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# C2S – Cruise towards Sustainability

## Executive summary

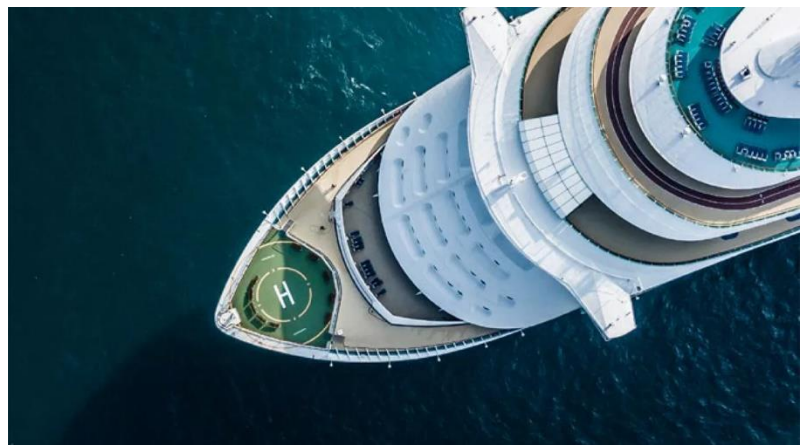
In recent decades, cruising around the world has become increasingly common, representing a multi-billion-dollar industry and attracting millions of tourists each year. Indeed, modern cruise ships are feats of engineering excellence with onboard amenities comparable to high-class resorts. Such floating cities offer a mix of luxury, entertainment, and adventure and reach out to a variety of sectors of the population, all of whom share a desire to discover unexplored lands by sea. The rapid expansion of this industry has brought it to general attention, especially concerning its sustainable footprint.

Cruise ships are among the most energy-consuming forms of transportation, requiring large amounts of fuel and consequently generating emissions. According to the International Maritime Organization (IMO), a single large cruise ship can emit as much particulate matter as one million cars every day. In addition to air pollution, what makes them highly impactful to the marine environment is the discharge of wastewater, sewage, and chemicals that may devastate ecosystems. The environmental impact is multiplied by the large scale of the industry with thousands of ships operating around the world every day. Under the current circumstances of increasing ecological insecurity and regulatory pressure, the cruise industry is at a turning point. To this, it is added the growing public awareness of the need to adopt practices to combat climate change in all sectors of our society

In this specific context, the difficulty lies in reconciling the economic goals and needs of the cruise ships with minimizing ecological impact. This balance is essential to maintain the industry reputation as well as to achieve effective protection of the surrounding environment.

This paper aims to analyze the potential of making a cruise ship sustainable by examining a range of innovative technologies and operational strategies.

The notion of the sustainable cruise vessel is a multi-dimensional and extremely complex one. A cruise ship, unlike any other means of transportation, must operate independently needing enormous quantities of energy and water and generating a substantial amount of waste at the same time. Therefore, achieving true sustainability requires a holistic approach that considers the entire lifecycle of the ship, from design and construction to operation and eventual decommissioning.



*Figure 1: Aerial view of a cruise ship*

It also necessitates the integration of cutting-edge technologies and innovative solutions that can reduce the ship's environmental impact while maintaining the high standards of service expected by passengers.

An in-depth analysis of the state of the art, starting with existing technologies that have been implemented and arriving at emerging solutions that hold promise for the future, is the core part of our exploration.

The report is organized around key themes including energy and propulsion systems, waste management, water management, route optimization, and the development of digital twin technology. An in-depth analysis is conducted for these areas to evaluate their potential to mitigate the environmental impact associated with cruise ships.

The energy and propulsion section explores alternative fuels, including ammonia, Liquefied Natural Gas (LNG), and hydrogen, as well as examines the potential of battery technology and renewable energy resources, such as wind and solar power. The abovementioned technologies have the potential to massively reduce emissions, while at the same time greening the cruise operations all the way. However, the adoption of these new fuels has been associated with several challenges: infrastructure requirements and high costs related to the retrofit of current fleet vessels.

Given the enormous volumes of waste generated every day, waste management represents another crucial area of concern. A look into state-of-the-art waste treatment technologies considered and updated within the report will involve advanced recycling systems, energy production from waste, and reusable products. The study stresses the need to reduce waste at source and employ closed life cycles that have minimal environmental impact. Although significant progress has been made in this area, major challenges still exist.

Water resources management is considered in a separate chapter, underlining technologies that reduce water usage and wastewater treatment. Cruise ships have a high demand for potable water for all applications like drinking, cooking, cleaning, and other purposes, and a substantial part is generated on board by desalination techniques. Current practices are evaluated for their efficiency and the possibility to utilize other techniques, such as nanofiltration and water recycling processes.

Route optimization is another vital focus area, it can reduce fuel consumption and related emissions by making a vessel's speed and course more efficient. The report discusses recent developments in digital navigation technology and data analytics that will be necessary to create more efficient routes for shipping, factoring in weather conditions, ocean currents, and other parameters.

Final investigations are on the concept of a digital twin, a virtual model representation of the cruise ship to simulate and optimally improve the performance of the vessel in real-time. Digital twins offer big efficiency and sustainability improvement for a cruise ship since they represent a platform where continuous monitoring and assessment of the performances are conducted.

Despite the evident progress in sustainable technologies for cruise ships, the report shows that there is still much that needs to be surmounted before the industry can be termed truly sustainable. The cost-benefit analysis for every area of interest indicates that some technologies, such as LNG and waste-to-energy systems, show a return on investment while others may still be just a bit too expensive with limited effectiveness. Technological innovation, together with regulatory incentives and industry collaboration, all hold promises of facilitating the growth toward more sustainable cruise ships.

Altogether, the cruise industry is at a crossroads where its ecological impact must be managed to ensure a sustainable future. This paper lays the foundation for how this can be realized, identifying the most effective technologies and methods for minimizing the ecological footprint cruise ships produce. Embracing such innovation can continue the industry's quest to create unmatched water experiences while protecting the planet for years.

## **Key Words**

Cruises, Sustainability, Net-Zero, Cost-Benefit Analysis, Maritime Industry





## Project description written by the Principal Academic Tutor

## Team description by skill

### Goal of the project

Considering the huge environmental impact of cruise ships, the project aims at detecting solutions for a more sustainable cruising. The latter must also consider the economic interests of the maritime industry, considering first and foremost the welfare of the cruise ship's customer-passenger.

### Strategy for addressing the challenge

To tackle the problem in a structured and coordinated manner the team identified seven crucial macro areas of intervention. For each of these areas, a careful analysis of the currently available and most promising technological solutions in terms of environmental sustainability was conducted. Once this initial screening was performed from a technological standpoint, each potential solution was evaluated through a cost-benefit analysis. Thus, the analysis allowed for handling an economic perspective to assess the actual implementation of the solutions within a cruise ship.

### The solution

In the end, the overall output of the project is the development and proposal of a sustainably improved cruise ship for the future. Thanks to the results of both the technical and economic feasibility analyses, it is possible to assess the overall impact of the solutions and understand which of them may soon be ready to lead the maritime industry transition.

The C2S team is composed of seven members, each bringing expertise from diverse fields of engineering: Mathematical Engineering, Space Engineering, Electrical Engineering, Mechanical Engineering, and Management Engineering. This multidisciplinary composition allows the team to leverage a broad spectrum of technical and analytical skills, fostering a rich environment for problem-solving and innovation.

**Gaya** was the Team Controller and managed both the budget and the communication with the tutors. At the same time, she leveraged her great analytical skills, derived from her studies in Mathematical Engineering, to evaluate possible new solutions to be implemented in the waste management's field.

**Virginia** brought strong communication skills to the team, enabling them to connect with numerous stakeholders at the various events they attended. The group's upcoming space engineer also focused on exploring water management solutions, further specializing in grey water treatment due to her interest in the topic and skills from previous coursework.

**Edoardo** and **Matteo** have investigated all the solutions inherent to the fields of alternative fuels, renewable sources of energy, and propulsion. Their degrees, in respectively Electrical Engineering and Mechanical Engineering, provided them with all the skills to be able to deal with and analyze complex technologies belonging to these fields, allowing them to perform a very thorough analysis of the risks and limitations of these innovations.

**Andrea** and **Daniele**, management engineers, added a business nuance to the consulting project merging the technological and market analyses. They primarily focused on exploring solutions related to the digital realm, from route optimization to digital twins, and ship disposal, leading the group in presentations to academic and external tutors.

Finally, **Domenico**, focused on solutions mainly related to waste management and ship disposal. As a management engineer, he oversaw the group's delivery schedules, internal organization, and division of labor for each intermediate engagement with the external institution and for the final deliverables.



*Figure 2: C2S Team at MIND Innovation District*



## Goal

The overarching goal of C2S project is to explore the potential avenues towards the net-zero transformation of the cruise industry, encompassing a more sustainable ship design and navigation, reducing energy consumption, emissions and on-board operating costs, by conducting a comprehensive analysis comparing the current state with a sustainable future scenario. This involves identifying, adapt (if necessary) to the cruise world, and applying the most advanced technologies and innovations that are being developed to improve environmental performance, focusing on key levers such as reducing pollutant emissions, particularly carbon dioxide, ensuring responsible innovation, and enhancing the overall customer experience without compromising sustainability. The multidisciplinary nature of the project, which integrates mechanical, energy, aeronautic, hydraulic, electrical, digital and business domains, has as main intended beneficiaries not just the shipowners but the entire stakeholders across the value chain, including energy providers, shipbuilders, local communities and service providers, by implementing sustainable and efficient practices.

## Understanding the problem

The cruise industry is a fascinating combination of tourism, engineering, and transportation. Still, it is one of the most harmful to the environment amongst contemporary industries: modern cruise ships are large vessels with extensive onboard facilities, therefore huge consumers of energy and producers of waste. This ecological impact poses a significant obstacle to the sustainability of the industry, particularly in light of increasing public awareness regarding climate change and global pollution levels.

The influencing factors upon the course of sustainable cruising range from political regulations through technological advancements to ecological issues. In respect to the ecological footprint of cruise vessels, governments and global institutions set new policies directed to enforce sustainability. For example, the IMO has enhanced its regulations concerning greenhouse gases emissions and the European Parliament has enforced legislation aimed at reducing those emissions. Nevertheless, there is still a considerable difference between the policy framework and how it is applied in the cruises sector. While most cruise operators are indeed making favorable efforts to be aligned or even ahead of regulatory demands, technological and operational challenges are still evident.

Simultaneously, the array of stakeholders involved in the cruise industry, including passengers advocating for environmentally responsible travel and suppliers seeking well-defined sustainability benchmarks, introduces an additional level of intricacy. Cruise line enterprises are required to navigate a delicate equilibrium among regulatory obligations, the anticipations of eco-aware consumers, and the necessity to implement sustainable technological advancements. Regulatory agencies advocate for more stringent environmental criteria, whereas local communities and conservation groups insist on enhanced initiatives to reduce pollution.



*Figure 3: Cruises emit nine times more than a transatlantic flight, with emissions per passenger ranging from 1.2 to 9 tons of CO<sub>2</sub> per trip*

Technologically speaking, cruise ships are uniquely challenging to be sustainable because of the great demand for energy and the complex requirements related to waste management. These cruise ships emit high amounts of  $\text{NO}_x$  and  $\text{CO}_2$ , wastewater, and toxic chemicals affecting marine life. Indeed, A single cruise ship has been shown to emit particulate matter equivalent to one million cars daily. Moreover, cruise liners are accountable for a massive share of marine pollution, discharging about 3.5 kilograms of garbage generated per passenger per day.

These problems are compounded by the need to balance economic viability with ecological responsibility. Although a segment of consumers is willing to pay the extra costs for sustainable tourism, the major market share remains resistant to the higher costs associated with eco-friendly technologies and practices. However, increasing social awareness to sustainability puts pressure on cruise operators to adopt more environmentally friendly practice as tourists with environmental conscious tourists tend to choose green travel options. This requires the industry to develop strategies that can meet the objectives of sustainability while at the same time remaining economically viable. In this respect, the cruise industry is standing at a critical juncture where innovation, sustainability and regulation must converge to enable a sustainable future.

### **Exploring the opportunities**

Nowadays, given the importance of environmental sustainability, major cruise ship companies are placing considerable emphasis on introducing cutting-edge technologies that will ensure a reduction in environmental impact. There are many opportunities to make the vessel less impactful in its surroundings, considering that a cruise ship consists of various areas, ranging from propulsion techniques to wastewater management and route optimization methods.

Many companies are exploring alternative fuels, such as hydrogen and liquefied natural gas (LNG), which significantly lower greenhouse gas emissions compared to traditional fuels. In addition, energy-efficient technologies, like solar panels, and innovative solutions such as Flettner rotors (which use wind power to assist propulsion), are being increasingly implemented to reduce reliance on fossil fuels. Added to these, are all the innovative practices and technologies for waste and wastewater management, considering the immense quantity that is generated daily by a single cruise ship.



*Figure 4: The C2S Team visiting Salone Nautico di Venezia 2024*

Innovative practices, including advanced filtration and treatment systems, as well as waste-to-energy technology, offer opportunities to significantly reduce the environmental footprint of cruise operations. These systems not only limit the pollution caused by waste disposal but also turn waste into valuable resources like energy, thereby increasing overall efficiency.

A rapidly expanding sector is represented by the development of data analysis and optimization systems which can be applied simultaneously to numerous areas of the vessel, making current practices more useful. Real-time monitoring and adjustments enhance efficiency and minimize environmental impact.

Exploring solutions in this broad context involves not only analyzing the strategies that major cruise companies are adopting but also carefully assessing the state of the art in each sector. In addition to the existing solutions, in fact, there are promising technologies not yet widely adopted in cruise ships. In this context it is therefore essential to work directly with startups that are central in the research and implementation of technologies that can be rethought to adapt them to a cruise ship (or already suitable for it).

A timely review of the literature, perfectly complemented by interaction with the leading startups in each sector, allowed the team to find the perfect intersection of the best innovations in the field today that it is possible to adapt on a cruise ship.

## **Generating a solution**

The reality of a cruise ship is extremely complex and intricate, in which many areas of competence on which to act at different levels of sustainability entangle with each other making the development of a solution complicated. For this reason, the team proceeded with the subdivision into seven strategic focus areas to look for the most sustainable solutions and develop what will be the ship of the future. Specifically, the sub-areas tackled were: Alternative Fuels, Renewable Energy Propulsion, Route Optimization, Digital Twin, Waste Management and Water Management.

From this starting point, in-depth research was conducted for each individuated sub-area of the main potential solution available on the market to date that could improve the overall sustainability of the cruise ship. Of crucial importance for this phase was the visits the team made to hands-on with the current technological solutions available: such as the participation in the Salone Nautico in Genoa and Venice, as well as meetings with experts suggested by Accenture and met during the visits to boat shows.

Once an initial assessment was conducted, taking into account the most sustainable options currently available on the market, a cost-benefit analysis was carried out to highlight that a solution was not only more environmentally sustainable, but also economically viable and, as a result, practically implementable on a cruise ship.

The output of the research is the development of a cruise ship of the future through the implementation of cutting-edge technologies that are currently available and economically feasible. The research concluded with insights into potential future developments, recognizing that sustainability is a continuous improvement and a daily commitment that goes hand in hand with technological innovations.

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