320	0.3370	0.0064
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.190	0.2001	0.0038
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.190	0.2001	0.0038
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.190	0.2001	0.0038
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2005–2008	0.410	0.4317	0.0082
			75 < kW ≤ 600	2005–2011	0.410	0.4317	0.0082
		0.9 ≤ Disp < 1.2	kW > 37	2004–2012	0.320	0.3370	0.0064
		1.2 ≤ Disp < 2.5	kW > 37	2004–2013	0.210	0.2211	0.0042
		2.5 ≤ Disp < 3.5	kW > 37	2007–2012	0.210	0.2211	0.0042
		3.5 ≤ Disp < 5	kW > 37	2007–2011	0.210	0.2211	0.0042
C2	All	5 ≤ Disp < 15	All	2007–2012	0.134	0.1411	0.0027
			2000 < kW ≤ 3700	2013	0.134	0.1411	0.0027
			kW > 3700	2013	0.134	0.1411	0.0027
		15 ≤ Disp < 30	All	2007–2013	0.134	0.1411	0.0027
Tier 3							
C1	All	All	0 < kW ≤ 8	2009+	0.430	0.4528	0.0086
			8 < kW ≤ 19	2009+	0.210	0.2211	0.0042
			19 < kW ≤ 37	2009+	0.410	0.4317	0.0082
C1	Propulsion	Disp < 0.9	37 < kW ≤ 75	2009+	0.300	0.3159	0.0060
			75 < kW ≤ 600	2012+	0.140	0.1474	0.0028
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	0.130	0.1369	0.0026
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	0.100	0.1053	0.0020
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	0.100	0.1053	0.0020
		3.5 ≤ Disp < 7	kW ≤ 600	2012+	0.100	0.1053	0.0020
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	0.100	0.1053	0.0020
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	0.100	0.1053	0.0020

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	HC (g/kWh)	VOC (g/kWh)	CH_4 (g/kWh)
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	0.100	0.1053	0.0020
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2014–2016	0.100	0.1053	0.0020
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	0.100	0.1053	0.0020
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	0.100	0.1053	0.0020
			kW > 1400	2012–2015	0.100	0.1053	0.0020
	Auxiliary	Disp < 0.9	37 < kW ≤ 75	2009+	0.300	0.3159	0.0060
			75 < kW ≤ 600	2012+	0.140	0.1474	0.0028
		0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	0.130	0.1369	0.0026
		1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	0.110	0.1158	0.0022
		2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	0.110	0.1158	0.0022
		3.5 ≤ Disp < 7	kW ≤ 600	2012+	0.110	0.1158	0.0022
		1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014–2017	0.110	0.1158	0.0022
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013–2017	0.110	0.1158	0.0022
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012–2017	0.110	0.1158	0.0022
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013–2016	0.110	0.1158	0.0022
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012–2016	0.110	0.1158	0.0022
			kW > 1400	2012–2015	0.110	0.1158	0.0022
C2	All	7 ≤ Disp < 15	kW ≤ 600	2013+	0.070	0.0737	0.0014
			600 < kW ≤ 1000	2013–2017	0.070	0.0737	0.0014
			1000 < kW ≤ 1400	2013–2016	0.070	0.0737	0.0014
			1400 < kW ≤ 2000	2013–2015	0.070	0.0737	0.0014
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2014–2015	0.090	0.0948	0.0018
Tier 4							

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	HC (g/kWh)	VOC (g/kWh)	CH_4 (g/kWh)
C1	Propulsion	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2017+	0.040	0.0421	0.0008
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	0.040	0.0421	0.0008
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	0.040	0.0421	0.0008
		3.5 ≤ Disp < 7	kW > 1400	2016+	0.040	0.0421	0.0008
	Auxiliary	1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		3.5 ≤ Disp < 7	600 < kW ≤ 1000	2018+	0.040	0.0421	0.0008
		2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	0.040	0.0421	0.0008
		3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	0.040	0.0421	0.0008
			kW > 1400	2016+	0.040	0.0421	0.0008
C2	All	7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	0.020	0.0211	0.0004
			1000 < kW ≤ 1400	2017+	0.020	0.0211	0.0004
			1400 < kW ≤ 2000	2016+	0.020	0.0211	0.0004
			2000 < kW ≤ 3700	2014+	0.020	0.0211	0.0004
			kW > 3700	2014–2016	0.060	0.0632	0.0012
				2017+	0.030	0.0316	0.0006
		15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	0.010	0.0105	0.0002

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	HC (g/kWh)	VOC (g/kWh)	CH_4 (g/kWh)
			2000 < kW ≤ 3700	2014+	0.010	0.0105	0.0002
			kW > 3700	2014–2016	0.070	0.0737	0.0014
				2017+	0.010	0.0105	0.0002

H.4 Carbon Monoxide (CO)

CO emission factors vary by engine category, group, cylinder displacement, engine power, and model year. Emission factors for C1 and C2 CO are presented in Table H.5. Note that unlike other pollutants listed in this appendix, the emission factors for CO do not change after Tier 2.

Table H.5. Category 1 and 2 CO Emission Factors (g/kWh)

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	CO (g/kWh)
Uncontrolled					
C1	All	All	0 < kW ≤ 8	Pre-2000	5.00
			8 < kW ≤ 19	Pre-2000	5.00
			19 < kW ≤ 37	Pre-1999	5.00
	Propulsion	Disp < 0.9	kW > 37	Pre-2004	1.60
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	1.60
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	1.60
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	1.60
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	1.80
	Auxiliary	Disp < 0.9	kW > 37	Pre-2004	2.00
		0.9 ≤ Disp < 1.2	kW > 37	Pre-2004	1.70
		1.2 ≤ Disp < 2.5	kW > 37	Pre-2004	1.50
		2.5 ≤ Disp < 3.5	kW > 37	Pre-2004	1.50
		3.5 ≤ Disp < 5	kW > 37	Pre-2004	1.80
C2	All	5 ≤ Disp < 30	All	Pre-2004	2.48
Tier 1					
C1	All	All	0 < kW ≤ 8	2000–2004	4.11
			8 < kW ≤ 19	2000–2004	2.16
			19 < kW ≤ 37	1999–2003	1.53
	Propulsion	Disp < 0.9	kW > 37	2004	1.60
		2.5 ≤ Disp < 3.5	kW > 37	2000–2006	1.60
		3.5 ≤ Disp < 5	kW > 37	2000–2006	1.80
	Auxiliary	Disp < 0.9	kW > 37	2004	2.00
		2.5 ≤ Disp < 3.5	kW > 37	2004–2006	1.50
		3.5 ≤ Disp < 5	kW > 37	2004–2006	1.80
C2	All	5 ≤ Disp < 30	All	2004–2006	2.48

Engine Category	Engine Group	Cylinder Displacement Range (L/cyl)	Power Range	Model Year Range	CO (g/kWh)
Tier 2					
C1	All	All	0 < kW ≤ 8	2005+	4.11
			8 < kW ≤ 19	2005+	2.16
			19 < kW ≤ 37	2004+	1.53
	Propulsion	Disp < 0.9	kW > 37	2005+	1.60
		0.9 ≤ Disp < 1.2	kW > 37	2004+	0.90
		1.2 ≤ Disp < 2.5	kW > 37	2004+	1.10
		2.5 ≤ Disp < 3.5	kW > 37	2007+	1.10
		3.5 ≤ Disp < 5	kW > 37	2007+	1.10
	Auxiliary	Disp < 0.9	kW > 37	2005+	1.60
		0.9 ≤ Disp < 1.2	kW > 37	2004+	0.80
		1.2 ≤ Disp < 2.5	kW > 37	2004+	0.90
		2.5 ≤ Disp < 3.5	kW > 37	2007+	0.90
		3.5 ≤ Disp < 5	kW > 37	2007+	0.90
C2	All	5 ≤ Disp < 30	All	2007+	2.00
Tier 3 and Tier 4					
C1	All	All	0 < kW ≤ 8	2005+	4.11
			8 < kW ≤ 19	2005+	2.16
			19 < kW ≤ 37	2004+	1.53
	Propulsion	Disp < 0.9	kW > 37	2005+	1.60
		0.9 ≤ Disp < 1.2	kW > 37	2004+	0.90
		1.2 ≤ Disp < 2.5	kW > 37	2004+	1.10
		2.5 ≤ Disp < 3.5	kW > 37	2007+	1.10
		3.5 ≤ Disp < 7	kW > 37	2007+	1.10
	Auxiliary	Disp < 0.9	kW > 37	2005+	1.60
		0.9 ≤ Disp < 1.2	kW > 37	2004+	0.80
		1.2 ≤ Disp < 2.5	kW > 37	2004+	0.90
		2.5 ≤ Disp < 3.5	kW > 37	2007+	0.90
		3.5 ≤ Disp < 7	kW > 37	2007+	0.90
C2	All	7 ≤ Disp < 30	All	2007+	2.00

H.5 Average Emission Factors

If cylinder displacement is unknown for a vessel, average emission factors by model year, power range, and engine group (propulsion or auxiliary) can be used instead of the detailed emission factors provided above. These average emission factors are presented in Table H.6, which are based on the detailed emission factors described in Section 4.5 and presented above in this appendix, weighted by national activity estimates presented in EPA's 2008 C1/C2 RIA.[17]

If engine tier is the only information available for a particular vessel, average emission factors by engine tier can be used, which are presented in Table H.7.[71]

Table H.6. Average Harbor Craft Emission Factors by Engine Group, Power Range, and Model Year

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
Pre-1999	0 < kW ≤ 8	All	13.4102	1.2128	1.1764	0.9058	2.0115	2.1181	0.0402	5.0000
Pre-1999	8 < kW ≤ 19	All	11.3987	1.0787	1.0463	0.8057	2.2797	2.4006	0.0456	5.0000
Pre-1999	19 < kW ≤ 37	All	9.2530	0.9446	0.9162	0.7055	2.4138	2.5418	0.0483	5.0000
Pre-1999	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
Pre-1999	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
Pre-1999	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
Pre-1999	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
Pre-1999	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
Pre-1999	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
Pre-1999	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
Pre-1999	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
Pre-1999	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
Pre-1999	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
1999	0 < kW ≤ 8	All	13.4102	1.2128	1.1764	0.9058	2.0115	2.1181	0.0402	5.0000
1999	8 < kW ≤ 19	All	11.3987	1.0787	1.0463	0.8057	2.2797	2.4006	0.0456	5.0000
1999	19 < kW ≤ 37	All	6.3430	0.3277	0.3179	0.2448	0.3755	0.3954	0.0075	1.5300
1999	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
1999	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
1999	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
1999	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
1999	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
1999	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
1999	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
1999	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
1999	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
1999	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2000	0 < kW ≤ 8	All	7.0135	0.4752	0.4610	0.3549	1.0192	1.0732	0.0204	4.1100
2000	8 < kW ≤ 19	All	5.9541	0.2338	0.2268	0.1747	0.5900	0.6213	0.0118	2.1600
2000	19 < kW ≤ 37	All	6.3430	0.3277	0.3179	0.2448	0.3755	0.3954	0.0075	1.5300
2000	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
2000	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
2000	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
2000	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
2000	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
2000	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2000	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2000	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2000	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2000	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2001	0 < kW ≤ 8	All	7.0135	0.4752	0.4610	0.3549	1.0192	1.0732	0.0204	4.1100
2001	8 < kW ≤ 19	All	5.9541	0.2338	0.2268	0.1747	0.5900	0.6213	0.0118	2.1600
2001	19 < kW ≤ 37	All	6.3430	0.3277	0.3179	0.2448	0.3755	0.3954	0.0075	1.5300
2001	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
2001	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
2001	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
2001	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
2001	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
2001	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2001	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2001	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2001	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2001	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2002	0 < kW ≤ 8	All	7.0135	0.4752	0.4610	0.3549	1.0192	1.0732	0.0204	4.1100
2002	8 < kW ≤ 19	All	5.9541	0.2338	0.2268	0.1747	0.5900	0.6213	0.0118	2.1600
2002	19 < kW ≤ 37	All	6.3430	0.3277	0.3179	0.2448	0.3755	0.3954	0.0075	1.5300
2002	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
2002	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
2002	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
2002	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
2002	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
2002	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2002	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2002	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2002	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2002	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2003	0 < kW ≤ 8	All	7.0135	0.4752	0.4610	0.3549	1.0192	1.0732	0.0204	4.1100
2003	8 < kW ≤ 19	All	5.9541	0.2338	0.2268	0.1747	0.5900	0.6213	0.0118	2.1600
2003	19 < kW ≤ 37	All	6.3430	0.3277	0.3179	0.2448	0.3755	0.3954	0.0075	1.5300
2003	37 < kW ≤ 600	Propulsion	10.0757	0.2422	0.2349	0.1809	0.2744	0.2890	0.0055	1.6196
2003	37 < kW ≤ 600	Auxiliary	10.0806	0.2917	0.2829	0.2178	0.2871	0.3023	0.0057	1.5691
2003	600 < kW ≤ 1000	Propulsion	10.2471	0.2076	0.2014	0.1550	0.2664	0.2805	0.0053	1.6549
2003	600 < kW ≤ 1000	Auxiliary	10.4064	0.2119	0.2056	0.1583	0.2700	0.2843	0.0054	1.6219
2003	1000 < kW ≤ 1400	Propulsion	10.4535	0.2172	0.2107	0.1623	0.2573	0.2709	0.0051	1.7101
2003	1000 < kW ≤ 1400	Auxiliary	10.9472	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2003	1400 < kW ≤ 2000	Propulsion	11.7994	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2003	1400 < kW ≤ 2000	Auxiliary	11.0000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2003	2000 < kW ≤ 3700	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2003	3700 < kW	Propulsion	13.3600	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2004	0 < kW ≤ 8	All	7.0135	0.4752	0.4610	0.3549	1.0192	1.0732	0.0204	4.1100
2004	8 < kW ≤ 19	All	5.9541	0.2338	0.2268	0.1747	0.5900	0.6213	0.0118	2.1600
2004	19 < kW ≤ 37	All	4.9752	0.2954	0.2865	0.2206	0.7242	0.7625	0.0145	1.5300
2004	37 < kW ≤ 600	Propulsion	6.5023	0.1311	0.1272	0.0979	0.2153	0.2267	0.0043	1.1694
2004	37 < kW ≤ 600	Auxiliary	6.3732	0.1901	0.1844	0.1420	0.2434	0.2563	0.0049	0.9888
2004	600 < kW ≤ 1000	Propulsion	7.8275	0.1600	0.1552	0.1195	0.2322	0.2445	0.0046	1.4409
2004	600 < kW ≤ 1000	Auxiliary	7.6211	0.1658	0.1608	0.1238	0.2396	0.2523	0.0048	1.3180
2004	1000 < kW ≤ 1400	Propulsion	7.2780	0.1466	0.1422	0.1095	0.2064	0.2174	0.0041	1.3922
2004	1000 < kW ≤ 1400	Auxiliary	9.1947	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2004	1400 < kW ≤ 2000	Propulsion	9.6573	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2004	1400 < kW ≤ 2000	Auxiliary	9.2000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2004	2000 < kW ≤ 3700	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2004	3700 < kW	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2005	0 < kW ≤ 8	All	5.8871	0.4965	0.4816	0.3708	0.9119	0.9602	0.0182	4.1100
2005	8 < kW ≤ 19	All	4.8679	0.2417	0.2345	0.1805	0.2816	0.2965	0.0056	2.1600
2005	19 < kW ≤ 37	All	4.9752	0.2954	0.2865	0.2206	0.7242	0.7625	0.0145	1.5300
2005	37 < kW ≤ 600	Propulsion	6.4562	0.1287	0.1249	0.0962	0.2153	0.2267	0.0043	1.1694
2005	37 < kW ≤ 600	Auxiliary	6.1050	0.1566	0.1519	0.1170	0.2434	0.2563	0.0049	0.9626
2005	600 < kW ≤ 1000	Propulsion	7.8275	0.1600	0.1552	0.1195	0.2322	0.2445	0.0046	1.4409
2005	600 < kW ≤ 1000	Auxiliary	7.6211	0.1658	0.1608	0.1238	0.2396	0.2523	0.0048	1.3180
2005	1000 < kW ≤ 1400	Propulsion	7.2780	0.1466	0.1422	0.1095	0.2064	0.2174	0.0041	1.3922
2005	1000 < kW ≤ 1400	Auxiliary	9.1947	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2005	1400 < kW ≤ 2000	Propulsion	9.6573	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2005	1400 < kW ≤ 2000	Auxiliary	9.2000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2005	2000 < kW ≤ 3700	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2005	3700 < kW	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2006	0 < kW ≤ 8	All	5.8871	0.4965	0.4816	0.3708	0.9119	0.9602	0.0182	4.1100
2006	8 < kW ≤ 19	All	4.8679	0.2417	0.2345	0.1805	0.2816	0.2965	0.0056	2.1600
2006	19 < kW ≤ 37	All	4.9752	0.2954	0.2865	0.2206	0.7242	0.7625	0.0145	1.5300
2006	37 < kW ≤ 600	Propulsion	6.4562	0.1287	0.1249	0.0962	0.2153	0.2267	0.0043	1.1694
2006	37 < kW ≤ 600	Auxiliary	6.1050	0.1566	0.1519	0.1170	0.2434	0.2563	0.0049	0.9626
2006	600 < kW ≤ 1000	Propulsion	7.8275	0.1600	0.1552	0.1195	0.2322	0.2445	0.0046	1.4409
2006	600 < kW ≤ 1000	Auxiliary	7.6211	0.1658	0.1608	0.1238	0.2396	0.2523	0.0048	1.3180
2006	1000 < kW ≤ 1400	Propulsion	7.2780	0.1466	0.1422	0.1095	0.2064	0.2174	0.0041	1.3922
2006	1000 < kW ≤ 1400	Auxiliary	9.1947	0.1910	0.1853	0.1427	0.2700	0.2843	0.0054	1.7842
2006	1400 < kW ≤ 2000	Propulsion	9.6573	0.1967	0.1908	0.1469	0.2239	0.2358	0.0045	2.0303
2006	1400 < kW ≤ 2000	Auxiliary	9.2000	0.1899	0.1842	0.1419	0.2700	0.2843	0.0054	1.8000
2006	2000 < kW ≤ 3700	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2006	3700 < kW	Propulsion	10.5500	0.2099	0.2036	0.1568	0.1340	0.1411	0.0027	2.4800
2007	0 < kW ≤ 8	All	5.8871	0.4965	0.4816	0.3708	0.9119	0.9602	0.0182	4.1100
2007	8 < kW ≤ 19	All	4.8679	0.2417	0.2345	0.1805	0.2816	0.2965	0.0056	2.1600
2007	19 < kW ≤ 37	All	4.9752	0.2954	0.2865	0.2206	0.7242	0.7625	0.0145	1.5300
2007	37 < kW ≤ 600	Propulsion	6.0580	0.1228	0.1191	0.0917	0.2062	0.2171	0.0041	1.1019
2007	37 < kW ≤ 600	Auxiliary	5.9624	0.1536	0.1490	0.1147	0.2406	0.2534	0.0048	0.9299
2007	600 < kW ≤ 1000	Propulsion	6.0612	0.1238	0.1201	0.0924	0.1885	0.1985	0.0038	1.1237
2007	600 < kW ≤ 1000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2007	1000 < kW ≤ 1400	Propulsion	6.2175	0.1365	0.1324	0.1020	0.1848	0.1946	0.0037	1.1840
2007	1000 < kW ≤ 1400	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2007	1400 < kW ≤ 2000	Propulsion	6.7892	0.1831	0.1776	0.1368	0.1710	0.1801	0.0034	1.4048
2007	1400 < kW ≤ 2000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2007	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2007	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2008	0 < kW ≤ 8	All	5.8871	0.4965	0.4816	0.3708	0.9119	0.9602	0.0182	4.1100
2008	8 < kW ≤ 19	All	4.8679	0.2417	0.2345	0.1805	0.2816	0.2965	0.0056	2.1600
2008	19 < kW ≤ 37	All	4.9752	0.2954	0.2865	0.2206	0.7242	0.7625	0.0145	1.5300
2008	37 < kW ≤ 600	Propulsion	6.0580	0.1228	0.1191	0.0917	0.2062	0.2171	0.0041	1.1019
2008	37 < kW ≤ 600	Auxiliary	5.9624	0.1536	0.1490	0.1147	0.2406	0.2534	0.0048	0.9299
2008	600 < kW ≤ 1000	Propulsion	6.0612	0.1238	0.1201	0.0924	0.1885	0.1985	0.0038	1.1237
2008	600 < kW ≤ 1000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2008	1000 < kW ≤ 1400	Propulsion	6.2175	0.1365	0.1324	0.1020	0.1848	0.1946	0.0037	1.1840
2008	1000 < kW ≤ 1400	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2008	1400 < kW ≤ 2000	Propulsion	6.7892	0.1831	0.1776	0.1368	0.1710	0.1801	0.0034	1.4048
2008	1400 < kW ≤ 2000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2008	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2008	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2009	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2009	8 < kW ≤ 19	All	3.6300	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2009	19 < kW ≤ 37	All	3.7100	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2009	37 < kW ≤ 600	Propulsion	6.0580	0.1227	0.1190	0.0916	0.2058	0.2168	0.0041	1.1019
2009	37 < kW ≤ 600	Auxiliary	5.9624	0.1510	0.1465	0.1128	0.2348	0.2472	0.0047	0.9299
2009	600 < kW ≤ 1000	Propulsion	6.0612	0.1238	0.1201	0.0924	0.1885	0.1985	0.0038	1.1237
2009	600 < kW ≤ 1000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2009	1000 < kW ≤ 1400	Propulsion	6.2175	0.1365	0.1324	0.1020	0.1848	0.1946	0.0037	1.1840
2009	1000 < kW ≤ 1400	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2009	1400 < kW ≤ 2000	Propulsion	6.7892	0.1831	0.1776	0.1368	0.1710	0.1801	0.0034	1.4048
2009	1400 < kW ≤ 2000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2009	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2009	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2010	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2010	8 < kW ≤ 19	All	3.6300	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2010	19 < kW ≤ 37	All	3.7100	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2010	37 < kW ≤ 600	Propulsion	6.0580	0.1227	0.1190	0.0916	0.2058	0.2168	0.0041	1.1019
2010	37 < kW ≤ 600	Auxiliary	5.9624	0.1510	0.1465	0.1128	0.2348	0.2472	0.0047	0.9299
2010	600 < kW ≤ 1000	Propulsion	6.0612	0.1238	0.1201	0.0924	0.1885	0.1985	0.0038	1.1237
2010	600 < kW ≤ 1000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2010	1000 < kW ≤ 1400	Propulsion	6.2175	0.1365	0.1324	0.1020	0.1848	0.1946	0.0037	1.1840
2010	1000 < kW ≤ 1400	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2010	1400 < kW ≤ 2000	Propulsion	6.7892	0.1831	0.1776	0.1368	0.1710	0.1801	0.0034	1.4048
2010	1400 < kW ≤ 2000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2010	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2010	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2011	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2011	8 < kW ≤ 19	All	3.6300	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2011	19 < kW ≤ 37	All	3.7100	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2011	37 < kW ≤ 600	Propulsion	6.0580	0.1227	0.1190	0.0916	0.2058	0.2168	0.0041	1.1019
2011	37 < kW ≤ 600	Auxiliary	5.9624	0.1510	0.1465	0.1128	0.2348	0.2472	0.0047	0.9299
2011	600 < kW ≤ 1000	Propulsion	6.0612	0.1238	0.1201	0.0924	0.1885	0.1985	0.0038	1.1237
2011	600 < kW ≤ 1000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2011	1000 < kW ≤ 1400	Propulsion	6.2175	0.1365	0.1324	0.1020	0.1848	0.1946	0.0037	1.1840
2011	1000 < kW ≤ 1400	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2011	1400 < kW ≤ 2000	Propulsion	6.7892	0.1831	0.1776	0.1368	0.1710	0.1801	0.0034	1.4048
2011	1400 < kW ≤ 2000	Auxiliary	6.1000	0.1388	0.1346	0.1037	0.2100	0.2211	0.0042	0.9000
2011	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2011	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2012	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2012	8 < kW ≤ 19	All	3.6300	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2012	19 < kW ≤ 37	All	3.7100	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2012	37 < kW ≤ 600	Propulsion	6.0405	0.1214	0.1177	0.0906	0.2034	0.2141	0.0041	1.1019
2012	37 < kW ≤ 600	Auxiliary	5.9235	0.1483	0.1439	0.1108	0.2299	0.2420	0.0046	0.9299
2012	600 < kW ≤ 1000	Propulsion	5.8723	0.1160	0.1125	0.0867	0.1742	0.1835	0.0035	1.1237
2012	600 < kW ≤ 1000	Auxiliary	5.6083	0.1149	0.1114	0.0858	0.1694	0.1783	0.0034	0.9000
2012	1000 < kW ≤ 1400	Propulsion	6.0511	0.1297	0.1258	0.0969	0.1722	0.1813	0.0034	1.1840
2012	1000 < kW ≤ 1400	Auxiliary	4.9539	0.0831	0.0806	0.0621	0.1153	0.1214	0.0023	0.9000
2012	1400 < kW ≤ 2000	Propulsion	6.0023	0.1509	0.1464	0.1127	0.1115	0.1174	0.0022	1.4048
2012	1400 < kW ≤ 2000	Auxiliary	4.8900	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2012	2000 < kW ≤ 3700	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2012	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2013	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2013	8 < kW ≤ 19	All	3.6300	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2013	19 < kW ≤ 37	All	3.7100	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2013	37 < kW ≤ 600	Propulsion	5.6678	0.1050	0.1019	0.0785	0.1703	0.1794	0.0034	1.1019
2013	37 < kW ≤ 600	Auxiliary	5.6613	0.1276	0.1237	0.0953	0.1964	0.2068	0.0039	0.9299
2013	600 < kW ≤ 1000	Propulsion	5.3033	0.0919	0.0892	0.0687	0.1377	0.1450	0.0028	1.1237
2013	600 < kW ≤ 1000	Auxiliary	5.4924	0.1098	0.1065	0.0820	0.1607	0.1692	0.0032	0.9000
2013	1000 < kW ≤ 1400	Propulsion	5.6593	0.1048	0.1016	0.0782	0.1544	0.1626	0.0031	1.1840
2013	1000 < kW ≤ 1400	Auxiliary	4.8837	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2013	1400 < kW ≤ 2000	Propulsion	5.3978	0.1000	0.0970	0.0747	0.0951	0.1002	0.0019	1.4048
2013	1400 < kW ≤ 2000	Auxiliary	4.8900	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2013	2000 < kW ≤ 3700	Propulsion	8.3300	0.1852	0.1796	0.1383	0.1340	0.1411	0.0027	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2013	3700 < kW	Propulsion	8.3300	0.3088	0.2995	0.2306	0.1340	0.1411	0.0027	2.0000
2014	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2014	8 < kW ≤ 19	All	2.3200	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2014	19 < kW ≤ 37	All	2.3200	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2014	37 < kW ≤ 600	Propulsion	4.6920	0.0690	0.0669	0.0515	0.1038	0.1093	0.0021	1.1019
2014	37 < kW ≤ 600	Auxiliary	4.5798	0.0847	0.0822	0.0633	0.1236	0.1301	0.0025	0.9299
2014	600 < kW ≤ 1000	Propulsion	4.7427	0.0711	0.0689	0.0531	0.0992	0.1045	0.0020	1.1237
2014	600 < kW ≤ 1000	Auxiliary	4.8188	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2014	1000 < kW ≤ 1400	Propulsion	4.8263	0.0737	0.0715	0.0551	0.0972	0.1024	0.0019	1.1840
2014	1000 < kW ≤ 1400	Auxiliary	4.8837	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2014	1400 < kW ≤ 2000	Propulsion	5.2690	0.0992	0.0963	0.0741	0.0915	0.0963	0.0018	1.4048
2014	1400 < kW ≤ 2000	Auxiliary	4.8900	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2014	2000 < kW ≤ 3700	Propulsion	1.3000	0.1818	0.1764	0.1358	0.0162	0.0171	0.0003	2.0000
2014	3700 < kW	Propulsion	1.3000	0.1796	0.1742	0.1341	0.0661	0.0696	0.0013	2.0000
2015	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2015	8 < kW ≤ 19	All	2.3200	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2015	19 < kW ≤ 37	All	2.3200	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2015	37 < kW ≤ 600	Propulsion	4.6920	0.0690	0.0669	0.0515	0.1038	0.1093	0.0021	1.1019
2015	37 < kW ≤ 600	Auxiliary	4.5798	0.0847	0.0822	0.0633	0.1236	0.1301	0.0025	0.9299
2015	600 < kW ≤ 1000	Propulsion	4.7427	0.0711	0.0689	0.0531	0.0992	0.1045	0.0020	1.1237
2015	600 < kW ≤ 1000	Auxiliary	4.8188	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2015	1000 < kW ≤ 1400	Propulsion	4.8263	0.0737	0.0715	0.0551	0.0972	0.1024	0.0019	1.1840
2015	1000 < kW ≤ 1400	Auxiliary	4.8837	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2015	1400 < kW ≤ 2000	Propulsion	5.2690	0.0992	0.0963	0.0741	0.0915	0.0963	0.0018	1.4048
2015	1400 < kW ≤ 2000	Auxiliary	4.8900	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2015	2000 < kW ≤ 3700	Propulsion	1.3000	0.1818	0.1764	0.1358	0.0162	0.0171	0.0003	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2015	3700 < kW	Propulsion	1.3000	0.1796	0.1742	0.1341	0.0661	0.0696	0.0013	2.0000
2016	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2016	8 < kW ≤ 19	All	2.3200	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2016	19 < kW ≤ 37	All	2.3200	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2016	37 < kW ≤ 600	Propulsion	4.6920	0.0690	0.0669	0.0515	0.1038	0.1093	0.0021	1.1019
2016	37 < kW ≤ 600	Auxiliary	4.5798	0.0847	0.0822	0.0633	0.1236	0.1301	0.0025	0.9299
2016	600 < kW ≤ 1000	Propulsion	4.7427	0.0711	0.0689	0.0531	0.0992	0.1045	0.0020	1.1237
2016	600 < kW ≤ 1000	Auxiliary	4.8188	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2016	1000 < kW ≤ 1400	Propulsion	4.8263	0.0737	0.0715	0.0551	0.0972	0.1024	0.0019	1.1840
2016	1000 < kW ≤ 1400	Auxiliary	4.8837	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2016	1400 < kW ≤ 2000	Propulsion	1.3000	0.0308	0.0299	0.0230	0.0324	0.0341	0.0006	1.4048
2016	1400 < kW ≤ 2000	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2016	2000 < kW ≤ 3700	Propulsion	1.3000	0.0338	0.0328	0.0252	0.0162	0.0171	0.0003	2.0000
2016	3700 < kW	Propulsion	1.3000	0.1796	0.1742	0.1341	0.0661	0.0696	0.0013	2.0000
2017	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2017	8 < kW ≤ 19	All	2.3200	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2017	19 < kW ≤ 37	All	2.3200	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2017	37 < kW ≤ 600	Propulsion	4.6920	0.0690	0.0669	0.0515	0.1038	0.1093	0.0021	1.1019
2017	37 < kW ≤ 600	Auxiliary	4.5798	0.0847	0.0822	0.0633	0.1236	0.1301	0.0025	0.9299
2017	600 < kW ≤ 1000	Propulsion	4.7427	0.0711	0.0689	0.0531	0.0992	0.1045	0.0020	1.1237
2017	600 < kW ≤ 1000	Auxiliary	4.8188	0.0800	0.0776	0.0598	0.1100	0.1158	0.0022	0.9000
2017	1000 < kW ≤ 1400	Propulsion	1.3000	0.0300	0.0291	0.0224	0.0381	0.0402	0.0008	1.1840
2017	1000 < kW ≤ 1400	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2017	1400 < kW ≤ 2000	Propulsion	1.3000	0.0308	0.0299	0.0230	0.0324	0.0341	0.0006	1.4048
2017	1400 < kW ≤ 2000	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2017	2000 < kW ≤ 3700	Propulsion	1.3000	0.0338	0.0328	0.0252	0.0162	0.0171	0.0003	2.0000

Model Year	Power Range	Engine Group	NOx (g/kWh)	PM10 & DPM10 (g/kWh)	PM2.5 & DPM2.5 (g/kWh)	BC (g/kWh)	HC (g/kWh)	VOC (g/kWh)	CH4 (g/kWh)	CO (g/kWh)
2017	3700 < kW	Propulsion	1.3000	0.0461	0.0447	0.0344	0.0178	0.0187	0.0004	2.0000
2018+	0 < kW ≤ 8	All	4.3900	0.2400	0.2328	0.1793	0.4300	0.4528	0.0086	4.1100
2018+	8 < kW ≤ 19	All	2.3200	0.1900	0.1843	0.1419	0.2100	0.2211	0.0042	2.1600
2018+	19 < kW ≤ 37	All	2.3200	0.1800	0.1746	0.1344	0.4100	0.4317	0.0082	1.5300
2018+	37 < kW ≤ 600	Propulsion	4.6920	0.0613	0.0595	0.0458	0.1038	0.1093	0.0021	1.1019
2018+	37 < kW ≤ 600	Auxiliary	4.5798	0.0770	0.0747	0.0575	0.1236	0.1301	0.0025	0.9299
2018+	600 < kW ≤ 1000	Propulsion	1.3000	0.0300	0.0291	0.0224	0.0395	0.0416	0.0008	1.1237
2018+	600 < kW ≤ 1000	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2018+	1000 < kW ≤ 1400	Propulsion	1.3000	0.0300	0.0291	0.0224	0.0381	0.0402	0.0008	1.1840
2018+	1000 < kW ≤ 1400	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2018+	1400 < kW ≤ 2000	Propulsion	1.3000	0.0308	0.0299	0.0230	0.0324	0.0341	0.0006	1.4048
2018+	1400 < kW ≤ 2000	Auxiliary	1.3000	0.0300	0.0291	0.0224	0.0400	0.0421	0.0008	0.9000
2018+	2000 < kW ≤ 3700	Propulsion	1.3000	0.0338	0.0328	0.0252	0.0162	0.0171	0.0003	2.0000
2018+	3700 < kW	Propulsion	1.3000	0.0461	0.0447	0.0344	0.0178	0.0187	0.0004	2.0000

Table H.7. Average Harbor Craft Emission Factors by Engine Tier

Tier	NOx (g/kWh)	PM_{10} (g/kWh)	$PM_{2.5}$ (g/kWh)	VOC (g/kWh)	CO (g/kWh)	CO_2 (g/kWh)	SO_2 (g/kWh)
Tier 0	10.28152	0.258902	0.251135	0.295615	1.612632	679.47	0.006246
Tier 1	9.624039	0.258902	0.251135	0.295615	1.61	679.47	0.006246
Tier 2	5.642273	0.148049	0.143608	0.295615	0.918732	679.47	0.006246
Tier 3	4.749214	0.082975	0.080486	0.124798	0.918732	679.47	0.006246
Tier 4	1.3	0.03	0.0291	0.124798	0.918732	679.47	0.006246

Appendix I ADDITIONAL DETAILS FOR CALCULATING AN ONROAD INVENTORY

This appendix provides additional details as a supplement to Section 7. Section I.1 discusses the Project Scale Refined Approach, which uses MOVES at the Project Scale to model a series of specific links that represent specific locations at the port. This approach is more detailed than the Project Scale Generic Link Approach (discussed in Section 7.6) and is applicable for port-related inventories intended to support refined air quality modeling requiring geographically allocated emissions.

Additionally, a hypothetical example is provided in Section I.2 to illustrate inputs for the Project Scale Generic Link Approach.

I.1 PROJECT SCALE REFINED APPROACH

The Project Scale Refined Approach uses MOVES at the Project Scale in Inventory calculation type, to create a series of links that represent specific locations at the port. Activity on each specific link is defined for a specific hour. In this approach, the MOVES user would include information about source types, vehicle volumes, and activity on each link. As noted, this method provides a total inventory for just one hour; additional runs would be needed to account for variation in activity over the course of a year. These results would then be "scaled up" to develop an inventory that covers an entire year. This approach is most appropriate for air quality dispersion modeling applications and is described in detail in EPA's PM Hot-spot Guidance.[48]

For the refined approach, multiple MOVES Project Scale runs are needed to represent activity and temperature differences over a 24-hour period, and activity, temperature, and fuel differences across seasons of the year. Refer to Section 4.3 of the PM Hot-spot Guidance for more details on developing representative hourly runs.[a] The emissions results from these runs would then be applied to all hours of the year in the air dispersion modeling step.

For the Project Scale Refined Inventory Approach, the output is emission mass quantities for the source types present and activities occuring within the one-hour period. These mass quantities should be multiplied by the number annual hours that the time span in the MOVES run represents (e.g., if the hourly run represents an 8-hour peak period during a typical weekday at the port, the emission quantity should be multiplied by 8 hrs × 5/7 days/week × 52 weeks). To produce a total annual inventory for a given pollutant, this calculation should be performed for each link for each run and aggregated to produce a total emission value.

I.2 HYPOTHETICAL PORT EXAMPLE

The following discussion provides a hypothetical example to illustrate how to estimate onroad emissions for a port in an unspecified county. The example illustrates some of the Project Data Manager (PDM)

[a] Note, the minimum of 16 runs specified in the PM Hot-spot Guidance—representing four time periods of a day, in each of four seasons—does not apply unless the emissions inventory is being conducted for hot-spot analysis purposes.

inputs for the Project Scale Generic Link Approach, detailed in Section 7, and how the results would be post-processed to develop an onroad inventory. Note that this example involves a hypothetical port, but the approach could be applicable for estimating emissions from a port-related onroad vehicle corridor or other onroad goods movement activity.

I.2.1 Details of Hypothetical Port

For simplicity, the number of sources and types of activity at this hypothetical port have been limited:

- There are only three source types present: combination short-haul trucks (sourceTypeID 61) and combination long-haul trucks (sourceTypeID 62) performing freight functions, and passenger cars (sourceTypeID 21) that arrive and park on port.
- The default fuel splits between gasoline and diesel for combination short-haul trucks and between gasoline, diesel, and E-85 for passenger cars are used. (MOVES can only model diesel combination long-haul trucks.)
- The port has only four types of activity, listed in Table I.1 below.

Table I.1. Example Project Scale Generic Link Approach Activity Types

Activity Type	MOVES Link Example
Driving to and from the port	Running link with observed 25 mph average speed
Queuing and creeping activities at gates	Running link with observed 1.8 mph average speed
Drayage driving activities on port	Running link with observed 10 mph average speed
Vehicle starts	Off-network Link

- In this example, all vehicles (the three source types) have start activity while on port. Passenger cars are parked for 12 or more hours before starting (opModeID 108), while combination short- and long-haul trucks are parked approximately 15 minutes before starting (opModeID 102), while queuing and loading.
- All running activity is on urban unrestricted roads (roadTypeID 5) with a 0% average road grade.

I.2.2 PDM Tabs Inputs

Links: In the Generic Link Approach, each link has only one source type. For this example, the *Link* input would include 9 links: 8 running links + 1 off-network link, and would look as follows in Table I.2:

Table I.2. Example Input for *Link* Table

linkID	countyID*	zoneID*	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	LinkAvgGrade
1			5	1	1	25.0	Drayage arterial	0
2			5	1	1	10.0	Drayage on port	0
3			5	1	1	1.8	Drayage queue	0
4			5	1	1	25.0	Long-haul arterial	0

linkID	countyID*	zoneID*	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	LinkAvgGrade
5			5	1	1	10.0	Long-haul on port	0
6			5	1	1	1.8	Long-haul queue	0
7			5	1	1	25.0	Car arterial	0
8			5	1	1	10.0	Car on port	0
9			1	0	3	0.0	Off-network	0

* The countyID and zoneID fields are populated based on selections made in the RunSpec.

Link 9 is the off-network link in this example. Note that unlike the other links, this link volume equals 3 to include the three source types (sourceTypeIDs 21, 61, and 62) present in the example.

Link Source Type: This input applies to running links only. In the Generic Link Approach, each link is set up with only one source type therefore the sourceTypeHourFraction is set to 1 (i.e., 100%). For the example, the *LinkSourceTypeHour* table would look as follows in Table I.3:

Table I.3. Example Input for *LinkSourceTypeHour* Table

linkID	sourceTypeID	sourceTypeHourFraction
1	61	1
2	61	1
3	61	1
4	62	1
5	62	1
6	62	1
7	21	1
8	21	1

Off-Network: This input describes the off-network link (see Table I.4). For the Generic Link approach, the user would indicate a vehicle population of 1 with 100% of the vehicles are starting during the hour (i.e., startFraction is 1) to get a start emission rate per vehicle for each source type in the MOVES output. No extended idling activity is assumed to occur on port, and therefore the last two columns should be left blank.

Table I.4. Example Input for *OffNetworkLink* Table

zoneID	sourceTypeID	vehiclePopulation	startFraction	extendedIdleFraction	parkedVehicleFraction
	21	1	1		
	61	1	1		
	62	1	1		

* The zoneID field is populated based on selections made in the RunSpec.

Operating Mode Distribution: This input is needed for an off-network link to describe how long vehicles have been soaking when they are started. The opModeID corresponds to the amount of soak time for each source type in the analysis. The pollutantProcessID is a combination of the pollutantID and the processID. While any number of pollutants may be of interest, for the purposes of this method, the only relevant process is "Start Exhaust," processID 02. In the example, nitrogen oxides (NOx), pollutantID 3, is the pollutant of interest, so the polProcessID is 302. The example specifies that passenger cars are parked for 12 or more hours (opModeID 108) while combination short- and long-haul trucks are parked for 15 minutes (opModeID 102) while queuing and loading.

A completed *OpModeDistribution* input table for this example would look as follows in Table I.5:

Table I.5. Example Input for *OpModeDistribution* Table

sourceTypeID	hourDayID*	linkID	polProcessID*	opModeID	opModeFraction
21		9	302	108	1
61		9	302	102	1
62		9	302	102	1

* The hourDayID and polProcessID fields are populated based on selections made in the RunSpec.

I.2.3 Post-Processing Project Scale Output for Inventory Development

As discussed in Section 7.6.5, MOVES will produce a link-by-link emission mass for each pollutant, for the hour specified within the RunSpec. The running links have emissions per mile and the off-network link has emissions per start. These emission rates by pollutant would then be multiplied by the corresponding vehicle activity. For purposes of illustration only, the hypothetical annual activity for combination long-haul trucks (sourceTypeID 62) is:

- 2,000,000 VMT approaching/leaving the port;
- 250,000 VMT on port;

- 500,000 hours of truck queuing activity, which includes the activity of idling and creeping at the gate as well as other idling while the truck is at the port, such as idling while loading and unloading; and
- 500,000 starts.

The total emissions of combination long-haul trucks would be calculated as:

Total emissions for sourceTypeID 62 = Link4 g/mi × (2,000,000 mi)

Link5 g/mi × (250,000 mi)

Link6 g/mi × (1.8 miles/hour) × (500,000 hr)

\+ Link9 g/start for sourceTypeID 62 × (500,000 starts)

Total g for sourceTypeID 62

Emissions from the activity of each source type would need to be summed in a similar fashion and all of them aggregated together for the total onroad inventory.

Appendix J HAP SPECIATION PROFILES FOR LOCOMOTIVE ENGINES

Hazardous air pollutants (HAPs) are calculated from various basis pollutants. The basis emission factors for diesel line-haul and switcher locomotives are given in Section 8.5.1. Emission factors for HAPs are calculated by multiplying the appropriate basis emission factor by the fraction listed in Table J.1.[72]

Table J.1. HAP Speciation Profiles for Locomotive Engines

Pollutant	Pollutant Code	Basis	Locomotive Type	Fraction
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394	$PM_{2.5}$	Line-haul (Class I)	2.63351E-09
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394	$PM_{2.5}$	Line-haul (Class II/III)	2.30432E-09
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394	$PM_{2.5}$	Switcher	1.43217E-09
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	35822469	$PM_{2.5}$	Line-haul (Class I)	5.08608E-09
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	35822469	$PM_{2.5}$	Line-haul (Class II/III)	4.45032E-09
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	35822469	$PM_{2.5}$	Switcher	2.76596E-09
1,2,3,4,7,8-Hexachlorodibenzofuran	70648269	$PM_{2.5}$	Line-haul (Class I)	9.78351E-10
1,2,3,4,7,8-Hexachlorodibenzofuran	70648269	$PM_{2.5}$	Line-haul (Class II/III)	8.56057E-10
1,2,3,4,7,8-Hexachlorodibenzofuran	70648269	$PM_{2.5}$	Switcher	5.32055E-10
1,2,3,6,7,8-Hexachlorodibenzofuran	57117449	$PM_{2.5}$	Line-haul (Class I)	5.16649E-10
1,2,3,6,7,8-Hexachlorodibenzofuran	57117449	$PM_{2.5}$	Line-haul (Class II/III)	4.52068E-10
1,2,3,6,7,8-Hexachlorodibenzofuran	57117449	$PM_{2.5}$	Switcher	2.80969E-10
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	57653857	$PM_{2.5}$	Line-haul (Class I)	1.25979E-10
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	57653857	$PM_{2.5}$	Line-haul (Class II/III)	1.10232E-10
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	57653857	$PM_{2.5}$	Switcher	6.85111E-11
1,2,3,7,8,9-Hexachlorodibenzofuran	72918219	$PM_{2.5}$	Line-haul (Class I)	3.69227E-10
1,2,3,7,8,9-Hexachlorodibenzofuran	72918219	$PM_{2.5}$	Line-haul (Class II/III)	3.23073E-10
1,2,3,7,8,9-Hexachlorodibenzofuran	72918219	$PM_{2.5}$	Switcher	2.00796E-10
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	19408743	$PM_{2.5}$	Line-haul (Class I)	5.81649E-10
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	19408743	$PM_{2.5}$	Line-haul (Class II/III)	5.08943E-10
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	19408743	$PM_{2.5}$	Switcher	3.16317E-10
1,2,3,7,8-Pentachlorodibenzofuran	57117416	$PM_{2.5}$	Line-haul (Class I)	1.68866E-09
1,2,3,7,8-Pentachlorodibenzofuran	57117416	$PM_{2.5}$	Line-haul (Class II/III)	1.47758E-09
1,2,3,7,8-Pentachlorodibenzofuran	57117416	$PM_{2.5}$	Switcher	9.18341E-10
1,3-Butadiene	106990	VOC	Line-haul (Class I)	1.86000E-03
1,3-Butadiene	106990	VOC	Line-haul (Class II/III)	1.86000E-03
1,3-Butadiene	106990	VOC	Switcher	1.86000E-03
2,2,4-Trimethylpentane	540841	VOC	Line-haul (Class I)	7.12000E-03

Pollutant	Pollutant Code	Basis	Locomotive Type	Fraction
2,2,4-Trimethylpentane	540841	VOC	Line-haul (Class II/III)	7.12000E-03
2,2,4-Trimethylpentane	540841	VOC	Switcher	7.12000E-03
2,3,4,7,8-Pentachlorodibenzofuran	57117314	$PM_{2.5}$	Line-haul (Class I)	2.70052E-09
2,3,4,7,8-Pentachlorodibenzofuran	57117314	$PM_{2.5}$	Line-haul (Class II/III)	2.36295E-09
2,3,4,7,8-Pentachlorodibenzofuran	57117314	$PM_{2.5}$	Switcher	1.46862E-09
2,3,7,8-Tetrachlorodibenzofuran	51207319	$PM_{2.5}$	Line-haul (Class I)	7.90722E-09
2,3,7,8-Tetrachlorodibenzofuran	51207319	$PM_{2.5}$	Line-haul (Class II/III)	6.91881E-09
2,3,7,8-Tetrachlorodibenzofuran	51207319	$PM_{2.5}$	Switcher	4.30017E-09
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	1746016	$PM_{2.5}$	Line-haul (Class I)	2.70722E-10
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	1746016	$PM_{2.5}$	Line-haul (Class II/III)	2.36881E-10
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	1746016	$PM_{2.5}$	Switcher	1.47226E-10
Acenaphthene	83329	VOC	Line-haul (Class I)	3.79000E-04
Acenaphthene	83329	VOC	Line-haul (Class II/III)	3.79000E-04
Acenaphthene	83329	VOC	Switcher	3.79000E-04
Acenaphthylene	208968	VOC	Line-haul (Class I)	4.95000E-04
Acenaphthylene	208968	VOC	Line-haul (Class II/III)	4.95000E-04
Acenaphthylene	208968	VOC	Switcher	4.95000E-04
Acetaldehyde	75070	VOC	Line-haul (Class I)	7.83000E-02
Acetaldehyde	75070	VOC	Line-haul (Class II/III)	7.83000E-02
Acetaldehyde	75070	VOC	Switcher	7.83000E-02
Acrolein	107028	VOC	Line-haul (Class I)	1.60000E-02
Acrolein	107028	VOC	Line-haul (Class II/III)	1.60000E-02
Acrolein	107028	VOC	Switcher	1.60000E-02
Anthracene	120127	$PM_{2.5}$	Line-haul (Class I)	9.46972E-05
Anthracene	120127	$PM_{2.5}$	Line-haul (Class II/III)	9.49449E-05
Anthracene	120127	$PM_{2.5}$	Switcher	1.38785E-04
Arsenic	7440382	$PM_{2.5}$	Line-haul (Class I)	1.07887E-03
Arsenic	7440382	$PM_{2.5}$	Line-haul (Class II/III)	9.44008E-04
Arsenic	7440382	$PM_{2.5}$	Switcher	5.86718E-04
Benz[a]Anthracene	56553	$PM_{2.5}$	Line-haul (Class I)	8.46970E-06
Benz[a]Anthracene	56553	$PM_{2.5}$	Line-haul (Class II/III)	8.48693E-06
Benz[a]Anthracene	56553	$PM_{2.5}$	Switcher	1.15358E-05
Benzene	71432	VOC	Line-haul (Class I)	2.25000E-02
Benzene	71432	VOC	Line-haul (Class II/III)	2.25000E-02

Pollutant	Pollutant Code	Basis	Locomotive Type	Fraction
Benzene	71432	VOC	Switcher	2.25000E-02
Benzo[a]Pyrene	50328	$PM_{2.5}$	Line-haul (Class I)	2.13000E-06
Benzo[a]Pyrene	50328	$PM_{2.5}$	Line-haul (Class II/III)	2.13000E-06
Benzo[a]Pyrene	50328	$PM_{2.5}$	Switcher	2.13000E-06
Benzo[b]Fluoranthene	205992	$PM_{2.5}$	Line-haul (Class I)	2.60000E-06
Benzo[b]Fluoranthene	205992	$PM_{2.5}$	Line-haul (Class II/III)	2.60000E-06
Benzo[b]Fluoranthene	205992	$PM_{2.5}$	Switcher	2.60000E-06
Benzo[g,h,i,]Perylene	191242	$PM_{2.5}$	Line-haul (Class I)	3.60144E-06
Benzo[g,h,i,]Perylene	191242	$PM_{2.5}$	Line-haul (Class II/III)	3.60797E-06
Benzo[g,h,i,]Perylene	191242	$PM_{2.5}$	Switcher	4.76314E-06
Benzo[k]Fluoranthene	207089	$PM_{2.5}$	Line-haul (Class I)	2.03000E-06
Benzo[k]Fluoranthene	207089	$PM_{2.5}$	Line-haul (Class II/III)	2.03000E-06
Benzo[k]Fluoranthene	207089	$PM_{2.5}$	Switcher	2.03000E-06
Chromium (VI)	18540299	$PM_{2.5}$	Line-haul (Class I)	5.21340E-06
Chromium (VI)	18540299	$PM_{2.5}$	Line-haul (Class II/III)	4.56173E-06
Chromium (VI)	18540299	$PM_{2.5}$	Switcher	2.83520E-06
Chrysene	218019	$PM_{2.5}$	Line-haul (Class I)	1.25129E-05
Chrysene	218019	$PM_{2.5}$	Line-haul (Class II/III)	1.25335E-05
Chrysene	218019	$PM_{2.5}$	Switcher	1.61789E-05
Dibenzo[a,h]Anthracene	53703	$PM_{2.5}$	Line-haul (Class I)	9.64000E-07
Dibenzo[a,h]Anthracene	53703	$PM_{2.5}$	Line-haul (Class II/III)	9.64000E-07
Dibenzo[a,h]Anthracene	53703	$PM_{2.5}$	Switcher	9.64000E-07
Ethyl Benzene	100414	VOC	Line-haul (Class I)	3.84000E-03
Ethyl Benzene	100414	VOC	Line-haul (Class II/III)	3.84000E-03
Ethyl Benzene	100414	VOC	Switcher	3.84000E-03
Fluoranthene	206440	$PM_{2.5}$	Line-haul (Class I)	1.02580E-04
Fluoranthene	206440	$PM_{2.5}$	Line-haul (Class II/III)	1.02859E-04
Fluoranthene	206440	$PM_{2.5}$	Switcher	1.52285E-04
Fluorene	86737	$PM_{2.5}$	Line-haul (Class I)	8.69565E-04
Fluorene	86737	$PM_{2.5}$	Line-haul (Class II/III)	8.72240E-04
Fluorene	86737	$PM_{2.5}$	Switcher	1.34567E-03
Formaldehyde	50000	VOC	Line-haul (Class I)	2.23000E-01
Formaldehyde	50000	VOC	Line-haul (Class II/III)	2.23000E-01
Formaldehyde	50000	VOC	Switcher	2.23000E-01

Pollutant	Pollutant Code	Basis	Locomotive Type	Fraction
Hexane	110543	VOC	Line-haul (Class I)	2.79000E-03
Hexane	110543	VOC	Line-haul (Class II/III)	2.79000E-03
Hexane	110543	VOC	Switcher	2.79000E-03
Indeno[1,2,3-c,d]Pyrene	193395	$PM_{2.5}$	Line-haul (Class I)	1.53000E-06
Indeno[1,2,3-c,d]Pyrene	193395	$PM_{2.5}$	Line-haul (Class II/III)	1.53000E-06
Indeno[1,2,3-c,d]Pyrene	193395	$PM_{2.5}$	Switcher	1.53000E-06
Manganese	7439965	$PM_{2.5}$	Line-haul (Class I)	2.31856E-03
Manganese	7439965	$PM_{2.5}$	Line-haul (Class II/III)	2.02874E-03
Manganese	7439965	$PM_{2.5}$	Switcher	1.26090E-03
Mercury	7439976	$PM_{2.5}$	Line-haul (Class I)	1.43000E-06
Mercury	7439976	$PM_{2.5}$	Line-haul (Class II/III)	1.25000E-06
Mercury	7439976	$PM_{2.5}$	Switcher	7.80000E-06
Naphthalene	91203	VOC	Line-haul (Class I)	2.73000E-03
Naphthalene	91203	VOC	Line-haul (Class II/III)	2.73000E-03
Naphthalene	91203	VOC	Switcher	2.73000E-03
Nickel	7440020	$PM_{2.5}$	Line-haul (Class I)	4.05412E-03
Nickel	7440020	$PM_{2.5}$	Line-haul (Class II/III)	3.54736E-03
Nickel	7440020	$PM_{2.5}$	Switcher	2.20475E-03
Octachlorodibenzofuran	39001020	$PM_{2.5}$	Line-haul (Class I)	2.25825E-09
Octachlorodibenzofuran	39001020	$PM_{2.5}$	Line-haul (Class II/III)	1.97597E-09
Octachlorodibenzofuran	39001020	$PM_{2.5}$	Switcher	1.22810E-09
Octachlorodibenzo-p-Dioxin	3268879	$PM_{2.5}$	Line-haul (Class I)	1.96340E-08
Octachlorodibenzo-p-Dioxin	3268879	$PM_{2.5}$	Line-haul (Class II/III)	1.71798E-08
Octachlorodibenzo-p-Dioxin	3268879	$PM_{2.5}$	Switcher	1.06775E-08
Phenanthrene	85018	$PM_{2.5}$	Line-haul (Class I)	1.87585E-03
Phenanthrene	85018	$PM_{2.5}$	Line-haul (Class II/III)	1.88136E-03
Phenanthrene	85018	$PM_{2.5}$	Switcher	2.85664E-03
Propionaldehyde	123386	VOC	Line-haul (Class I)	3.86000E-02
Propionaldehyde	123386	VOC	Line-haul (Class II/III)	3.86000E-02
Propionaldehyde	123386	VOC	Switcher	3.86000E-02
Pyrene	129000	$PM_{2.5}$	Line-haul (Class I)	1.40005E-04
Pyrene	129000	$PM_{2.5}$	Line-haul (Class II/III)	1.40360E-04
Pyrene	129000	$PM_{2.5}$	Switcher	2.03327E-04
Toluene	108883	VOC	Line-haul (Class I)	2.15000E-02

Pollutant	Pollutant Code	Basis	Locomotive Type	Fraction
Toluene	108883	VOC	Line-haul (Class II/III)	2.15000E-02
Toluene	108883	VOC	Switcher	2.15000E-02
Xylenes (Mixed Isomers)	1330207	VOC	Line-haul (Class I)	1.64400E-02
Xylenes (Mixed Isomers)	1330207	VOC	Line-haul (Class II/III)	1.64400E-02
Xylenes (Mixed Isomers)	1330207	VOC	Switcher	1.64400E-02

Appendix K ESTIMATING NUMBER OF TRUCKS AND RAIL CARS

This appendix provides a detailed methodology for estimating the number of trucks and rail cars moved by a port based on waterborne cargo activity. This method should be applied when more precise values cannot be obtained from relevant organizations (e.g., the railroad company servicing the port), as described in Sections 7.4.2 and 8.4.

This methodology relies upon publicly available data on tonnage and TEUs of waterborne cargo throughput from the U.S. Army Corps of Engineers (USACE). These data are used to determine the tonnage (for non-containerized cargo) and TEUs (for containerized cargo) of cargo throughput in each commodity class. Mode split for each commodity class is estimated based on data from the Federal Highway Administration, which enables the calculation of tonnage and TEUs moved by truck and rail. Average tonnage per rail car and truck by commodity class is determined based on rail car and truck configuration (e.g., volume capacity, payload) and commodity density.

As part of the *Waterborne Commerce Series*, USACE publishes annual data on tonnage of freight traffic by commodity (*Waterborne Commerce of the United States* reports[a]) and TEUs of container traffic moved by port (*Waterborne Container Traffic* statistics[63]). In the *Waterborne Commerce of the United States* reports, commodities are coded using nine major commodity classes and approximately 140 detailed classes. These data allow the commodity mix at each port to be determined, which is valuable given that the mode share of the domestic leg of a foreign movement is generally correlated with the commodity carried. The same is true for domestic waterborne movements.

This commodity mix can be applied to both containerized and non-containerized cargo, resulting in number of TEUs and tonnage, respectively, by port and by commodity. The USACE commodity classes can be divided in four categories based on the transportation equipment that is most likely to be utilized to transport the commodity by truck or rail: containerized, liquid bulk, dry bulk, and break bulk. This division is necessary to estimate the number of rail cars and trucks generated by each commodity at each port. Table K.1 provides a list of commodities moved by each conveyance type. It is important to note that for some commodities, this correspondence will vary by port; the specialization of the port should be considered when classifying such commodities. For example, food and agricultural products can be shipped as dry bulk or containerized cargo. Such commodities are more likely to be shipped as containerized cargo at ports that handle substantial amounts of containerized cargo and shipped as dry bulk at ports that predominantly handle bulk products. Although this adds some degree of uncertainty to the calculation of rail loads associated with specific equipment types (i.e., intermodal cars, tank cars, flat cars), the total number of rail cars and trucks should not vary widely depending on the classification of specific commodities.

[a] For more information, see https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center.

Table K.1. Commodities by Conveyance Type

Conveyance Type*	Commodities**
Containerized	Petrol. jelly & waxes; fertilizers (nitrogenous fert.; phosphatic fert.); other chemicals & related products (nitrogen func. comp.; organo-inorganic comp.; organic comp. NEC***; sulfuric acid; sodium hydroxide; inorganic elements, oxides & halogen salts; inorganic chem. NEC; radioactive material; pigments & paints; coloring mat. NEC; medicines; perfumes & cleansers; plastics; starches, gluten, glue; explosives; chemical additives; wood & resin chem.; chem. products NEC); rubber & gums; wood chips; non-ferrous scrap; non-metallic min. NEC; paper products; glass & glass products; misc. mineral products; primary non-ferrous metal products (smelted products NEC; fab. metal products); fish; grain (wheat; rice; oats; sorghum grains); oilseeds (soybeans; flaxseed); vegetable products; wheat flower; hay & fodder; other agricultural products (meat, fresh, frozen; meat, prepared; dairy products; fish, prepared; tallow, animal oils; animals & prod. NEC; bananas & plantains; fruit & nuts NEC; fruit juices; sugar; coffee; alcoholic beverages; groceries; food products NEC; tobacco & products; cotton; natural fibers NEC; farm products NEC); manufactured equipment & machinery products (machinery [not elec.]; electrical machinery; ordnance & access; manufactured wood products; textile products; rubber & plastic products; empty containers; manufactured products NEC); waste & scrap NEC; unknown or NEC
Liquid bulk	Crude petroleum; petroleum products (gasoline; kerosene; distillate fuel oil; residual fuel oil; lube oil & greases; naphtha & solvents; asphalt, tar & pitch; hydrocarbon & petrol gases, liquefied & gaseous; petrol. products NEC); fertilizers (potassic fert.; fert. & mixes NEC); other chemicals & related products (acyclic hydrocarbons; benzene & toluene; other hydrocarbons; alcohols; carboxylic acids; sulfur, liquid; ammonia; pesticides)
Dry bulk	Coal; petroleum coke; metallic salts; soil, sand, gravel, rock & stone (limestone; sand & gravel; dredged material; waterway improv. material; soil & fill dirt); iron ore & scrap; marine shells; non-ferrous ore & scrap (copper ore; aluminum ore; manganese ore; non-ferrous ores NEC); sulfur, dry; salt; slag; lime; cement & concrete; grain (corn, barley & rye); peanuts; other agricultural products (molasses; cocoa beans; water & ice)
Break bulk	Forest products & wood (fuel wood; wood in the rough; lumber; forest products NEC); pulp & waste paper; building stone; gypsum; phosphate rock; clay & refractory material; primary iron & steel products; copper; aluminum; primary wood products; oilseeds NEC; grain mill products; animal feed, prep.; vehicles & parts; aircraft & parts; ships & boats

* The provided commodity classifications are for a typical port. For some commodities, the correspondence with conveyance type may vary across ports.

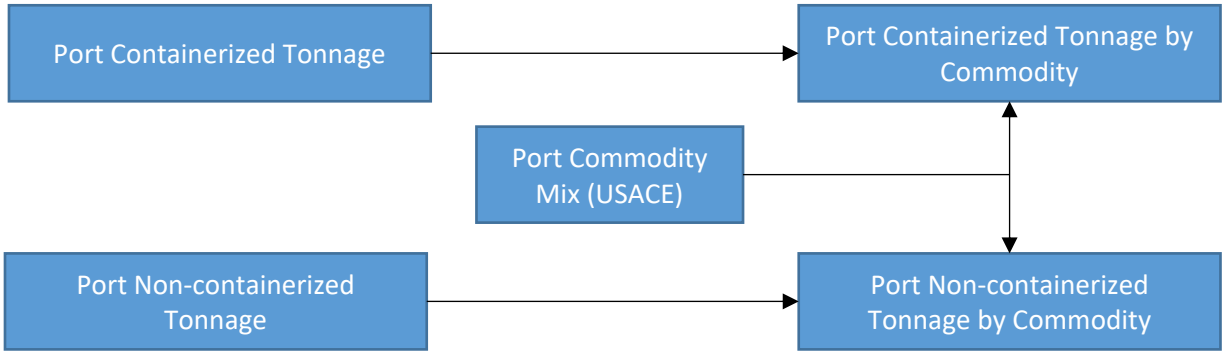
** Listed commodities may not be inclusive of all cargo handled at ports.

*** NEC indicates “not elsewhere classified”.

The number of containers moved by the port in TEUs can be taken directly from the USACE *Waterborne Container Traffic* statistics. The commodity split should then be determined based on the latest *Waterborne Commerce of the United States* report for the port. More specifically, TEUs should be allocated in proportion to the percentage of total tonnage belonging to a given USACE commodity type.

In the case of non-containerized cargo, the tonnage of non-container freight throughput by commodity should be determined using the latest *Waterborne Commerce of the United States* report for the port. The number of non-container equipment (e.g., rail gondolas, flat cars) used to move this cargo will be estimated below based on this information. Figure K-1 summarizes this step.

Figure K-1. Calculation of Port Tonnage by Commodity

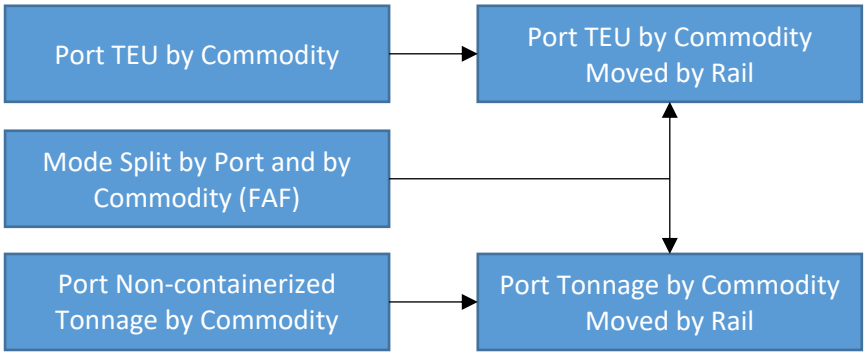


For ports without on-dock rail terminals, it can be assumed that all commodities will be moved by truck. For those ports with on-dock rail accessibility, it is necessary to understand how different shipments are distributed amongst truck and rail pathways. Aside from infrastructure availability (e.g., rail terminals), the best indicator of transportation mode is commodity type.

Mode split data can be taken from the Freight Analysis Framework (FAF).[15] It includes international and domestic shipments with information on origin, destination, port of entry (for international imports) or exit (for international exports), commodity type, transportation mode used on the domestic leg, value, and weight. Modes included are truck, rail, water, air, and others. The geographical zones for which estimates are available are varied; some zones include a large part of a state, while other zones are limited to a single metropolitan area.

Based on mode split by port and by commodity, it is possible to estimate the number of TEUs of containerized cargo and tonnage of non-containerized cargo of each commodity type that is moved by rail and truck. To do so, the total TEUs/tonnage of a given commodity moved by the port (derived from the USACE *Waterborne Commerce Series*) should be multiplied by the proportion of that commodity type moved by truck/rail (derived from the FAF), as shown in Figure K-2.

Figure K-2. Calculation of Port Tonnage by Commodity



To estimate the number of trucks and rail cars for non-containerized cargo, it is necessary to investigate commodity densities to determine whether a commodity would "weigh out" or "cube out." Very dense commodities tend to weigh out (i.e., reach tonnage capacity before it reaches the volume capacity of transportation equipment), while less dense commodities tend to cube out (i.e., reach volume capacity before it reaches tonnage capacity). Average densities for 18 commodity groups, based on the Standard International Trade Classification (SITC) system of classifying commodities and listed by Standard Classification of Transported Goods (SCTG) code, are presented in Table K.2.[73] The USACE commodity types can be matched to the SITC commodity groups for which densities are available.

Table K.2. Commodity Densities

SCTG Code	Product Name	SITC Code	Product Name	Density (lb/ft^3)	Density (ton/m^3)
4	Animal Feed and Prod. of Animal	8	Feeding-Stuff for Animals	20	0.3204
7	Prepared Foodstuffs and Fats and Oils	9	Miscellaneous Food Preparations	38	0.6087
18	Fuel Oils	22	Oil-Seeds, Oil-Nuts and Oil Kernels/Essential Oils and Perfume Products	29	0.4645
25	Logs and Other Wood in the Rough	24	Wood, Lumber, and Cork	25	0.4005
27	Pulp, Newsprint, Paper, and Paperboard	25	Pulp and Waste Paper	34	0.5446
22	Fertilizer	27	Crude Fertilizers and Crude Materials	64	1.0252
15	Coal	32	Coal, Coke, and Briquettes	53	0.8490
19	Coal and Petroleum Products, NEC*	33	Petroleum and Petroleum Products/Mineral Tar and Crude Petroleum Chemicals	51	0.8169
17	Gasoline and Aviation Turbine Fuel	34	Gas, Natural and Manufactured	26	0.4165

SCTG Code	Product Name	SITC Code	Product Name	Density (lb/ft^3)	Density (ton/m^3)
20	Basic Chemicals	51	Chemical Elements and Compounds	64	1.0252
20	Basic Chemicals	59	Chemical Materials and Products	36	0.5767
27	Pulp, Newsprint, Paper, and Paperboard	64	Paper, Paperboard and Manufactured Thereof	20	0.3204
12	Gravel and Crushed Stone	66	Concrete Brick/Block—Glazed Brick/Block	80	1.2815
31	Nonmetallic Mineral Products	66	Non-Metallic Mineral Manufactures	60	0.9611
32	Base Metal in Primary or Semifinished Forms and in Finished Basic Shapes	67	Iron and Steel	139	2.2266
32	Base Metal in Primary or Semifinished Forms and in Finished Basic Shapes	69	Manufactures of Metal	39	0.6247
26	Wood Products	82	Furniture	7	0.1121
43	Mixed Freight	89	Miscellaneous Manufactures Articles, NEC	21	0.3364

* NEC indicates “not elsewhere classified”.

Because of packaging issues, transportation equipment cannot be 100% utilized, even for commodities that cube out. For example, some beverage products are bottled and packaged in boxes. The space between bottles and the packaging material account for a share of the total volume being shipped. Additionally, depending on the shape of the packaging material, it might not be possible to utilize the full volume capacity of the transportation equipment. Bulk materials, on the other hand, can utilize 100% of the rail car or truck capacity if they do not weigh out first.

The commodity densities in Table K.2 can be multiplied by equipment utilization rates to obtain adjusted commodity densities. Table K.3 presents utilization assumptions for the four commodity types, as well as the equipment types commonly used to move each commodity type by truck and rail.

Table K.3. Truck and Rail Equipment Types and Utilization Rates by Conveyance Type

Conveyance Type	Truck/Rail Equipment Types	Equipment Utilization Rate
Containerized	Truck: Container on chassis Rail: Container on double-stack train	85%
Liquid bulk	Truck: Tanker truck Rail: Rail tank car	100%

Conveyance Type	Truck/Rail Equipment Types	Equipment Utilization Rate
Dry bulk	Truck: Dump truck Rail: Gondola	100%
Break bulk*	Truck: Flat trailer Rail: Flat car	85%

* The following break bulk commodities are assumed to have a rail car utilization rate of 50%:

- Aircraft and aircraft parts
- Electrical machinery
- Explosives
- Fabricated metal products
- Glass and glass products
- Non-electrical machinery
- Radioactive material
- Vehicles and vehicle parts

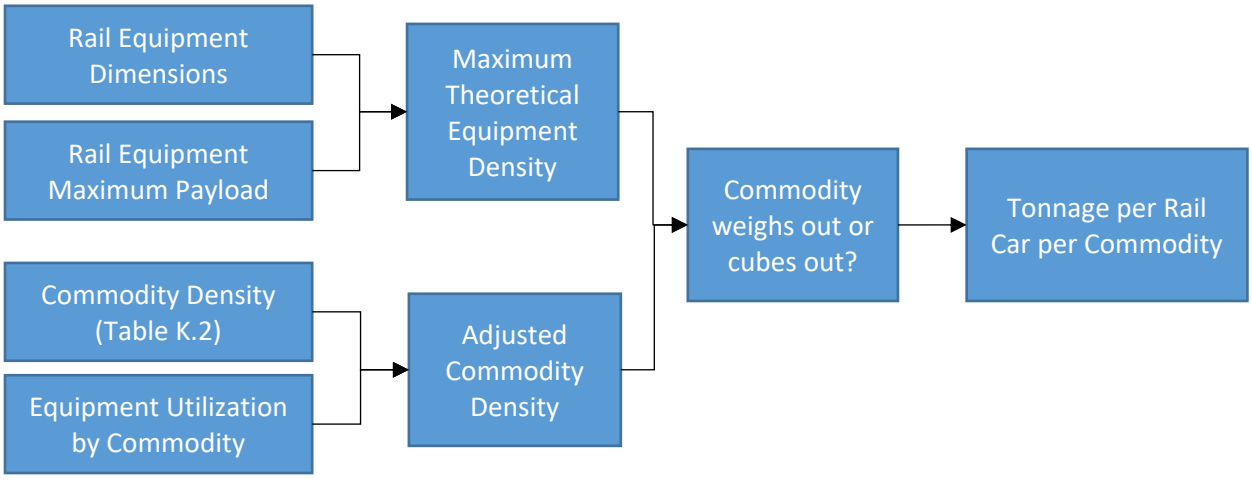
Table K.4 presents assumed physical dimensions and payload capacities for these rail and truck equipment types.

Table K.4. Equipment Dimensions

Equipment	Length (in)	Width (in)	Height (in)	Volume (in^3)	Volume (m^3)	Maximum Payload (tons)	Maximum Theoretical Density (ton/m^3)
20' Container	233	92	95	2,036,420	33	22	0.65
40' Container	475	93	94	4,152,450	68	27	0.39
Flat Car	804	96	102	7,872,768	129	120	0.93
Gondola	660	108	84	5,987,520	98	120	1.22
Rail Tank	240	96	102	2,350,080	39	120	3.10
Flat Trailer	570	102	110	6,395,400	105	21	0.20
Dump Truck	570	102	110	6,395,400	105	40	0.48
Tanker Truck	570	102	110	6,395,400	105	27	0.25

A maximum theoretical equipment density can be calculated as the ratio between the equipment's payload capacity and volume. Commodities with adjusted densities that are lower than the maximum theoretical equipment density will cube out, and commodities with adjusted densities that are higher than the maximum theoretical equipment density will weigh out. Based on the adjusted commodity densities and whether commodities generally weigh out or cube out, the average tonnage per rail car could be determined for each commodity, as shown in Figure K-3.

Figure K-3. Calculation of Tonnage per Rail Car by Commodity



If a given commodity type will weigh out, the maximum payload per container should be assumed. For commodities that will cube out, average tonnage per rail car/truck can be calculated using Equation K.1:

$$T = D \times V \qquad \textbf{Equation K.1}$$

Where T = average tonnage per rail car/truck
D = adjusted commodity density (ton/m^3)
V = equipment volume (m^3)

To calculate the total number of rail cars moved annually, the total tonnage of the commodity moved by truck/rail can be divided by the maximum payload tonnage (if the commodity weighs out) or the calculated average tonnage per rail car/truck value (if the commodity cubes out).