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Green Maritime Technology

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ABSTRACT

Technology refers to the application of knowledge for human benefits. Green technology deals with using science and technology to protect the environment as well as curb the negative impacts of human involvement. It is any mode of technology that lovers CO2 emissions. Green technologies include green energy, green IT, green food, green, manufacturing, green business, green economics, green supply chain, green logistics, green building, and green nanotechnology. Green maritime technology represents a concerted effort to mitigate the environmental footprint of the maritime industry. The technology fundamentally aims to reduce the environmental impact of the shipping industry through innovative solutions and by reducing harmful emissions and promoting ecological sustainability within shipping and port operations. This paper will delve into the innovative green technologies that are reshaping the maritime sector.

KEYWORDS: *green technology, sustainable technology, environmental technology, clean technology, green maritime technology, green ship, green port*

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INTRODUCTION

There has been rapidly-increasing awareness of the environmental impact of mankind's modern lifestyle in recent years. This impact arises from pollution, consumption, and destruction of natural resources. This has led to greater awareness of the need for sustainable and environmentally-friendly practices. This awareness has led to the emergence of green technologies in recent years. Here green technology is used to mean effort to promote sustainability and reduce greenhouse gas emissions. Green technologies and practices are those that lessen the environmental impact of a business's operations. As with any technology, the development of green technology requires investment and initiative to support development projects. It also requires encouraging the whole society to participate in the green technology innovation and forming green consumption consciousness [1].

The maritime industry has been around for centuries and has revolutionized the way we live by connecting countries and cultures all over the globe, as typically shown in Figure 1 [2]. The industry has long been a symbol of tradition, guided by centuries-old practices steering its course. The influx of food, goods, and information from countries around the world has broadened people's diets and minds and is a vital part of maintaining our world economy. This industry, vital for global trade, has enabled the transportation of goods across vast distances. However, it has historically been a significant contributor to pollution, as their CO_2 emissions account for an estimated 3-4% of all global emissions. Conventional maritime practices rely heavily on fossil fuels, leading to substantial emissions, air pollution, and water contamination. Shipowners around the world face the choice of how to adapt to the requirements of International Marine Organization (IMO) and are looking for innovative and green technologies for shipping. Green technology in the maritime industry focuses on reducing the environmental impact of shipping through various innovations in vessel design, alternative fuels, and operational practices. The industry is not only shifting to cleaner fuels based on oil but also some companies are considering alternative sources of energy: solar and wind. These advancements aim to minimize emissions, improve

fuel efficiency, and promote sustainable practices across the sector. These advancements are crucial for the maritime industry to meet increasingly stringent environmental regulations and achieve a more sustainable future [3].

CONCEPT OF GREEN TECHNOLOGY

The term "green" denotes life, harmony, stability, neutralization of the negative. The concept of green is in the heart of creation. Everything around us is predominantly green. We depend on the green herbs, grass, trees, etc. for life [4]. The term "technology" refers to the application of knowledge for practical purposes. Green technology helps to reduce negative effects on the environment while improving productivity, efficiency, and operational performance of a given technology.

Green technology, also known as clean technology or eco-friendly technology, is a broad term encompassing various technologies and practices that aim to minimize environmental impact and promote sustainability. Figure 2 shows a representation of green technologies [5]. The main goal of green technologies is to meet the needs of society in the way that avoids depleting or damaging natural resources on earth. By harnessing the potential of green technology, societies can create a more sustainable and resilient future, balancing economic growth with environmental protection and societal well-being.

The key components of green technologies are recycling, environmental remediation, and renewable energy sources.

- *Recycling*: Green technology helps manage and recycle waste material. Recycle objects are made of glass, metal, paper, and plastic. These materials are reusable and should be recycled to prevent further depletion of the earth's resources.
- *Environmental Remediation*: This involves removing contaminates from the soil, air, and water. It is the removal of pollutants or contaminants for the general protection of the environment.
- *Renewable Energy Sources*: Green technology includes the conversion of renewable resources to useful energy.

The four pillars of green technology are [6]: (1) Energy harvesting - This seeks innovative ways to extract useful energy from waste by-products, as well as to develop new technologies to maximize the harnessing of energy; (2) Environment -All human activities have an impact on the environment and we must conserve and minimize the impact; (3) Economy - Enhancing the national economic development through the use of technology will assists us in building a strong and vibrant local community; and (4) Social – We improve the quality of life for all and emphasizes the importance of individual well-being, including full access to effective health care, housing, food, and education. Thus, green technology addresses social, economic, and environmental values.

GREEN MARITIME TECHNOLOGY

In the face of climate change and environmental degradation, there is a growing global call for industries to embrace sustainability and implement eco-friendly practices. The maritime industry is under increasing pressure to contribute to a more sustainable future.

Ocean shipping, the backbone of international trade, is significantly more energy efficient than air or land transport. When compared to other transportation modes, the environmental advantages of ships become even more evident, as shown in Figure 3 [5].

Shipowners worldwide are confronted with the decision of how to comply with the regulations set by the International Maritime Organization (IMO). The insatiable demand of our skyrocketing population for imports is unlikely to change anytime soon, but by employing newer, greener technologies, shipping companies are finding more ways to soften their environmental impact. It is not just about adopting a single technology, but about fostering a culture of sustainability across the entire maritime industry. It is more than mere emission reduction; it is about fundamentally transforming the maritime industry to align with global sustainability goals. Green maritime technology incorporates diverse strategies, from cleaner fuels and energy efficiency to digital optimization and sustainable port operations [7]. By reducing their fuel consumption, large ships can make significant cuts to their carbon emissions, and companies are continuously seeking new ways to do so.

IMPLEMENTATIONS OF GREEN MARITIME TECHNOLOGY

Green trends and technologies are revolutionizing the shipping industry, cutting fuel consumption, carbon emissions, and costs for shipping companies. The international shipping industry is actively implementing green technology to reduce its impacts on the global environment. These advancements include improvements in engine efficiency, water cooling, and the adoption of innovative technologies. Here are some notable ways in which innovative technologies are being introduced [5,8,9]:

- *Voyage Optimization:* Modern-day technologies allow us to predict the weather and likely maritime conditions with impressive accuracy, making voyages far safer and less unpredictable. Bypassing routes in which the ship may not run as efficiently due to rough seas or high winds, many companies in the shipping industry use the practice of voyage optimization to reduce fuel consumption effectively. Using this technology to select the most energy-efficient routes of passage, shipping companies can reduce both their costs and their carbon footprint significantly.
- *Optimized Cooling System:* By implementing an optimized cooling system for the ship's main engine, a significant reduction of 60% in electrical power demand can be achieved. This power reduction leads to substantial savings in marine diesel oil consumption.
- *Adoption of Sail and Kite Propulsion System*: The implementation of sail and kite propulsion systems in conjunction with the conventional propulsion system, offers significant benefits in terms of fuel efficiency and emissions reduction. The sail and kite propulsion systems contribute to a substantial decrease in emissions of harmful pollutants such as NOx, SOx, and CO2. The sail and kite system will use wind energy to move a ship through the water.
- *Battery-Powered Ship:* When it comes to storing green energy, batteries are often the most efficient approach, but they are too bulky for use in airplanes and ships. The use of battery power has gained significant popularity in the transportation sector, as evidenced by the widespread adoption of electric cars on roads. The marine industry has also embraced battery technology to reduce greenhouse gas (GHG) emissions and drive the transition to cleaner energy sources.
- *Slow Steaming:* This is the process of operating transoceanic ships at less than their top speed to reduce fuel consumption. The practice can significantly reduce fuel consumption on a voyage. This method of conserving fuel began as a way for companies to cut costs, and by 2010 almost all global shipping companies made slow steaming a regular practice. Today, it is perhaps one of the most important trends in the shipping industry for reducing carbon emissions and is a highly simple, effective, and beneficial.
- *More Efficient Port Management:* By optimizing port management and refining operating procedures, shipping companies have progressively shortened the amount of time ships wait in the dock, and improved turnaround time. The optimization of harbor operating procedures is a practice now adopted by almost all major shipping companies and is of great benefit when it comes to making the shipping industry greener. Several major ports, including those in Rotterdam, Singapore, and Los Angeles, are collaborating with shipping companies to create green corridors. Figure 4 shows a typical port [10].
- *Alternative Fuels:* The original IMO policy was to phase out fossil fuels as soon as possible in this century while continuing efforts to lower the carbon intensity of international shipping by 70% by 2050. It is recommended to replace primary marine fuels such as LSHFO and MDO because replacing them would take time. In some areas, hydrogen and ammonia are the best fuels for coastal shipping since they are carbon-free fuels with already promising futures in the road transportation sector. Shifting towards renewable energy sources and use of cleaner fuels like liquefied natural gas (LNG), biofuels, and hydrogen fuel cells is being preferred.
- *Renewable Energy Integration*: Maritime sustainability also embraces renewable energy sources. Solar panels and wind turbines are being integrated into ship structures to harness the power of the sun and wind, providing auxiliary energy and reducing reliance on conventional fuels. Figure 5 shows an example of solar panel [2].

APPLICATIONS OF GREEN MARITIME TECHNOLOGY

Clean propulsion systems, energy-efficient designs, renewable energy integration, advanced waste management, and digitalization are leading the way towards a cleaner and more sustainable future for maritime operations. Common areas of applications of green maritime technology include the following [10,11]:

- *Green Ships:* Today, we ship a lot of goods by ocean freight, and there is certainly an environmental impact with shipping. Shipping is a serious source of greenhouse gas emissions. Ships, which have long been associated with pollution and environmental degradation, are now setting sail towards a greener and more sustainable future. An international treaty aims to bring the shipping industry to net-zero emissions by around 2050. While shipping is only a small part of the whole picture affecting the world's oceans, reducing just some of the pressures on marine life can help ecosystems be more resilient

to other stressors, such as noise pollution, fishing, and coastal development. The global shipping sector is advancing its environmental sustainability initiatives in response to stricter international regulations and growing pressure to combat climate change. At a July 2023 meeting of the International Maritime Organization, member states voted unanimously to adopt more ambitious climate goals for the international shipping industry. The meeting is displayed in Figure 6 [12]. A holistic approach is needed to make shipping more sustainable. The adaptation of autonomous ships can significantly reduce operating costs while reducing the shipping carbon, CO_2, and NOx emissions for all considered contexts. A typical green ship is shown in Figure 7 [13], while Figure 8 shows how to make a green ship [2].

- *Green Port*: Besides green ships, port development projects are also more eco-friendly these days. Ports are focusing on reducing carbon footprints, minimizing pollution, conserving natural resources and strive for zero energy wastage. A green port invests and promotes environmentally friendly, long-term operations in all forms of the port and marine sector. Green ports aim to minimize their ecological footprint by implementing various measures such as reducing air and water pollution, optimizing energy consumption, and using renewable energy sources. Most ports go green by first identifying recycling possibilities (or re-use even) and put a solid waste segregation plan in action. The "green" vision of ports has prompted the implementation of carbon reduction programs that includes monitoring of gas, electricity, and water usage in ports. Many notable ports and terminals have already implemented solar panels on their sites.

- *Water Transportation:* As coastal populations continue to grow, safe and efficient water transportation is becoming increasingly important. The focus for future ferries should be on safety and low emissions, with many being designed as entirely electric and powered by solar energy. Climate change is expected to further worsen the decline in food and water supplies, driving up the demand for waterborne trade worldwide. Seaborne transportation and port infrastructure are likely to be under significant strain to support large-scale food movement and clean water supply while minimizing environmental impact. Ships with water ballast pull water into the hull of the ship and store that water below the ship's vertical center of gravity. Water ballast ships generally take in the water when starting their journey and dump the water ballast when they arrive at their destination.

- *Clean Propulsion Systems:* One of the most impactful changes in the maritime industry is the shift towards clean propulsion systems. Hybrid and electric propulsion systems are becoming increasingly popular in the maritime industry, promising lower emissions, and decreased fuel consumption. Traditional fossil fuel engines are being replaced with cleaner alternatives, such as LNG (liquefied natural gas) and hydrogen fuel cells. These technologies reduce greenhouse gas emissions, making ships more environmentally friendly. Wind-assisted propulsion is another exciting development.

BENEFITS

Maritime shipping plays a critical role in maintaining efficient supply chains in the future. The imperative for sustainability has led to the development and adoption of green technologies that aim to reduce emissions, conserve resources, and minimize the impact on marine ecosystems. Balancing innovation with tradition requires involving all stakeholders—policy makers, owners, operators, equipment manufacturers, integration engineers, shipbuilders, and seafarers—in the process for adopting green technologies. This approach ensures that new technologies meet practical needs while respecting traditional knowledge. Other benefits include the following [14,15]:

- *Cut Carbon Emissions:* The maritime industry's transition to a decarbonized future is an economic necessity, driven by regulatory pressures, market volatility, innovation, and the need for long-term financial resilience in an increasingly complex and competitive global economy. The shipping industry is under increasing pressure to reduce carbon emissions. Maritime transportation is responsible for 3% of the world's carbon emissions, so the industry is being pushed by governments, regulators, and the wider society to improve. The IMO ambition is for the industry to reduce its greenhouse gas (GHG) emissons by 70% by 2050 compared to 2008 levels. Increasingly strict regulations related to carbon emissions have resulted in growing industry interest in different approaches to achieve the goal of zero emission vessels.

- *Minimize Pollution:* The development of smart and self-driving ships is a result of changes in the shipping industry that aim to improve fleet management, safety, and efficiency, while

lowering operating costs. Green and flexible vessels are also being designed to minimize pollution and adapt to different waterways.

- *Energy Efficiency:* As part of the industry's efforts to decarbonise, from January 2023, it was made mandatory for all ships to calculate their Energy Efficiency Existing Ship Index (EEXI) to measure their energy efficiency and to start the collection of data for the reporting of their annual operational carbon intensity indicator. These advancements aim to revolutionize ship operations, creating a safer, more sustainable, and more efficient industry. Green ship is about marine biology, cleaner fuels, and energy wastage minimization.
- *Autonomous Vessels:* The use of autonomous vessels can improve energy efficiency and operational flexibility. By 2030, ICT is expected to connect most ships globally. This would create an abundance of opportunities and a future for autonomous and automated vessels. As on-board automation increases, present-day innovations in the seaborne industry may compete to ensure that remote vessel operations become possible, eventually leading to complete vessel autonomy.
- *Ballast-Free System:* This is a move towards a ballast-free system. Ballast water brings unwanted species. A ballast-free ship would reduce the potential hauling of contaminated water. Limiting the amount of ballast taken is the first step in an effective ballast management plan. No ballast system decreases negative impact on aqua biology.

CHALLENGES

One of the main challenges shipowners encounter in retrofitting their vessels for green shipping is securing financing for energy efficiency upgrades. Regulatory uncertainties, the high costs of clean fuels, limited infrastructure, and often slow returns on investment complicate green investment efforts. The maritime industry faces the dual challenges of ensuring operational reliability and incorporating advanced technologies, often with limited financial support or clear guidelines from regulatory agencies. Other challenges include the following [16-18]:

- *Cost:* Going "green" is not achievable overnight. It takes lots of effort from all authorities and parties involved. Until now, implementation of more environmental friendly and "green" systems are hindered by the costs involved. However, the energy consumption in the long-term may be a great investment. The cost for implementing sustainable practices initially is expensive, but at the later stages it will ultimately lead to cost savings. Fuel efficiency improvements, better maintenance procedures, and optimized operations can lower operating expenses and boost profitability.
- *Support:* To overcome these obstacles, innovative lending options from banks and public financial support are essential. Additionally, governments can either directly fund projects that build zero-emission infrastructure or offer grants, incentives, and tax breaks. The governments incentivize radical reductions in harmful emissions as an overall priority. If the politics do not change, the continuous implementation of stricter government regulations for reducing emissions will eventually result in the mandatory use of, what we currently consider, alternative fuels. The International Maritime Organization (IMO) and the entire shipping industry have a role to play in reducing emissions.
- *Regulations:* Decarbonization is not a catchword; it is mandated by a multitude of new environmental regulatory directives. Regulatory bodies such as the International Maritime Organization (IMO), Class and Flag state, as well as other government agencies must provide clear guidelines, financial incentives, and opportunities to adopt energy-efficient technologies.
- *Training*: Ongoing training for crew members is needed for operating and maintaining new equipment and assuming new responsibilities on board the vessel, such as route optimization, better cargo management, and energy-efficient technologies. The seafarer's role becomes increasingly more challenging with the installation of multiple energy-efficient technologies on a single vessel.
- *Ship Waste:* Most people think the shipping industry's biggest contribution to pollution is fuel emissions, but ship disposal generates a significant amount of waste. Improper ship disposal has resulted in ship graveyards around the world where ships at the end of their life are sunk and abandoned. Thankfully, green ship recycling has arrived. Reusable and valuable components of a ship, like steel, brass, and silver, are converted into materials to be used elsewhere. The implementation of waste heat recovery and waste-to-energy systems in shipping offers benefits. Waste heat recovery systems are becoming more eco-friendly. Waste-to-energy systems allow us to convert waste materials produced on ships into energy.

- *Environmental Impact:* The environment must be considered in all the details of shipping, from a build of a new vessel through its decommissioning. Carbon emissions and other gases are caused by the burning of fuels in the environment. A green ship is any seagoing vessel that contributes towards improving the present environmental condition in some way. The International Maritime Organization (IMO) is helping to reduce the impact on the marine industry by regulating exhaust emissions, anti-fouling, ballast water, and more. The maritime industry will become more environmentally friendly by regulation. Adopting safer practices is urgently required to minimize detrimental effects on the environment.

CONCLUSION

Green technology has emerged as an important trend and development in the 21st century. Its importance has increased worldwide since the turn of the century. Its development will lead to global and sustainable powers that will impact our economics, societies, cultures, and way of life. Green trends and technologies are revolutionizing the shipping industry, cutting fuel consumption, carbon emissions, and costs for shipping companies. Recognizing the need for change, the shipping industry is gradually incorporating eco-friendly technologies and adjusting its operations.

The concept of green maritime technology transcends simplistic notions of environmental friendliness and has become a subject of rigorous scholarly inquiry. It is influenced by a complex web of global policies, technological ecosystems, economic mechanisms, societal demands, and geopolitical dynamics. As the maritime industry navigates the uncharted waters of sustainability, embracing green technologies is not just a choice but a necessity. In the crucible of greener technology, the future of shipping takes shape. More information about green maritime technology can be found in the books [19-23] and the following related journals:

- Journal of Marine Science and Engineering
- International Journal on Marine Navigation and Safety of Sea Transportation
- Cleaner Engineering and Technology

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Figure 1 The maritime industry connects countries and cultures all over the globe [2].

Figure 2 A representation of green technologies [5].

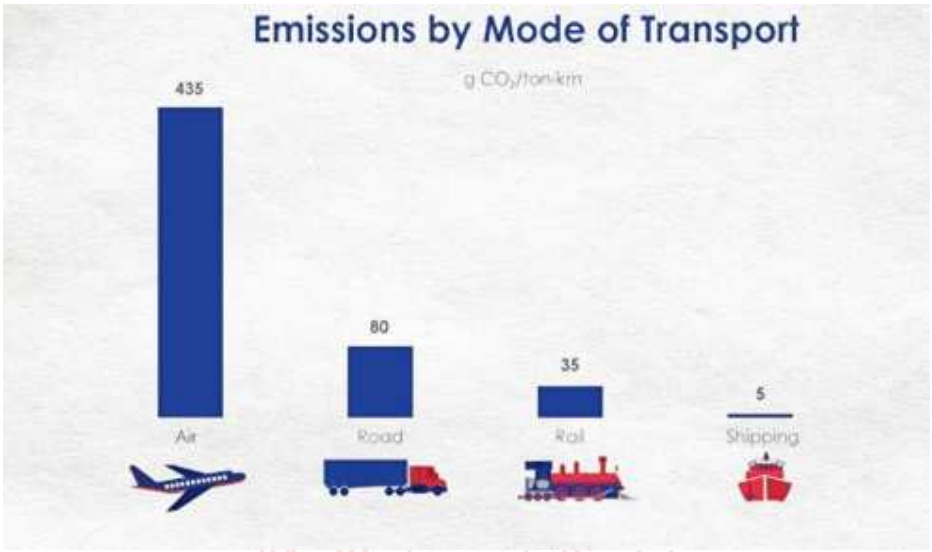

Figure 3 Emissions by mode transport [5].

Figure 4 A typical port [10].

Figure 5 Solar panel [2].

Figure 6 Meeting of the International Maritime Organization [12].

Figure 7 A typical green ship [13].

Figure 8 How to make a green ship [2].