

Green Shipping: Technologies and Innovations for a Sustainable Future

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Abstract—

From early on in 1987 the maritime industry is undergoing a transformative shift toward sustainability, driven by the urgent need to reduce its environmental impact and align with emerging technologies, innovations, rules, regulations, certificates, daily life challenges faced by officers, focusing on alternatives, advantages, limitations, and why it became necessary for the industry to do changes. Smart ship technology, including AI-driven route optimisation and predictive maintenance, enhances operational efficiency and reduces fuel consumption. Digitalisation and IoT-based fleet management improve voyage planning and emissions monitoring. The transition to autonomous and hybrid-electric vessels further supports decarbonisation efforts. As the industry moves toward IMO's 2050 net-zero target, collaborative efforts among shipowners, regulators, and technology providers will be essential in shaping a greener, more sustainable future for global shipping. By examining both technological advancements and regulatory frameworks, this paper offers a comprehensive overview of the path forward for a sustainable and environmentally friendly future in global shipping.

Keywords— Maritime Industry, Sustainability, Smart ship technology, IMO 2050,

Environmental friendly shipping.

INTRODUCTION-

Seaborne trade exhibits a continual expansion with technological advancement, reportedly 10.7 billion tons in 2017, with a 3.8% growth annually. It is forecast to double in the next two decades (UNCTAD, 2018). With the great development of world trade, shipping accounts for 90% of the trade volume because of its dependable, efficient, and low-cost means of transporting goods globally compared to other transport modes. During the 1980s and 1990s, increasing awareness and proactive regulatory responses resulted in the advent of green shipping—an initiative devoted to reducing the maritime industry's environmental footprint. The International Maritime Organization (IMO) is persistently

heading to stricter regulatory amendments to steer shipping towards a greener and more sustainable future. Different regulations and guidelines were formulated, and ongoing technological developments are being pursued in an effort towards achieving the ambitious zero carbon emissions by 2050 target. Green shipping entails a group of practices and technologies that aim to reduce the environmental footprint of sea operations. Some of the most significant innovations driving sustainable shipping are:

- Alternative Fuels
- Energy-Efficient Ship Design
- Renewable Energy Integration
- Smart and Autonomous Shipping

Maritime stakeholders and officers have it rough in their bid to integrate these technologies into green shipping because of the challenges associated with them. Some of these include:

- Exorbitant Expenses
- Fuel Accessibility and Infrastructure
- Regulatory Requirements
- Operating and Safety Issues

Policy makers especially IMO face great challenges on making shipping industries from different countries implement treaties effectively. After all, shipping industries need to increase their costs to balance the relationship between environmental and economic performance in the short term.

All this aside, the business continues to commit itself to leading green innovations, regulation standards, and sustainable innovation into building a clean and more sustainable shipping future across the globe.

History of Green Shipping -

Early Beginnings (Pre-20th Century) Shipping, as an industry, dates back thousands of years, but early shipping was primarily driven by the availability of wind (through sails) or manual labor. Environmental concerns were not a significant factor at this time, as fossil fuel-driven vessels had not yet emerged.

20th Century: Rise of Fossil Fuels and Early Environmental Concerns.

1912: The sinking of the Titanic brought attention to the safety and technological limits of ships.

Mid-20th Century: The shipping industry saw an increasing reliance on fossil fuels, particularly after World War II, and later, diesel-powered vessels.

1970s: The oil crises and the growing awareness of

environmental issues sparked the first discussions about the environmental impact of various industries, including shipping. However, regulations were still in their infancy.

1980s-1990s: Growing Awareness and Early Regulatory Actions

1982: The United Nations Convention on the Law of the Sea (UNCLOS) was adopted, establishing guidelines on marine pollution.

1990s: International conventions such as the International Maritime Organization's (IMO) MARPOL (Marine Pollution) Annexes began to address pollution from ships, covering oil, sewage, garbage, and air emissions. These early regulations were crucial in setting the stage for more sustainable practices in the shipping industry.

2000s: The Push Toward Sustainability and Cleaner Technologies

2000s: As global trade expanded, so did the environmental impact of shipping. The use of lowsulfur fuel, eco-friendly technologies (e.g., energyefficient hulls), and improved waste management systems began to be more widely explored. 2004: The International Maritime Organization (IMO) introduced the International Ship and Port Facility Security Code (ISPS), which, while primarily focused on security, also indirectly contributed to better operational standards that could be used for environmental sustainability.

2005: The Kyoto Protocol, although not directly related to shipping, led to global efforts to reduce carbon emissions, indirectly influencing shipping companies to begin considering the environmental cost of their operations.

2010s: The Green Shipping Movement Takes Shape

2010: The IMO adopted MARPOL Annex VI which included stricter regulations on sulfur oxide (SOx) and nitrogen oxide (NOx) emissions from ships.

2015: The Paris Agreement on climate change called for significant reductions in greenhouse gas emissions by the mid-century. Shipping, which is a major emitter of CO₂, came under increasing scrutiny.

2016: The IMO's Initial Strategy on Reducing Greenhouse Gas (GHG) Emissions from Ships was introduced, setting ambitious goals for reducing the industry's carbon footprint. This included a target to cut the carbon intensity of international shipping by 40% by 2030, compared to 2008 levels.

2020s: Innovations and International Commitments
2020: The European Union's "Green Deal" and other global climate strategies began to include the shipping industry more directly, requiring a reduction in emissions, the promotion of renewable fuels, and the development of new technologies. - 2020: The launch of the IMO's revised GHG strategy aimed to decarbonize shipping by 2050, with the goal of reducing greenhouse gas emissions by at least 50% compared to 2008 levels.

2020-2021: Shipping companies started to experiment with alternative fuels like LNG, hydrogen, biofuels, and ammonia, as well as technologies like wind-assisted propulsion (e.g., using sails or kites to reduce fuel consumption). 2021: A number of major shipping companies, such as Maersk and CMA CGM, made commitments to achieve net-zero emissions by 2050. This shift has seen companies invest in sustainable technologies, such as battery-powered vessels and carbon capture systems.

International Ship and Port Facility Security Code (ISPS)-

The ISPS Code is a set of measures to enhance the security of ships and port facilities. It was developed in response of the perceived threats to ships and port facilities after the 9/11 attacks. Part A of the ISPS Code contains the mandatory requirements regarding the amended provisions of chapter XI-2 of SOLAS, 1974; Part B provides guidance regarding these amended provisions.

ISPS security trainers

Maritime & Port Authority of Singapore (MPA) has endorsed maritime training providers to help guide Singapore flagged ships and Singapore port facilities in the training of their maritime security personnel. These training providers conduct training for Company Security Officers (CSOs), Ship Security Officers (SSOs) and Port Facility Security Officers (PFSOs) according to the requirements of the ISPS Code and IMO model.

The Kyoto Protocol-

- Overview: Adopted in 1997, it aims to reduce greenhouse gas emissions by setting binding targets for developed countries. It focuses on six major GHGs but does not directly regulate international shipping.
- Relation to Maritime Sector: The protocol delegates responsibility for addressing maritime emissions to the International Maritime Organization (IMO). The IMO has developed regulations like the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) to reduce emissions.

- Future Directions: The IMO continues to evolve its strategies, aiming to reduce total GHG emissions from international shipping by at least 50% by 2050 and achieve net-zero emissions by or around

2050. Paris Agreement-

The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016.

Its overarching goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”

The agreement aims to substantially reduce global greenhouse gas emissions in an effort to limit the global temperature increase in this century to 2 degrees Celsius above pre-industrial levels, while pursuing the means to limit the increase to 1.5 degrees. Green Deal-

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring:

- no net emissions of greenhouse gases by 2050
- economic growth decoupled from resource use
- no person and no place left behind

Shipping companies made commitments to achieve net-zero emissions by 2050-

- Maersk
- Mitsui O.S.K. Lines (MOL)
- CMA CGM

| COMPANY | TOTAL VESSELS | TYPE |
|-----------|---------------|---|
| • Maersk | 50-60 | dual-fuel vessels |
| • MOL | Over 800 | <ul style="list-style-type: none"> • LNG-fueled fleet • Wind Challenger |
| • CMA CGM | 153 (by 2029) | dual-fuel vessels |

Carbon Credits in Maritime-

- EU Emissions Trading System (EU ETS): As of 2024, the EU has included maritime shipping in its carbon market. Shipping companies must purchase carbon credits to cover a portion of their emissions when operating in EU waters. The coverage increases from 40% in 2024 to 100% by 2026.

- Voluntary Carbon Market: Shipping companies can also participate in the voluntary carbon market, purchasing credits from projects that reduce emissions elsewhere. This helps offset emissions from shipping operations, especially where alternative fuels are not available.

- Benefits and Challenges:

- Benefits: Carbon credits provide a financial incentive for reducing emissions and can offer a competitive advantage by appealing to environmentally conscious consumers.

- Challenges: The maritime industry faces challenges in transitioning to low-carbon fuels and technologies, making carbon credits a temporary solution while more sustainable options are developed.

- Insurance and Risk Management: The inclusion of shipping in the EU ETS has increased demand for insurance solutions to manage potential credit risks associated with purchasing carbon credits
- WHY IT BECAME NECESSARY ?

1. Exxon Valdez Oil Spill (1989)

Location: Prince William Sound, Gulf of Alaska, USA

Details: This oil spill is consider the second major oil spill in the US after the Deepwater Horizon oil spill. After this oil spill in 1990 oil pollution act mandated that oil companies take more precaution by operating double hull tankers and pay significant penalties in case of future oil spill.

2. Deepwater Horizon Oil Spill (2010)

Location: Gulf of Mexico, US

Largest marine oil spill in history

Details: It led to the release of approximately 4.9 million barrels of oil into the Gulf of Mexico, resulting in extensive damage to marine life, fisheries, and coastal communities. The spill continues to have long-lasting environmental and health effects.

3. MV Wakashio Oil Spill (2020)

Location: Mauritius, Indian Ocean

Details: The Japanese-owned bulk carrier MV Wakashio ran aground off the coast of Mauritius, spilling nearly 1,000 tons of oil into the pristine waters. The oil spill caused severe damage to the coral reefs, mangroves, and marine life, severely impacting the island's biodiversity and local economy, which heavily relies on tourism and fishing.

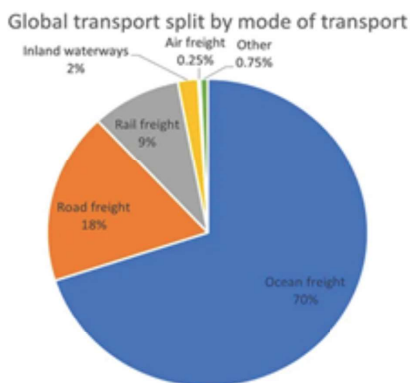
Other incidents such as -

The Sanchi Oil Tanker Collision, The Prestige Oil Spill (2002), The Ever Given Suez Canal Blockage (2021), The Hebei Spirit Oil Spill (2007), The Baltic

Sea—Invasive Species Introductions (Ongoing) etc. These incidents demonstrate the wide-ranging environmental and societal harms caused by shipping, including oil spills, ecosystem disruption, and safety issues. The shipping industry has since worked toward implementing stricter regulations and adopting more sustainable practices to mitigate these impacts, but these events continue to serve as stark reminders of the vulnerabilities and consequences of maritime activities.

What is Green Shipping ?

Green shipping refers to a set of practices that aim to minimize the environmental impact of freight transportation. These revolve around key aspects such as reducing carbon emissions, optimizing fuel efficiency, adopting cleaner technologies, and establishing sustainable practices. As today's supply chain operations are increasingly complicated, a collaborative approach in working with sustainable stakeholders is key in achieving success in global green shipping.



The most used modes of transport in global freight SHIPS. Therefore, it is necessary for ships to with more stringent environmental regulations to become cleaner and greener in their operations. Although sea transportation is generally considered cleaner transportation compared to other modes, it also faces significant environmental challenges : The environmental impact of shipping include air pollution, water pollution, acoustic, and oil pollution. Ships are responsible for more than 18% of nitrogen oxides pollution, and 3% of greenhouse gas emissions. Ships are responsible for more than 18% of nitrogen oxides and 3% of greenhouse gas emission.

1. Marine Pollution

Oil Spills: Accidental oil spills from ships are one of the most harmful types of pollution. These spills cause severe damage to marine ecosystems, harming wildlife and ecosystems and making coastal areas toxic.

Ballast Water: Ships take on ballast water in one location and discharge it in another. This often introduces invasive species that disrupt local ecosystems and biodiversity.

Wastewater Discharge: Ships discharge untreated sewage and wastewater into the oceans, leading to contamination and health risks for marine life and coastal communities.

2. Air Pollution

Ships burn large amounts of fuel, which releases sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter into the atmosphere. This contributes to acid rain, smog, and respiratory diseases in coastal communities and beyond.

Emissions of greenhouse gases, such as carbon dioxide (CO2), contribute significantly to climate change, with shipping being responsible for about 2-3% of global CO2 emissions.

3. Noise Pollution

Ship engines and propellers create underwater noise pollution, which affects marine life, particularly species like whales and dolphins that rely on echolocation for communication, navigation, and hunting.

4. Solid waste-

Solid waste generated on a ship includes glass, paper, cardboard, aluminium and steel cans, and plastics. It can be either non-hazardous or hazardous in nature.

5. Shipwrecks and Toxic Cargo

Shipwrecks can release toxic substances, including chemicals and heavy metals, into the ocean. For example, sunken ships might leak hazardous cargo like pesticides or industrial waste, causing longterm environmental damage.

The shipping industry is increasingly being pressured to adopt cleaner, more sustainable practices to reduce its environmental impact, such as using low-sulfur fuels, adopting ballast water treatment systems, and exploring alternative energy sources like wind and solar.

Greenhouse gas emissions

Maritime transport accounts for about 3% of all greenhouse gas emissions, primarily carbon dioxide. According to the World Bank, in 2022, the shipping industry's 3% of global greenhouse gas emissions make it "the sixth largest greenhouse gas emitter worldwide, ranking between Japan and Germany.

Fig 2 shows the Co2 emissions in 2012-3023

Decarbonization of shipping

Decarbonizing the shipping industry, a goal set by the International Maritime Organization (IMO), involves reducing greenhouse gas emissions to netzero by or around 2050, through strategies like switching to low-carbon fuels, improving energy efficiency, and adopting alternative technologies.

CO2 Emissions Distribution by Vessel Type, 2012–2023

| Year | Tankers | Dry bulk and general cargo | Container | Other |
|------|---------|----------------------------|-----------|--------|
| 2012 | 25.04% | 28.57% | 27.80% | 18.59% |
| 2013 | 24.61% | 28.77% | 27.47% | 19.15% |
| 2014 | 24.50% | 28.87% | 27.18% | 19.45% |
| 2015 | 25.03% | 28.42% | 26.99% | 19.56% |
| 2016 | 25.31% | 28.33% | 26.83% | 19.53% |
| 2017 | 25.62% | 28.06% | 26.91% | 19.41% |
| 2018 | 25.76% | 27.42% | 27.09% | 19.73% |
| 2019 | 26.41% | 27.22% | 25.84% | 20.53% |
| 2020 | 27.38% | 28.13% | 25.35% | 19.14% |
| 2021 | 26.71% | 28.28% | 26.13% | 18.88% |
| 2022 | 27.28% | 27.56% | 25.35% | 19.81% |
| 2023 | 28.55% | 27.52% | 24.03% | 19.90% |

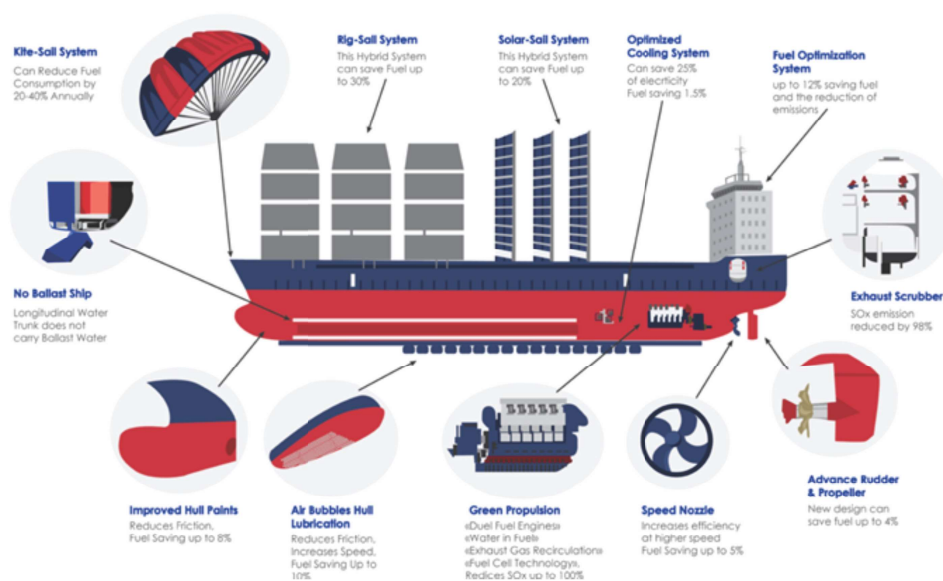
The group "other" includes vehicles and roll-on/roll-off ships, passenger ships, offshore ships and service and miscellaneous ships.

Technologies uses by company to Trends and technologies follow green shipping -

1. Slow Steaming among the innovative developments are more efficient systems, such as higher engine efficiency and better water cooling, which dramatically reduce environmental impact, Kite-Sail, and Rig-Sail systems. An optimized cooling system can save up to 25% of electricity and 1.5% of fuel. Greener engines can minimize NOx output by up to 35% and up to zero SOx emission (as is the use of an exhaust scrubber). Shipbuilders focusing on integrating solar panels on ships can save up to 20% in fuel and, accordingly, harmful emissions. Newly developed propellers save up to 4% fuel. The Speed injector, which improves efficiency at high speeds, can save up to 5% fuel. And new body paint technologies have been improved to reduce friction, which has a

positive effect on consumption by up to 8%. Slow steaming is the practice of simply running at a lower speed, which can significantly reduce fuel consumption on a voyage. 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 way of doing so.

2. 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. Using this technology to select the most energy-efficient routes of passage, shipping companies can reduce both their costs and their carbon footprint significantly.



2. Sky Sails

Sky sails are an ingeniously simple and relatively new invention that uses large kites to tow a cargo ship along during a voyage. The significant potential for savings in fuel costs, along with the low price of installation, makes sky sails a very popular green trend in today's shipping industry.

3. Using Low Carbon Fuels

Cutting fuel consumption is an effective way for shipping companies to slash carbon emissions. The development of low-carbon fuels is a promising new technology and should reduce the number of greenhouse and other noxious gases emitted by large cargo ships. By stripping away a larger quantity of impurities, such as ash and sulfur, these fuels can also have less impact on toxicity to both the environment and human health.

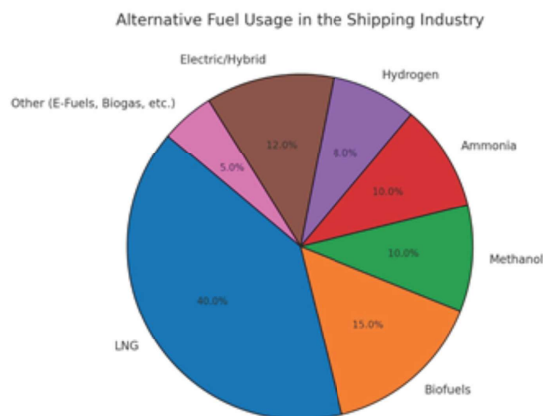
4. More Efficient Port Management

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. This reduces the time ships spend idling in harbors, belching out tons of carbon dioxide, and makes the whole process of shipping goods more efficient.

Different Types Fuels

**Alternative Fuels for Green Shipping
Liquefied Natural Gas (LNG)**

- LNG is a transitional fuel that reduces sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter emissions.
- However, methane slip remains a challenge, as it contributes to greenhouse gas emissions.
- Biofuels (Biodiesel, Bio-LNG, Bio-Methanol)
- Derived from biomass, waste oils, and organic residues.
- **Bio-LNG and Bio-Methanol can significantly reduce lifecycle carbon emissions.** Limited availability and higher production costs hinder large-scale adoption.



Methanol (Green Methanol)

- Can be produced from biomass or renewable electricity (e-methanol).
- Easily stored and transported, compatible with existing infrastructure.
- Requires modifications to ship engines for widespread adoption. Ammonia (Green Ammonia)
- A zero-carbon fuel that produces only water vapor and nitrogen upon combustion.
- High energy density but presents toxicity and safety challenges.
- Research is ongoing to develop ammonia-compatible engines and fuel cells.

Hydrogen (Green Hydrogen)

- Produced via electrolysis using renewable energy (solar, wind, hydro).
- Can be used in fuel cells to generate electricity with zero emissions.
- Storage and transportation challenges due to its low energy density and cryogenic requirements.

E-Fuels (Synthetic Fuels)

- Includes e-methanol, e-ammonia, and e-diesel, produced via carbon capture and renewable energy.
- A promising long-term solution but energy-intensive to produce.
- Biogas (Renewable Natural Gas – RNG)
- Derived from anaerobic digestion of organic waste.
- Can be used in LNG-powered ships with minimal modifications.
- Offers a closed carbon loop, making it nearly carbon-neutral.

Here's a pie chart showing the approximate distribution of alternative fuels used in the shipping industry. LNG currently holds the largest share, followed by biofuels, methanol, ammonia, and hydrogen.

The construction of ships has undergone significant changes due to the increasing focus on "green shipping"

1. Design More Efficient Ship Hulls

The shape of a ship's hull directly impacts the performance efficiency of the vessel, and an optimally designed hull can significantly increase speed and cut fuel costs. Particularly innovative designs employ air-cushion technology, where the front of the boat is shaped to allow for a cushion of air to form beneath the hull when the ship is in motion. This reduces friction between the ship and the water, allowing for greater propulsion with less expenditure of fuel, with the potential to achieve a 10-15% reduction of carbon emissions.

2. Optimize Propulsion Efficiency

Increasing the propulsion efficiency of cargo ships is

the best way to reduce fuel consumption and carbon emissions, and there are many innovative technologies available today that do so effectively and inexpensively (eg. Hi-FIN). This is not only cost-effective for the company, but it also helps to reduce the amount of air pollution caused by the shipping industry.

3. Use of Lightweight Materials

High-Strength Steel: The use of high-strength, lightweight steel in ship construction reduces improving fuel efficiency and reducing carbon emissions.

Composites and Aluminum: Some ships are incorporating composite materials (such as carbon fiber-reinforced polymers) or aluminum alloys in non-structural parts of the ship to reduce weight without compromising strength or durability.

Eco-friendly Paints: Ships are now being coated with eco-friendly paints that reduce biofouling (the accumulation of marine organisms on the hull), leading to better fuel efficiency and fewer harmful chemicals being released into the water.

4. Energy-Efficient Power Generation and Use

Waste Heat Recovery Systems: Ships are equipped with systems that capture and reuse waste heat from engine exhaust gases. This recovered energy can be used to power auxiliary systems (lighting, air conditioning) reducing the need for additional fuel.

Solar Panels: Many ships are being fitted with solar panels on their roofs and decks to generate renewable energy, which help power non-essential systems on the ship, further reducing fuel consumption.

5. Scrubber Systems and Emission Reduction Technologies

Exhaust Gas Cleaning Systems (Scrubbers): Some ships built with scrubbers that remove sulfur oxides (SO_x) from the exhaust gases, allowing vessels to continue using high-sulfur fuel while complying with global sulfur emission standards. These systems treat exhaust gases before they are released into the atmosphere.

Selective Catalytic Reduction (SCR) Systems: SCR technology is being increasingly used to reduce nitrogen oxides (NO_x) emissions from ships. These systems use a catalyst and a urea solution to convert harmful NO_x gases into harmless nitrogen and water vapor.

6. Ballast Water Treatment Systems

Ballast Water Management Systems (BWMS): Ships are now being constructed with integrated ballast water treatment systems that prevent the spread of invasive species. These systems treat ballast water before it's discharged into the ocean, reducing the

environmental impact of shipping.

Zero Discharge Ballast Water Technology: Some ships are being built with zero-discharge systems, which treat and store ballast water in a way that avoids any potential for contamination of marine ecosystems.

7. Advanced Waste Management Systems

Zero-Emission Waste Treatment: Modern ships are being equipped with advanced waste management systems that convert waste into energy or safely dispose of it in a way that reduces pollution. This includes treating sewage and food waste on board before discharging it in compliance with regulations.

Waste-to-Energy Systems: Some ships now use waste-to-energy systems that convert waste materials into electricity, helping to power auxiliary systems and reduce reliance on fuel.

8. Smart Ship Technology

Energy Monitoring Systems: Ships are increasingly equipped with real-time energy monitoring systems that track fuel consumption, emissions, and overall environmental performance. These systems enable engineers to make adjustments to optimize efficiency.

9. Reduction in the Use of Harmful Chemicals

Low-Sulfur Fuels: Ships are being built with fuel systems designed to accommodate low-sulfur fuels, such as Very Low Sulfur Fuel Oil (VLSFO) or LNG, reducing the impact of air pollution.

Non-Toxic Antifouling Coatings: Advances in antifouling technology have led to the development of coatings that do not contain toxic chemicals, such as biocides, reducing the environmental impact of ships.

10. Sustainable Ship Recycling

Green Ship Recycling: The construction of ships is now increasingly focused on the long-term sustainability of the vessel, including the ship's eventual disposal. "Green ship recycling" practices are being promoted to ensure that ships are dismantled in an environmentally responsible manner, with materials being safely recycled or disposed of.

11. Modular and Flexible Designs

Modular Ship Construction: Some shipbuilders are moving toward modular ship construction, where standardized sections of a ship can be built separately and then assembled. This method reduces material waste, improves construction efficiency, and allows for easier retrofitting with eco-friendly technologies during the ship's life cycle.

Rules and regulations -

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of

pollution of the marine environment by ships from operational or accidental causes.

A ship is allowed to sail only when documents listed by IMO are carried shall include but not limited to,

1. International oil pollution prevention certificate
2. Oil record book
3. Shipboard oil pollution emergency plan
4. International Sewage pollution prevention certificate
5. Document of approval for the rate of sewage discharge
6. Garbage management plan/garbage record book
7. SO_x emission, compliance certificate and exhaust gas cleaning system technical manual
8. International air pollution prevention certificate
9. International energy efficiency certificate
10. Ozone depleting substances record book
11. Logbook or electronic record, book-nitrogen oxides emission
12. International blast, water management certificate
13. Blast water record book
14. Crude oil washing operation and equipment manual
15. International pollution prevention certificate for the carriage of noxious liquid substance in bulk NLC certificate
16. Certificate of fitness for the carriage of dangerous chemicals in bulk
17. Certificate of fitness for the carriage of liquid gases in bulk limitation

Challenges :

While the adoption of low sulfur fuels is a crucial step in reducing air pollution and complying with environmental regulations, it introduces several operational challenges for the shipping industry, including

1. **Higher Fuel Costs**
Low sulfur fuel is typically more expensive than traditional high sulfur fuel oils.
2. **Lower Energy Density**
Low sulfur fuels, such as very low sulfur fuel oil (VLSFO) or marine gas oil (MGO), generally have a lower energy density than higher sulfur fuels. This means ships need to burn more fuel to achieve the same power output.
3. **Increased Maintenance Costs**
Low sulfur fuels often contain different chemical compositions, which can lead to increased wear and tear on engine components. Some low sulfur fuels may have more paraffin wax or other compounds that can cause deposits or clog fuel filters.
4. **Compatibility Issues**
Switching from high sulfur to low sulfur fuel can create compatibility issues, especially for ships that

were not initially designed to use these fuels. Some vessels may need modifications to their engines or fuel systems, which involves significant investment.

5. Impact on Existing Fuel Infrastructure

The switch to low sulfur fuel increases the demand for specific types of fuel, putting pressure on the existing fuel supply infrastructure, including refineries, storage, and distribution networks. This can result in supply chain challenges, particularly in regions where low sulfur fuel is less available.

6. Sulfur Scrubber Costs

As an alternative to using low sulfur fuel, some ships have installed sulfur scrubbers to remove sulfur emissions from exhaust gases. While this may be a viable solution for certain vessels, the installation, operation, and maintenance of scrubbers are expensive. Moreover, some ports and countries are banning scrubbers or limiting their use due to the discharge of contaminated wash water, creating regulatory hurdles for ships using this technology.

7. Increased Risk of Fuel Contamination

Low sulfur fuels, particularly VLSFO, have a higher risk of contamination, including the presence of water, sediments, or other impurities. The higher risk of contamination can cause engine failures, increased maintenance, and operational downtime, which may lead to disruptions in shipping schedules.

8. Limited Availability

In some regions, low sulfur fuels may not be as readily available.

9. Maintenance of New Technologies

Increased complexity in maintaining alternative fuel engines, fuel cells, and carbon capture systems. Training crew to handle new propulsion technologies safely and efficiently. Limited availability of spare parts for cutting-edge green technology.

10. Safety and Risk Management

Fire and Explosion Risks

Hydrogen and ammonia are highly flammable and require extreme caution in handling and storage. New fire suppression techniques and emergency response plans needed for alternative fuels.

Risk of gas leaks, pressure vessel failures, and toxicity hazards (e.g., ammonia is toxic to humans).

11. Handling Complex Machinery and Systems

LNG fuel systems require specialized knowledge of cryogenic handling and vapor management. Ammonia and hydrogen fuel cells need highly trained engineers due to their unique operating principles.

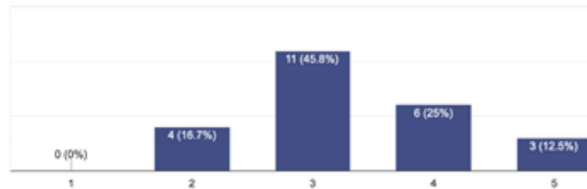
Need for real-time monitoring systems to detect fuel leaks, energy losses, and system failures.

12. Compliance with Evolving Environmental Regulation

13. Cybersecurity Risks

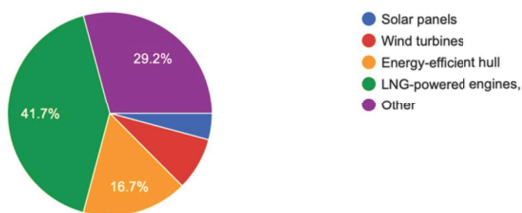
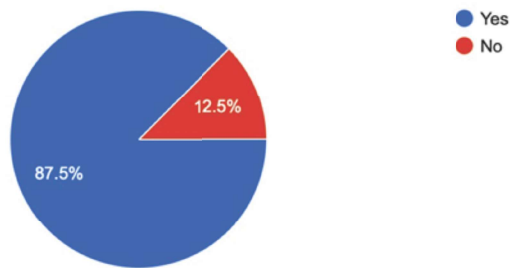
Increased reliance on digital ship operations makes vessels more vulnerable to cyberattacks. Need for cybersecurity training for engineers and crew members.

14. Crew Training and Skill Development
Specialized Training for Alternative Fuels – Hydrogen, LNG, and ammonia require advanced training for handling and risk management.
What are the opinions of officers on Green Shipping-



Question asked -

Do you think the maritime industry is doing enough to adopt sustainable technologies? LNG powered Engines



Others are-

- LPG Dual Fuel Propulsion
- Methanol powered vessels
- Lpg powered engine
- Using alternative fuels
- adopting different routes
- Ammonia fueled Vessel
- Less sulfur Fuel oil using for engine

Challenges according to them-

More than 50% thinks that the major challenge for green shipping is Cost. Other challenges such as

- The infrastructure is still not well development
- The production of fuel is still not enough
- The initial investment cost and no guarantees that the cost will be recoverable in the near future, at the same time remaining competitive in the market
- All actors in shipping industry need to chip in

Research Methodology-

1. Introduction

The research in this study looks into green shipping technologies and innovations by examining data gathered from internet surveys, academic research, and industry regulations. Both primary and secondary data sources were combined to gain insight into the challenges and developments in sustainable shipping.

2. Research Design-

The descriptive research design was employed in order to investigate the influence of green shipping practice. Data were gathered through means of completed online questionnaires within our college and comprehensive literature studies, i.e., MARPOL regulations and maritime industry publications.

3. Data Collection Methods-

- The Primary Data: An online questionnaire was conducted among our college teachers and students in order to gauge awareness and opinion towards green shipping.
- Secondary Data: Information was collected from MARPOL (Marine Pollution

Convention), books, research papers, and online sources such as maritime industry websites and social media.

4. Sampling Technique-

The convenience sampling method was used, targeting students and teachers who were interested in maritime studies. This was a convenient means of acquainting the participants who were already familiar with the topic.

5. Data Analysis-

- Survey Data: Information was utilized to determine recurring perceptions, issues, and solutions to green shipping.
- Literature Review: Books, MARPOL, and internet sources were searched to identify significant

findings supporting survey results.

6. Ethical Considerations-

The purpose of the research was communicated to all the respondents in the survey, and answers were kept anonymous for the ethical conduct of research. Authentic sources were used in order to uphold academic integrity.

7. Limitations

The research is limited by the sample size and the range of the available data online. Although MARPOL and books offer valid data, shipping companies' real-time data would further enrich the study.

conclusion:

Green shipping represents a crucial shift towards sustainability in the maritime industry, aiming to reduce environmental impacts while ensuring operational efficiency. Through advancements in technology, regulatory frameworks, and industry initiatives, shipping companies are progressively adopting ecofriendly practices. However, challenges such as high implementation costs, regulatory compliance, and operational limitations remain significant hurdles for officers and stakeholders. Despite these obstacles, certifications and international standards play a vital role in ensuring that ships adhere to environmentally responsible practices.

As the industry continues to evolve, collaboration between governments, shipowners, and regulatory bodies will be essential in overcoming these challenges. The future of green shipping lies in continued innovation, investment in sustainable technologies, and stricter enforcement of environmental policies. By addressing these aspects, the maritime sector can significantly contribute to global efforts in reducing carbon emissions and protecting marine ecosystems, paving the way for a cleaner and more sustainable future.

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