ENVIRONMENTAL COMMITMENT, INNOVATION, AND RESULTS OF THE CRUISE INDUSTRY

REPORT PRODUCED FOR: CRUISE LINES INTERNATIONAL ASSOCIATION

OCTOBER 2021

EXECUTIVE SUMMARY

Cruise Lines International Association (CLIA) member cruise lines and shipping industry partners have demonstrated a commitment to the development and implementation of environmentally responsible technologies, policies, and practices. While cruise ships comprise less than 1% of the global maritime community and the cruise industry has been one of the most acutely impacted industries by the global pandemic, cruise lines remain at the forefront in developing responsible environmental practices and innovative technologies, which benefit the entire shipping industry. Despite the slowdown in industry operations as a result of the pandemic, the cruise industry continued to make significant investments in new technologies to reduce its environmental footprint. Through retirements of older, less efficient ships, and the introduction of new, cleaner ships – including two new LNG-propelled vessels – the cruise industry remains on the cutting edge of maritime environmental protection efforts. CLIA members satisfy and often exceed the regulatory structures set by the International Maritime Organization's (IMO) International Convention for the Prevention of Pollution from Ships (MARPOL) and more stringent regional standards, where applicable. The industry has also aligned to implement CLIA's Environmental Policy as a condition of CLIA membership and have commenced unified efforts to achieve ambitious goals and meet rising expectations.

The 2021 Environmental Technologies and Practices (ETP) inventory conducted by CLIA covered 242 oceangoing ships representing 96.7% of existing CLIA passenger capacity as well as build specifications for 62 ships currently on order. The data reflects two key approaches being utilized to improve fleetwide environmental performance – new ships built to more sustainable specifications and retrofitting ships in operation to replace and improve existing technologies. Progress across multiple strategies demonstrates CLIA's view that it is integral, urgent, and feasible to balance fostering growth with policy and technology changes that help preserve the air and oceans in which the industry operates.

To contribute to a broader understanding of the environmental progress of the global cruise industry, CLIA commissioned Oxford Economics to analyze the CLIA initiatives and performance across key topics of interest and provide case study examples that highlight advancements within the industry. This report summarizes the results of that analysis.

1. AIR EMISSIONS

3 Tiers

For NO_x regulation based on ship build date & engine rpm

Regulatory Environment

The International Maritime Organization (IMO) administers global and regional regulatory guidelines through the International Convention for the Prevention of Pollution from Ships (MARPOL). MARPOL drives global compliance for prevention of pollution of oil, sewage and garbage (including plastic) from ships, among others. In total, there are six technical annexes to MARPOL.

Annex VI addresses regulations for the prevention of air pollution from ships. A key feature of MARPOL Annex VI is its designation of Emission Control Areas (ECAs) for certain air emissions which are subject to varying and more stringent regulations and provide a model for ocean management policy in other high-traffic regions. There are currently four ECAs: the Baltic Sea ECA, the North Sea ECA, the North American ECA, and the US Caribbean ECA. Regulations 13 and 14 which concern nitrogen oxides (NO_x) and sulfur oxides (SO_x), respectively, therefore provide different guidance for global and ECA compliance.

MARPOL Annex VI Regulation 13 – Nitrogen Oxides (NO_x)

Regulation 13 of MARPOL defines limits on diesel engine NO_x emissions in terms of three tiers which correspond to the date when a ship was built. For marine diesel engines with over 130kW output power, the tiers apply as follows:

IMO MARPOL Annex VI Regulation 13 NO_x Caps by Tier

Nitrogen Oxide Emissions Caps - Global

		Total weighted cycle emission limit (g/kWh)		
Tier	Ship built on/after:	rpm < 130	130 ≤ rpm ≤ 1999	rpm ≥ 2000
I	January 2000	17	45·rpm(-0.2)	9.8
II	January 2011	14.4	44·rpm(-0.23)	7.7
III	January 2016 *	3.4	9·rpm(-0.2)	2

Source: IMO

* January 2021 for Baltic Sea and North Sea ECAs

Since 1 January 2016, compliance with the Tier III standard has been mandatory in the North American ECA and the United States Caribbean ECA for all new build ships, irrespective of the above finer ship characteristics. Starting on 1 January 2021, mandatory Tier III compliance for all new build ships expanded to include the Baltic Sea ECA and North Sea ECA as well.

MARPOL Annex VI Regulation 14 – Sulfur Oxides (SO_x) and Particulate Matter (PM)

Regulation 14 of MARPOL Annex VI dictates limits on sulfur content in fuel oil with the objective of limiting SO_x and PM emissions. Regulation 14 also allows alternative means of compliance with low sulfur fuel requirements such as exhaust gas cleaning systems. Similar to NO_x caps, required levels differ between oceangoing vessels operating globally and the more stringent caps for those that operate within regional ECAs and both have tightened over time.

However, unlike NO_x regulation, these limits apply to all fuel oil, combustion equipment, and devices on board regardless of ship construction date and are measured by mass in fuel oil. The recent history of regulatory advancement is as follows:

IMO MARPOL Annex VI Regulation 14 Sulfur Content in Fuel Oil Caps

Sulfur Content in Fuel Oil Caps

Global		ECA	
Effective Date	Sulfur Cap (mass share in fuel oil)	Effective Date	Sulfur Cap (mass share in fuel oil)
prior to January 2012	4.50%	prior to January 2010	1.50%
January 2012	3.50%	January 2010	1.00%
January 2020	0.50%	January 2015	0.10%

Source: IMO

0.5%

Maximum global fuel oil sulfur content (by mass) beginning 1 January 2020

Existing 0.1% cap within all ECAs

CLIA Initiatives and Performance

Liquified Natural Gas (LNG) and Other Alternative Fuel Sources

CLIA cruise line members are addressing air emissions by transitioning to cleaner-burning fuels such as Liquified Natural Gas (LNG), biofuels, and synthetic fuels while installing Exhaust Gas Cleaning Systems (EGCS) on ships that rely on legacy fuel sources. Presently, LNG is the primary alternative fuel source being implemented due to its strong environmental performance, growing land-based infrastructure, and established technological viability. Burning LNG produces virtually zero sulfur emissions, 85% fewer nitrogen oxide emissions, 95-100% fewer particulate emissions, and the industry estimates up to 20% fewer greenhouse gas emissions (GHG). The industry is working closely with partners to mitigate the potential risk associated with burning LNG and methane slip. Natural gas extraction, refinement, and distribution operations have grown, aided by both environmental and economic efficiency, enabling cruise ships to refuel at ports worldwide.

26 Ships

Currently sailing, on order, or under construction powered by LNG for primary propulsion

52% of new global passenger capacity to be LNG-powered

The debut of two new LNG-operated ships to the global cruise fleet increased the LNG-enabled global capacity 62% relative to 2020 – more than quadruple that of 2019. As of August 2021, there are 22 ships on order or under construction committed to relying on LNG for primary propulsion, representing 52% of new passenger capacity. In addition to LNG, over three-quarters of the global cruise fleet by passenger capacity is capable of using other alternative fuels, such as biodiesel or methanol. However, investment, development, and widespread adoption of cleaner-burning biofuels and synthetic fuels face key hurdles such as fuel density, safe storage, global availability, and regulatory obstacles. Looking ahead, the contemporary engine technology enables LNG-reliant ships to transition to future fuel sources with minimal structural intervention required.

LNG Case Study:

CLIA Executive Partner – Nauticor

Nauticor, a subsidiary of Gasum, is a Hamburg, Germany-based provider of LNG as bunker fuel to the shipping industry. They enable operators of cruise liners, tankers, ferries, container liners, and more to improve their environmental performance by moving away from conventional fuels. Toward this end, Nauticor accomplished its first ship-to-ship LNG bunkering operation for a new Meyer Werft-built LNG-powered cruise ship in 2020. LNG outperforms key legacy fuel sources such as Heavy Fuel Oil (HFO), which composes around 84% of marine bunker fuel utilization, and Marine Gas Oil (MGO).[1]HFOs and MGOs can be also utilized in Low Sulfur (LS-HFO and LS-MGO) forms and/or be used in conjunction with Exhaust Gas Cleaning Systems (EGCS) to meet ECA standards for sulfur content below 0.1%; however, it may be outperformed by LNG's complete elimination of SO_x emissions.[2]

DNV GL, a global vessel classification society, expressed the benefits of LNG fuel:

> "LNG fuel as a solution to curb harmful emissions is indisputable. It emits zero sulphur oxides (SO_x) and virtually zero particulate matter (PM). Compared to HFO, it emits up to 90% less nitrogen oxides (NO_x) The environmental agenda is today shifting to focus more on greenhouse gases. Employing current best practices and appropriate technologies to minimize methane leakage, gas offers the potential for up to a 25% reduction."

Exhaust Gas Cleaning Systems (EGCS), Water Fuel Emulsion (WFE), Selective Catalytic Reduction (SCR), and Data Solutions

76%

Portion of global passenger capacity utilizing EGCS to meet or exceed air emissions requirements

Seven percentage point growth over 2020

While the global COVID-19 pandemic hastened the pace of retirement and recycling of CLIA member ships, the longevity of cruise ships and their engines, in general, tempers the rate of transition to alternative fuel sources but does not impede the goal of fleetwide emissions reduction. EGCS are currently installed on ships that comprise 76% of global passenger capacity, reflecting a seven-percentage point increase over 2020 ETP inventory levels, and 94% of new ships not relying on LNG as their primary fuel source will have EGCS installed. These systems reduce exhaust sulfur oxide levels by as much as 98%, typical total particulate matter levels by 50% or more, and nitrogen oxide levels by up to 12%. The future cruise fleet will leverage EGCS technology and LNG fuel to lessen air emissions.

Alongside EGCS, WFE treatments further limit the air emissions of heavy fuels and diesel oil. By mixing water with the fuel using various methods, emulsified fuels are able to simultaneously reduce nitrogen oxide emissions by as much as 50% and particulate matter emissions by up to 90%.[3] In addition to fewer

[1] International Energy Agency, 2017
[2] Marquard and Bahls, 2015
[3] Holtbecker and Geist, 1998

emissions, WFE technology grants a 5% savings on fuel consumption.[4] Currently, over one-fifth of global passenger capacity is equipped with WFE technology.

Selective Catalytic Reduction (SCR) Systems are another advanced technology used to control air emissions and reduce pollution levels caused by fuel combustion. A SCR System injects a liquid-reductant agent, usually Diesel Exhaust Fluid (DEF), into the exhaust stream of a diesel engine. The use of DEF converts nitrogen oxides into nitrogen, water, and a small amount of CO_2. SCR technologies can be used to eliminate up to 95% of NO_x emissions in cruise ships.[5] In 2021, about 10% of CLIA member lines' global passenger capacity is equipped with SCR Systems – a four percentage point improvement from the approximately 6% coverage in 2020.

EGCS, WFE, and SCR empower cruise ships to meet or exceed MARPOL requirements using existing engine technology and demonstrate the value of implementing auxiliary technologies that produce desired environmental outcomes in retrofitting initiatives.

Data analysis, optimization, and automation have long played key roles in the broader shipping industry, and the cruise industry has been among the leaders. Multiple shipbuilders have entered this market, offering digital solutions that operate alongside upgraded or improved ship components. These digital solutions broadly operate on two levels: optimizing internal functions such as engine and fuel type utilization and optimizing vessel-level decisions such as route and trim. Digital solutions are available both for new builds and for retrofitting jobs and are flexible to account for the pace of adoption of newer physical components.

EGCS and Data Solutions Case Study:

CLIA Executive Partner – MAN Energy Solutions

MAN Energy Solutions is an Augsburg, Germany-based engine and auxiliary system producer that develops and installs solutions for addressing emissions and efficiency goals. MAN offers DeNOx and DeSOx EGCS for ships operating diesel fuel engines which are implemented alongside scrubbers and additional catalytic converters, when necessary, to bring ships within the most stringent IMO ECA standards.

MAN's ECOMAP digital solution produces efficiency gains that can reduce overall annual fuel consumption by 1-2%. The ECOMAP system operates MAN's diesel engines' entirely electronic fuel injection systems, applying calculated electronic parameters to maximize emissions compliance and power utilization. The ECOMAP system is capable of managing multiple engines in conjunction with a vessel's power management system as well.

[4] Hielscher Ultrasound Technology, 2020
[5] Blunox

Multi-dimensional digital systems now require further digitization for decision-making. These systems rely on Artificial Intelligence (AI) and Machine Learning (ML) for map selection and application, driving development into an entirely new space. Further, ECOMAP enables ship operators to directly manage their ships remotely from control centers. Specialists which may otherwise have been allocated across the fleet can now focus on fleetwide refinements for safety, cost, and performance. The spill-over of investment in digital solutions by larger segments of the international shipping community will benefit cruise lines as digital solutions are naturally less costly to implement fleetwide compared to upgrades to physical infrastructure.

2. WASTEWATER

Regulatory Environment

Wastewater treatment falls under IMO MARPOL Annex I and IV as well as various, more stringent regional and national regulations.

Wastewater is categorized as either graywater, blackwater, or oily waters (bilge water, etc.).

- Graywater – water that is incidental to the operation of the ship and results from activities such as food preparation, laundry, and showers.
- Blackwater – consists of sewage from toilets and urinals, residuals from cleaning the black water collections, storage and treatment systems, and wastewater from the sinks showers and drains of the medical facility
- Bilge water – water that collects on the lowest part of a ship's hull and can contain oil, grease, or other contaminants that have dripped from various sources such as shaft seals, evaporators, or other machinery

MARPOL Annex IV provides a framework to ensure environmentally friendly wastewater practices regarding the discharge of blackwater are implemented, while Annex I, Regulation 15, focuses on the discharge of oil or oily mixtures such as bilge water.

While graywater is not regulated by MARPOL, there do exist some national regulations for the treatment of this waste stream, such as the Vessel General Permit implemented by the United States Environmental Protection Agency. However, if graywater and blackwater are mixed at any point, the resulting effluent must be treated as blackwater.

MARPOL Annex IV Regulation 11 – Discharge of Sewage

The MARPOL Annex IV discharge standards prohibit discharging untreated sewage within 12 nautical miles from shore. Additionally, Annex IV requires ships over 400 gross tonnage or which may carry more than 15 persons to be equipped with an approved sewage treatment plant, an approved sewage comminuting and disinfecting system, or a sewage holding tank of approved capacity.

For ships not using an approved sewage treatment plant (STP), further restrictions under MARPOL Annex IV are that no comminuted and disinfected sewage can be discharged within three nautical miles of land, and that sewage that is either treated or untreated that is discharged more than 12 nautical miles from land must be stored in holding tanks and must be discharged at a rate no greater than the moderate rates defined by the IMO while traveling at a minimum speed of 4 knots.

Additionally, the sewage treatment plant must adhere to the ship's International Sewage Pollution Prevention Certificate, and the effluent must not produce visible floating solids nor cause discoloration of the surrounding water.

MARPOL Annex IV Regulation 11.3 - Special Areas

As of January 2013, new regulations entered force requiring a sewage treatment plant that meets stringent nitrogen and phosphorous removal standards for all passenger ships or a holding tank for wastewater to be stored until landed at a port facility. The only current Special Area this applies to is the Baltic Sea Special Area.

Member states in Special Areas must ensure that reception facilities for sewage are provided in ports and terminals in the Special Area and which are used by passenger ships. These facilities must be adequate to meet the needs of those passenger ships and operated so as not to cause undue delay to them.

MARPOL Annex IV – Sewage Treatment Plant Amendment

The IMO Sub-committee on Pollution Prevention and Response (PPR) drafted amendments to MARPOL Annex IV regarding the lifetime performance of sewage treatment plants (STPs) in early-2021. The objectives of the amendments are to enhance and monitor the performance of STPs.

If adopted, the new regulations would establish testing standards for STP effluent and include minimum STP standards for new STPs and periodic performance evaluations of existing STPs. Additionally, ships equipped with STPs would be required to maintain a Sewage Management Plan and a sewage record-keeping book for all discharges, incinerations, and sampling related to the STP.

MARPOL Annex I Regulation 15 – Discharge of Oil

Under Annex I Regulation 15, ships of more than 400 gross tonnage seeking to discharge oil or oily mixtures into the sea must observe certain standards and procedures. The ship must be proceeding en route, and the oily liquid must be processed through approved oil filtering equipment such that the oil content of the discharge without dilution does not exceed 15 parts per million. Discharge in one of the 10 special areas designated in the Annex follows the same guidelines as outside of special areas but with different requirements for the oil filtering equipment.

The discharge shall also not contain chemicals or other substances in quantities that are hazardous for the marine environment or are used for the dilution of the discharge to meet regulations. When traces of oil from the discharge are visible following expulsion from the ship, then a prompt investigation must be conducted to determine whether there has been a violation of this regulation. Lastly, the residual oil that is removed from the bilge water must be held for either reuse or disposal in reception facilities ashore.

There are additional restrictions in the Annex relevant to oil tankers but are not applicable for other ships.

CLIA Initiatives and Performance

CLIA Policies

Wastewater	MARPOL Annex IV	CLIA Policy
Untreated Sewage	Discharge allowed at distance >12 nm	Treat all sewage prior to discharge during normal operations
Treated Sewage	Discharge allowed at distance >3 nm and speed >4 knots	Discharge allowed at distance >4 nm and speed >6 knots*
Baltic Sea Special Area	In effect for all ships June 1, 2021	Since 2016, observed Special Area requirements for all ships where adequate port reception facilities available

* Not applicable for ships utilizing an Advanced Waste Water Treatment System (AWTS).

Under MARPOL Annex IV, the discharge of untreated sewage is permitted at a defined rate at an approved distance from shore. However, CLIA's more stringent policy further provides that during normal operations all sewage be treated prior to discharge, regardless of location.

The IMO's standards allow for the discharge of treated sewage under the conditions that the ship is either using an approved STP or is using a comminuting and disinfecting system and discharging greater than three nautical miles from shore and traveling at a minimum speed of four knots. Again, CLIA Policy is more restrictive and environmentally friendly, as the Compendium of Member Policies lays out that member lines must be at least four nautical miles from nearest land and traveling at a minimum speed of six knots to discharge treated sewage.

With regards to oily liquids such as bilge water or other oil-based wastewater, all of CLIA's members have agreed to meet or exceed the international standards for oil removal prior to discharge.

Advanced Water Treatment Systems (AWTS)

74%

Portion of global passenger capacity utilizing AWTS to generate effluent discharge equivalent to best shoreside treatment plants

Four percentage point increase over 2020

CLIA's member ships have broadly adopted Advanced Wastewater Treatment Systems (AWTS). AWTS rely on tertiary-level treatment, which refers to bacteriological methods of breaking down contaminants in gray and black water. The treated effluent, which may then be discharged at sea, is often equivalent to effluent produced by the best shoreside treatment plants, and consistent with CLIA policy, far exceeds international requirements. CLIA stipulates that any bio-residual from AWTS may be landed ashore, incinerated, or discharged at sea in accordance with MARPOL Annex IV.

The fraught economic situation has led to a reduction in the number of new ships on order to 62 as of August 2021 from 76 as of August 2020, but notably, 100% of new capacity on order are specified to have AWTS installed. This will increase global capacity coverage from 74% of current global capacity to just

100%

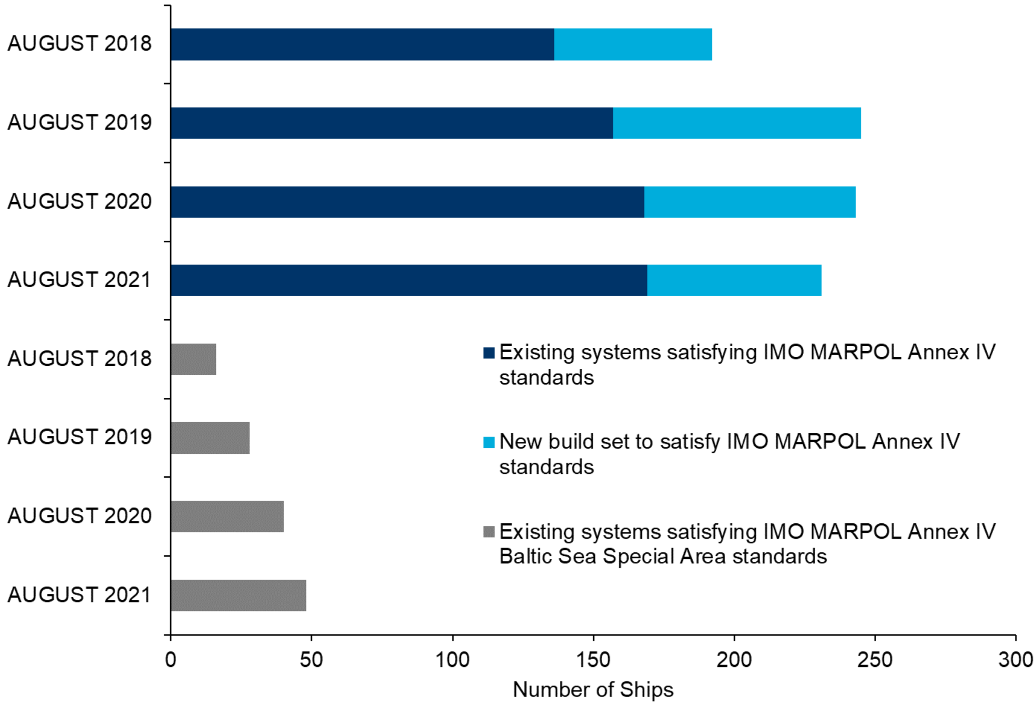
New capacity on order specified to have AWTS

Will bring total global passenger capacity utilizing AWTS to 80.5%

under 81% of expected future capacity if projected installations are completed without change. Furthermore, there has been a 20% increase in the current number of ships with AWTS capable of meeting the rigorous Baltic Sea Special Area standards enacted in 2019, representing a 28% increase in current global capacity coverage.

The Baltic Sea Special Area restrictions took effect for new passenger ships on June 1, 2019 and was implemented for existing passenger ships on June 1, 2021 with certain exceptions. Despite the delay between passage and implementation of the Special Area, CLIA member lines, recognizing the extraordinary eutrophication situation in the Baltic Sea, had voluntarily begun following this new regulation ahead of schedule. By 2016, five years before required, all CLIA Member lines had adopted a policy of following the Special Area restriction where adequate port reception facilities are available under a 'no special fee' arrangement.

Current and Committed Implementation of AWTS



AWTS Case Study:

CLIA Executive Partner – Wärtsilä

Located in Helsinki, Finland, Wärtsilä emphasizes technological innovation and total efficiency to maximize the environmental and economic performance of vessels and power plants. They provide a number of technologies for the cruise industry to improve environmental performance including Advanced Wastewater Treatment Systems (AWTS). They supply complete waste treatment systems for cruise vessels that are able to handle all the waste streams and comply with the strictest regulatory requirements found in maritime. These solutions are able to clean the waste streams of liquid (food, graywater, blackwater) so that the effluent is removed of all substances that are harmful for the environment and it is safe to discharge back to sea again.

AWTS use processes to reduce the level of contaminants in wastewater to a level unattainable through conventional secondary or biological treatments. Membrane bioreactors, which use the combination of a membrane process along with a biological wastewater treatment process, are now a widely used AWTS in land-based wastewater treatment.

In the initial step, the wastewater is screened to separate solids. The liquid is then sent into the bioreactor and membrane filtration system to remove the impurities, followed by ultraviolet light or chemical treatment to destroy any remaining germs. The treated liquid is then either discharged or kept in a holding tank. These water treatment systems are tested regularly to ensure they are meeting international standards.

The innovative Wärtsilä Membrane BioReactor (MBR) system allows for the high purity treatment of wastewater, exceeding effluent discharge standards worldwide. This system uses biological degradation and external membrane separation to treat gray and black water without the need for additional chemicals hazardous to the maritime or shipboard environments. This system is compliant to the Baltic Sea Special Area regulation and can achieve such performance with lower energy and chemical consumption than other alternatives. The latest Wärtsilä AWTS optimization results in more than a 25% savings in energy consumption plus consumables, achieving outstanding performance in Alaska under scrupulous testing.

3. RECYCLING

Regulatory Environment

Annex V of MARPOL contains regulations for the prevention of pollution by garbage from ships. One of the leading concerns is plastics, which can remain floating in the ocean for years.

MARPOL Annex V – Prevention of Pollution by Garbage from Ships

MARPOL Annex V applies to all ships operating in the marine environment. This Annex prohibits the discharge of all garbage into the sea, with the exception of food waste when following guidelines set forth by in regulations 4-6 of the Annex.

Annex V obliges governments to provide adequate port reception facilities for the reception of garbage without causing undue delay to ships in order to facilitate compliance with these discharge requirements. The Annex also recognizes a number of special areas, which due to their oceanographic and ecological conditions require special mandatory methods for the prevention of marine pollution by garbage.

Additionally, Annex V requires all ships over 100 gross tonnage or which may carry more than 15 persons to carry a garbage management plan on board and a garbage record book, which include written procedures for minimizing, collecting, storing, processing and disposing of garbage and recording all disposal and incineration operations.

MARPOL Annex V Regulation 4 – Outside special areas and Arctic waters

Regulation 4 sets the standards for discharge of garbage while ships are outside of special areas and Arctic waters.

Food waste that is comminuted or ground so that it passes through screens with smaller than 25 millimeter openings may be discharged when greater than three nautical miles from nearest land. Food waste that is not comminuted or ground may still be discharged, but the ship must be greater than 12 nautical miles from nearest land.

MARPOL Annex V Regulation 5 – Alongside or near offshore platforms

This regulation is relevant for ships located within 500 meters of offshore platforms that are more than 12 nautical miles from nearest land. In such a circumstance, the only garbage discharge permitted is comminuted or ground food wastes that can pass through a screen with mesh no larger than 25 millimeters.

MARPOL Annex V Regulation 6 – Within special areas and Arctic waters

Annex V specifies eight special areas, which along with Arctic waters, require stricter regulations than what is prescribed in Regulation 4.

Discharge of comminuted or ground food wastes are only permitted when the nearest distance to land, ice-shelf, or fast ice is greater than 12 nautical miles away. In the Antarctic area, the discharge of avian products is not permitted unless incinerated, autoclaved, or treated to be made sterile.

The discharge of cleaning agents and additives contained in deck and external surfaces washwater that are not harmful to marine environments may be discharged. Cleaning agents and additives in cargo hold washwater are permitted to be discharged when the ship is greater than 12 nautical miles from the nearest land, ice-shelf, or fast ice and en route.

Cargo residues contained in washwater that cannot be recovered and are not harmful to the marine environment may be discharged when the ship is greater than 12 nautical miles from the nearest land, ice-shelf, or fast ice and en route.

The discharge of all other garbage is prohibited under Regulation 6.

CLIA Initiatives and Performance

CLIA Procedures

Specified garbage management practices may fall outside of regulatory frameworks, as a result the CLIA Waste Management policy provides a framework both for the reduction of single-use materials onboard and for the care and transfer to land of waste that is produced. These policies are synthesized in the CLIA Compendium of Member Policies which outlines, among other categories, how best to address domestic waste. Domestic waste refers to waste generated in the accommodation spaces on board, aside from waste water which is processed separately.

CLIA policy provides a variety of accepted waste management techniques such as compactors and shredders to pre-treat waste for transaction to land-based recycling and disposal programs. Aligning techniques with municipal and private land-based treatment sites presents another venue for collaboration and stewardship from the cruise industry with the goal of keeping waste out of the ocean.

Plastic goods are an aspect of domestic waste that CLIA has placed emphasis on as the impact of macro and microplastic pollution has risen in priority. CLIA member lines have successfully implemented initiatives to reduce the use of plastic with reusable or biodegradable alternatives where possible, such as reusable bottles and totes instead of plastic bottles and bags. In order to make sure that what little plastic is still in use gets properly recycled, member cruise lines hand-sort trash, carefully separating plastics and other recyclable materials from what can be incinerated or sent to a shoreside landfill.

CLIA members have adopted best industry practices for the handling and management of hazardous waste. These practices include identifying and segregating hazardous waste aboard cruise vessels for individual handling and to not comingle or mix materials identified as hazardous waste with other waste streams. This practice helps in preventing harmful discharges such as silver from photo processing and arsenic from electronic waste from entering marine ecosystems.

Shipboard dry-cleaning facilities typically use a chlorinated solvent that produces a small amount of hazardous waste. CLIA members have been implementing methods that do not produce hazardous waste, such as using non-toxic solvents or using wet cleaning processes that do not use any solvents.

CLIA members have agreed upon the preferred handling method by various authorities for the recycling of fluorescent lamps and high intensity discharge lamps. These lamps contain small amounts of mercury that can be harmful to human health and the environment.

CLIA Member Lines' Performance

Many CLIA member lines demonstrate their commitment to the environment by taking the initiative to exceed CLIA policy on recycling and environmental protection practices, which already surpass international regulations. Highly trained environmental officers aboard cruise ships have helped some cruise ships to repurpose 100% of all waste generated onboard. This has been achieved through five key methodologies:

1. Working with suppliers to **reduce** materials and use more sustainable materials.
2. Improving the **reusability** of materials, such as opting for aluminium or reusable glass bottles over single-use plastics alternatives.
3. **Donating** discarded materials to vulnerable communities throughout the world.
4. Maximizing **recycling** onboard by hand-sorting trash and storing the recyclable waste onboard in appropriate facilities until a recycling hub is reached. To this end, crew members - regardless of their position - are trained to reduce waste and identify and sort recyclables.
5. **Converting** waste into energy through numerous potential avenues, such as repurposing food waste into energy for onboard use and recycling hot water to heat passenger cabins.

In addition to the implementation of these practices, CLIA member lines actively encourage passengers to participate in the effort to reduce the environmental impact through providing receptacles for recycling drink containers and offering environmental education classes.

Alongside protecting the environment through reducing waste, CLIA member lines acknowledge the importance of a robust biosecurity system to prevent the introduction of invasive species between operating areas. Members are strongly committed to the prevention of transferring aquatic species through hull fouling. To aid in this effort, nearly all of CLIA member ships follow strict biofouling management plans, which include rigorous maintenance requirements and the use of anti-fouling paint, and many ships in the CLIA fleet are equipped with Ballast Water Treatment Systems designed to eliminate the transfer of micro-organisms from port to port. The measures to prevent fouling on ship hulls significantly reduce the risk of invasive species and even provide supplementary benefits in the form of reduced fuel use and air emissions.

Recycling Case Study:

CLIA Executive Partner – Power Knot

In the aim of reducing onboard food waste, Power Knot, a California-based leader in biodigesters, specializes in practical alternatives to traditional food waste disposal. Biodigesters mitigate the volume of food waste on cruise ships by breaking down organic material through aeration and the introduction of beneficial microorganisms. This process liquifies the waste without the use of chemicals and yields a fraction of the net waste volume as traditional food disposal methods. Rather than solid waste, the result is a liquid waste that CLIA members treat as food waste as governed by MARPOL Annex V Regulations 4 and 6 which set forth the maximum food particle size, discharge rates, and distance from the nearest land or ice-shelf when discharged.

Alternative methods of disposing of food waste include incineration and storing the waste onboard until an environmental management company can collect the waste at a dock and transport it for processing. These options come at a cost of higher carbon emissions, either through the incineration process or through the reduced energy efficiency from the added size and related carrying cost required to store the waste.

The biodigesters currently aboard some cruise ships are stronger than their shoreside counterparts, despite the added design complexity necessary for maritime conditions. At-sea biodigesters are also equipped with the added functionality of sifting accidental plastic from food waste to prevent inadvertent plastics from entering the ocean.

4. CARBON REDUCTION

Regulatory Environment

In 2011, the IMO adopted a new chapter for MARPOL Annex VI to enact ship energy efficiency regulations for ships of 400 gross tonnage and above. Improved energy efficiency for ships would reduce carbon emissions as well as other greenhouse gases.

Annex VI includes regulations for the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships.

MARPOL Annex VI – Energy Efficiency Design Index (EEDI)

The EEDI is a design-based regulation. There are no specified requirements as long as ships meet the minimum mandatory energy-efficiency design level. This gives ship designer and builders autonomy in what cost-efficient technologies and ship designs they prefer to use to comply with the regulation.

This regulation addresses technical- and design-based improvements for reducing carbon emissions by stimulating continued development in technologies that influence the fuel efficiency of a ship.

MARPOL Annex VI – Ship Energy Efficiency Management Plan (SEEMP)

Regulation 22 requires ships to keep a SEEMP on board. The SEEMP provides a management framework designed to improve the operational energy efficiency of a ship while at sea and in port. Examples of operational measures that could improve energy efficiency would be weather routing, trim and draught optimization, and just-in-time arrivals in ports.

New MARPOL Annex VI Amendments

In June 2021, the IMO's Marine Environment Protection Committee adopted new amendments to MARPOL Annex VI in an effort to further curb greenhouse gas (GHG) emissions. All ships will be required to calculate their Energy Efficiency Existing Ship Index (EEXI) and to establish their annual operational carbon intensity indicator (CII) and associated CII rating. Carbon intensity is a measure of carbon emissions relative to the gross tonnage of the ship.

As part of the CII implementation, certain ships over 5,000 gross tonnage, including cruise ships, will have to demonstrate improvements in their operational carbon intensity beginning in 2023, through 2030. Vessels will record evidence of carbon intensity reduction in their existing SEEMP and submit emissions data to the IMO.

Using this data, a ship's energy efficiency will be transparently rated on a letter-grade scale with "A" indicating the highest rating. Ships not achieving a satisfactory rating – either "D" for three consecutive years or "E" in one year – will need to submit a corrective action plan outlining steps to reach a rating of "C" or above. The purpose of the EEXI and CII amendments is to recognize ships that have successfully reduced their GHG emissions and to provide incentive to ships to continue striving for future energy efficiency improvements.

The EEXI and CII certifications are expected to take effect in 2023, meaning the first annual reporting will be completed in 2024 for 2023 data and the first ratings will be issued in 2024.

CLIA Initiatives and Performance

CLIA Initiative

40% Target

For reduction in rate of carbon emissions by 2030

Compared to 2008 level

We are three years into CLIA's commitment to a 40% reduction in the rate of carbon emissions across the cruise industry's global fleet by 2030 consistent with the IMO Initial Strategy for reduction in carbon intensity and towards the ultimate goal of being carbon-free as soon as possible this century. The cruise industry's decarbonization challenge will be accomplished through a blend of optimizing energy efficiency through conservation and energy management and transitioning to lower-carbon fuels, and CLIA members have demonstrated their commitment to these measures through the continued investment in and adoption of these sustainable technologies. The industry's carbon intensity reduction commitment and progress toward it will need to be evaluated against recent IMO requirements for Carbon Intensity Indicators (CII) which are currently under review.

Carbon intensity reduction will be fuelled by innovative technologies and optimized procedural practices. Some such technological improvements on this front that are being implemented include:

- The advent and widespread use of ecological, non-toxic, slick hull paint coatings, which have been estimated to improve fuel efficiency by five percent and has been adopted by about 95 percent of CLIA member ships.
- More bulbous bow designs that reduce fuel usage for propulsion upwards of 15 percent when compared to the traditional V-shape.
- The use of advanced materials in ship applications, such as advanced strength-enhanced steel, that provide energy savings through reducing ship weight and providing a more hydrodynamic surface.
- The installation of tinted windows, high efficiency appliances and HVAC systems, and windows that capture and recycle heat reduce energy use from heating and air conditioning.
- Switching to LED lights which use 80 percent less energy and last 25 times longer than previous lighting systems.
- Use of solar panels for emissions-free energy.

$26.3 Billion

Invested in new ships with energy efficiency technologies and cleaner fuels

CLIA member cruise lines are investing heavily in implementing these carbon reduction technologies along with continual funding for research and development of further carbon reducing technologies, such as zero-carbon fuels. There are a number of zero-carbon fuels being researched and developed, such as ammonia used in internal combustion engines, fuel cells, and electric motors combined with batteries – as discussed in greater detail in Section 5. Fuels of the Future.

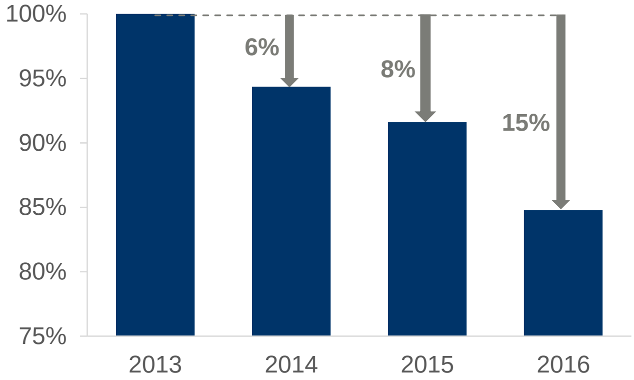
Procedurally, the cruise industry has been performing data analytics for itineraries to maximize fuel efficiency. Findings in this field have led to reductions in fuel consumption through optimized speed, routes, and distances travelled.

Individual CLIA member lines have set and achieved ambitious company carbon reduction goals. Some of these goals include designing energy efficient hulls to help reduce CO_2 emissions of new ships by 20 percent when compared to ships built just a few years ago to refitting older ships with improved propulsion technology that is 10% more energy efficient.

Member cruise lines have pledged to achieve carbon neutrality through the implementation of carbon reducing technologies to help reduce carbon emissions along with blue carbon credits for the conservation and restoration of coastal and marine ecosystems. Some member cruise lines also have set forth plans to offer carbon-neutral ships and routings to begin the process of reaching fleet-wide carbon neutrality. CLIA's member lines' continual pursuit of minimizing cruise ship carbon footprint by investing in and implementing innovative technologies has allowed cruising to offer differentiated tourism experiences while producing fewer CO_2 emissions.

CO_2-e Emissions per Cruise Passenger

% of 2013 level



Source: CLIA, Griffith University

Shore-Side Electricity (SSE)

Alongside these new technologies to meet CLIA's carbon reduction goal, cruise lines continue to implement shore-side electricity (SSE), also known as cold-ironing, which allows cruise ship operators to turn off the ship engines while in port and rely on more efficient municipal power systems when available, to reduce overall emissions. For the Port of Charleston (USA), Corbett and Comer (2013) estimated that the implementation of SSE would reduce CO_2 emissions by 26% under the same fuel mix for the electrical grid as in 2011 – which coal constituted 48% of the fuel used – and another study found that SSE offers the potential to reduce CO_2 emissions by over 800,000 tons in Europe alone.[6,7]

82%

New ships on order specified to fitted with SSE systems

32 percentage point increase over 2020

The objective of expanding SSE availability at ports presents a valuable opportunity for advocacy and cooperation with port operators that could have influence on the broader adoption of SSE capabilities by other shipping industry participants. Today, 65 CLIA member ships are outfitted with SSE capacity and 109 ships are set to be built new or retrofitted with the technology in the coming years. As a result, 35% of current global passenger capacity is covered by

[6] Corbett and Comer, 2013

[7] Winkel et al., 2016

ships fitted with SSE capacity and, if the current order book was to remain the same, that would rise to 66% of expected future capacity.

The primary bottleneck for SSE utilization remains the availability of high-wattage power sources and interfaces at port. To date, 14 ports, of more than 800 ports visited by CLIA member ships each year, provide SSE capacity; however, not all berths at each port have the technology. SSE availability is also limited geographically, appearing at a variety of ports on the east and west coasts of North America, Germany, Norway, and China. While the introduction of shore power capabilities in ports has been limited in comparison to the adoption by CLIA member ships, progress is expected to accelerate over the coming years thanks to governmental support with the expected expansion and completion of shoreside power facilities at ports in Miami, Seattle, numerous ports throughout Norway, Southampton, Tallinn, Valletta, Barcelona, Marseille, Genoa, Civitavecchia, and many more.

CLIA's global reach and proximity to industry partners will privilege it to share best practices from these leading ports with others as additional ports begin to implement SSE technology, underlining CLIA's role in representing industry leadership in matters of shared infrastructure.

SSE Case Study:

CLIA Executive Partner – Cruise Gate Hamburg

While ships SSE capabilities have been increasing rapidly, a secondary requirement for the use of SSE is port compatibility. Cruise Gate Hamburg, the terminal operator of the Port of Hamburg, has been at the forefront of the proliferation of SSE use in Europe. Hamburg has enjoyed extraordinarily high growth in the cruise sector over the past few years with the number of passengers increasing approximately 75 percent between 2015 and 2018.

650 ton

Reduction in carbon emissions in the Port of Hamburg thanks to SSE technology

To become 100% of current emissions upon completion of shore-side power expansion project

Hamburg first launched its onshore power station pilot project in 2016. Since then, Hamburg's Altona cruise terminal has begun regular operations of the onshore power station, supplying cruise ships with eco-friendly power from ashore. With ship's own generators shut down completely, and instead being powered by emissions-free energy from its berth, SSE technology has significantly contributed to emissions reduction in the Port of Hamburg. Despite only one of its three terminals having an operational shore power station, in 2018 this was estimated to have reduced CO_2 emissions by over 650 tons.

While Hamburg's Altona terminal is already equipped with SSE capability, a new project expanding shore power supply to all terminals with an alternative marine power station is underway and is expected to be completed in 2022. Switching the energy source from the ship's main and auxiliary engines to a municipal power system reduces emissions but having the shore-side power grid be reliant on renewable power will eliminate all existing CO_2 and pollutant emissions at berth.

5. FUELS OF THE FUTURE

CLIA Initiatives and Outlook

CLIA Commitment

The global shipping industry has been reliant on marine diesel and heavy fuel oil for many years, but CLIA member cruise lines have been highly receptive and early adopters of the technological innovations of the energy industry. While cruise lines are not petrochemical companies, CLIA and cruise line members have been highly involved in instigating and supporting the advancement of cleaner low- and zero-carbon fuels by providing demand and financial support for the research of these fuels, bringing together leaders in the industry to help spur development, and creating coalitions of experts to assess the cruise industry's environmental impact and the progress these fuels can offer. CLIA and an array of other maritime organizations proposed a $5 billion IMO research and development fund to accelerate the development of zero GHG fuels and propulsion technologies. This initiative is under consideration for approval in late-2021, and, if approved, funding would come from a contribution on a per ton basis of fossil fuels purchased.

Alternative fuel sources to heavy fuel oils (HFOs) being developed and implemented with hopes of widespread commercial use include LNG, biodiesel, methanol, ammonia, hydrogen, and electric batteries. There remain engineering, supply, and regulatory hurdles before the large-scale adoption of these fuels can take place, but the cruise industry's investment in facilitating the research and development of these fuels has shortened the expected timeline.

The LNG and Biodiesel Transition

Today, the only commercially available fuel options for the international shipping industry that greatly reduce emissions are LNG and biofuels. The cruise industry has been a proactive early adopter of these technologies, with the LNG-capable global capacity rising more than 400% between 2019 and 2021.

95-100%
Less particulate matter emitted by LNG

Relative to heavy fuel oil

LNG is currently still a fossil fuel that is relatively high in energy content but also offers lower emissions as compared to HFO, emitting virtually zero sulfur, 85% less nitrogen oxide, 95-100% less particulate matter, and up to 20% less greenhouse gas.

At the completion of the current orderbook, 17% of global cruise capacity will be able to operate on LNG. Lengthy construction of new LNG-fuelled cruise ships provides headwinds for a quicker transition. LNG requires cryogenic storage at -162° C together with a regasification system in order to be pumped into a combustion chamber. This additional engineering coupled with legacy engine rooms aboard cruise ships designed prior to the adoption of LNG as a cruise fuel source do not allow for a ready pathway to retrofit these vessels to LNG-use.

Biofuels, on the other hand, present potential as a drop-in petroleum fuel alternative, meaning they can readily replace HFOs in existing infrastructure and engines. Biofuels are produced from renewable biomass, such as vegetable oils and animal fats. The most commonly used first-generation biofuel being used today is fatty acid methyl esters (FAME), more commonly referred to as biodiesel. Biodiesel reduces GHG emissions by up to 86% and particulate matter by nearly 50% relative to petroleum diesel. In addition to improving emissions when burned, biofuels are generally non-toxic, biodegradable, and less waste is produced in production than in petroleum diesel production.[8]

LNG and biofuels are viewed as vital transitional fuel sources, but both feature limitations that encourage the industry's strong investment in even better solutions. Despite LNG's impressive environmental record – virtually eliminating sulfur and particulate emissions – its ability to reduce up to 20% of GHG emissions is not sufficient enough to meet ambitious long-term goals for carbon reduction and runs the risk of methane slip occurring from gas leaking during bunker transfers or from fuel that fails to burn during the combustion process.

Biofuels generally produce less pollution in production and usage, but there are significant headwinds in producing the quantity needed to satisfy demand. While the US Energy Information Administration forecasts renewable diesel production capacity in the US will exceed five billion gallons per year by 2024 from less than 600 million gallons in 2020, it is still only a fraction of petroleum fuel output.[9] The rising demand for agricultural products by energy companies has also created strains on agricultural prices, as food producers face greater competition over valuable inputs and shortages of some staple ingredients used in biodiesel production, such as soy and canola oil.[10]

Biofuels have also been found under certain conditions to emit slightly greater levels of NO_x than petroleum diesel.[11] The potential rise in NO_x emissions compared to conventional bunker fuels potentially conflicts with MARPOL Annex VI Regulation 18, which prohibits the use of fuel oils derived by methods other than petroleum refining that can cause an engine to exceed the applicable NO_x emission limit. Meeting this requirement is complex for biofuels because a biofuel's NO_x emissions vary based on idiosyncrasies of the organic material used in its production and its combustion characteristics. Thus, this regulation could unintentionally impede the adoption of biofuels by mandating extensive on-board testing of biofuel formulations on each engine prior to use.

Refining Natural Gas and Biofuels

Medium-term goals indicate the necessity to further refine LNG and biofuel technology and develop alternatives with lower carbon implications and greater scalability. These improved fuels would be able to be utilized in existing and

[8] Iowa Renewable Fuels Association, 2021
[9] U.S. Energy Information Administration, 2021
[10] Kelly et al., 2021
[11] Chen et al., 2018

currently under construction infrastructure and could be readily substituted to quickly improve the sustainability of the cruise industry.

Producing LNG from renewable sources can reduce its carbon footprint, resolving LNG's shortfall of insufficient long-term GHG reductions. In fact, depending on the feedstock used in the production process, it is possible for these next generation natural gas fuels to overcome fossil-based LNG's limitation and cut 100% of CO_2 emissions.[12] These fuels are known as bio-LNG, synthetic natural gas (SNG), renewable natural gas (RNG), or electro-methane which can be produced from coal, organic biomass, or electric power. Renewably sourced natural gas maintains the same functionality as fossil LNG and can seamlessly replace contemporary natural gas in the infrastructure being installed on ships and in ports today. A core advantage of some of these next generation fuels is that some, such as renewable methanol, do not require cryogenic storage conditions and thus fewer modifications to the engine and fuel supply system are necessary.

The environmental gains of these under-development fuels prove substantial. For example, renewable methanol curtails CO_2 emissions by up to 95%, NO_x emissions by up to 80%, and SO_x and PM emissions entirely relative to conventional fuels.[13] RNG is generally considered a carbon-neutral fuel, but when it is produced from organic waste it captures more GHGs than it emits, since the organic waste would otherwise decay and create methane – a GHG that has a 100-year Global Warming Potential (GWP) between 28 and 36 times greater than CO_2.[14] This net effect makes RNG derived from organic waste carbon-negative and a valuable tool in the cruise industry's plans towards carbon-neutrality.

The next step in the development of biofuels is hydrotreated vegetable oil (HVO) or renewable diesel. This advanced biofuel is produced by hydrotreating and refining plant oils or animal fats. The hydrotreatment removes oxygen from the oils, reducing NO_x emissions, and does not use chemicals in production, curbing the downsides of biodiesel. While HVOs eliminate some of the concerns of biodiesel, the ability to produce at the necessary scale to fully decarbonize the cruise industry is a serious question.

60%

Of shipowners view hydrogen and ammonia as the most attractive long-term fuels

According to a 2020 survey by the American Bureau of Shipping (ABS)

Advancements in the research and development has brought these next generation fuels closer to today, with renewable diesel in its initial stages and the first methanol-operated fuel cell system on a cruise ship expected in 2021.[15]

A Hydrogen Future

Practical hydrogen-based fuel solutions are presently being researched with the aim of enabling a zero-GHG energy path. In a 2020 survey by the American Bureau of Shipping (ABS) of shipowners, 60 percent of respondents viewed

[12] MAN Energy Solutions, 2021
[13] Methanol Institute, 2021
[14] Environmental Protection Agency
[15] Ovcina, 2020

hydrogen and ammonia as the most attractive long-term fuels.[16] These advanced fuels offer zero-carbon propulsion and can be used directly in internal combustion engines or fuel cells. The demand for green fuels from the cruise industry and maritime industry at-large reduces development risk of these fuels and enables energy professionals to commit more resources towards these innovations.

Hydrogen (H_2) can be derived from fossil fuels, known as gray, brown, or blue hydrogen depending on the method, but the use of fossil fuels does result in some carbon emissions. Green hydrogen, produced through electrolysis of water using renewable energy, is the preferred low-carbon process but has higher production costs. The price of green hydrogen is expected to decline alongside the costs of renewable energy and needed electrolysis equipment in the coming decades, facilitating its adoption.

Ammonia (NH_3) can operate as a hydrogen carrier, due to its concentration of hydrogen, or it can be used as a direct fuel source for internal combustion engines or fuel cells. The affiliated nitrogen contained in ammonia molecules does result in some NO_x emissions, but this challenge can be overcome through ordinary selective catalytic reduction (SCR) systems.[17] Ammonia's higher volumetric energy density compared to hydrogen tempers some storage concerns. Combined with its zero-carbon content, and suitability with existing and emerging technologies lead ammonia-based fuels to be strong contenders in the drive for cleaner fuels.

Additionally, further development of green methanol (CH_3OH) provides a potentially sustainable low-carbon fuel solution. Like ammonia, methanol acts as a hydrogen carrier, carrying the highest hydrogen-to-carbon ratio of any liquid fuel, although its volumetric density is still less than conventional fuels. However, methanol does not require cryogenic storage and is therefore easier to store than hydrogen or ammonia which could facilitate a speedier transition. While methanol is most commonly produced from natural gas, it can be produced in a environmentally friendly manner, either from biomass or renewable powered electrolysis.

$750 billion

Market size for hydrogen-based energy in 2050

As estimated by McKinsey in 2020 study

Hydrogen fuel's exciting proposition is an energy source with near-zero GHG emissions through the production and burning process, whose only direct emission is water vapor. Hydrogen is one of the most abundant elements on Earth, with a virtually limitless supply, giving it the ability to satisfy the energy needs of even the most energy-intensive industries. Hydrogen-based fuels contain potential for scalability and should be significant portions of the fuel mix by 2030. The market for hydrogen-based energy in the US alone is anticipated to reach $140 billion in 2030 before ballooning to $750 billion in 2050.[18]

Key impediments to the adoption of hydrogen and ammonia fuels are storage costs and implementing an accommodative regulatory framework. Similar to LNG, hydrogen and ammonia fuel must be stored at extreme cryogenic temperatures which enhances storage costs and poses the risk of turning

[16] Ship & Bunker, 2020
[17] Hayakawa et al., 2019
[18] Fuel Cell and Hydrogen Energy Association, 2020

metals brittle. Both fuels have relatively low energy concentrations by volume – hydrogen being about one-eighth as energy dense per liter as petroleum-based fuels and ammonia being about one-quarter.[19] This escalates engineering concerns over cargo volume dedicated to fuel storage, as an up to fivefold increase in fuel tank size introduces complexities both onboard and ashore at refueling stations in ports. Proper containment of these fuels is under research as well, as the small size of hydrogen molecules exacerbate the risk of it escaping through cracks or seams and potential ammonia leaks would be hazardous. However, key CLIA partners have made significant strides in developing economically viable engine systems. As one example, Wärtsilä anticipates its first ship engine capable of running solely on ammonia by 2023.[20]

Methanol faces similar storage and safety issues as hydrogen and ammonia fuels but to a lesser extent. While methanol does not require cryogenic storage, its relatively volumetric density as compared to conventional fuels would require more than 2.5 times more storage volume than conventional fuels. Methanol is a toxic substance and corrodes certain materials, thus necessitating special containment methods. A unique issue to methanol is its relatively low flash point. Its high flammability and difficulty in detecting methanol flames, as they are odorless and nearly invisible, combined with its toxicity presents safety concerns that have to be resolved prior to use on commercial cruise liners.[21] Ongoing research has led to promising developments, as methanol-based fuels have begun to be implemented in various marine vessels.[22]

Presently, the US Coast Guard Office of Design and Engineering Standards deems hydrogen too hazardous for bulk carriage, partly due to its flammability.[23] Hydrogen fuels are not currently approved for marine vessels in the US, but on a vessel-specific case-by-case basis, approval can be sought from the Coast Guard. The intricacies of the regulations in place to build a commercial zero-emission hydrogen-powered ship hinder not only shipbuilding but also the development of hydrogen refueling infrastructure shore-side that is necessary to operate a hydrogen-powered ship. Widespread acknowledgement of hydrogen and ammonia as key fuel sources in the drive to decarbonize shipping, including support from the International Energy Agency and the World Bank, and increased governmental support of the cruise industry's effort to limit the maritime-linked environmental impact, such as the creation of the Healthy Ports program in the US and large global investments in installing SSE technology, provide indications that a more supportive regulatory framework is possible.

The cruise industry is involved in a number of green energy initiatives around the world to address long-term environmental challenges and promote the adoption of next-generation fuels, such as hydrogen, ammonia, and methanol.

[19] Ash, et al., 2019
[20] Wärtsilä, 2021
[21] ABS, 2021
[22] The Maritime Executive, 2021
[23] US Coast Guard, 2020

These alternative fuels may be poised to be ideal future fuels but necessitate continued research in storage requirements, due to safety concerns and volumetric density, and a less obstructive regulatory framework.

Fuels of the Future Case Study:

CLIA Executive Partner – Snam

Italy-based Snam, one of the world's leading energy infrastructure operators, seeks to enable the cleaner energy evolution through securely supplying sustainable and technologically advanced fuels, such as hydrogen fuels and biomethane. Energy infrastructure plays a pivotal role in progressing to a less environmentally impactful system. Snam has been facilitating the evolution towards hydrogen-based fuels in energy-intensive industries, becoming the first energy company in Europe to introduce a 5% hydrogen-natural gas blend into its transmission network and accomplishing the first 30% hydrogen-natural gas blend in steel manufacturing.[24,25]

Hydrogen storage and transportation introduces added infrastructure complications due to its need to be stored at extreme temperatures and its small molecule size being prone to escaping through cracks and seams. By successfully blending hydrogen fuel with natural gas such that the existing natural gas transportation networks can be utilized, Snam has accelerated the clean energy transition and improved the availability of hydrogen fuels.

Snam has already begun hydrogen fuel trials with railway operators, industrial manufacturers, and power generators among other industries, and in July 2021 Snam co-announced a study to assess the feasibility of designing and building the world's first oceangoing hydrogen-powered cruise ship. Key factors being evaluated in this study include ship space arrangement to accommodate hydrogen fuel technologies, the potential greenhouse gas emissions savings, and a technical and economic analysis of hydrogen supply and infrastructure. Snam's experience and innovative techniques in implementing hydrogen fuels in energy-intensive sectors provides a template that the cruise industry is seeking to replicate in its goal of providing a unique and environmentally friendly tourism experience.

[24] Snam, 2019
[25] Mangiapane, 2021

WORKS CITED

ABS. February 2021. “Sustainability Whitepaper: Methanol As Marine Fuel.” *American Bureau of Shipping*.

Ash, N., I. Sikora, and B. Richelle. 2019. “Electrofuels for shipping: How synthetic fuels from renewable electricity could unlock sustainable investment in countries like Chile.” *Environmental Defense Fund*.

Blunox. “NO_x reduction for Cruise Ships.” www.blunox.com/home/scr-system/scr-for-cruise-ships

Chen, H., Y. Chen, J. Ma, and B. Xie. 2018. “NOx emission of biodiesel compared to diesel: Higher or lower?” *Applied Thermal Engineering*, 137, pp. 584-593.

Corbett, J., and B. Comer. 2013. “Clearing the air: Would shoreside power reduce air pollution emissions from cruise ships calling on the Port of Charleston, SC?” *Energy and Environmental Research Associates*.

Cornell University. 2020. “Hotel Footprinting Tool.” *Greenview*. www.hotelfootprints.org/footprinting

Cruise Lines International Association. 2020. “Environmental Technologies and Practices: CLIA Global Oceangoing Cruise Lines – August 2020.” cruising.org/en.

Environmental Protection Agency. “Understanding Global Warming Potentials.” www.epa.gov/ghgemissions/understanding-global-warming-potentials

Fuel Cell and Hydrogen Energy Association. 2020. "Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation." www.fchea.org/us-hydrogen-study

Griffith University. 2021. "Global Sustainable Tourism Dashboard." www.tourismdashboard.org/

Hayakawa, A., H. Koboyashi, K. Kunkuma., E. Okafor, and A. Somarathne. 2019. "Science and technology of ammonia combustion." *Proceedings of the Combustion Institute*. 37(1), pp. 109-133.

Hielscher Ultrasound Technology. 2020. "NOx-Reduction by Oil/Water-Emulsification." *hielscher.com*. www.hielscher.com/oil_nox_reduction

Holtbecker, R., and M. Geist. 1998. "Exhaust emissions reduction technology for Sulzer marine diesel engines: General aspects," Wärtsilä NSD Switzerland Ltd., Winterthur, Switzerland, July 1998.

International Energy Agency. 2017. “Tracking Progress: International Shipping.” *IEA.org.* 16 May. www.iea.org/etp/tracking2017/internationalshipping/.

International Maritime Organization. 2019. “Nitrogen Oxides (NOx) - Regulation 13.” *IMO.org.* www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

Iowa Renewable Fuels Association. 2021. "Biodiesel and the environment." iowarfa.org/biodiesel-and-the-environment/

Kelly, S., C. Prentice, and J. Renshaw. 2021. "U.S. bread, donut makers urge Biden to roll back biofuel requirements." *Reuters*. www.reuters.com/business/energy/us-bread-donut-makers-urge-biden-roll-back-biofuel-requirements-2021-08-03/

MAN Energy Solutions. 2021. "SNG - Synthetic Natural Gas." www.man-es.com/discover/decarbonization-glossary---man-energy-solutions/synthetic-natural-gas

Mangiapane, G. 19 May 2021. "Italy's Snam in world first with test of 30% gas-hydrogen blend in steel forging." *Reuters*. www.reuters.com/business/italys-snam-world-first-with-test-30-gas-hydrogen-blend-steel-forging-2021-05-19/

Marquard & Bahls. 2015. "Marine Gasoil (MGO)." *Marquard-Bahls.com.* December. www.marquard-bahls.com/en/news-info/glossary/detail/term/marine-gasoil-mgo

Methanol Institute. 3 June 2021. "Renewable Methanol." www.methanol.org/renewable/.

Neste. 13 April 2018. "California cruise company Red and White Fleet switches to Neste MY Renewable Diesel." www.neste.com/releases-and-news/renewable-solutions/californian-cruise-company-red-and-white-fleet-switches-neste-my-renewable-diesel

Neste. 1 September 2021. "Reduced emissions." www.neste.com/products/all-products/renewable-road-transport/reduced-emissions#0cb19e71

Ovcina, J. 13 November 2020. "AIDAnova on track to get its methanol-operated fuel cell in 2021." *Offshore Energy*. www.offshore-energy.biz/aidanova-on-track-to-get-its-methanol-operated-fuel-cell-in-2021/

Ship & Bunker. 26 May 2020. "ABS Survey Respondents See Hydrogen and Ammonia as Best Long-Term Bunker Options." shipandbunker.com/news/world/188388-abs-survey-respondents-see-hydrogen-and-ammonia-as-best-long-term-bunker-options

Snam. 1 April 2019. "Snam: Europe's First Supply of Hydrogen and Natural Gas Blend into Transmission Network to Industrial Users." www.snam.it/en/Media/Press-releases/2019/Snam_Europe_first_supply_hydrogen_natural_gas_blend

The Maritime Executive. 24 June 2021. "Recycled Methanol Fuels Stena Ferry in Demonstration Project." www.maritime-executive.com/article/recycled-methanol-fuels-stena-ferry-in-demonstration-project

U.S. Coast Guard. Spring 2020. "Proceedings of the Marine Safety & Security Council." *The Coast Guard Journal of Safety & Security at Sea*.

U.S. Energy Information Administration. 2021. "U.S. renewable diesel capacity expected to increase significantly through 2024." www.eia.gov/petroleum/weekly/archive/2021/210721/includes/analysis_print.php

Wärtsilä. 14 July 2021. "Wärtsilä launches major test programme towards carbon-free solutions with hydrogen and ammonia." www.wartsila.com/media/news/14-07-2021-wartsila-launches-major-test-programme-towards-carbon-free-solutions-with-hydrogen-and-ammonia-2953362

Winkel, R. et al., 2016. "Shore Side Electricity in Europe: Potential and environmental benefits." *Energy Policy*, 88: 584-593.

October 2021

The modelling and results presented here are based on information provided by third parties, upon which Oxford Economics has relied in producing its report and forecasts in good faith. Any subsequent revision or update of those data will affect the assessments and projections shown.

To discuss the report further please contact:

Daniel Molon: dmolon@oxfordeconomics.com

Adam Sacks: asacks@oxfordeconomics.com

Oxford Economics

Broadwall House, 21 Broadwall, London, SE1 9PL, UK

Tel: +44 203 910 8000