

Final Report: Evaluation of Cruise Industry Global Environmental Practices and Performance

Prepared for Cruise Lines International Association (CLIA)

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Executive Summary

This research evaluates current wastewater and air quality management practices in the international cruise industry. The purpose of the effort was to document where the cruise industry may be demonstrating leadership and innovation in technological and operational controls that reduce the impact of vessel wastewater discharges and air emissions.

This work was performed by Energy and Environmental Research Associates (EERA) under contract to Cruise Lines International Association (CLIA), during the summer of 2016. EERA reviewed relevant peer-reviewed literature, corporate policies, and white papers regarding the Cruise industry efforts to evaluate and address fleet wastewater discharges and air emissions. Most of the research in this report relies upon data from public sources. EERA also incorporated industry data provided by CLIA to review the current state of wastewater and air quality management and practices in the cruise industry. These data included land-based data on vessel location and activity, using Automated Identification System (AIS) reports for CLIA member vessels, market analyses reporting fleet modernization and growth, and other non-public vessel data. This work provides a baseline snapshot of cruise industry practices and voluntary policies with regard to the environment and makes initial comparisons to the wider maritime community. This report also documents innovations led by and unique to the cruise industry to protect the environment.

Background and overview

CLIA actively supports its members in environmental stewardship and policy development internationally and regionally. CLIA is very active at IMO, maintaining a delegation that has contributed many documents related to MARPOLV Annex IV (wastewater) and MARPOL Annex VI (air pollution). CLIA is also engaged in national and local evaluation of environmental technologies and practices, such as regional organizations for Alaskan and Baltic Sea cruise destinations and engages through workshops with a range of environmental and regulatory organizations.

EERA provides services to industry, government agencies, and non-governmental organizations, and enterprise sector clients across a variety of technical and regulatory fields, mainly related to transportation and environment. EERA projects include technology assessment; regulatory analysis and management; alternative fuels analysis; and health impact analysis, among others. Combining quantitative modeling skills with in-depth, qualitative analysis, many of EERA work products have been peer-reviewed and published in professional and academic journals internationally.

Key findings

EERA conducted this research to provide an evidence-based baseline assessment of the cruise industry's role in advancing environmental performance, focused in this work on wastewater

discharges and air pollution. This is important because cruise industry growth and modernization represents an opportunity for environmental leadership relative to other maritime fleets; cruise vessels on the current order book maintained by CLIA represent ~32% of the current CLIA vessel count, and ~38% of berths. This statistic suggests that passenger needs for vessel-based management of wastewater and energy systems will continue to motivate adoption of environmental stewardship practices and technologies.

With regard to air emissions, this report evaluated cruise fleet demonstration and adoption of cleaner marine fuels and efficient low-emission propulsion, exhaust emissions control technologies, shore power technology, and other fleet modernization to adopt energy efficient designs as the industry grows. Comparing cruise fleets with other maritime vessel types, CLIA members are leaders in adopting cleaner fuels, controlling air emissions, and preparing vessels to connect to advanced shore-based energy systems. This report specifically documents that CLIA member cruise lines are leaders in at least four areas regarding air emissions:

- Fleet Adoption of Cleaner Fuels and Advanced Engine Technology: Orders are in place for the addition of 87 vessels to the cruise fleet from the period 2017 to 2026, including at least thirteen LNG powered vessels; and vessels where keel laying began after 1 January 2016 will be required to use advanced Tier III low-emissions marine engines in the growing number of regions in which required.
- Exhaust Gas Cleaning Systems (EGCS): EGCSs are installed, or will be retrofit on at least 106 vessels, as one novel alternative of reducing air emissions, or approximately 38% of the current CLIA member fleet, and include exhaust gas cleaning systems on at least 18 newly built vessels.
- In Port Emission Reduction Systems: Shore power connections are equipped on at least 25 cruise vessels (around 9% of the CLIA members' fleets), usable where the land-based electric power grid may produce fewer emissions than onboard power systems; many cruise lines are incorporating shore power capability into their new vessel orders, including plans to add or retrofit at least 18 more vessels for shore power.
- Compliance with Emission Control Area Requirements: Using publicly available data, we find that the cruise industry generally meets or exceeds international, national, and regional air quality standards and rates of non-compliance in the cruise industry are commensurate or better than the fraction of all marine vessel activity attributable to cruise vessels.

With regard to wastewater discharges, this report evaluated cruise fleet demonstration and adoption of advanced water treatment systems (AWTSs), and CLIA member voluntary zero-discharge practices. This report specifically documents that CLIA member cruise lines are leaders in four areas regarding wastewater:

- CLIA Member No Untreated Sewage Discharge Policy: Existing and newly built CLIA Member ships, follow CLIA's policy of no discharge of untreated sewage, a restriction that exceeds international standards.
- Fleet Adoption of Advanced Water Treatment: CLIA members have ordered at least 26 new builds with AWTs. Based on these numbers, we estimate that at least 47% of newly built capacity over the next 10 years will be using advanced wastewater treatments.

- Compliance with Wastewater Discharge Requirements: Using publicly available data, we find that the cruise industry generally meets or exceeds international and national wastewater quality standards and overall the cruise industry's rate of compliance is commensurate or better than the rest of the maritime industry.
- Baltic Sea Practices for Wastewater Reception Facilities: CLIA and HELCOM indicated that almost 31% of cruise ships voluntarily use port wastewater reception facilities in the Baltic Sea when available; this voluntary practice precedes implementation of new requirements.

Organization of report

Section 1 summarizes regulatory requirements governing air emissions and wastewater discharges. Section 2 identifies the data used in this study. Section 3 presents the equations and methods used to quantify air emissions and wastewater discharges. Section 4 presents our analysis of the three hypotheses with regard to air emissions. Section 5 presents our analysis of the CLIA three hypotheses with regard to wastewater discharges. Section 6 presents our key findings. An Appendix is provided with related background analytical data.

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Final Report: Evaluation of Cruise Industry Global Environmental Practices and Performance

1. Introduction

This report summarizes research and analysis of some environmental practices and performance indicators for the Cruise industry. The study was commissioned by CLIA and conducted by EERA. The overall purpose of the study was to identify where the cruise industry demonstrates stewardship, innovation, and/or leadership with regard to reducing or controlling air emissions and wastewater discharges and to compare the cruise industry performance to the broader maritime community.

CLIA developed a set of three working hypotheses that form the framework of this report. These three hypotheses apply to air emissions and to wastewater discharges from ships (summarized in Table 1). For the purposes of this report, the terms “ship” and “vessel” are used interchangeably to describe marine watercraft that transport cargo, including passengers.

Table 1: Hypotheses investigated for this report

- Hypothesis 1** Compared with the wider global maritime industry, cruise industry wastewater discharge is less harmful and air emissions are reasonable or much better.
- Hypothesis 2** Cruise industry wastewater discharges and air emissions are within the law or exceed the requirements of national and international laws.
- Hypothesis 3** Cruise industry wastewater and air emissions are socially responsible based on existing regulatory schemes, existing technology, and the industry’s self-regulated practices, and are improving through continuous innovation by cruise lines.

1.1. Air Emissions Rules and Requirements

This section describes air emissions rules and requirements internationally, nationally, and regionally.

1.1.1. International

The International Maritime Organization (IMO) regulates international air emissions from ships under Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL). MARPOL Annex VI regulates criteria pollutants contained in ships’ exhaust gas, including sulfur oxides (SO_x), nitrogen oxides (NO_x), ozone depleting substances (ODS), and volatile organic compounds (VOC) from tankers. The IMO has also given extensive consideration to controlling greenhouse gas (GHG) emissions from ships and has adopted a suite of technical

and operational emission reduction measures. Greenhouse gases include carbon dioxide (CO₂), and other exhaust gases that have the potential to cause atmospheric warming including, but not limited to, methane (CH₄) and nitrous oxide (N₂O). Though CH₄ and N₂O can have significant warming impacts, for the purposes of this report we focus on CO₂ emissions from ships.

Sulfur

MARPOL Annex VI Regulation 14 mandates a global sulfur cap of 3.5% in fuel, with a reduction to 0.5%, effective 1 January 2020, confirmed at the 70th meeting of the Marine Environmental Protection Committee (MEPC 70)¹. Effective 1 January 2015, vessels operating within the North American and United States Caribbean Emission Control Areas (ECAs) are required to use fuels not exceeding 0.1% sulfur, or use alternative fuels or equipment such as exhaust gas cleaning systems (scrubbers) to reduce exhaust emissions to levels comparable to using 0.1% sulfur fuel. The currently enforced ECAs are the Baltic Sea area, the North Sea area, and the North American and United States Caribbean Sea area, as shown in blue in Figure 1. Additionally, under the European Directive², the allowable fuel sulfur in all European Union and European Economic Area waters will be limited to 0.5% in 2020, consistent with the recently-decided global sulfur cap. China is also implementing a 0.5% fuel sulfur rule in the Bohai Sea, and Pearl and Yangtze River deltas, to be phased in by 2019³.

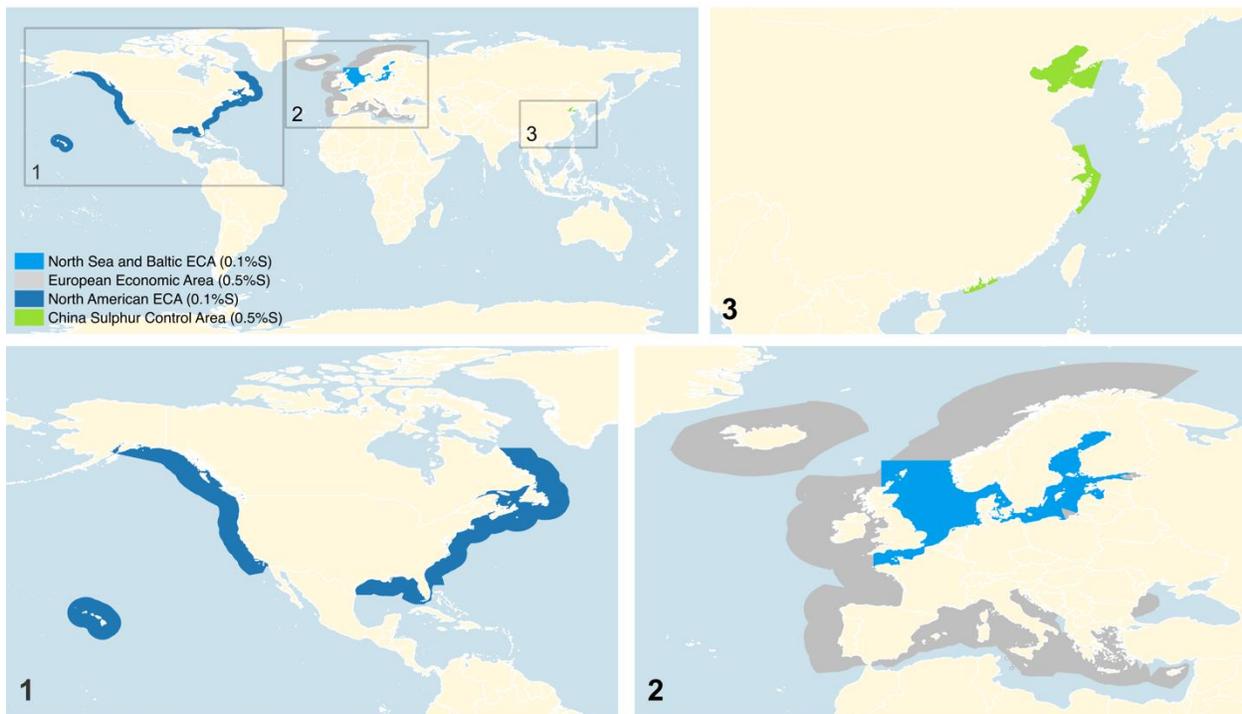


Figure 1: Global Sulfur Control Regions

Based on 2015 terrestrial Automated Identification System (AIS) data, Figure 2 illustrates the near-shore distribution of cruise ship activity. Using these data, 12.5% of cruise activity

¹ <http://www.imo.org/en/MediaCentre/PressBriefings/Pages/MEPC-70-2020sulphur.aspx>

² <http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32012L0033>

³ <https://www.dnvgl.com/news/china-introduces-sulphur-requirements-for-marine-fuels-50359>

observed in the data set occurs in the Baltic and North Sea ECA region. The North American ECA accounts for a further 11.2% of observed cruise activity. Outside of the Baltic and North Sea ECA, the European Economic Area is home to an additional 40.8% of observed cruise activity. In total, 64.5% of observed cruise activity occurs in the North American, US Caribbean Sea, Baltic and North Sea, and European Economic Area regions, areas which are currently subject to stricter air and wastewater rules and regulations than the rest of the globe. It is important to note that the AIS data provided are terrestrial-based, and therefore are typically limited to capturing AIS signals from vessels within approximately 400 kilometers from shore. Further analysis of additional satellite data would be needed to complete activity estimates on the high seas, and estimating the percent of activity both in and outside low-sulfur regions.

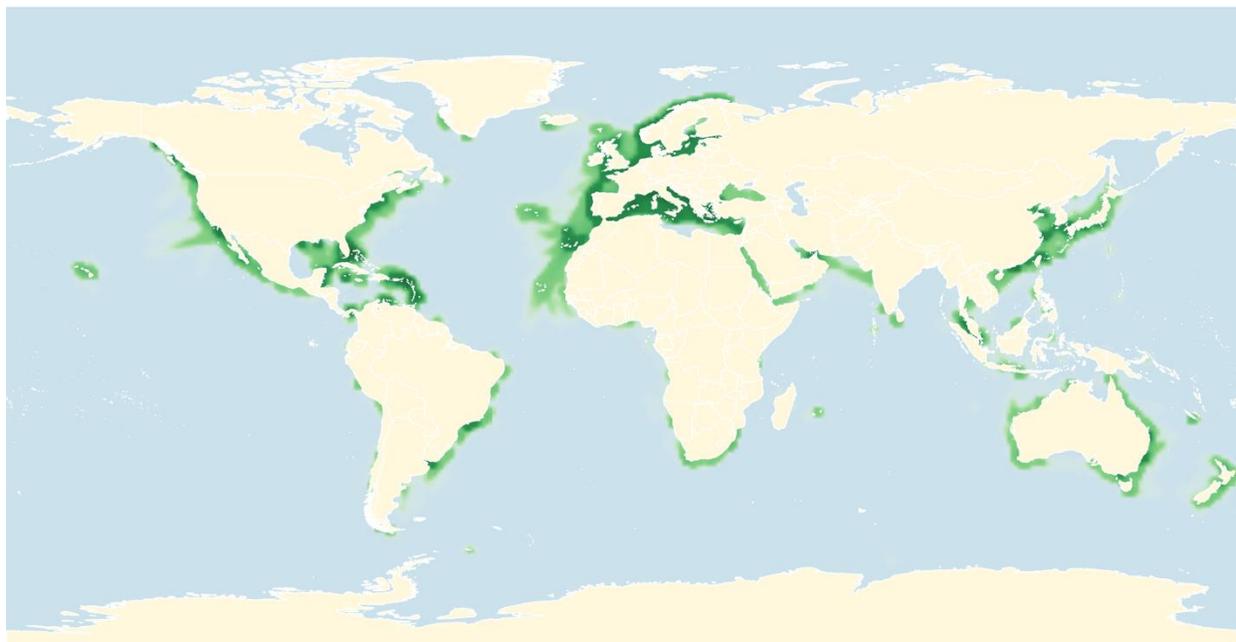


Figure 2: CLIA cruise vessel density in 2015 from terrestrial AIS data

Nitrogen Oxides

Under IMO policy set forth in MARPOL Annex VI, limits for oxides of nitrogen (NO_x) apply to newer marine vessels, if and while operating in a designated NO_x Emission Control Area. Tier II operation by newer vessels was first required in the North American and U.S. Caribbean NO_x ECAs for vessel constructed on or after 1 January 2016. MEPC 70 approved designation of the existing North Sea and Baltic Sea sulfur emission control areas as emission control areas for nitrogen oxides under regulation 13 of MARPOL Annex VI.⁴ Draft amendments will be formally considered at MEPC 71. When adopted, the draft amendments will go into effect on 1 January 2021 for both the North Sea and Baltic ECAs. Once in effect, the NO_x ECA would require vessels using marine diesel engines to comply with Tier III NO_x emission standards when installed on ships operating inside those NO_x ECAs if constructed on or after 1 January 2021.

⁴ <http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC-70th-session.aspx>

MARPOL Annex VI Regulation 13 mandates tiered NOx controls for vessels with diesel engines with installed power greater than 130kW. These tiers apply to the vessel construction date, and vary by engine speed, as shown in Table 2.

Table 2: IMO MARPOL VI NOx emission limits based on construction date and engine speed. (Adapted from IMO website)

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh)		
		rpm < 130	130 ≤ rpm ≤ 1999	rpm ≥ 2000
I	1 January 2000	17.0	45·rpm ^(-0.2)	9.8
II	1 January 2011	14.4	44·rpm ^(-0.23)	7.7
III	1 January 2016	3.4	9·rpm ^(-0.2)	2.0

Depending upon rates of fleet replacement (not studied here), modernization that results in more Tier II and Tier III cruise ships may outpace fleet modernization among other vessel types. **The current orderbook (2016) shows the addition of 87 vessels to the cruise fleet from the period 2017 to 2026. Of these newly delivered vessels, those where keel laying began on or after 1 January 2016 will be required to adhere to Tier III standards** in the growing number of regions in which required.

1.1.2. National

National requirements for China are described in this subsection.

1.1.2.1. China

As of 1 July 2015, Hong Kong implemented a 0.5% cap on fuel sulfur for vessels at berth in Hong Kong waters, including the use of exhaust gas cleaning systems to meet the requirement⁵.

China will further phase in a 0.5% sulfur cap in the Bohai Sea, Pearl River Delta, and Yangtze River Delta areas. The sulfur cap will be phased in at relevant ports, beginning on 1 January 2016, to first include vessels moored offshore. The rule expands to vessels at dock on 1 January 2017, to all vessels in the port area on 1 January 2018, and finally extending to all Chinese sulfur control areas (shown in green in Figure 1) on 1 January 2019⁶. The control measures will be assessed over the course of 2019 in order to determine if additional regulations to require 0.1% sulfur fuels are necessary.

1.1.2.2. Canada

Canada has issued regulations on the density of smoke under Division 6, Subdivision 2 of Vessel Pollution and Dangerous Chemicals Regulations⁷ (SOR/2012-69). Visual observations are taken by observers and using smoke charts to match the smoke density. These regulations apply to vessels operating underway (not in maintenance or start up) within 1 nautical mile of the

⁵ http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/frequently-asked-questions.html#compliant

⁶ http://www.moc.gov.cn/zfxxgk/bzsdw/bhsj/201512/t20151204_1942434.html (translated into English using translate.google.com)

⁷ <http://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-69/>

Canadian shoreline, and state that a vessel that does not use hand fired boilers may emit black smoke, not exceeding density number 2 (approximately 40% black space on the smoke chart), for an aggregate of 4 minutes in any 30-minute period. For the purposes of this rule, smoke that is not black is considered to be of the same density as black smoke that is of approximately the same degree of opacity.

1.1.2.3. Australia

The Australian Maritime Safety Authority recently issued direction in a Marine Notice that, in an effort to limit sulfur emissions from cruise vessels when at berth in Sydney Harbour, cruise vessels accommodating more than 100 passengers are required to use fuel with maximum sulfur content of 0.1 percent or an alternative that achieves an equivalent outcome. AMSA relies on subsection 246(1)(b) of the Navigation Act of 2012. The limit on Sulphur emissions applies from one hour after the vessel's arrival at berth until one hour before the vessel's departure.⁸

1.1.3. Regional

Regional requirements for Alaska, California, and Europe are described in this subsection.

1.1.3.1. Alaska

Alaska uses EPA Method 9 to monitor air emissions. EPA Method 9 uses trained observers to determine if visible vessel emissions reduce visibility through the exhaust plume by more than 20% within 3 miles of the coastline.⁹

1.1.3.2. California

The California Air Resources Board (CARB) has adopted a set of regulations related to ocean going vessels (OGVs). CARB specifies that OGVs are required to use low sulfur marine distillate fuels within 24 nautical miles of the coastline or utilize equipment technologies to achieve equivalent emission reductions. CARB additionally requires recordkeeping and reporting of onboard incineration, mandating that incineration take place more than 3 nautical miles from shore. Vessels transiting California waters within 20 nautical miles of a port must employ vessel speed reduction (VSR). By reducing the fraction of total installed power required to travel at lower speeds, vessels emit fewer greenhouse gases and criteria pollutants.

CARB also instituted the At-Berth Regulation in 2007, which requires large container, reefer, and passenger vessels that are frequent callers (five or more visits per year to any single CA port) to use cleaner shore based electricity instead of auxiliary engines while at berth, or utilize exhaust gas cleaning systems to scrub auxiliary air emissions to equivalent emission reductions.

⁸ <https://apps.amsa.gov.au/MOReview/MarineNoticeExternal.html>

⁹ https://dec.alaska.gov/water/cruise_ships/reg/Alaska_Opacity&Excess_Emissions_Regulations.pdf; <https://www3.epa.gov/ttnemc01/methods/VEFieldManual.pdf>; <https://www3.epa.gov/ttnemc01/promgate/m-09.pdf>

1.1.3.3. European Union (EU Directive)

EU Directive 2012/33/EU reduces the maximum sulfur content of marine fuels from the current 3.5% to 0.5% by January 2020; this requirement is consistent with the timing of the global 0.5% sulfur cap, subject to any implementation considerations to be considered by the IMO. Under certain conditions, this Directive also requires the use of fuel containing maximum 0.1% sulfur when at berth and maximum 0.1% sulfur when on regular service in EU waters.

By Regulation 2015/757 (EU-MRV for Monitoring, Reporting and Verification), beginning in 2018, all ship owners and operators must monitor and report the verified amount of CO₂ emitted by vessels greater than 5000 Gross Tonnage (GT) on voyages to, from and between EU ports. Information such as fuel consumption, cargo loads and energy efficiency parameters will be required to be reported.

1.2. Wastewater Discharge Rules and Requirements

This section describes wastewater discharge rules and requirements.

1.2.1. International

MARPOL Annex IV contains regulations pertaining to the discharge of sewage into the sea from ships. MARPOL Annex IV regulations cover vessel equipment and sewage discharge systems. Generally, the mixing action, aerobic conditions, and bacteria in waters on the high seas are capable of assimilating raw sewage without adverse environmental impacts.^{10, 11, 12, 13} As such, the regulations in MARPOL Annex IV prohibit dumping of untreated sewage into the sea within a specified distance of shore. MARPOL Annex IV requires vessels of 400 gross tonnage and above to carry an approved sewage treatment plant, or sewage holding tank. CLIA has set more stringent policies for its members, setting a standard for no discharge of untreated sewage anywhere.

IMO MARPOL Annex IV regulations permit discharge of untreated sewage at a moderate, defined rate, not instantaneously, when traveling at more than 4 knots and more than 12 nautical miles from the nearest land (MEPC.157(55)).

1.2.2. National

Under US regulations, any vessel greater than 67 feet in length, or with more than 15 persons on board, must use either a Type II (flow through treatment device) or Type III (holding tank) marine sanitation device (MSD). Type II MSDs are essentially equivalent to older IMO type

¹⁰ <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Sewage/Pages/Default.aspx>

¹¹ Grunseich, G. S., & Duedall, I. W. (1978). The decomposition of sewage sludge in seawater. *Water Research*, 12(8), 535–545. [https://doi.org/http://dx.doi.org/10.1016/0043-1354\(78\)90130-6](https://doi.org/http://dx.doi.org/10.1016/0043-1354(78)90130-6).

¹² McIntyre, A. D. (1982). Effects on the Ecosystem of Sewage Sludge Disposal by Dumping from Ships. *Water Science and Technology*, 14(3), 137 LP-143. Retrieved from <http://wst.iwaponline.com/content/14/3/137.abstract>

¹³ Costello, M. J., & Read, P. (1994). Toxicity of sewage sludge to marine organisms: A review. *Marine Environmental Research*, 37(1), 23–46. [https://doi.org/10.1016/0141-1136\(94\)90061-2](https://doi.org/10.1016/0141-1136(94)90061-2)

approved Sewage Treatment Plants (STP).¹⁴ However, as of 1 January 2010 any United States vessel operating subject to MARPOL Annex IV should obtain an International Sewage Pollution Prevention Certificate (ISPPC) or Statement of Voluntary Compliance (SOVC) for onboard MSDs, or risk being detained overseas for MARPOL Annex IV violations.¹⁵

1.2.2.1. Unites States Clean Water Act Section 312 (33 U.S.C. 1322)

The Clean Water Act allows the US EPA and US Coast Guard to issue regulations with regard to sewage discharges from vessels (CWA section 312(a), 301, and 313 (33 U.S.C. 1322)). Vessel operators are exempt from obtaining National Pollution Discharge Elimination System (NPDES) permits prior to discharging sewage, but may be required to obtain a permit under EPA's NPDES Vessel General Permit (VGP) if sewage is co-mingled with greywater and the vessel is operating on the Great Lakes.¹⁶ Data from CLIA suggest that medium and large cruise vessels may not meet the greywater effluent criteria in the VGP¹⁷ without installing AWTs in order to meet the standards for discharge within U.S. waters as outlined in the VGP (Sections 5.1.1.1.1/2 and 5.2.1.1.1/2) and the U.S. Secondary Treatment Standards¹⁸ (40 CFR 133.102).

1.2.2.2. No Discharge Zones

The US EPA provides a list of current no-discharge zones (NDZs), in which release of vessel sewage is strictly prohibited under section 312 of the Clean Water Act¹⁹. The release of both treated and untreated sewage is prohibited in NDZs, and vessels are required to retain sewage discharges on board for proper disposal on shore or at sea, beyond 3 miles from shore. By policy, CLIA member ships not using onshore reception facilities and travelling regularly on itineraries beyond the territorial water of coastal states, treated sewage discharge is to take place only when the ship is more than 4 nautical miles from the nearest land and traveling at a speed of not less than 6 knots, exceeding regulatory requirements.

Additionally, vessels are generally prohibited from discharging material in US National Marine Sanctuaries. NDZs established in notable areas on the west coast include the Puget Sound²⁰, Olympic Coast National Marine Sanctuary and all California marine waters, including the Gulf of Farralon, Cordell Bank, Monterey Bay and Davidson Seamount, and Channel Islands National Marine Sanctuaries. On the US east coast offshore NDZs include all state waters in New Hampshire and Massachusetts, all Rhode Island state waters, Long Island Sound, and state waters within the Florida Keys National Marine Sanctuary²¹.

¹⁴ https://www.uscg.mil/hq/cg5/nvic/pdf/2009/NVIC_1-09.pdf

¹⁵ https://www.uscg.mil/hq/cg5/nvic/pdf/2009/NVIC_1-09.pdf

¹⁶ <https://www.epa.gov/vessels-marinas-and-ports/vessel-sewage-discharges-statutes-regulations-and-related-laws-and>

¹⁷ https://www3.epa.gov/npdes/pubs/vgp_permit2013.pdf

¹⁸ <https://www.gpo.gov/fdsys/pkg/CFR-2006-title40-vol21/pdf/CFR-2006-title40-vol21-sec133-102.pdf>

¹⁹ <https://www.epa.gov/vessels-marinas-and-ports/vessel-sewage-discharges-no-discharge-zones-ndzs>

²⁰ <http://www.ecy.wa.gov/programs/wq/nonpoint/CleanBoating/ndzstatus.html>

²¹ <https://www.epa.gov/vessels-marinas-and-ports/no-discharge-zones-ndzs-state>

1.2.3. Regional

Regional efforts have been specially applied to Alaska and the Baltic Sea. These are described in this subsection.

1.2.3.1. Alaska

The state of Alaska has implemented a set of statewide standards for cruise ships in Alaska waters, which generally extend 3 nautical miles from shore.²²

The state of Alaska acknowledges that “[s]ince 2000, cruise ships have used more advanced and evolving MSDs, ultimately known as AWTs to treat sewage and graywater prior to discharge. Since 2001, cruise ships have been required by either federal or State law to use AWTs as a condition to discharge in Alaskan waters.”²³

Advanced wastewater treatment systems (AWTSs) employed by cruise ships in Alaska treat wastewater to a higher quality than the systems used by Alaskan coastal communities, resulting in a clear liquid with no visible solids. Water quality in effluents processed by AWTS are described in detail in section 5. The best available data on AWTS installations are from the State of Alaska Large Cruise Ship Wastewater General Permit.²⁴ Publicly available data for other regions are scarce.

1.2.3.2. Alaska Rule HB 80

“Alaska cruise ship law requires large cruise ships that discharge wastewater into state waters to first treat the wastewater using state of the art wastewater treatment technology. Alaska uses state of the art regulatory and permitting mechanisms to protect water quality and aquatic life.”²⁵

“Under the new legislation, only large cruise ships with Advanced Wastewater Treatment Systems are eligible to apply for authorization of a mixing zone. This assures that large cruise ships operating in Alaska will continue to have the best available wastewater treatment systems on-board. They must then satisfy the rigorous 19-part “test” in the mixing zone regulations that assure protection of marine life, both within and outside the authorized mixing zone. HB 80 does not automatically authorize mixing zones for cruise ship discharges, rather, it allows them to apply just as every other coastal community discharging in Alaska can. Mixing zones are used throughout the U.S.

1.2.3.3. Baltic Sea Special Area

MARPOL Annex IV Regulation 11, article 3, states that new passenger vessels shall be prohibited from discharging sewage in special areas except when operating an approved sewage discharge plant and vessel effluents must meet stringent nitrogen and phosphorus

²² http://dec.alaska.gov/WATER/CRUISE_SHIPS/pdfs/CPVEC_GP_Map_2011.pdf

²³ https://dec.alaska.gov/water/cruise_ships/pdfs/SAP_2013_Preliminary_Report_Wastewater.pdf

²⁴ http://dec.alaska.gov/WATER/CRUISE_SHIPS/gp/Auth_14.html

²⁵ https://dec.alaska.gov/water/cruise_ships/faq.htm

standards²⁶. By Regulation 12, the States which require ships to comply with the requirements of Regulation 11 undertake to ensure the provision of facilities at ports and terminals for the reception of sewage, without causing delay to ships, adequate to meet the needs of the ships using them. At MEPC 69, the MEPC agreed to establish the effective dates for implementation of the Baltic Sea Special Area as 1 June 2019 for new passenger ships and 2021 for existing passenger ships.²⁷ The resolution adopted at MEPC 69 encourages immediate voluntary compliance with the Special Area Requirements.

CLIA Member lines recognize the extraordinary eutrophication situation in the Baltic Sea, which necessitated its designation as a Special Area under MARPOL Annex IV. CLIA Member lines have adopted a policy that, when operating in the Baltic, ships are to discharge MARPOL Annex IV waste ashore where adequate port reception facilities are available under a ‘no special fee’ arrangement.

2. Data

This section describes the necessary data and information used to evaluate air emissions and water discharges from cruise ships against the hypotheses. For air emissions, this includes publicly available information on emissions rates, air pollution control strategies such as advanced fuels, exhaust treatment, and shore power systems, and on European and United States landside power characteristics. For wastewater discharges, this includes daily effluent production rates, and wastewater treatment strategies.

2.1. Air emissions

We present generally representative air emissions information used in modeling ship greenhouse gas and criteria pollutant emissions.

2.1.1. Modeling Data Emissions Factors

For this work, emissions factors used by the U.S. EPA in port related emissions inventories, are as documented in Table 3.

Table 3: Criteria pollutant emission factors

Species	Emission Factor (g/kWh)
NO _x	13.2*
SO _x	0.40
PM _{2.5}	0.17
CO ₂	646.08

* Assumes Tier 3 Medium Speed Diesel (MSD)²⁸

²⁶

[http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Sewage/Documents/Resolution%20MEPC.227\(64\).pdf](http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Sewage/Documents/Resolution%20MEPC.227(64).pdf)

²⁷ <http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC-69th-session.aspx>

²⁸ EPA. Current methodologies in preparing mobile source port related emission inventories. **09-024**, (2009).

2.1.2. Air Pollution Control Strategies

2.1.2.1. Fuel Switching

Fuel switching is a practice commonly employed by large ocean going vessels in order to comply with fuel restrictions and regulations. For vessels operating on the high seas, fuel sulfur content is currently limited 3.5%, and set to be reduced to 0.5% in 2020. Within emission control areas (ECAs), designated under MARPOL Annex VI, the sulfur content of fuels is limited to 0.1% in the Baltic, North Sea, and North American and United States Caribbean Sea Emission Control Areas. The European Economic Area (EEA), has imposed a 0.5% fuel sulfur limit in EEA areas outside of ECAs via the European Directive, and the Chinese are implementing 0.5% rules in the Bohai Sea, and the Yangtze and Pearl River Deltas.

Unless operating equivalent emissions treatment technology like exhaust gas cleaning systems, when vessels enter areas with reduced fuel sulfur requirements, they are required to switch from high sulfur fuels to compliant fuels. Records of fuel switching are maintained in the ship's logs. Fuel switching has the benefit of not requiring retrofits as vessels can in most all cases continue to use the same engines under high or low sulfur conditions after a short switchover period. Vessels must maintain separate fuel tanks, however, to facilitate switching fuels.

2.1.2.2. Exhaust Gas Cleaning Systems

MARPOL Annex VI Emission Control Area (ECA) regulations require vessels to use low sulfur fuels, or to reduce SO_x, NO_x, and PM emissions to equivalent levels. Ships can use exhaust gas cleaning systems (EGCSs), or scrubbers, to reduce criteria pollutant emissions to MARPOL Annex VI standards, and beyond. EGCSs have the benefit of allowing vessels to carry one type of fuel and then clean the exhaust to comply with applicable regulations. However, EGCSs are expensive to install and require regular maintenance, such as disposing of captured pollutant sludge in the case of closed-loop systems, and replenishment of buffering solutions in open-loop systems.

A paper by Carr and Corbett (2015) estimated the switchover points at which different types of EGCSs become economical over using ECA compliant fuels. Using the RATES model, Carr and Corbett (2015) found that open loop systems are economical to retrofit on vessels operating for more than 4,500 hours in an ECA. For new builds the switchover point is at around 500 hours. Closed-loop systems, which capture pollutants in a sludge to be disposed of on land were not economical in Carr and Corbett's analysis.

2.1.2.3. Shore Power

Typically, large ocean going vessels will use their auxiliary engines to power the electrical systems while at berth. The cities where ports are located power their electricity grids with fossil fuels and renewable energy resources that may contain less fuel-sulfur than marine fuels powering auxiliary engines to satisfy ship demand at dockside. In order to reduce vessel emissions while at-berth, specially equipped vessels can plug into the local electricity grid, which typically produces lower levels of greenhouse gas and criteria pollution than vessel auxiliaries. As such, vessels in port using shore power do not burn bunker fuel, and emissions

are shifted from the stack of the vessel to the local or regional electricity grid. Emissions reductions will occur where the local electricity grid is cleaner than vessel auxiliaries.

CLIA officially supports continued port infrastructure development, including shore power, in the ports where cruise ships call and when the availability of a clean supply of power, close to the port, will achieve an overall emission reduction. The cruise industry is a recognized leader in developing shore power. Shore power is most commonly used in the US, where EERA has identified seven ports; these are Juneau, AK; Seattle, WA; San Francisco, CA; Los Angeles, CA; Long Beach, CA; San Diego, CA; and Brooklyn, NY. CLIA vessels currently also use shore power at two ports in Canada. The Chinese recently announced that they are in the process of developing shore power for cruise vessels at two Chinese ports, which are not yet operational as of November, 2016.²⁹ A number of ferry terminals in Europe also use shore power, including, but not limited to, the ports of Gothenberg and Rotterdam. A summary of major cruise ports using shore power is in Table 4. Data compiled from publicly available sources.

Table 4: Major world cruise ports using shore power technology to reduce at-berth emissions from cruise vessels.

Year Introduced	Port	Country	Capacity (MW)	Frequency (Hz)	Voltage (kV)
2001	Juneau	U.S.A	7-9	60	6.6 & 11
2004	Los Angeles	U.S.A	7.5-60	60	6.6
2005-2006	Seattle	U.S.A	12.8	60	6.6 & 11
2009	Vancouver	Canada	16	60	6.6 & 11
2010	San Diego	U.S.A	16	60	6.6 & 11
2010	San Francisco	U.S.A	16	60	6.6 & 11
2011	Long Beach	U.S.A	16	60	6.6 & 11
2014	Halifax	Canada	20	60	6.6 & 11
2015	Brooklyn	U.S.A	20	60	6.6 & 11
2016*	Lianyungang	China			
2016*	Shanghai	China			

* Seven Chinese terminals are being commissioned for shore power, including two cruise berths, but are not yet fully operational as of November 2016.

Typically, regional electricity grids have lower criteria pollutant emissions than large ocean-going vessels, and so vessels utilizing shore power, where available, can see significant reductions in criteria pollutants. Vessels using shore power in the US can reduce air emissions of sulfur by 30%, nitrogen oxides by more than 95%, and greenhouse gas emissions by 36% depending on the renewable mix of the regional grid (Table 5). Proximity of electricity generation to the port also plays an important role, as electricity transmission losses can average 6% in the US grid³⁰, the European Union, and China, and up to 13.1% globally³¹. Transmission losses require electricity generators to generate larger amounts of energy in order

²⁹http://www.ioc.com/regulation-policy/transportation-regulations/international-transportation-regulations/china-studies-shore-power-supplement-new-emissions-rules_20160714.html

³⁰ <https://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3>

³¹ <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2013&start=1960>

to compensate for losses and deliver the required level of energy. Estimated emission reductions for a cruise vessel with a 10,000kW auxiliary engine using shore power over auxiliary engines at Port of Charleston is shown in Table 5. Differences between shore power and auxiliary engine emissions were estimated by Corbett and Comer (2013) using facility-specific emission factors³²

Table 5: Estimated emission reductions of criteria pollutants from a 3,500 passenger cruise vessel with an 11,000kW auxiliary engine using shore power at Port of Charleston (Corbett and Comer (2013))

Pollutant	Percent Reduction Using Shore Power
Nitrogen Oxides (NO _x)	99%
PM ₁₀ *	58%
PM _{2.5} *	71%
Sulfur Dioxide (SO ₂)	30%
Carbon Dioxide (CO ₂)	36%

*PM Emissions factors are not available in eGRID. EERA substituted Emission factors for the Charleston, SC region, as shown in Corbett and Comer (2013)

Average US and European (EU-28) grid emission factors are shown in Table 6, with more detail in the Appendix (Appendix Table 8 and Appendix Figure 14). Grid emission factors are calculated for the EU from statistics on electricity generation³³ and associated pollution³⁴, and for the US from EPA’s eGRID³⁵ (PM_{2.5} estimates from National Renewable Energy Laboratory³⁶). EPA’s eGRID can provide more detailed breakdown of electricity grid emissions factors for parts of the US.

Table 6: Comparison of US and European electricity grid emissions factors

Pollutant	Electricity Grid Emissions Factor (g/kWhr)	
	United States	Europe-28
NO _x	0.73	0.497
SO _x	1.07	0.536
PM _{2.5}	-	0.017
PM ₁₀	0.042	0.028

It is important to note that the voluntary, mandatory, and regulatory methods used in California, resulting in high shore power compliance by the cruise industry, may not be transferrable to all markets. Additionally, the growing adoption of exhaust gas cleaning systems

³² Corbett, J. J., & Comer, B. (2013). *Clearing the air: Would shoreside power reduce air pollution emissions from cruise ships calling on the Port of Charleston, SC?* Pittsford, NY: Energy and Environmental Research Associates. Retrieved from <http://coastalconservationleague.org/wp-content/uploads/2010/01/EERA-Charleston-Shoreside-Power-Report-.pdf>

³³ http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview

³⁴ <http://www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap>

³⁵ <https://www.epa.gov/energy/egrid>

³⁶ <http://www.nrel.gov/docs/fy07osti/38617.pdf>

may obviate the need for shore power as vessels will be able to meet both at-berth and IMO ECA standards while also maintaining full control over their technology investments.

Cruise vessels call on approximately 1,000 ports worldwide, making the number of ports where shore power is available a small fraction of the total. In ports where shore power is available, there are issues of insufficient berths to meet the demand presented by multiple cruise ships in port at the same time. Future shore power infrastructure development should be designed to currently employed international standards (IEC/ISO/IEEE 80005-1:2012³⁷) and be designed to meet the needs of a highly mobile and growing international fleet.

EERA has identified at least 25 vessels that are equipped for shore power or around 9% of the CLIA fleet, with many cruise lines incorporating shore power into their new vessel orders.

2.2. Fleet Modernization Trends

This section includes a summary of public data accessed to evaluate fleet activity. This section also describes non-public data related to adoption of advanced technologies, and characterizing fleet modernization and order book trends.

2.2.1. Public Fleet Activity Data (US and EU Data)

In the US as a whole, using USACE entrances and clearances data, cruise vessel at-berth emissions comprise around 3% of the total, which is dominated by container, tanker, bulk, and RORO vessels. These results are consistent with the international shipping emissions estimates from Third IMO Greenhouse Gas Study. When considered in the context of the wider maritime industry, the cruise industry is responsible for only a small fraction of total emissions (Figure 8).

2.2.2. Fleet Modernization Trends

Fleet modernization is evaluated based on the cruise fleet order book, and considers publicly available technology developments by cruise lines.

2.2.2.1. Cruise Fleet Order Book

At present, CLIA member cruise lines have orders in place totaling an estimated \$28.46 billion and total capacity of 200,392 persons. The 2016 order book has orders for 72 ocean and 17 river cruise vessels to be delivered between 2017 and 2026 (Figure 3). The Seatrade Cruise Orderbook³⁸ contains updated numbers indicating fleet investment in new orders out to 2024 may be as high as \$47.6 billion, with ordered berths totaling 196,196. Values given in Figure 4 through Figure 6 are based on CLIA orderbook estimates.

In general, Gross Tonnage and Capacity are increasing among CLIA member vessels. CLIA members do continue to order smaller vessels, however, as shown in Figure 3, the majority of new orders are for larger vessels, above 100,000 GT or approximately 3,000 berths. (Data with missing values not shown.)

³⁷ http://www.iso.org/iso/catalogue_detail.htm?csnumber=53588

³⁸ <http://www.seatrade-cruise.com/Orderbook.html>

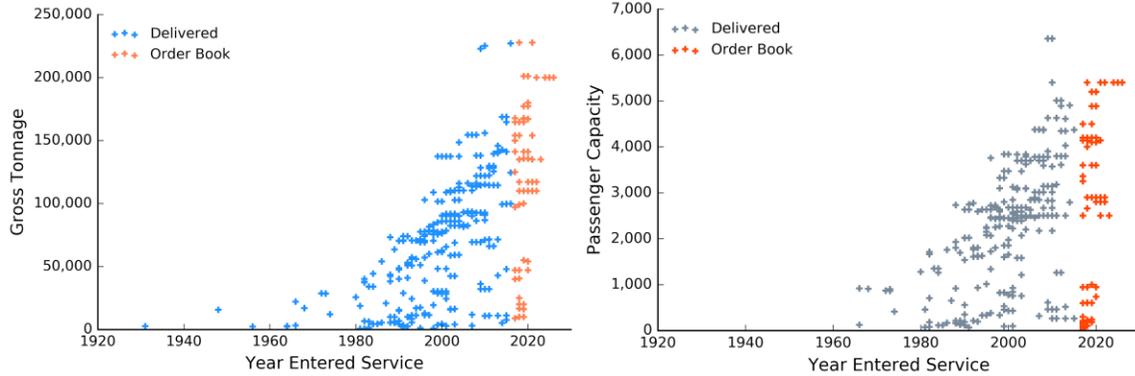


Figure 3: Current and ordered vessels by a. gross tonnage and year; and b. berth capacity and year.

The cruise vessels on the current order book are equivalent to 32% of the current CLIA vessel count, and 38% of berths. 99.2% of the capacity currently on order is in the ocean-going cruise sector (Figure 4 by number, Figure 5 by berth capacity, and Figure 6 by passenger capacity). (Note: Two ordered vessels not shown as delivery date was unavailable.)

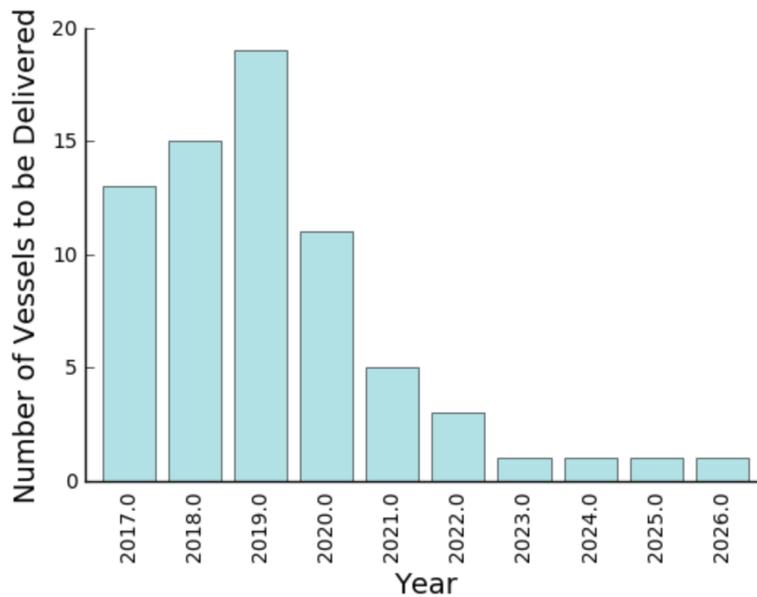


Figure 4: Delivery dates of currently ordered ocean cruise vessels.

2.2.2.2. Alternative Marine Fuels

LNG has emerged as a low-cost, low-emissions alternative to conventional marine bunker fuels. Retrofit and initial capital expenditures can be significant, but operators have the potential to recover high CAPEX costs through low fuel costs, while also exceeding MARPOL Annex VI regulations.

The significant investments made by the cruise industry to utilize a cleaner and more cost effective marine fuel adds to the many commercial ships which are already using LNG; the

logical expectation is that the necessary infrastructure will follow to overcome challenges with storage, transportation and CAPEX costs.

2.2.2.3. Cruise fleet adoption rates of emissions control measures

As of 2016, CLIA member cruise lines have orders in place for at least thirteen LNG powered vessels in the coming years,³⁹ resulting in a significant reduction in air pollution for these vessels. Additionally, EERA found that CLIA members have plans to retrofit exhaust gas cleaning systems on at least 106 vessels. In addition, CLIA member lines plan to add or retrofit at least 18 vessels for shore power. To date, no viable LNG fuel retrofit option has been identified for cruise ships while underway, although there is some future technical possibility for this while at berth.

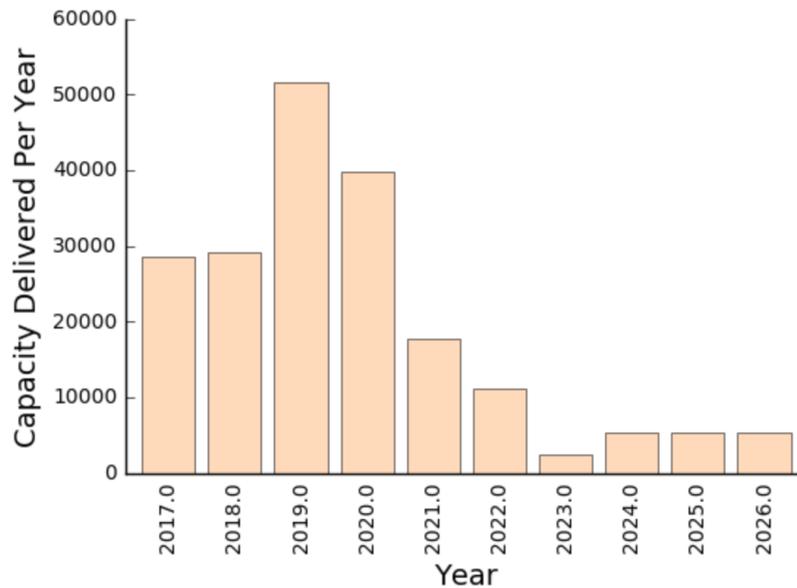


Figure 5: Berth capacity by delivery date for ordered ocean and river cruise vessels

³⁹ <http://www.cruiseindustrynews.com/cruise-news/cruise-ship-orderbook.html>

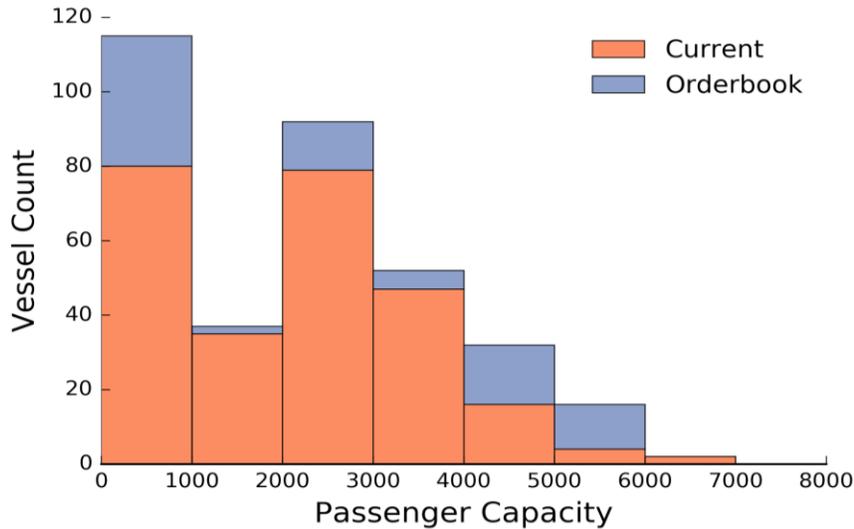


Figure 6: Number of vessels current and on order presented by passenger capacity.

2.2.2.4. Cruise fleet adoption of wastewater discharge control measures

From a wastewater perspective, **CLIA members have ordered at least 26 new builds with AWTs. Based on these numbers, we estimate that at least 47% of newly built capacity over the next 10 years will be using advanced wastewater treatments as the chosen type of MSD technology.** It should be noted, however, that existing and newly built CLIA Member ships without AWTs must still exceed current MARPOL requirements under CLIA’s policy of no discharge of untreated sewage, which is a restriction that goes beyond international requirements.

2.2.3. AIS Data on Fleet Activity by Region (Proprietary CLIA Data)

EERA’s analysis of AIS data for 2015 showed that 89 CLIA vessels operated in ECA regions for more than 4500 hours (Figure 7). Review of publicly available sustainability reports suggests that **CLIA members have installed, or have plans to retrofit, EGCSs on at least 106 vessels, or approximately 38% of the current CLIA member fleet.** This rate of installation of EGCSs exceeds the rate that might be suggested by economic decision making, demonstrating leadership by CLIA vessels in willingness to invest in new and innovative technology to reduce air emissions.

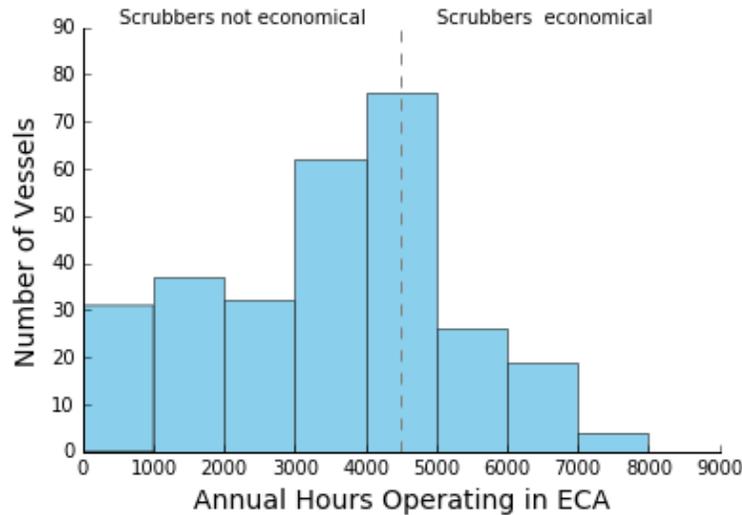


Figure 7: Number of hours of operation for CLIA vessels in ECA regions

2.2.4. Notices of Violation Published for US and EU

This section describes the review of publicly available statistics of violations with existing requirements for air emissions and wastewater in both the United States and Europe.

2.2.4.1. Air Emissions Violations in US and EU Waters

EERA found that the Alaska Department of Environmental Conservation issued 19 notices of violations for 49 alleged violations during the period 2010-2014. Of the 343 opacity readings taken in 2015, 80% met or exceeded the 20% opacity standard⁴⁰. These data are not comparable to the rest of the Alaskan fleet, as the observation locations are heavily concentrated in Juneau, and spotters focus on cruise vessels. The cruise industry has raised concerns regarding the consistency of measurements taken using EPA’s Method 9⁴¹. To further improve compliance, the cruise industry has installed monitoring equipment on their vessels in order to better validate emissions for compliance with the requirements⁴².

Zero notices of MARPOL Annex VI violations were found for CLIA cruise vessels in US waters during the period July 2015 to June 2016, per the United States Coast Guard Foreign & Offshore Compliance Division list of IMO Reportable Detentions⁴³. EERA found 2 MARPOL Annex VI violations for other vessel types during the period July 2015-June 2016, one by a bulk carrier in Long Beach, CA, and one by a dry cargo vessel in Baltimore, MD.

⁴⁰ http://dec.alaska.gov/water/cruise_ships/pdfs/2015_CPVEC_Report.pdf

⁴¹ <http://www.seatrade-cruise.com/news/news-headlines/alleged-cruise-ship-air-violations-a-murky-matter-in-alaska.html?print=1&tmpl=component>

⁴² <http://cruisesafely.com/are-scrubbers-the-answer-to-cruise-ship-air-pollution/>

⁴³ <https://www.uscg.mil/hq/cgcvc/cvc2/psc/safety/detentions.asp>

The European Union Thetis⁴⁴ Database lists 20 MARPOL Annex VI deficiencies by CLIA member vessels during the period 1 January 2014 - 22 August 2016. **No cruise vessels were detained for violations.** During that same time period the Thetis database records 1,160 deficiencies by the remainder of the maritime freight and transportation sector, resulting in 148 detentions and 5 bans. During the period 1 January 2014 - 8 August 2016 the cruise industry was responsible for 1.7% of MARPOL Annex VI deficiencies in the European Union.

Using publicly available data, we find that the cruise industry generally meets or exceeds international, national, and regional air quality standards and rates of non-compliance in the cruise industry are commensurate or better than the fraction of all marine vessel activity attributable to cruise vessels.

2.2.4.2. Wastewater Discharge Violations in US and EU Waters

No notices of MARPOL Annex IV violations were found for cruise vessels in US waters, per the United States Coast Guard Foreign & Offshore Compliance Division list of IMO Reportable Detentions. The United States is not a party to MARPOL Annex IV, but instead uses the Clean Water Act to regulate marine pollution⁴⁵. U.S.-registered vessels may apply to the USCG for a Statement of Voluntary Compliance (SOVC), which is granted if found to be in compliance with the provisions of MARPOL Annex IV, and may be recognized by other nations.

In Alaska, Cruise vessel operators received notice of 18 exceedances out of 220 samples of the 2014 General Permit maximum limits. **Data for small and other vessels are not publicly available, making fleet comparisons challenging.**

The European Union Thetis Database lists 5 MARPOL Annex IV deficiencies and no detentions by CLIA member vessels during the period 1 January 2014 - 31 December 2015. During this same period, other passenger vessels accounted for 54 MARPOL Annex IV deficiencies. All other maritime sectors listed in the Thetis database recorded 5,211 MARPOL IV deficiencies, resulting in 93 detentions. During the period 1 January 2014 - 31 December 2015, the cruise industry was responsible for 0.1% of MARPOL Annex IV deficiencies in the European Union.

Using publicly available data, we find that the cruise industry generally meets or exceeds international and national wastewater quality standards and rates of non-compliance in the cruise industry are commensurate or better than the fraction of all marine vessel activity attributable to cruise vessels.

⁴⁴ <https://portal.emsa.europa.eu/web/thetis/inspections>

⁴⁵ <https://www.epa.gov/vessels-marinas-and-ports/vessel-sewage-discharges-statutes-regulations-and-related-laws-and>

3. Analytical Methods

This section presents a summary of equations and methods for quantifying air emissions and wastewater emissions, including reflecting where leading adoption of best practices or advanced technologies may support the hypotheses.

3.1. Equations Characterizing Air Emissions and Water Discharges

Air emissions estimates necessarily rely on vessel propulsion activity. Wastewater discharge estimates are directly related to the number of berths and passenger occupancy. EERA estimated the **hourly** emission rates for seven vessel types operating at typical cruising speeds while underway. We use a hypothetical vessel with a gross tonnage of 70,338 metric tons, which represents the median cruise vessel size from the CLIA Ships Database. Emissions are calculated using the formula

$$E = P \times LF \times EF \times A \quad \text{Equation 1}$$

E: Emissions (g/kWh)

P: Installed power (kW)

LF: Load factor

EF: Emissions factor (g/kWh), shown in Table 3

A: Activity hours (h)

As main engine power is unknown, we estimate the relationship between gross tonnage (GT) and main engine installed power (kW) using ordinary least squares (OLS) regression. We performed regressions using the CLIA Ships Database provided to estimate the relationship between gross tonnage and main engine power. We used Lloyd’s List data from 2004 for the other vessel types. OLS regressions indicate a simple linear relationship between GT and installed power for all vessel types modeled. This linear relationship is shown as “Coefficient” in Table 7.

The 95th percentile tonnage for all vessels listed in the CLIA database is 141,580 gross tonnage. More recently built cruise vessels are larger, on average, than older cruise vessels, indicating the fleet is shifting to larger cruise ships. Larger vessels offer increased fuel efficiency per unit cargo (including passengers)⁴⁶ and as newly built vessels comply with IMO Energy Efficient Design Index (EEDI) standards⁴⁷. For all vessels entering into service up to and including the year 2000 (139 vessels), the median size is 37,300 gross tons, and the 95th percentile tonnage is 80,150 gross tons. For all vessels entering into service after the year 2000 (137 vessels), the median tonnage is 92,400 gross tons, and the 95th percentile tonnage is 154,700 gross tons.

⁴⁶ <http://new.abb.com/turbocharging/maritime-cargo-vessels---is-bigger-better>

⁴⁷ <http://www.imo.org/en/MediaCentre/hottopics/ghg/Pages/default.aspx>

4. Air Emissions

Table 7 presents the typical duty-cycle emissions for a vessel operating for one hour at a load factor of 0.7, as specified in the Third IMO greenhouse Gas Report⁴⁸ (GHG3). (The coefficient describes the linear relationship between gross tonnage and main engine power for each vessel type.) We estimate emissions assuming operation in an Emission Control Area (ECA), burning 0.1% Sulfur fuel, using the emission factors shown in Table 3. All at-berth calculations shown for US ports assume the use of ECA-compliant fuels or use of technologies to achieve an equivalent emissions results. As shown in Table 7, for vessels of equivalent gross tonnage, the installed main engine power can vary significantly. Oil tankers and bulk carriers typically move very slowly and so their power requirements are lower than those of faster moving vessels such as cruise and container vessels. Moreover, cruise ships generally use diesel electric drive designs, where engines can generate electromotive power for either propulsion or hotel and hospitality purposes, including electricity, HVAC, and entertainment. Refrigerated cargo vessels have an additional energy burden on the main engines, as they must also provide refrigeration for the on-board containers. As such, cruise vessel emissions rank fourth in total installed power for vessels of equivalent tonnage behind refrigerated cargo vessels (59%), container ships (86%), and RORO cargo vessels (98%). (Percentages show ratio of cruise vessel power to respective vessel types for a vessel of a given tonnage.)

At a global level, however, emissions from cruise vessels comprise a small fraction of the total fleet-wide emissions. Sustainability reports published by Carnival Corporation & plc⁴⁹ and Royal Caribbean Cruises⁵⁰ for 2014 note direct carbon dioxide equivalent emissions from fuel consumption to be 10.3 million and 4.4 million metric tonnes respectively. Together, these two cruise lines account for 70% of berths in the industry⁵¹. Berths are proportional to tonnage and installed power, therefore extrapolation of these values to the rest of industry yields a value of approximately 21 million metric tonnes. The Third IMO Greenhouse Gas Study estimates total CO₂ emissions from the cruise sector of 35 million tonnes. Total international (excluding fishing vessels and domestic shipping) maritime CO₂ emissions were estimated to be 800 million tonnes in 2012. Thus, the cruise industry accounts for less than 4.5% of worldwide international shipping greenhouse gas emissions. The attributable fraction of criteria pollutants is on the same order of magnitude.

At MEPC 70, the IMO adopted a mandatory data collection system for fuel oil consumption for vessels over 5,000 GT.⁵² Data from these requirements will be valuable for informing future decisions and validating estimates of greenhouse gases from various shipping sectors.

⁴⁸<http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf>

⁴⁹http://phx.corporate-ir.net/phoenix.zhtml?c=140690&p=irol-sustainability_env

⁵⁰<http://www.royalcaribbeanincentives.com/content/uploads/2014-RCL-Sustainability-Report.pdf>

⁵¹<http://www.cruisemarketwatch.com/capacity/>

⁵²<http://www.imo.org/en/MediaCentre/PressBriefings/Pages/28-MEPC-data-collection-.aspx>

Table 7: Main engine power (kW) and typical duty cycle emissions for a 77,338 ton vessel operating for one hour at typical load factors, as described by the Third IMO GHG report⁵³.

Vessel Type	Coefficient	Power (kW)	Emissions (kg)			
			CO ₂	SO _x	NO _x	PM _{2.5}
Refrigerated Cargo Ship	1.064	74,800	33,840	20.9	691.3	8.9
Container Ship	0.730	51,300	23,210	14.4	474.2	6.1
Ro-Ro Cargo Ship	0.642	45,200	20,420	12.6	417.3	5.4
Passenger (Cruise) Ship	0.630	44,300	20,030	12.4	409.3	5.3
General Cargo Ship	0.541	38,000	17,210	10.7	351.6	4.5
Oil Products Tanker	0.382	26,900	12,160	7.5	248.4	3.2
Bulk Carrier	0.227	16,000	7,230	4.5	147.8	1.9

4.1. At-Berth Emissions

This section presents at-berth air emissions comparisons among vessel types for the United States and Europe.

4.1.1. United States

Using entrance and clearance data from the United States Army Corps of Engineers (USACE), EERA estimated at-berth emissions from cruise ships compared with other vessel types at US ports. At-berth emissions of criteria pollutants such as sulfur oxides (SO_x), particulate matter (PM), and nitrogen oxides (NO_x, and ozone pollution precursor) are important to consider because ports are typically located near major cities.

In addition to criteria pollutants, EERA also estimated emissions of carbon dioxide (CO₂). CO₂ emissions are generally considered to mix evenly in the atmosphere and reside for many decades as the major greenhouse gas, meaning that the impacts are not specific to the region in which they were released. Criteria pollutant emissions were calculated concurrently with CO₂ emissions, however, as the ratios of pollutants are identical, except in cases where shore power is used, we only present CO₂ results. As shown in Figure 8, **cruise vessels contribute approximately 3% of all at-berth emissions at U.S. ports, which as a fraction is lower than the overall estimated contribution of cruise vessels to global CO₂ as estimated by the Third IMO Greenhouse Gas report (4.4%).**

⁵³ Load factor shown is average load factor weighted by number of vessels, estimated from IMO GHG3 average operating and design speeds (GHG3 Table 14)



Figure 8: Pie chart showing at-berth CO₂ emissions for vessels at U.S. ports by vessel type

4.1.2. European Union

EERA analysed aggregated entrances and clearances data for vessels calling at European Union (EU) ports⁵⁴. Data are provided aggregated by country and gross tonnage, and are grouped into eight vessel types; 'Liquid bulk tanker', 'Dry bulk carrier', 'Container ship', 'Specialised carrier', 'General cargo, non-specialised', 'Cruise ship', 'Passenger ship (excluding cruise ship)', and 'Dry cargo barge'. These categories differ slightly from those provided by USACE, making direct comparison of EU and US results difficult.

⁵⁴ <https://data.europa.eu/euodp/en/data/dataset/4DEfgC9nhWcP0gcFdClrTA>



Figure 9: Total fraction of EU at-berth emissions by vessel type

As a whole, **cruise ships contribute approximately 1.24% of at berth emissions from maritime vessels in the European Union** (Figure 9). These estimates assume full compliance with International and EU regulations, but do not take into account the impact of shore power usage at European ports as insufficient data were available to adequately model changes in emissions due to the use of shore power. Croatia currently has the highest fraction of at-berth emissions attributable to cruise vessels at 9.4%, followed by Italy at 4.1%, and Greece at 3.1% (Figure 10).

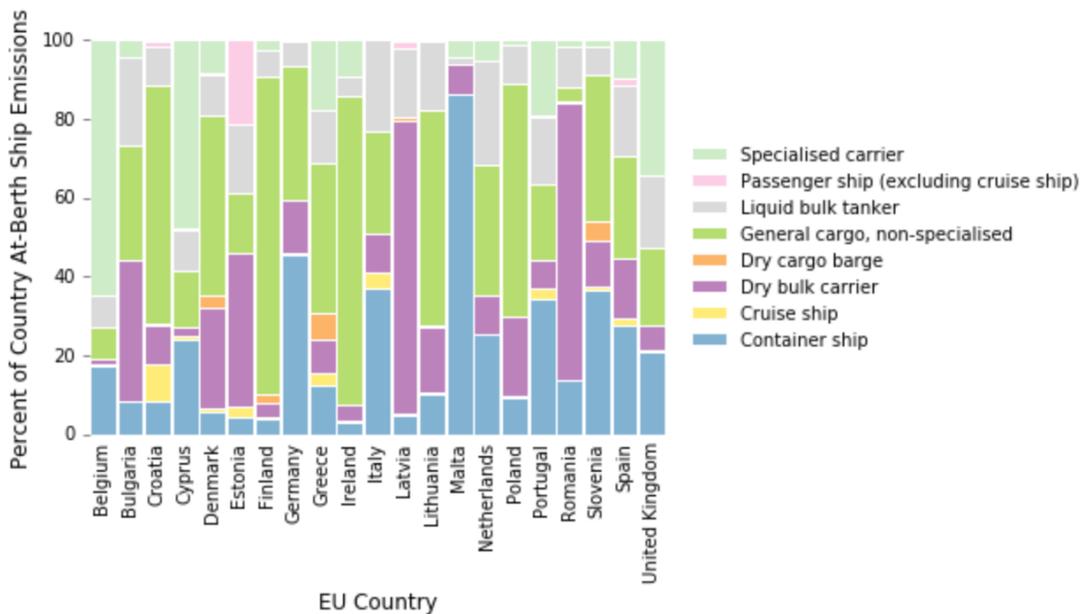


Figure 10: Fraction of total at-berth emissions in EU countries by vessel type (No Data: France)

These results for EU ports are consistent with the US data, where both regions identify ports with specialized business serving the cruise industry, ports serving cruise and cargo vessels, and

many ports serving mainly cargo vessels. For example, recent reports for the Spanish port of Barcelona (Porte de Barcelona Study⁵⁵) are very consistent in methodology and finding with the review of US ports in Section 4.1.1. Emissions from the stacks of ships at berth (estada, in the Barcelona study) represent one component of air emissions in port communities, which can also include vessels in transit or maneuvering, cargo handling equipment, drayage trucks, and intermodal rail yards. For the purposes of this report, and in light of limited data, the above results have focused on the fractions of at-berth emissions attributable to different vessel types. The Barcelona study suggests that non-cruise vessels contribute some 86% of PM10 emissions and 84% of NOx emissions while at berth, with cruise ships contributing 14% and 16% of PM10 and NOx, respectively (Porte de Barcelona Study⁵⁶, Grafic 5.4 and 5.2). While the Port of Barcelona is a major emission source for the City of Barcelona (PMQAB 2014⁵⁷, Taula 12 and Taula 13), the Port of Barcelona study reports that cruise ships contribute between 0.23% and 1.2% of PM10 and NOx on a larger regional scale.

5. Wastewater Discharges

As noted by Heinze (2008) in “Assessment of Waste Discharges from Cruise Lines International Association (CLIA) Ships,” CLIA members have agreed that all sewage will be processed through a MSD prior to discharge into the ocean, irrespective of distance from shore. Therefore, **all cruise vessel wastewater effluents exceed the standards prescribed by IMO for international shipping.**

Additionally, a number of cruise vessels have adopted Advanced Wastewater Treatment systems (AWTSs), a subset of MSD’s, which provide improved screening and separation of solids, biological treatment and ultraviolet disinfection over Type II systems. EPA has noted in Cruise Ship Discharge Assessments that AWTSs are very effective at removing pathogens and eutrophication substances, oil and grease, metals, and suspended solids. AWTSs remove volatile organics to levels below detection limits. 17 out of 30 cruise vessels operating in Alaskan waters in 2016 used AWTS to treat wastewater effluents.⁵⁸ Of the remaining 13 cruise vessels, 12 did not discharge wastewater into Alaskan waters in 2016.

EPA data show that effluents from vessels operating AWTS⁵⁹ meet or exceed state standards⁶⁰ in the following categories; pH, turbidity, fecal coliform, and total dissolved solids (See appendix). **These data show that vessels operating AWTS to treat wastewater are highly effective at removing contaminants from wastewater effluents.**

⁵⁵ <http://www.portdebarcelona.cat/web/el-port/109>

⁵⁶ <http://www.portdebarcelona.cat/web/el-port/109>

⁵⁷ http://ajuntament.barcelona.cat/qualitativa/sites/default/files/pdfs/PMQAB_CAT_2014.pdf

⁵⁸ https://dec.alaska.gov/water/cruise_ships/pdfs/Largeship_Wastewater_2016.pdf

⁵⁹ <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=P1002SVS.txt>

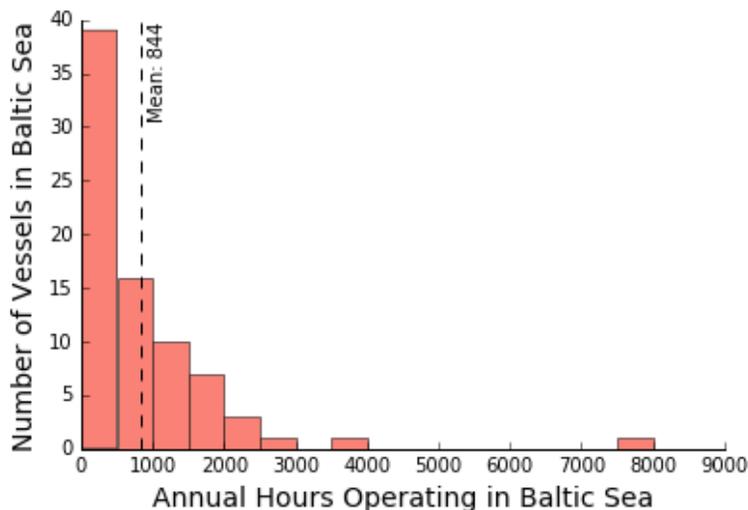
⁶⁰ <http://dec.alaska.gov/commish/regulations/pdfs/18%20AAC%2070.pdf>

5.1. Baltic Sea Special Area

The Baltic Sea has been designated a Special Area under MARPOL Annex IV, requiring passenger vessels (> 400 GT and more than 15 persons on board) to dispose of Annex IV waste at onshore facilities or to significantly reduce phosphate and nitrogen emissions through treatment. The Special Area is thus a no discharge zone requiring discharge of wastewater to port reception facilities (PRF). A rule exception applies for vessel operating wastewater treatment systems that meet or exceed the standards set in the Special Area. This rule will impact cruise ships and passenger ferries. The rule is anticipated to go into effect starting in 2019 and 2021 for new and existing passenger ships, respectively. Prior to these dates, the general MARPOL Annex IV requirements apply to regulate the discharge of sewage. As of 2016, CLIA Member lines have already adopted a policy that, when operating in the Baltic, ships are to discharge MARPOL Annex IV waste ashore where adequate port reception facilities are available under a 'no special fee' arrangement.

Cruise ship calls have been steady, around 2100 per year since 2006, while total passengers rose from 2.3 million to 3.8 million over that same time period.⁶¹ HELCOM estimates that passenger sewage production is around 0.1 to 0.17 m³ per day (22-37 gallons per day). Based on a joint survey sent out in 2014, **CLIA and HELCOM indicated that almost 31% of cruise ships in the Baltic were already voluntarily using port wastewater reception facilities when available and this practice was ahead of the development of new requirements that will go into effect soon, demonstrating the industry's leadership.**

EERA identified 78 unique vessels operating in the Baltic Sea area from available AIS data. The majority of vessels identified in the region were operating for fewer than 3000 hours in 2015, with a mean of 844 hours (Figure 11).



⁶¹<http://www.helcom.fi/Lists/Publications/Baltic%20Sea%20Sewage%20Port%20Reception%20Facilities.%20HELCOM%20overview%202014.pdf>

Figure 11: Annual hours of operation for CLIA member vessels in the Baltic Sea Special Area in 2015

The HELCOM report provides discharges and usage rates (See appendix). As of 2014, observed maximum discharge rates were far below theoretical maximum discharge rates. However, the aggregated data are too coarse to allow sufficient detailed analysis of adequacy of PRFs. Estimated theoretical discharge histograms are provided in the report and reproduced in Appendix Table 10 (Appendix) along with observed maximum discharge rates in 2014. In addition, CLIA member lines initiated a simulation during the 2016 cruising season whereby they only discharged wastewater at port reception facilities, thus simulating the enforcement of the special area regulations. The goal of this simulation exercise was to proactively and transparently assess the adequacy of port reception facilities and provide more complete information regarding the adequacy of port reception facilities in the Baltic Sea.⁶² The results of this study are in progress as of the time of this writing, and will be reported to HELCOM when available.

CLIA member vessels operating in the Baltic Sea have voluntarily agreed to meet the spirit of the Baltic Sea Special Area sewage standards ahead of regulation, with all member vessels discharging all sewage ashore when adequate reception facilities are available as part of the HELCOM no special fee regime. In 2014 eleven ports received 90% of cruise calls in the Baltic, all of which are reported via HELCOM to have adequate sewage reception facilities either to the municipal sewer systems or to tank trucks as of 2014.

6. Key Findings

EERA conducted this research to provide an evidence-based baseline assessment of the cruise industry's role in advancing environmental performance, focused on wastewater discharges and air pollution. This is important because cruise industry growth and modernization represents an opportunity for environmental leadership relative to other maritime fleets; **cruise vessels on the current order book maintained by CLIA represent ~32% of the current CLIA vessel count, and ~38% of berths.** This statistic suggests that passenger needs for vessel-based management of wastewater and energy systems will continue to motivate adoption of environmental stewardship practices and technologies.

With regard to air emissions, this report evaluated cruise fleet demonstration and adoption of cleaner marine fuels and efficient low-emission propulsion, exhaust emissions control technologies, shore power technology, and other fleet modernization to adopt energy efficient designs as the industry grows. **Comparing cruise fleets with other maritime vessel types, CLIA members are leaders in adopting cleaner fuels, controlling air emissions, and preparing vessels to connect to advanced shore-based energy systems. This report specifically**

⁶² <https://portal.helcom.fi/meetings/MARITIME%2016-2016-328/MeetingDocuments/5-7%20Update%20on%20the%20process%20and%20expected%20outcomes%20of%20the%20CLIA%20simulation%20exercise%20on%20MARPOL%20Annex%20IV%20Special%20Area.pdf>

documents that CLIA member cruise lines are leaders in at least four areas regarding air emissions:

- **Fleet Adoption of Cleaner Fuels and Advanced Engine Technology:** Orders are in place for the addition of 87 vessels to the cruise fleet from the period 2017 to 2026, including at least thirteen LNG powered vessels; and vessels where keel laying began after 1 January 2016 are required to use advanced Tier III low-emissions marine engines in the growing number of regions in which required.
- **Exhaust Gas Cleaning Systems (EGCS):** EGCSs are installed, or will be retrofit on at least 106 vessels, as one novel alternative of reducing air emissions, or approximately 38% of the current CLIA member fleet, and include exhaust gas cleaning systems on at least 18 newly built vessels.
- **In Port Emission Reduction Systems:** Shore power connections are equipped on at least 25 cruise vessels (around 9% of the CLIA members' fleets), usable where the land-based electric power grid may produce fewer emissions than onboard power systems; many cruise lines incorporating shore power capability into their new vessel orders, including plans to add or retrofit at least 18 more vessels for shore power.
- **Compliance with Emission Control Area Requirements:** Using publicly available data, we find that the cruise industry generally meets or exceeds international, national, and regional air quality standards and rates of non-compliance in the cruise industry are commensurate or better than the fraction of all marine vessel activity attributable to cruise vessels.

With regard to wastewater discharges, this report evaluated cruise fleet demonstration and adoption of advanced water treatment systems (AWTSs), CLIA member voluntary zero-discharge practices. **This report specifically documents that CLIA member cruise lines are leaders in four areas regarding wastewater:**

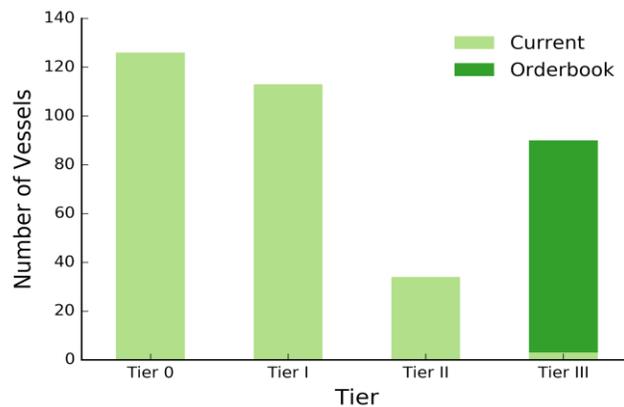
- **CLIA Member No Untreated Sewage Discharge Policy:** Existing and newly built CLIA Member ships follow CLIA's policy of no discharge of untreated sewage, a restriction that exceeds international standards.
- **Fleet Adoption of Advanced Water Treatment:** CLIA members have ordered at least 26 new builds with AWTs. Based on these numbers, we estimate that at least 47% of newly built capacity over the next 10 years will be using advanced wastewater treatments.
- **Compliance with Wastewater Discharge Requirements** Using publicly available data, we find that the cruise industry generally meets or exceeds international and national wastewater quality standards and rates of non-compliance in the cruise industry are commensurate or better than the fraction of all marine vessel activity attributable to cruise vessels.
- **Baltic Sea Practices for Wastewater Reception Facilities:** CLIA and HELCOM indicated that almost 31% of cruise ships voluntarily use port wastewater reception facilities when available; this voluntary practice precedes development of new requirements.

Appendix

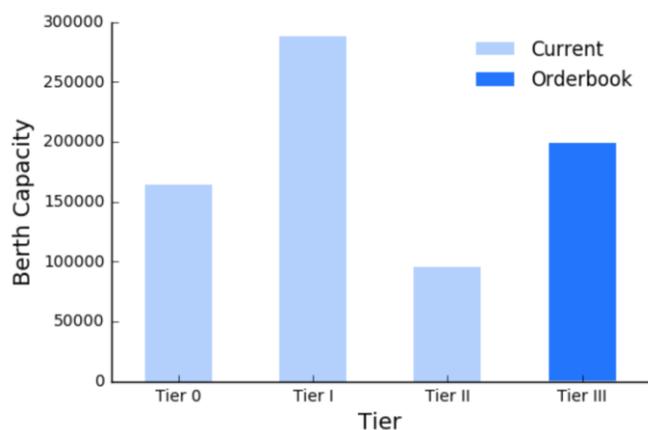
This appendix includes summary results of analyses based on the data reported in the main report.

Tier III Standards

Tier III controls only apply within NO_x ECAs, outside of which Tier II controls apply. Based on orderbook data, as of 2016 87% of vessels currently in operation were delivered prior to 1 January 2011 and thus are likely to be either Tier 0 or Tier I vessels. 34 out of 276 vessels in the CLIA database were delivered on or after 1 January 2011, and thus are likely required to comply with Tier II standards. 3 vessels were delivered after 1 January 2016; however, construction likely began prior to that date and as such these are likely Tier II vessels. New vessels built after 1 January 2016 are required to comply with Tier III standards in the North American and U.S Caribbean Sea ECAs (Appendix Figure 12 by counts, Appendix Figure 13 by capacity). A Nitrogen Emission Control Area (NECA) will be applied to ships built in or after 2021 and operating in the Baltic and North Sea areas. It is important to note that these descriptive data are based on delivery date, as the original date of keel laying, upon which the Tier I, II, and III standards are based, was not available. As such, values presented in Appendix Figure 12 and Appendix Figure 13 may not fully reflect additional engine upgrades or vessels where construction and delivery occurred on different sides of the Tier I, II, and III implementation dates.



Appendix Figure 12: CLIA cruise vessel counts for Tier I, II, and III emissions standards including the orderbook as of 2016



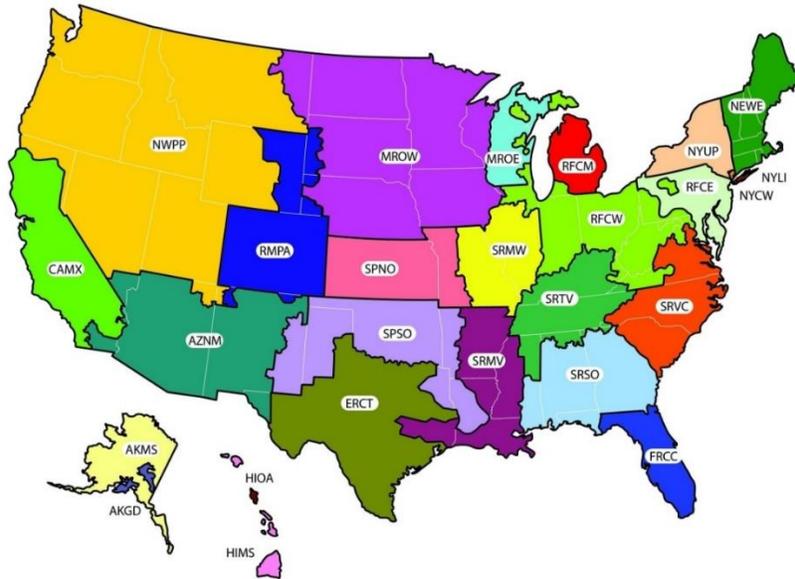
Appendix Figure 13. CLIA cruise vessel capacity for Tier I, II, and III emissions standards per orderbook as of 2016

eGrid Data

A more detailed summary of EPA eGRID characteristics and regions is provided in Appendix Table 8 and Appendix Figure 14 for the benefit of the reader in the context of shore power in the United States.

Appendix Table 8. eGRID Regional Grid Emission Factors and Grid Regions (see Appendix Figure 14)

Coastal and Great Lakes Subregion		Annual Region Emissions Rate (g/kWh)					
eGRID Subregion	Subregion Name	NO _x	SO ₂	CO ₂	CH ₄	N ₂ O	CO ₂ eq
AKGD	ASCC Alaska Grid	1.15	0.21	570.12	0.012	0.003	571.37
AKMS	ASCC Miscellaneous	2.69	0.08	203.47	0.009	0.002	204.17
CAMX	WECC California	0.18	0.08	277.07	0.013	0.003	278.18
ERCT	ERCOT All	0.30	1.02	552.56	0.008	0.006	554.70
FRCC	FRCC All	0.32	0.64	542.83	0.018	0.006	545.13
HIMS	HICC Miscellaneous	2.54	1.71	603.36	0.034	0.006	606.02
HIOA	HICC Oahu	1.13	1.82	735.68	0.045	0.010	739.78
MROE	MRO East	0.63	2.37	730.66	0.011	0.012	734.76
MROW	MRO West	0.90	1.72	696.89	0.013	0.012	700.86
NEWE	NPCC New England	0.24	0.64	327.53	0.033	0.006	330.04
NWPP	WECC Northwest	0.46	0.46	382.19	0.007	0.006	384.19
NYCW	NPCC NYC/Westchester	0.12	0.04	282.33	0.011	0.001	282.95
NYLI	NPCC Long Island	0.43	0.25	606.06	0.037	0.005	608.28
RFCE	RFC East	0.39	0.97	454.38	0.012	0.007	456.79
RFCM	RFC Michigan	0.76	2.38	739.09	0.014	0.012	743.15
RFCW	RFC West	0.63	2.26	681.97	0.008	0.011	685.63
SRMV	SERC Mississippi Valley	0.61	0.66	467.13	0.009	0.005	468.83
SRSO	SERC South	0.51	1.62	614.22	0.010	0.009	617.37
SRVC	SERC Virginia/Carolina	0.36	0.92	487.01	0.010	0.008	489.69



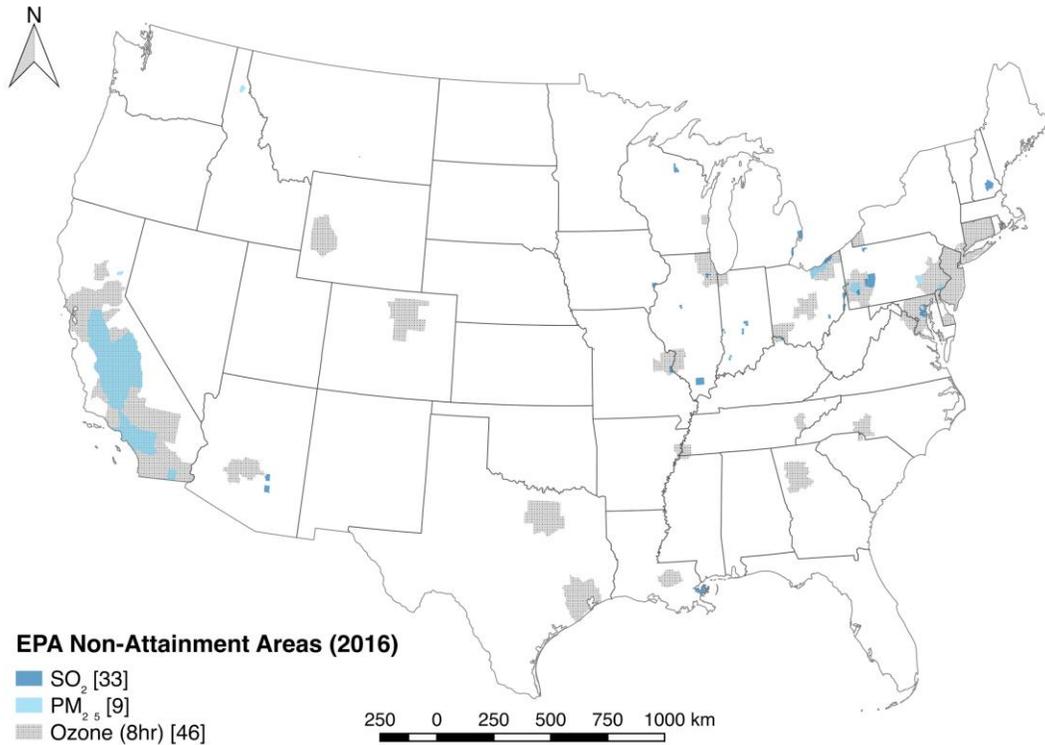
This is a representational map; many of the boundaries shown on this map are approximate because they are based on companies, not on strictly geographical boundaries.
 USEPA eGRID2010 Version 1.0 December 2010

Appendix Figure 14. US eGRID zones

EPA Non-Attainment Areas

The US EPA assesses air quality and designates regions that are in nonattainment of the current set of air quality regulations⁶³. Current data (Appendix Figure 15) show nonattainment of ozone in 46 areas. These areas are clustered around major US cities, with notable coastal counties in Northern and Southern California, the New York - Washington, DC metropolitan area, and Houston, Texas. There are 9 areas currently in PM_{2.5} nonattainment, with coastal areas including the Los Angeles - South Coast air basin, Delaware County, PA, and Cleveland, OH. There are 33 areas currently in nonattainment status for SO_x, notable coastal areas include Anne Arundel County and Baltimore County, MD; Nassau County, FL; Hillsborough County, FL; St. Bernard Parish, LA; Detroit, MI; St. Claire, MI; and Lake County, OH.

⁶³ <https://www.epa.gov/green-book/green-book-gis-download>



Appendix Figure 15: EPA SO_x, PM_{2.5}, and ozone nonattainment areas in the United States

It is notable that there are a number of areas where cruise vessels operate in significant numbers in areas that are in attainment of EPA standards (e.g. Florida, Puget Sound, Boston). While there are also areas where cruise vessels operate that are in non-attainment, assessment of the contribution of cruise vessels to nonattainment status is, as yet, unquantified. Characterization of the contributions of cruise vessels may provide valuable information to the cruise industry and the port communities where they operate.

Alaska AWTs Water Quality Results

This section details results comparing EPA data on wastewater emissions from cruise vessels operating AWTs in Alaska with Alaskan state marine water quality standards.

Appendix Table 9: Alaska cruise vessel effluents and associated state standards met

Analyte	AWTs Cruise Effluent (\pm SE)	Alaskan State Standard(s) met
pH	99.5% in range 6.0-9.0	(18)(A)(iii) Water supply for industrial use ($5 \leq \text{pH} \leq 9$) (marine)
Temperature	31.3°C \pm 0.198	25°C standard not met
Turbidity	2.31 NTU \pm 0.894	(24)(A)(i) Water supply for aquaculture (25 NTU) (marine) (24)(B)(i) Water recreation: contact recreation (25 NTU) (marine)
Fecal Coliform	14.5 CFU/100mL	(14)(A)(i) Water supply for aquaculture (200 FC/100ml) (marine) (14)(A)(ii) Water supply for seafood processing (20FC/100ml) (marine) (14)(A)(iii) Water supply for industrial use (200FC/100ml) (14)(B)(i) Water recreation: contact recreation (100FC/100ml)
Total Dissolved Solids	819 mg/L \pm 169	(4)(A)(ii) Water supply for agriculture, including irrigation and stock watering (1,000 mg/l) (fresh) (4)(A)(iii) Water supply for aquaculture (1,000 mg/l) (fresh)

Port Reception Facilities in the Baltic Sea

This section provides additional information on the use of port reception facilities by cruise vessels in the Baltic Sea. Results shown in the table include the annual number of expected calls, as well as presently observed maximum wastewater discharge rates. These results are presented in the context of the theoretical maximum discharge rate (calculated by HELCOM, 2014) that may be required by cruise vessels utilizing port reception facilities at those ports

Appendix Table 10: Observed and estimated theoretical maximum discharge rates at the top ten cruise ports by calls in the Baltic Sea

Port Name	Cruise Calls	Observed Maximum Discharge Rate (m ³ /hr)	Theoretical Maximum Discharge Rate (HELCOM, 2014)
Saint Petersburg	312	28	500
Copenhagen	300	30	1500
Talinn	285	40	1600
Helsinki	257	120	1500
Stockholm	236 (Port Statistics, 280)	85	1000
Rostock	181	NA	1100
Kiel	120	36	900
Gothenburg	71	37	1600
Klaipeda	63	28	1200
Riga	52	40	700

<http://www.helcom.fi/Lists/Publications/Baltic%20Sea%20Sewage%20Port%20Reception%20Facilities.%20HELCOM%20overview%202014.pdf>