Appendix H

2021 Update to the Emission Inventory for Commercial Harbor Craft: Methodology and Results

Proposed Amendments to the
Commercial Harbor Craft Regulation

Date of Release: September 21, 2021
Date of Hearing: November 19, 2021

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Table of Contents

List of Figures

List of Tables

I. Executive Summary

Commercial Harbor Craft (CHC) include a wide range of commercial marine vessels, such as, but not limited to, commercial fishing vessels, commercial passenger fishing vessels, ferries, excursion vessels, tugboats, pilot vessels, crew and supply vessels, and workboats. Ocean-going vessels and recreational marine vessels are not considered harbor craft, except for ocean-going tugboats, tank barges, and dredges, which are specifically included. For a complete list of vessel categories and more information on the applicability of vessel types in the Proposed Amendments, refer to Appendix A of the Initial Statement of Reasons (ISOR). The majority of CHC are equipped with diesel engines, which are significant emitters of particulate matter (PM) and oxides of nitrogen (NOx). Furthermore, CHC emissions are concentrated around the seaports, harbors, marinas, and other communities adjacent to Regulated California Waters, and pose significant health risks to communities residing near these seaports. Communities near seaports are often low-income and disproportionately communities of color, and they experience a higher concentration of air pollution than other areas due to emissions from mobile sources such as CHC, trucks, locomotives, and ships.[1, 2]

California Air Resources Board's (CARB) CHC inventory covers vessels that operate in Regulated California Waters (RCW, 24 nautical miles of the mainland coastline), as shown in Figure H-1. Using the most recent and comprehensive information on CHC in California, the updated 2021 inventory has a base year of 2018, with emission projections out to 2050.

[1] Marshall JD., Environmental Inequality: Air Pollution Exposures in California's South Coast Air Basin, Atmospheric Environment, February 4, 2008, last accessed July 19, 2021, https://depts.washington.*edu*/airqual/Marshall_15.pdf.
[2] Marshall JD., et al., Prioritizing Environmental Justice and Equality: Diesel Emissions in Southern California, February 21, 2014, last accessed July 19, 2021, *https://pubs.acs.org/doi/pdf/10.1021/es405167f*.

Figure H-1. California RCW Boundary for CHC

The major inventory updates include the following items, which will be described in greater detail throughout the report:

1) Engine profile data, such as horsepower (HP), model year (MY), and annual hours, were obtained from reported data by vessel operators to CARB as of February 2019[3] (hereinafter referred to as CARB Reporting Data). Because the engine report was collected in early 2019, it was assumed to more closely represent the 2018 fleet inventory. All engines on vessels that were repowered as a result of receiving funding through the Carl Moyer Memorial Air Quality Standards Attainment Program were reconciled with CARB Reporting Data in this 2021 emission inventory update.[4]

[3] CHC engine data reported to CARB by owners/operators under the CHC Regulation, Feb 2019
[4] Carl Moyer Incentive Repowers data, 2019.

2) Vessel population data were collected from various sources, including CARB Reporting Data, the Merchant Vessel database from US Coast Guard (USCG)[5], and population data from Seaport of Los Angeles, Long Beach, and Oakland.
3) Population and activity growth factors were estimated based on historical trends in the past decade.
4) Engine survival and purchasing curves were developed from the age distribution of CHC from CARB Reporting Data.
5) Engine load factors were updated using CARB Reporting Data and engine control module (ECM) data requested and received from vessel owners/operators.
6) Emission factors (EFs) were updated using U.S. Environmental Protection Agency (EPA) marine[6] and off-road[7] engine certification data.
7) Spatial allocation of emissions within the RCW were updated using Automatic Identification System (AIS) data.[8]

CARB's first CHC inventory was released in 2007[9], with vessel and engine profile data largely based on a 2004 CARB CHC survey. The amendments in 2010 updated emissions from crew supply vessels and barge dredge vessels using reporting data from CARB's 2007 CHC regulation[10]. Figure H-2 shows the impact of the updated 2021 CHC emissions inventory compared to the 2010 inventory. The previous inventory is over twice as high as the updated inventory. All the inventory updates summarized above have contributed to the changes in emissions. Most notably previous CHC engine population and engine profile data were largely based on a survey, and the spatial allocation of emissions was based on staff's engineering judgment due to a lack of data. Staff were able to fill in a lot of the data gaps in the 2021 inventory.

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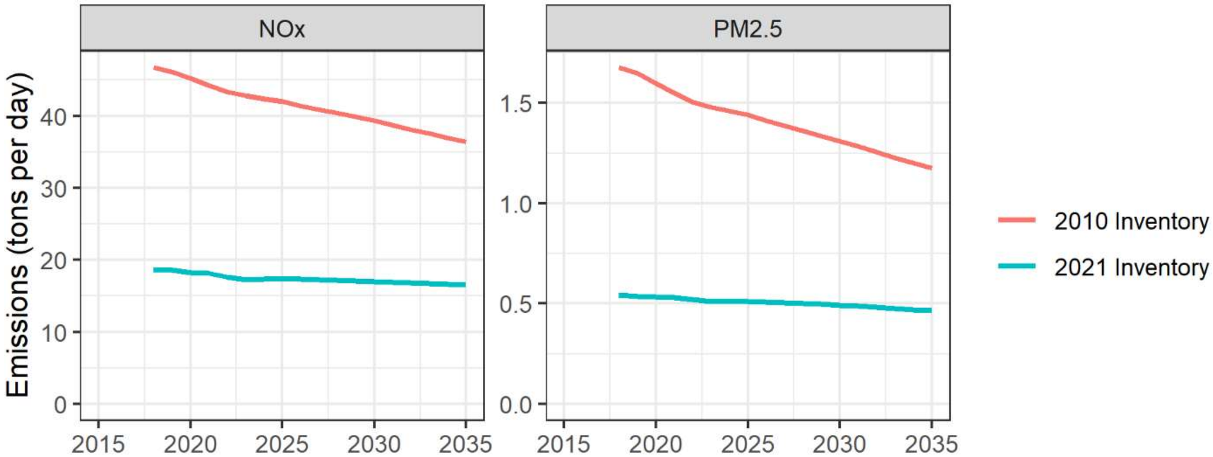
[5] U.S. Coast Guard, Merchant Vessels of the United States, last accessed May 30, 2019, *https://www.dco.uscg.mil/OurOrganization/AssistantCommandantforPreventionPolicy(CG-5P)/InspectionsCompliance(CG-5PC)/OfficeofInvestigationsCasualtyAnalysis/MerchantVesselsoftheUnitedStates.aspx*.
[6] U.S. EPA, Annual Certification Data for Vehicles, Engines, and Equipment: Marine Compression-Ignition (CI) Engines, 2020, *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*.
[7] U.S. EPA, Annual Certification Data for Vehicles, Engines, and Equipment: Nonroad Compression Ignition (NRCI) Engines, 2020, *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*.
[8] Marine Cadastre, Vessel Traffic Data, last accessed July 19, 2021, *https://marinecadastre.gov/ais/.*
[9] CARB, Appendix B: Emissions Estimation Methodology for Commercial Harbor Craft Operating in California, 2007, last accessed July 19, 2021, *https://ww3.arb.ca.gov/msei/chc-appendix-b-emission-estimates-ver02-27-2012.pdf*.
[10] CARB, Appendix C: Emission Inventory Methodology, 2011, last accessed July 19, 2021, *https://ww2.arb.ca.gov/sites/default/files/classic/regact/2010/chc10/appc.pdf*.

Figure H-2. Comparison of Statewide CHC Emissions in Updated and Previous Inventory (out to 100nm)



The 2021 CHC inventory is used to support health risk assessments near the seaports and the Proposed Amendments by CARB. See Appendix G of the ISOR for the Health Analyses. The Proposed Amendments would reduce NOx emissions by 53 percent and PM2.5 by 89 percent greenhouse gas (GHG) emissions by 8 percent by 2035.

The Proposed Amendments would apply to all CHC operating within RCW, which includes all internal, estuarine, and waters within 24 nm of the California Baseline as defined in subsection (d) of the regulatory text (Appendix A). This inventory is based on best available data. However, estimates may be subject to greater uncertainty in some parts of the State due to lack of data, such as at the Colorado River in Mojave Desert Air Basin, or in other air basins, especially internal waters, where CHC may operate periodically, but do not have a homeport at all locations where they operate. Notwithstanding the modeled vessel population in any one locale, the Proposed Amendments would still apply to all CHC operating in internal, estuarine, and coastal waters within 24 nm of the California Baseline.

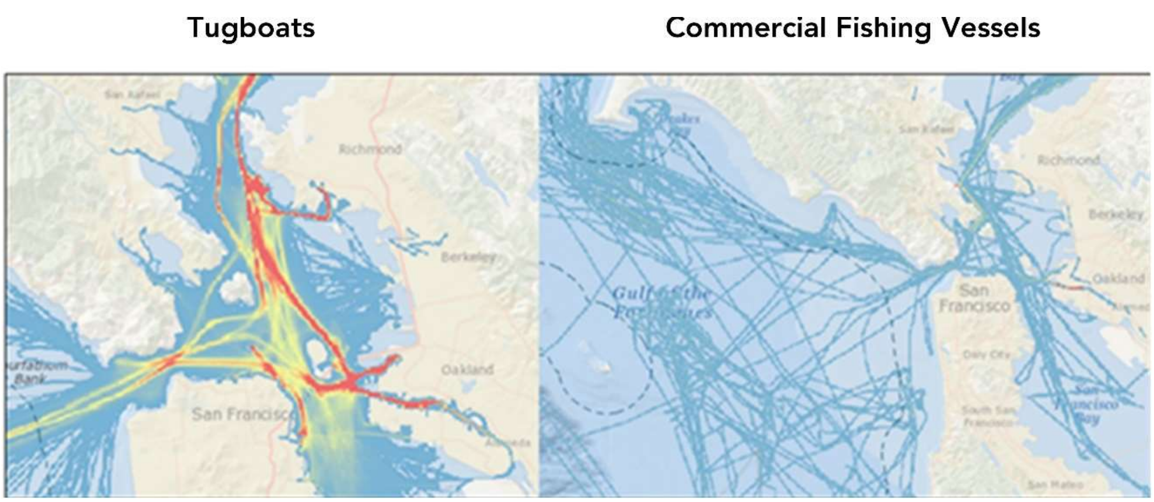
II. CHC Background Information

Emissions from CHC are produced by the propulsion engines (or main engines) and auxiliary engines that provide electric power or directly drive other onboard components. The vast majority of CHC have one or more auxiliary engine. While the main engines generally have more horsepower, the auxiliary engines can also contribute to health risk as they are often run continuously over long periods at or near seaports and population centers. Figure H-3 shows an example of a main engine on a tugboat.

Figure H-3. Tugboat Engine Room with 3,600 Horsepower Main Engine

CHC engine size varies with vessel type, as does the area where vessels operate. Figure H-4 shows the vessel transit intensity (shown in red for high traffic areas) for tugboats on the left, and commercial fishing vessels on the right. The activities of tugboats tend to be concentrated near major seaports and vessel travel lanes, while the activities of commercial fishing vessels are spread over a much larger area and are less concentrated. The operating areas of vessels are important in assessing the health impacts of vessel activities and detailed vessel operating geographic patterns will be explored in the health impact analysis in Appendix G of the ISOR.

Figure H-4. Bay Area Map of Vessel Traffic Density[11]



[11] Marine Cadastre, National Viewer, last accessed July 19, 2021, *https://marinecadastre.gov/nationalviewer/*.

III. Emissions Inventory Methodology

In this inventory, CHC are grouped into 18 vessel types: articulated tug barge (ATB), bunker barge, towed petrochemical barge, other barge, dredge, commercial passenger fishing, commercial fishing, crew and supply, catamaran ferry, monohull ferry, short run ferry, excursion, ATB tug, push and tow tug, escort/ship assist tug, pilot vessel, research vessel, and workboat. For details of vessel category definitions, please refer to Chapter 1 of the ISOR. CHC emissions in each calendar year are calculated using the following equation:

$$E = \sum_{i,j,k,l,m} POP_{i,j,k,l,m} * A_{j,k} * HP_{i,j,k,l} * LF_{j,k} * EF_{l,m} * FCF_m$$

Where:

- E: CHC emissions for each calendar year (ton/day)
- i, j, k, l, m: location, vessel type, engine type, horsepower bin, model year;
- POP: engine population;
- A: average activity in annual operating hours (hr);
- HP: average brake-horsepower (bhp);
- LF: load factor (unit-less);
- EF: emission factor, adjusted for deterioration (grams/bhp-hr); and
- FCF: fuel correction factor (unit-less).

The remainder of this report details the methodology for estimating each of the inputs for the base year, as well as forecasting them (e.g., population and age distributions) in future years.

A. Base Year Inputs

This section will cover the development of model inputs for the base year 2018 inventory, such as population, activity, and load factor.

1. Vessel Population and Engine Profile

As required by the 2007 CHC regulation, all CHC with diesel engines that operate in RCW are required to report detailed engine and vessel data to CARB. As of February 2019, CARB received compliance reports from 1,919 vessels. Detailed engine profile data are summarized in Table H-1. In the Merchant Vessel database from USCG, however, staff identified 3,272 CHC vessels with valid status of Certificate of Documentation (COD) that with a hailing seaport in California. In addition, CARB worked with vessel owners/operators to confirm that 19 ATB barges and 19 ATB tugboats that have home seaports in other states but regularly operate within California RCW. ATB tugboats were assumed to spend 80 percent of their time in San Francisco (SF) Bay Area and 20 percent in South Coast, while ATB barges were assumed to spend half of the time in SF Bay Area and the other half in South Coast.[12] CARB also identified an estimated 156 commercial passenger fishing vessels that are gasoline powered and thereby exempted from the CHC regulation[13, 14, 15, 16, and 17]. That brings the total of diesel powered CHC vessels in California to 3,154 (3,272+19+19-156=3,154). These data suggest about 39 percent of the operating CHC had not been reported to CARB as of February 2019.

To account for the unreported CHC vessels, staff scaled up the CARB Reporting data to match the total vessel population in California, assuming the unreported vessels having similar emission profiles as the reported vessels. For vessels with home ports in Port of Los Angeles, Long Leach, Oakland, and Richmond, comprehensive reporting and active inventory developments at the seaports allowed CARB to maintain seaport-specific population (i.e., the population at these seaports were not scaled to match USCG totals). Vessel population for the four seaports are provided in Table H-2. For the rest of the vessels, reported CHC population was scaled up to match that from USCG by vessel type. Detailed vessel population data, scaling factors for vessels excluding the four seaports, and final population used in the inventory are presented in Table H-3.

Table H-1. Summary of Engine Profile Data from CARB Reporting Data

Vessel Type	Vessel Count	Auxiliary Engine Count	Auxiliary Engine Average HP	Auxiliar Engine Average MY	Main Engine Count	Main Engine Average HP	Main Engine Average MY
Barge-ATB	13	81	381	2006	-	-	-
Barge-Bunker	12	33	170	2009	-	-	-
Barge-Other	46	102	224	2002	-	-	-
Barge-Towed Petrochemical	9	26	331	2005	-	-	-
Commercial Fishing	797	377	86	1999	888	305	1996
Commercial Passenger Fishing	274	196	67	2003	488	416	2005

[12] ATB Barges activity was split 50/50 between Bay Area and South Coast Air Basin based on data from petrochemical barges. ATB Tugs activity was quantified by the Air Basins using Marine Cadastre, Vessel Traffic Data, last accessed July 19, 2021, *https://marinecadastre.gov/ais/.*

[13] Staff estimated there are 334 6-pack CPFVs in the state. Staff used the resources in footnotes 14-17 to determine whether these vessels are powered by gasoline or diesel. It appears that 47% are gasoline, based on a sample of 45 randomly identified vessels. CARB therefore concluded there are 156 (334 *47%) CPFVs that are gasoline powered.

[14] Sportfish San Diego, Best of 3,4-Pack, 6-Pack Sport Fishing, Spearfishing Charters, last accessed July 20, 2021, *www.sportfishsandiego.com/6-pack.html*.

[15] Sportfishing Report, Charter Boats, last accessed July 20, 2021, *https://www.sportfishingreport.com/charter_boats/?page=8*.

[16] San Diego Fishing Company, Private Six Pack Sportfishing Charter, last accessed July 20, 2021, *http://www.sandiegofishing.co/*.

[17] Six Pack Fishing, Private Sportfishing Charters, last accessed July 20, 2021, *http://www.sixpackfishing.com/boats.html*.

Vessel Type	Vessel Count	Auxiliary Engine Count	Auxiliary Engine Average HP	Auxiliar Engine Average MY	Main Engine Count	Main Engine Average HP	Main Engine Average MY
Crew/Supply	71	77	107	2003	156	570	2006
Dredge	20	28	390	2009	16	441	2007
Excursion	177	170	109	2001	311	412	2000
Ferry-Catamaran	32	52	121	2010	78	1810	2010
Ferry-Monohull	19	26	80	2003	38	1194	2000
Ferry-Short Run	16	14	44	2002	26	400	2010
Pilot Vessel	9	9	74	2004	17	781	2007
Research Vessel	44	45	171	1998	86	635	1996
Tugboat-ATB	11	34	296	2005	22	4395	2006
Tugboat-Escort/Ship Assist	58	122	179	2009	117	2450	2008
Tugboat-Push/Tow	108	162	93	2003	211	731	2002
Workboat	204	149	247	1998	327	471	2000

Table H-2. CHC Population in Seaport of Los Angeles, Long Leach, Oakland, and Richmond

Seaport	Reported Population
Los Angeles and Long Beach	360
Oakland	27
Richmond	30
Total	417

Table H-3. CHC Baseline Year Vessel Population and Scaling Factor by Vessel Type in California (California Final Population is Used in the Inventory)

Vessel Type	CA Reported Population	CA Final Population	CA Excluding the Four Seaports Reported Population	CA Excluding the Four Seaports Final Population	CA Excluding the Four Seaports Scaling Factor
Barge-ATB	13	19 [i]	13	19	1.46
Barge-Bunker	12	31 [i]	2	21	10.50
Barge-Other	46	88 [i]	35	77	2.20
Barge-Towed Petrochemical	9	22 [i]	1	14	14.00
Commercial Fishing	797	1199 [ii]	689	1091	1.58
Commercial Passenger Fishing	274	352 [iii]	229	307	1.34
Crew/Supply	71	168 [iv]	37	133	3.61
Dredge	20	47 [i]	17	44	2.59
Excursion	177	417 [iv]	155	395	2.55
Ferry-Catamaran	32	32 [i]	29	29	1.00
Ferry-Monohull	19	19 [i]	14	14	1.00
Ferry-Short Run	16	16 [i]	11	11	1.00
Pilot Vessel	9	10 [i]	5	6	1.20
Research Vessel	44	25 [ii]	32	13	0.41

Vessel Type	CA Reported Population	CA Final Population	CA Excluding the Four Seaports Reported Population	CA Excluding the Four Seaports Final Population	CA Excluding the Four Seaports Scaling Factor
Tugboat-ATB	11	19 [i]	11	19	1.73
Tugboat-Escort/Ship Assist	58	63 [i]	16	21	1.31
Tugboat-Push/Tow	108	147 [i]	72	111	1.54
Workboat	204	481 [iv]	134	411	3.07
Total	1919	3154	1502	2737	-

i. Total barge, dredge, tugboat, ferry, and pilot vessel population are identified by CARB's research with the respective vessel owner/operators, and the seaports.
ii. Commercial fishing and research vessel population are provided in the Merchant Vessel database by USCG
iii. Commercial passenger vessel population are obtained through CARB's consultation with the California Department of Fish and Wildlife
iv. Workboat, crew/supply, and excursion vessel population are scaled up proportionally to match the remaining vessel population

2. Engine Activity

About 80 percent of the engines in the CARB Reporting data include cumulative hour meter readings and annual activity hours provided by vessel owners/operators. CARB's reporting form specifies that annual hours within 24 nautical miles (nm) of the CA coastline should be reported. However, upon contacting several operators, staff found that some operators reported total activity in all areas. Reported annual hours are also subject to human errors and biases. Non-resettable engine hour meters have been required for all CHC vessels in California since 2009. The average annual hour meter reading (cumulative hour meter reading divided by engine age) should represent average total annual activity. However, delayed hour meter installation and hour meter malfunctioning could also result in uncertainties in the data.

Considering the uncertainties in both reported annual hours and annual hour meter readings, staff used the larger of the two to represent annual total engine activity hour in all areas. The annual hours and the percentage of activity within 24 nm by vessel and engine type are presented in Table H-4Table H-4. The percentages of CHC activity spent within 24 nm in Regulated California Waters were obtained through vessel AIS data.[18]

Low-use engines, which are defined as the regulated vessels which used less than 300 hours for excursion, crew and supply, and tugboat vessels, or less than 80 hours for barge and dredge vessels, are not required to repower to Tier 2 or 3 standards under the Current CHC Regulation.

[18] Marine Cadastre, Vessel Traffic Data, last accessed July 19, 2021, *https://marinecadastre.gov/ais/.*

Low-use CHC engines for regulated in-use vessels were separated as their own category in the calculation of the average activity in Table H-4.

Table H-4. Average Total CHC Annual Hours and Activity Fraction Within 24nm by Vessel and Engine Type

Vessel Type	Regular Engines Auxiliary engine (hours)	Regular Engines Main Engine (hours)	Low-Use Engines (regulated vessels) Auxiliary engine (hours)	Low-Use Engines (regulated vessels) Main Engine (hours)	Activity Fraction within 24nm
Barge-ATB	856	-	138	-	100%
Barge-Bunker	1616	-	141	-	100%
Barge-Other	1031	-	80	-	100%
Barge-Towed Petrochemical	1930	-	117	-	100%
Crew/Supply	2104	1811	100	206	100%
Dredge	1969	1227	66	218	98%
Excursion	1040	1070	189	202	99%
Ferry-Catamaran	1774	2372	231	289	100%
Ferry-Monohull	1654	2327	94	128	100%
Ferry-Short Run	2605	2674	213	131	100%
Tugboat-ATB	4504	2466	59	126	39%
Tugboat-Escort/ Ship Assist	2433	2676	186	157	100%
Tugboat-Push/Tow	1822	1550	153	153	86%
Commercial Fishing	1190	997	-	-	92%
Commercial Passenger Fishing	1650	1193	-	-	83%
Pilot Vessel	1887	2269	-	-	100%
Research Vessel	1037	957	-	-	82%
Workboat	717	639	-	-	97%

3. Population Growth

Port of Los Angeles and Long Beach have been publishing detailed CHC inventory data over the last decade.[19, 20] The inventories show that CHC population at the two seaports stayed relatively constant from 2010-2018, as presented in Figure H-5. Figure H-6 shows that CHC population growth from CARB Report were also mostly flat for most vessel types, except for commercial

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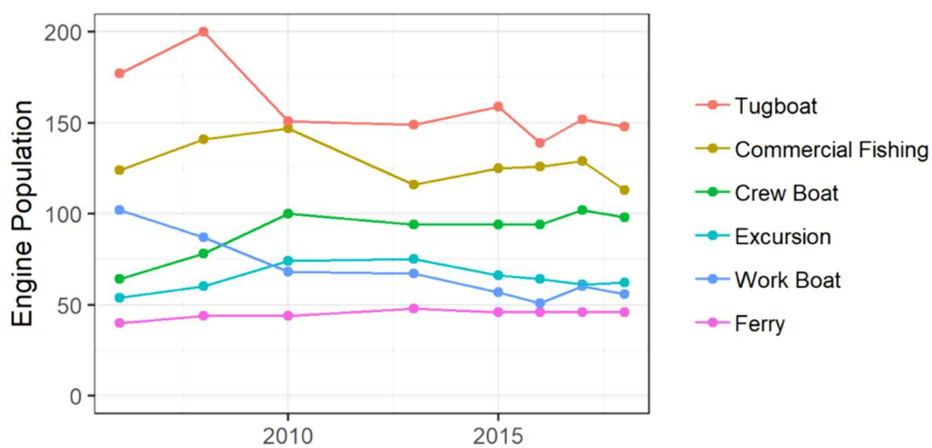
[19] Starcrest Consulting Group, Port of Los Angeles Inventory of Air Emissions, 2018, last accessed July 19, 2021, *https://kentico.portoflosangeles.org/getmedia/0e10199c-173e-4c70-9d1d-c87b9f3738b1/2018_Air_Emissions_Inventory*.

[20] Starcrest Consulting Group, Port of Long Beach Air Emissions Inventory, 2017, last accessed July 19, 2021, *https://safety4sea.com/wp-content/uploads/2018/08/POLB-2017-Air-Emissions-Inventory-2018_08.pdf?__cf_chl_jschl_tk__=pmd_b82d2e13ea42959b205f5bb3fc1675897a86df68-1626736313-0-gqNtZGzNAiKjcnBszQji*.

fishing and commercial passenger fishing vessels. Discussions with regulatory staff and industry suggested that trends in commercial fishing vessel population were more likely to reflect increases in reporting rates than actual changes in population. Based on these trends, staff projected zero population growth for CHC from 2018-2050 (except for ferries). SF Bay Area Water Emergency Transportation Authority (WETA) has developed a Strategic Plan outlining potential growth of its fleet from 12 vessels in 2016 to 44 vessels in 2035[21], an annual growth rate of about 7 percent. The four ferry companies (WETA, Golden Gate ferry, Tideline and Prop SF) in SF had a total fleet of 45 vessels in 2018. Although no other ferry operators in the San Francisco Bay Area developed growth projections, CARB staff applied the projected growth from WETA to all other ferry vessels operating in the air basin.

It is notable that nearly all forms of freight transportation, containers, and bulk goods had generally increased during 2010-2018[22]. The container counts measured in Twenty-Foot Equivalent Units (TEUs) in Port of Los Angeles and Long Beach increased by 24 percent from 2010-2018[23,24]. This initially led CARB to assume tugboat population would grow at the same rate as other freight sources (such as ocean-going vessels). However, the seaports' inventory data showed a 2 percent decrease in tugboat main engine population. This may be due to operational changes, increased engine size, or increased efficiency in tugboat activity.

Figure H-5. CHC Main Engine Population from Port of Los Angeles and Long Beach



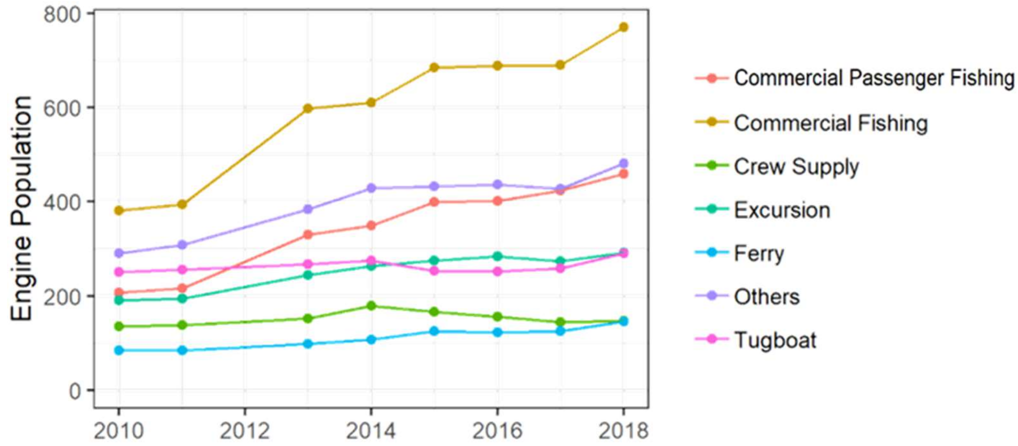
[21] San Francisco Bay Area Water Emergency Transportation Authority, 2016 Strategic Plan, 2016, last accessed July 19, 2021, *https://weta.sanfranciscobayferry.com/sites/default/files/weta/strategicplan/WETAStrategicPlanFinal.pdf*.

[22] Bureau of Transportation Statistics, National Transportation Statistics, last accessed July 19, 2021, *https://www.bts.gov/topics/national-transportation-statistics*.

[23] Port of Long Beach, Port Statistics, last accessed July 19, 2021, *https://polb.com/business/port-statistics/#yearly-teus.*

[24] Port of Los Angeles, Annual Container Statistics, last accessed July 19, 2021, *https://www.portoflosangeles.org/business/statistics/container-statistics*.

Figure H-6. CHC Main Engine Population from CARB Reporting Data



4. Activity Growth

While CHC population remained relatively constant, CARB staff evaluated whether activity rates for CHC were increasing to handle the increase in freight movement at their respective seaports over the same period.

Figure H-7 shows that CHC average activity in annual hours from CARB reporting data stays relatively constant from 2010-2018. Figure H-8 shows average activity for most vessel types from Port of LA/LB first decreased from 2006-2010, and then stayed relatively constant from 2010-2015, and finally increased after 2015. Based on these trends, staff projected that CHC average annual hours will remain at current levels through 2050. Note that overall activity from the ferry categories increased due to population growth as noted above; however, the average annual activity per ferry is not projected to change.

Figure H-7. Average Engine Activity from CARB Reporting Data

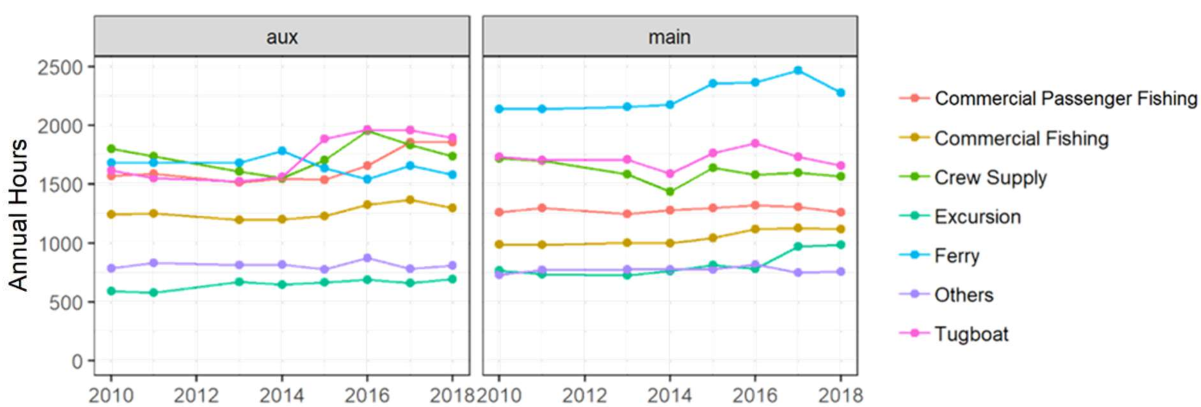
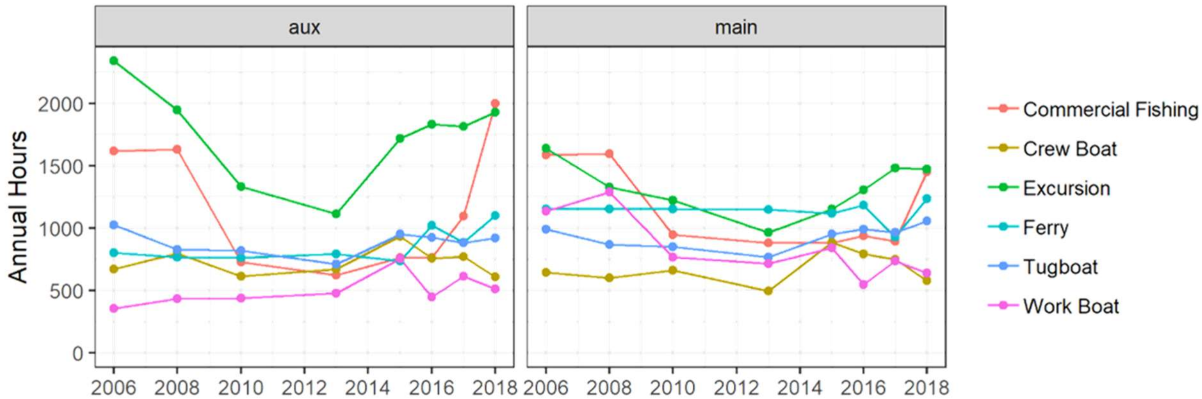


Figure H-8. Average Engine Activity from Port of Los Angeles and Long Beach



The onset of the global situation that began in 2020 had a temporary impact on freight movement, reducing overall freight in the first half of 2020. However, by 2021, freight at major ports had increased significantly over the same period in 2019, showing that the global situation that began in 2020 did not appear to have consistently or permanently reduced freight demand. These data are explored further in this discussion paper.[25]

B. Population Turnover: Survival and Purchasing Curves

The turnover or survival rate represents the relationship between equipment age and the proportion of equipment that is retired from the fleet. Equipment generally leaves a fleet due to scrappage or being sold to another fleet. Purchasing rates represent the age distribution of newly purchased equipment. Survival and purchasing rates determine the fleet age distribution. Staff used the vessel age distributions in the most recent and most complete CARB reporting data from February 2019 to develop the survival and purchasing rates, assuming future age distributions of CHC will be similar to the current age distribution.

Figure H-9 shows CHC age distributions by vessel and engine type for several vessel categories. Because of the combined effects of turnover and purchasing, age distributions for a fleet generally have a bell-shaped curve. To model a similar age distribution in the future, age distribution curves were separated into two curves from the peak population point: purchasing curves and survival curves. The purchasing curve reflects new purchases without any turnover before the age where the population reaches its peak. No new purchasing was assumed to happen after population peak age. The two curves were fitted separately using logistic regression, and then purchasing and survival rates were derived from the curves. Figure H-10 shows an example of the purchasing and survival curves for excursion vessels and main engines.

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[25] CARB, Emissions Impact of Recent Congestion at California Ports, June 28, 2021, last accessed August 11, 2021, *https://ww2.arb.ca.gov/sites/default/files/2021-06/ogvcongestion_ada.pdf.*

Figure H-9. CHC Age Distribution by Vessel and Engine Type from CARB Reporting Data

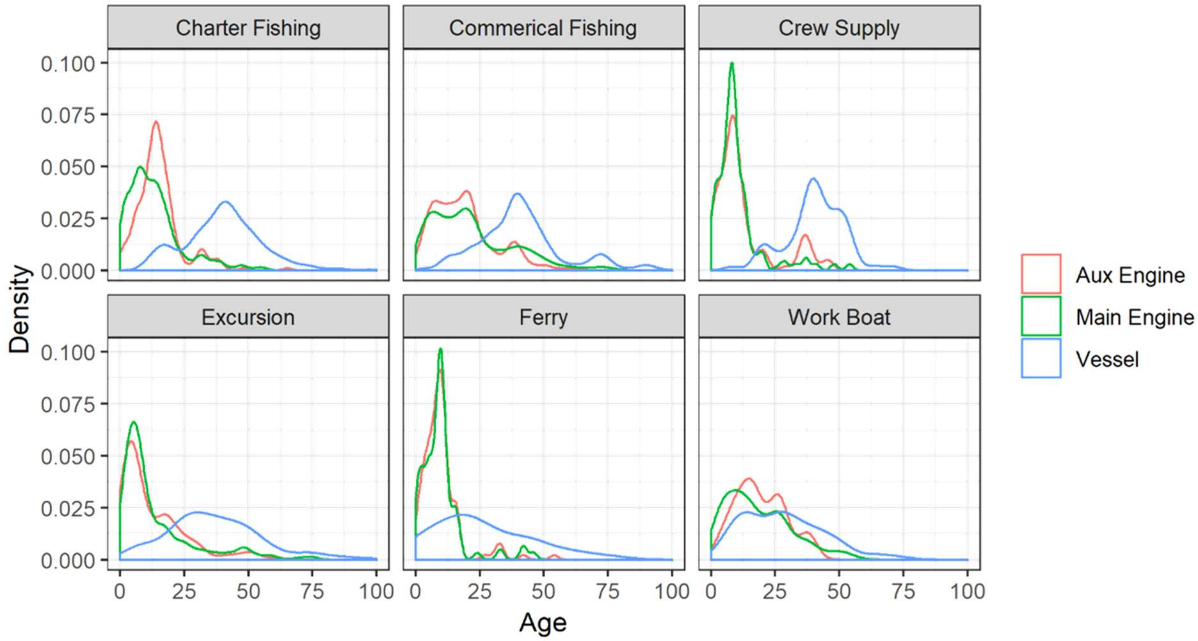
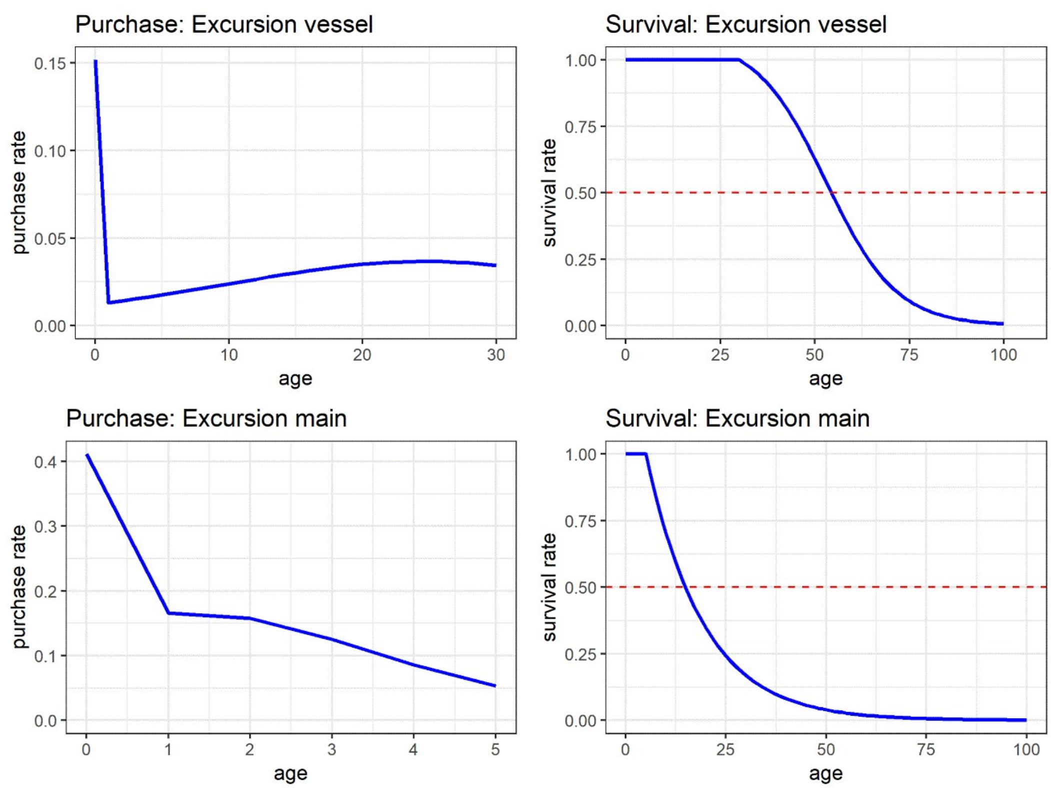
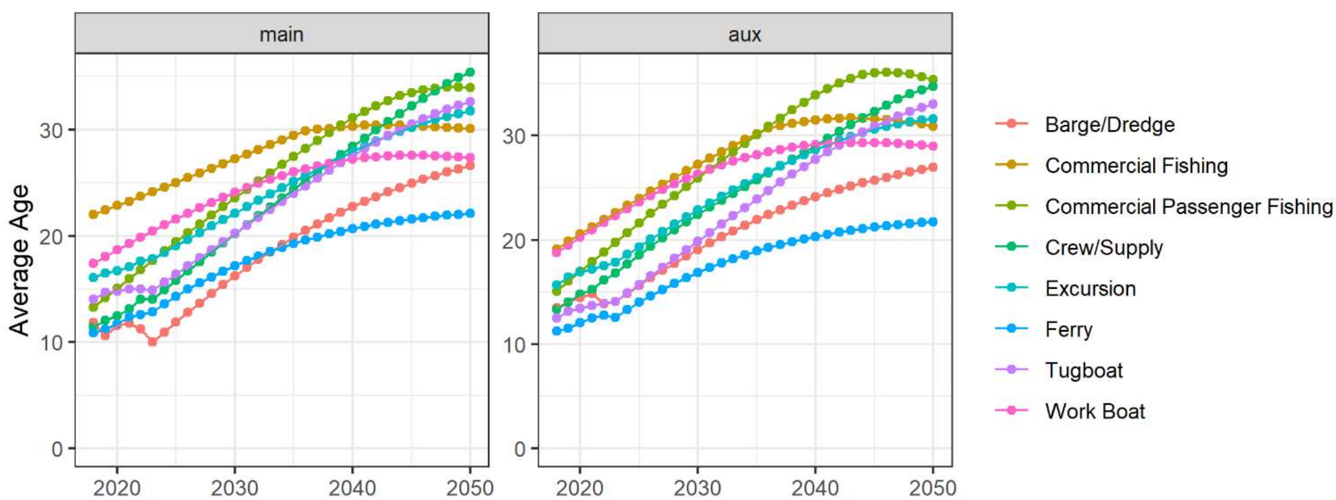


Figure H-10. Purchasing and Survival Curves for Excursion Vessel and Main Engine



Historically, CHC engines have significantly higher turnover rates than vessels, meaning that vessels are repowered with new engines more often than vessels are being replaced. Vessel lifetime is about two to three times that of engines as shown in Figure H-9. However, discussions with the CHC industry indicated that wherever possible, fleets will rebuild engines rather than repower vessels with newer engines meeting current standards. This is due to increased costs of engines meeting newer standards, potential logistical considerations associated with installing newer engines that may require different components, and vessel upgrades required for components such as the engine cooling systems or transmission systems. Therefore, this inventory currently reflects that engines will be rebuilt to the original standard to which they were certified until the vessel is replaced. Therefore, vessel survival rates are used for both main and auxiliary engines. As vessels generally last at least twice as long as engines, this means that the average engine age is expected to significantly increase and would eventually more closely match the vessel ages seen in the inventory. This trend may also have been increased by the accelerated turnover to Tier 2 and Tier 3 vessels under the Current Regulation, making it unlikely that vessel owners will voluntarily replace the current engines with Tier 4 main or auxiliary engines, even if the engines are available and could be installed. In the absence of additional regulation, Tier 4 adoption rates are likely to remain extremely low. The shift of average age by vessel and engine type from 2018-2050 is shown in Figure H-11.

Figure H-11. Average CHC Engine Age by Vessel and Engine Type



C. Emission Factors

Emission factors are the rates (most commonly in grams per brake-horsepower-hour) that engines produce emissions of air pollutants. For most pollutants, emission factors depend on the size and model year of the engine, and the deterioration of engines and engine controls over time. For carbon dioxide (CO2) and brake specific fuel consumption (BSFC) rates, no deterioration is applied.

In this inventory, emission factors of diesel particulate matter (DPM), NOx, CO, and HC are determined using the following equation:

$$EF = EF_0(1 + DF \times Age/UL)$$

Where:

- **EF_0**: zero-hour emission factor, when engine is new or rebuilt (g/bhp-hr);
- **DF**: the horsepower and pollutant specific engine deterioration factor, which is the percentage increase of emission factors at the end of the useful life of the engine;
- **Age**: the age of the engine when the emissions are estimated; and
- **UL**: the vessel and engine type specific engine useful life.

1. Zero-Hour Emission Factors

CHC engines are a mix of marine certified category 1 and category 2 engines, and off-road certified engines. Among the 4,393 engines in CARB reported data, 828 were identified in the U.S. EPA certified marine engine list[26] via engine family name, 217 were identified in the U.S. EPA certified off-road engine list[27], and the rest of the engines either did not have a valid engine family name or cannot be identified in the certification database. No significant differences in EFs have been found between marine category 1 and category 2 engines by Tier, nor between marine and off-road certified engines. Staff applied the certification levels of all identified 1,045 CHC engines to develop zero-hour EFs of DPM and NOx. PM2.5 (particles that have diameter less than 2.5 micrometers) EFs are assumed to be 95.6 percent of the DPM EFs, based on CARB's latest DPM speciation profile[28] to convert DPM to PM2.5.

EFs were estimated for main and auxiliary engines by horsepower bin and Tier group using the 1,045 certification levels. Engines were grouped into four horsepower bins based on available engine population and ranges in EFs: 0–49, 50–99, 100–799, and over 800 hp. NOx certification values for all engines by horsepower bin and Tier standard are demonstrated in Figure H-12. As shown in Figure H-12, only engines in the 100-799 horsepower bin have sufficient data to development EFs for both main and auxiliary engines. Therefore, for engines in the 100-799 horsepower bin group, EFs were estimated by averaging certification values by horsepower bin, Tier standard, and engine type; for engines in other horsepower bins, EFs were grouped by horsepower bin and Tier standard and were applied to both main and auxiliary engines. Because of limited number of Tier 0 engines (also known as pre-Tier 1 engines or uncontrolled),

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[26] U.S. EPA, Annual Certification Data for Vehicles, Engines, and Equipment: Marine Compression-Ignition (CI) Engines, 2020, *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*.

[27] U.S. EPA, Annual Certification Data for Vehicles, Engines, and Equipment: Nonroad Compression Ignition (NRCI) Engines, 2020, *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*.

[28] CARB, Speciation Profiles Used in CARB Modeling, April 2021, last accessed July 20, 2021, *https://ww2.arb.ca.gov/speciation-profiles-used-carb-modeling*.

their EFs were adopted from general off-road EFs[29][30], and Tier 4 EFs were obtained from average EFs of Tier 4 engines in the U.S. EPA marine certification database. Final NOx and DPM EFs by Tier and horsepower bin are shown Table H-5.

Figure H-12. CHC NOx Certification EF Values by Horsepower Bin and Tier Standard

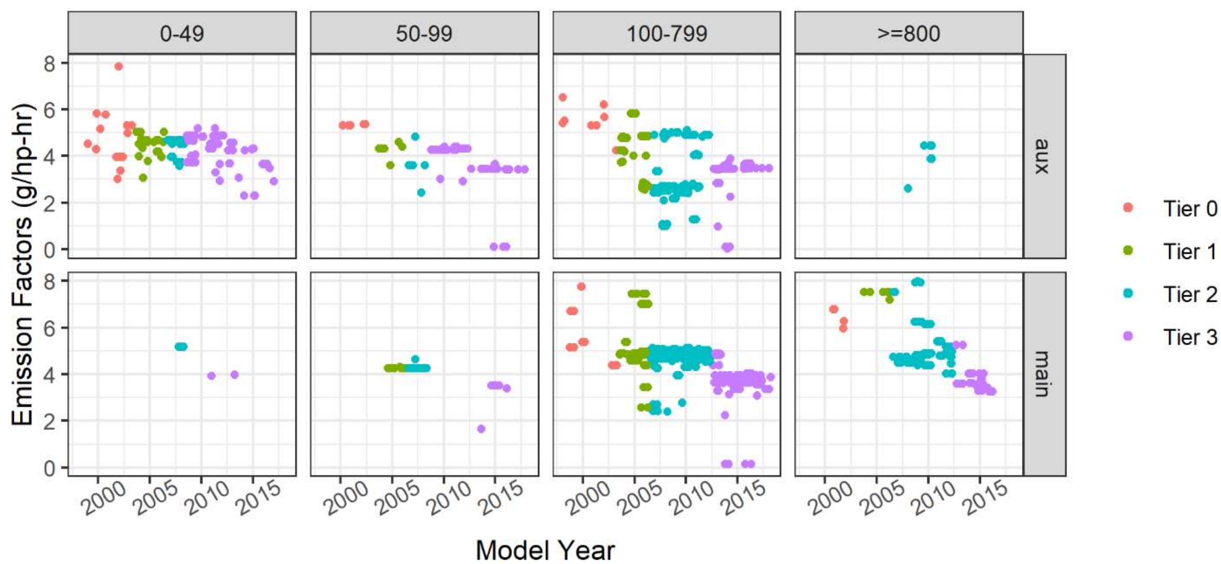


Table H-5. Emission Factors (gram/bhp-hr) of CHC Engines by Horsepower Bin and Tier Standard

Pollutant	Horsepower Bin	Tier Standard	Main Engine	Auxiliary Engine
NOx	0-24	0 (pre-MY 2000)	9.00	9.00
NOx	0-24	0 (MY 2000-2003)	4.67	4.67
NOx	0-24	1	4.52	4.52
NOx	0-24	2	4.57	4.57
NOx	0-24	3	4.29	4.29
NOx	100-174	0 (pre- MY 1988)	12.20	12.20
NOx	100-174	0 (MY 1988-1999)	9.61	9.61
NOx	100-174	0 (MY 2000-2003)	5.62	5.62
NOx	100-174	1	5.20	4.17
NOx	100-174	2	4.76	3.02
NOx	100-174	3	3.73	3.22
NOx	175-799	0 (pre-MY 1988)	12.20	12.20

[29] CARB, 2017 Off-Road Diesel Emission Factor Update for NOx and PM, 2017, last accessed July 19, 2021, *https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf*.

[30] CARB, 2017 Off-Road Diesel Emission Factor Update for NOx and PM, 2017, last accessed July 19, 2021, *https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf*.

Pollutant	Horsepower Bin	Tier Standard	Main Engine	Auxiliary Engine
NOx	175-799	0 (MY 1988-1999)	7.34	7.34
NOx	175-799	0 (MY 2000-2003)	5.62	5.62
NOx	175-799	1	5.20	4.17
NOx	175-799	2	4.76	3.02
NOx	175-799	3	3.73	3.22
NOx	25-49	0 (pre-MY 2000)	8.00	8.00
NOx	25-49	0 (MY 2000-2003)	4.67	4.67
NOx	25-49	1	4.52	4.52
NOx	25-49	2	4.57	4.57
NOx	25-49	3	4.29	4.29
NOx	50-99	0 (pre-MY 1988)	13.00	13.00
NOx	50-99	0 (MY 1988-1999)	8.30	8.30
NOx	50-99	0 (MY 2000-2003)	5.33	5.33
NOx	50–99	1	4.26	4.26
NOx	50–99	2	4.02	4.02
NOx	50–99	3	3.75	3.75
NOx	>=800	0 (pre- MY1988)	12.20	12.20
NOx	>=800	0 (MY 1988-2003)	7.34	7.34
NOx	>=800	1	6.97	6.97
NOx	>=800	2	5.08	5.08
NOx	>=800	3	3.69	3.69
NOx	>=800	4	1.04	1.04
DPM	0-24	0 (pre-MY 2000)	0.90	0.90
DPM	0-24	0 (MY 2000-2003)	4.67	4.67
DPM	0-24	1	0.26	0.26
DPM	0-24	2	0.19	0.19
DPM	0-24	3	0.17	0.17
DPM	100-174	0 (pre-MY 1988)	0.62	0.62
DPM	100-174	0 (MY 1988-1999)	0.44	0.44
DPM	100-174	0 (MY 2000-2003)	0.12	0.12
DPM	100-174	1	0.09	0.13
DPM	100-174	2	0.09	0.11
DPM	100-174	3	0.05	0.07
DPM	175-799	0 (pre-MY 1988)	0.62	0.62
DPM	175-799	0 (MY 1988-1999)	0.37	0.37
DPM	175-799	0 (MY 2000-2003)	0.12	0.12
DPM	175-799	1	0.09	0.13
DPM	175-799	2	0.09	0.11

Pollutant	Horsepower Bin	Tier Standard	Main Engine	Auxiliary Engine
DPM	175-799	3	0.05	0.07
DPM	25-49	0 (pre-MY 2000)	0.76	0.76
DPM	25-49	0 (MY 2000-2003)	0.28	0.28
DPM	25-49	1	0.26	0.26
DPM	25-49	2	0.19	0.19
DPM	25-49	3	0.17	0.17
DPM	50-99	0 (pre-MY 1988)	0.84	0.84
DPM	50-99	0 (MY 1988-1999)	0.72	0.72
DPM	50-99	0 (MY 2000-2003)	0.72	0.72
DPM	50–99	1	0.17	0.17
DPM	50–99	2	0.17	0.17
DPM	50–99	3	0.12	0.12
DPM	>=800	0 (pre-MY 1988)	0.59	0.59
DPM	>=800	0 (MY 1988-2003)	0.37	0.37
DPM	>=800	1	0.12	0.12
DPM	>=800	2	0.09	0.09
DPM	>=800	3	0.05	0.05
DPM	>=800	4	0.03	0.03

CO2 emission factors (g/bhp-hr) were developed using the U.S. EPA marine engine certification database and then converted to Brake Specific Fuel Consumption (BSFC, gallon/bhp-hr) rates using U.S. EPA's diesel CO2 factor of 10.21 kg-CO2/gallon.[31] Table H-6 shows the BSFC rates for Tier 3 and Tier 4 CHC engines by horsepower group. Due to the lack of CO2 emission data for pre-Tier 3 engines, staff used the U.S. EPA's BSFC rates of 0.367 lbs/bhp-hr for pre-Tier 3 engines for engines with horsepower rating larger than 99, and 0.408 lbs/bhp-hr for engines with horsepower rating lower than 99.[32]

Table H-6. CO2 Emission Factors and BSFC Rates of CHC Engines by Tier Standard and Horsepower Bin

Tier Standard	Horsepower Bin	CO2 EF (g/bhp-hr)	BSFC (lbs/bhp-hr)
0/1/2	0–99	592	0.408
0/1/2	>= 100	533	0.367
3	0–24	675	0.465
3	25–49	628	0.433

[31] U.S. EPA, Emission Factors for Greenhouse Gas Inventories, March 9, 2018, last accessed July 19, 2021, *https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf*.

[32] U.S. EPA, Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b, July 2018, last accessed July 19, 2021, *https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=541846&Lab=OTAQ*.

Tier Standard	Horsepower Bin	CO2 EF (g/bhp-hr)	BSFC (lbs/bhp-hr)
3	50–174	554	0.382
3	175–799	531	0.366
3	>= 800	515	0.355
4	>= 800	498	0.343

2. Engine Deterioration

As engines age, the pollutant-specific emission factors slowly increase with age. This deterioration is primarily due to the wear on the various parts of an engine associated with its day-to-day activities and is a result of malfunction of emissions related components. Deterioration occurs at different rates for different pollutant.

Deterioration factors were adopted from the previous CARB inventory[33], as shown in Table H-7. The values represent the increase of emission factors at the end of the useful life of engines. For example, for an engine larger than 250 horsepower, the NOx and PM, emission factors will increase 21 percent and 67 percent respectively, at the end of its useful life. Useful life is defined as the age when 50 percent of the engines retire in the fleet. The inventory reflects that engines continue to deteriorate until they reach their useful life, and rebuilding engines will not reset the deterioration. Useful life for each vessel and engine type was determined using the survival curves developed from CARB Reporting data and are summarized in Table H-8.

Table H-7. CHC Deterioration Rates by Horsepower Bin (percentage increase by end of useful life)

Horsepower Bin	NOx	PM
0–50	6	31
51–250	14	44
>250	21	67

Table H-8. CHC Engine Useful Life (Years) by Vessel Type and Engine Type

Vessel Type	Main Engine	Auxiliary Engine
Barges – All	25	14
Commercial Fishing	31	28
Commercial Passenger Fishing	16	19
Crew Supply	13	17
Dredge	15	13
Excursion	15	14
Ferries - All	15	13
Pilot Vessel	15	13
Research Vessel	22	28
Tugboats - All	14	16
Workboat	22	28

[33] CARB, 1999 Mobile Source Mailouts, MSC 99-32, January 27, 2000, last accessed July 19, 2021, *https://ww3.arb.ca.gov/msprog/mailouts/mouts_99.htm*.

D. Load Factors

Engine load factor is the portion of maximum engine power used on average by the engine while it is operating. CHC load factors were updated using the fuel and activity data from CARB Reporting data. ECM readings were also used to develop load factors for some vessel categories, including ferries, excursion vessels, and ship-assist and escort tugboats[34]. Equation 3, shown below, were used to determine the load factors for each CHC engine. The average load for each vessel and engine type is presented in Table H-9. The engine load factors are overall lower than those in the previous model except for bunker and other barges.

$$Load\ Factor = \frac{Fuel}{HP * Activity * BSFC}$$

Where:

- **Fuel**: annual fuel use (gallons) reported to CARB;
- **HP**: rated engine horsepower reported to CARB;
- **Activity**: annual hours of engine run time reported to CARB; and
- **BSFC**: brake specific fuel consumption rate (gallon/bhp-hr).

Table H-9. CHC Load Factor by Vessel and Engine Type

Vessel Type	Main Engine	Auxiliary Engine
Barge – All	-	0.31
Commercial Fishing	0.27	0.44
Commercial Passenger Fishing	0.29	0.45
Crew/Supply	0.26	0.40
Dredge	0.44	0.57
Excursion	0.27	0.40
Ferries - All	0.31	0.39
Pilot Vessels	0.33	0.32
Research Vessels	0.32	0.44
Tugboat-ATB	0.50	0.50
Tugboat-Escort/Ship Assist	0.16	0.34
Tugboat-Push/Tow	0.33	0.37
Workboat	0.33	0.32

E. Existing and Proposed CHC Rule

1. Current CHC Rule

The Current CHC Regulation applies to all CHC vessels operating in Regulated California Waters. For specific vessel types—ferries, excursions, tugboats, crew and supply vessels, barges, and

[34] CARB collected engine ECM data directly from industries

dredges—engines must meet Tier 2 or higher standards that were in effect on the compliance date. For example, for vessels with homeports outside of South Coast Air Quality Management District, a 2000 model year (pre-Tier 1) engine with annual usage of more than 1,500 hours needed to comply with the in-use requirement by repowering to a Tier 3 engine before December 31, 2015. A detailed compliance schedule starting in 2019 and lasting through 2022 is available in the official regulatory language[35]. According to CARB enforcement data, currently around 94 percent of regulated in-use vessels are in compliance with the Current CHC Regulation.

2. Proposed Amendments

The Proposed CHC Amendments require all existing pre-Tier 1 and Tier 1 CHC engines to turn over to Tier 3/4 engines, and all Tier 2 to Tier 4 engines must meet Tier 3 or Tier 4 standard in effect and be retrofitted with diesel particulate filter (DPF) following an 8-year phase-in schedule starting in 2023, except for commercial fishing vessels. Tier 4 is required for engines if available starting in 2023, except for commercial fishing vessels. Currently Tier 4 engines are available for engines at or above 600 hp. Pre-Tier 1 and Tier 1 commercial fishing vessels are required to turn over to Tier 3 engines starting in 2030. A detailed rule compliance schedule is presented in Table H-10. Zero-emission requirements for certain vessel types are also included. Rule compliance extensions are available upon CARB approval for up to six years but no later than 2034 for most vessel categories.

[35] CARB, Final Regulation Order: Airborne Toxic Control Measure for Diesel Engines on Commercial Harbor Craft Operated Within California Waters and 24 Nautical Miles of the California Baseline, 2007, last accessed July 19, 2021, *https://ww3.arb.ca.gov/regact/2007/chc07/chcfro17.pdf.*

Table H-10. Implementation Timeline for Proposed CHC Rule Amendments

Current Regulation		Proposed Amendments (Implementation Dates) – December 31st of compliance year									
2021 & Earlier	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
IN-USE VESSEL REQUIREMENTS											
Tier 2 or 3 (Tugs, Ferries, Excursion, Crew & Supply, Barge, Dredge)		**Any Pre-Tier 1 and 1 → Tier 4*** (generally Workboats, Research, Pilot, Tank Barges, and CPFV)									
		≤ MY 1993	MY 1994-2001	MY 2002-2006							
			Tier 2, 3, 4 → Tier 4*+DPF** Ferries (Except Short Run), Pilot***, All Tugs								
			MY 2007-2009	MY 2010-2012	MY 2013-2015	MY 2016-2019	MY 2020-2021	MY 2022+			
					Tier 2, 3, 4 → Tier 4*+DPF** Research, CPFV, Excursion						
					MY 2007-2010	MY 2011-2012	MY 2013-2014	MY 2015-2017	MY 2018+		
							Tier 2, 3, 4 → Tier 4*+DPF** Dredges, Barges, Crew & Supply, Workboats				
							MY 2007-2009	MY 2010-2013	MY 2014-2017	MY 2018+	
									Any Pre-Tier 1 and 1 → Tier 2 or Cleaner *Commercial Fishing*		
									≤ MY 1987	MY 1988-1997	MY 1998+
Other VESSEL REQUIREMENTS											
Tier 2, 3, or 4 All New Vessels Tier 3 + BACT New Ferries Carrying 75+ Passengers			New Excursion: Zero-Emission Capable (e.g., Plug-in Hybrid) 30% or more of power must be derived from a zero-emission tailpipe source								
				New and In-Use Short-Run Ferries: Zero-Emission							

*All engines ≥600 kW would be required to be certified to Tier 4. For engines <600 kW, a Tier 4 certified engine would be required if certified by U.S. EPA or CARB and available by the compliance date.
**Retrofit DPF requirements would apply to all Tier 3 and Tier 4 engines.
***Pilot vessels at Tier 2, 3, or 4 with MY 2007-2009 would not need to comply until December 31, 2025

Other Proposed CHC Amendments starting in 2023 include renewable diesel requirement for all vessels, and zero-emission requirement for all auxiliary engines. Renewable diesel could result in 30 percent reduction in PM, and 10 percent reduction in NOx except for Tier 4 engines equipped with selective catalytic reduction (SCR) catalyst, 5 percent reduction in THC, 10 percent reduction in CO, and 5 percent increase in fuel consumption[36].

Credits and other incentives will also be provided to encourage the adoption of zero-emission technology. Discussions with industry suggest a potential zero-emission adoption rate of 33 percent for non-short-run ferries, 30 percent for pilot vessels, 15 percent for ship-assist tugs, and 10 percent for workboats by 2031. Staff assumed a linear increase in zero-emission adoption rate from 2023 to 2031 for these vessel types. These voluntary zero-emission adoptions will help reduce greenhouse gas emissions. For criteria pollutants, however, staff assumed no additional emission benefits as the increased emissions from issued credits and Alternative Control of Emissions (ACE) and/or Zero-Emission and Advanced Technology (ZEAT) credits plan could offset the benefits from zero emissions adoption.

Low-use exceptions are applied to vessels that operate below certain annual hour limits. The low-use annual hour limits are presented in Table H-11. To help reduce emissions from disadvantaged communities, CHC vessels with a homeport or regularly scheduled stops within 2 miles of a disadvantage community have lower low-use threshold than vessels operating in other areas.

Table H-11. Low-Use Annual Hour Limits by Engine Tier

Region	Tier 0	Tier 1	Tier 2	Tier 3/4
Disadvantaged Community Area*	40	150	200	350
All Other Areas	80	300	400	700

* Vessels with a home port or regularly scheduled stops within 2 miles of a disadvantage community.

3. Compliance Extensions

Because CARB staff anticipates a substantial fraction of vessels may be subject to replacement and eligible for feasibility-based compliance extensions, CARB staff modeled the delayed emission reductions through linear interpolation in a post-processing procedure. This procedure aligned the assumptions of the percentage of vessels receiving the extension with the criteria outlined in the SRIA based on feasibility, and the fraction of vessels that would be required to repower by removing vessels operating under low-use exceptions.

CARB staff did not quantify delayed emission impacts from scheduling extensions, because they were infrequently requested during the implementation of the Current Regulation. CARB staff also did not quantify delayed emission reductions due to infrastructure delays, because CARB

[36] CalEPA, Staff Report: Multimedia Evaluation of Renewable Diesel, May 2015, last accessed July 19, 2021, *https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf*.

staff considered infrastructure deployment timelines when establishing the ZEAT deadlines, and therefore they would be requested and granted in limited circumstances.

IV. Emission Results

A. Statewide Emissions from CHC

Baseline emission projections of NOx and PM from CHC (out to 100 nm) by Tier standard group are presented in Figure H-13. While emissions are decreasing from 2018 to 2050 due to the fleet turnover to cleaner engines, Tier 0 to Tier 2 engines still make up over 50 percent of the total emissions by 2050. Figure H-14 and Figure H-15 show baseline CHC emissions by vessel type and air basin, respectively. Tugboats are the largest emitters for both NOx and PM, mainly because of their large engine size and high activity level. Commercial fishing vessels are the second largest emitter mostly because of their large population.

Figure H-13. CHC Baseline Emission Projection by Tier Group (out to 100 nm)

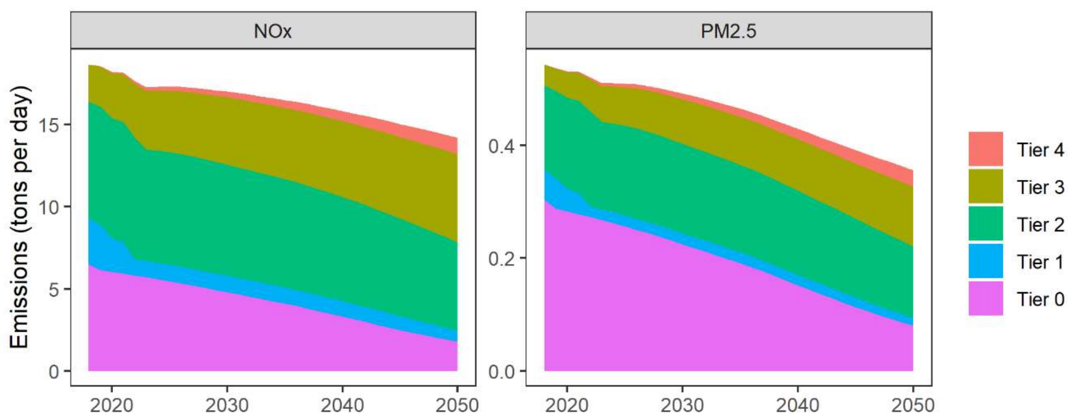


Figure H-14. CHC Baseline Emission Projection by Vessel Type (out to 100 nm)*

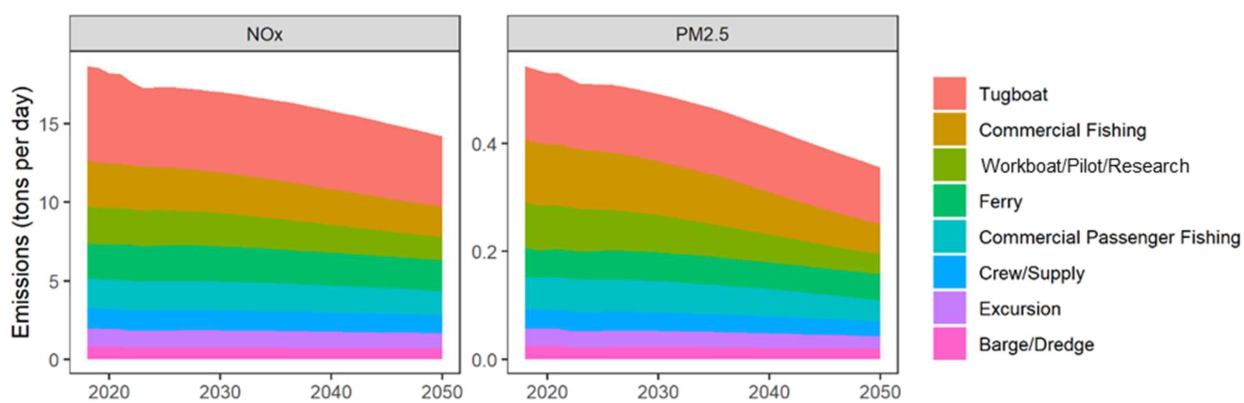
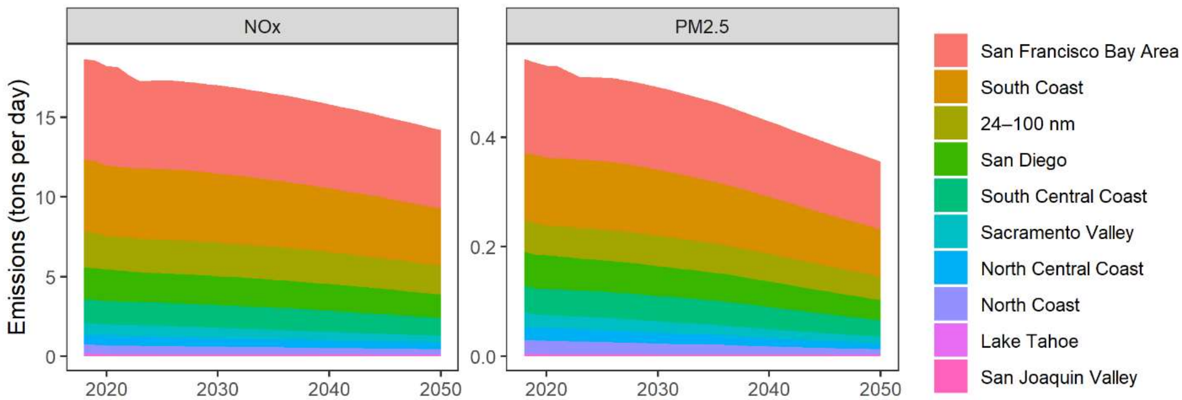


Figure H-15. CHC Baseline Emission Projection by Air Basin (out to 100 nm)*



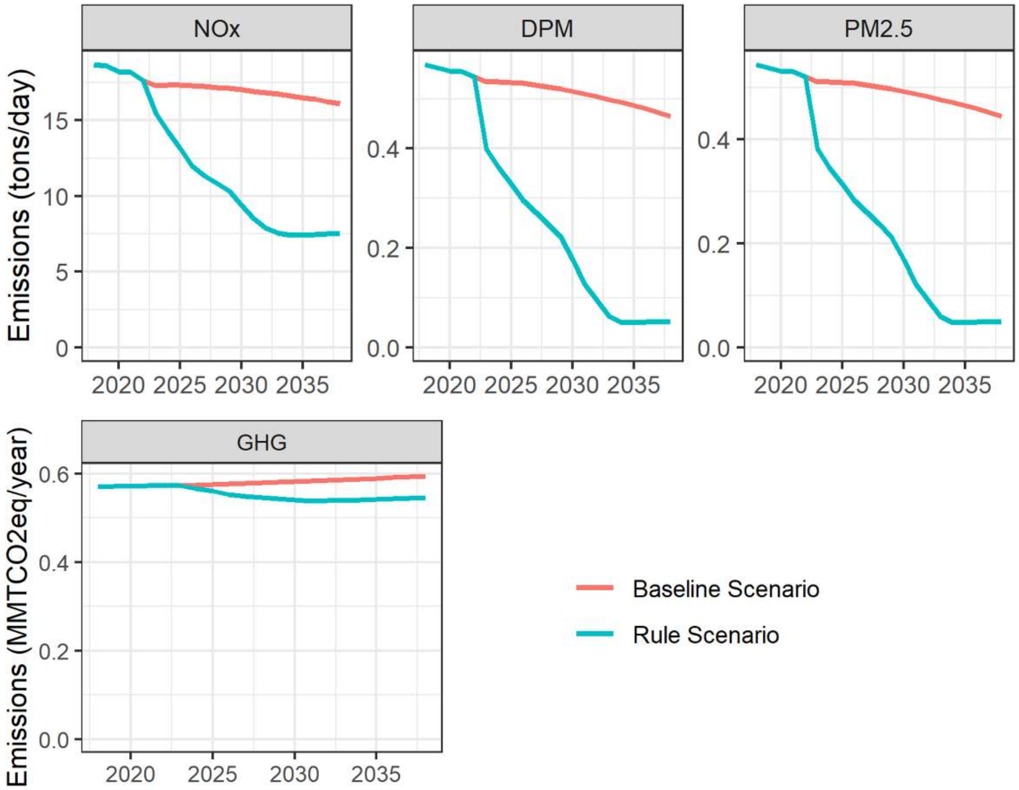
*Vessel location based on home ports; air basin covers emissions from 0–24 nm, emissions from 24-100nm are grouped into one region.

B. Statewide Emission Reductions from Proposed Amendments

Comparisons of emissions under the CHC Baseline and Proposed Amendments are shown in Figure H-16. By 2035, the proposed rule would reduce NOx emissions by 55 percent, PM2.5 by 90 percent, and GHG emissions (CO2 equivalent)[37] by 8 percent. The large reductions in criteria pollutant emissions will play an important role in protecting the public health in communities near the ports as well as attainment of National Ambient Air Quality Standards in regions such as the South Coast Air Basin.

Figure H-16. Comparison of CHC Emissions Under Baseline and Proposed Rule Amendments (out to 100 nm)

[37] CO2 equivalent emissions are calculated from CO2, N2O, CH4 emissions, unit is in million metric tonne (MMT) per year. CO2_eq = CO2 + 298*N2O + 25*CH4.



NOx
DPM
PM2.5
GHG
Emissions (tons/day)
Emissions (MMTCO2eq/year)
15
10
5
0
0.4
0.2
0.0
0.6
2020
2025
2030
2035
Baseline Scenario
Rule Scenario