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Analysis of the Impact of Carbon Neutrality on Energy Saving and Emission Reduction in the Shipping Industry

Runxin XU

Dalian Maritime University, Dalian City, Liaoning Province, China, 116026

E-mail: xuexixin22@163.com

***Corresponding author**

Abstract

Carbon neutrality is the focus of the world's attention in terms of green energy efficiency and emission reduction, and is a measure developed by all mankind to mitigate unusual weather conditions such as climate change. The IMO's stricter carbon regulations, which will come into force in 2023, will make it imperative for the world to focus on reducing emissions from ships in order to meet the 2030 carbon peaking and 2060 carbon neutral targets.

By analyzing three types of currently mainstream low-carbon and zero-carbon ship power energy representatives, namely: LNG-powered ships, hydrogen-fuelled-powered ships and nuclear-powered ships. This paper illustrates the disadvantages, current applications and future prospects of these ship power energy sources, as well as some measures to reduce greenhouse gas emissions from ships in addition to energy sources. With the expectation that this paper will provide a reference for the cause of energy saving and emission reduction in the shipping industry.

Keywords: Carbon neutrality; GHG; IMO regulations; nautical science.

1. Introduction

Maritime transport is a crucial part of the global economy, carrying over 85% of the world's commodities trade and more than that in most developing countries, as well as large volumes of goods such as crude oil and ores. [1-3] Maritime transport is divided into cargo and non-cargo, with cargo ships including container ships and bulk carriers and non-cargo ships including ferries and passenger ships. However, large ships, such as those of 400 gross tonnage and above for international voyages, are required to implement Annex VI to the MARPOL Convention, which imposes certain limits on the emission of carbon dioxide and air pollutants such as sulphur dioxide during the operation of such ships.

The researchs have shown that emissions from burning fossil fuels account for 33% of total global shipping emissions and 3.3% of global CO_2 emissions. [1-4] NOx and SOx from global ship transport account for 10% and 15% of total human pollution sources each year [5]. As one of the players contributing to the greenhouse effect and air pollution, the shipping industry should be taken seriously in its efforts to reduce carbon emissions.

2. IMO 2050's objectives

The IMO is a UN (United Nations) organization whose objective is to increase safe, secure, ecologically sound, efficient, and viable shipping through partnership. [6] The IMO has played a positive role in the adoption of many conventions for the shipping industry, such as the SOLAS Convention, the STCW Convention and the MLC Convention.

In April 2018, the IMO adopted the world's first preliminary strategy for GHG emission reductions from shipping. The goal is to reduce the intensity of GHG emissions from shipping to 40% by 2030 compared to 2008, and to 50% by 2050 compared to 2008, with a 50% reduction in total carbon emissions. And to phase out GHG emissions from shipping as soon as possible within this century. [7]

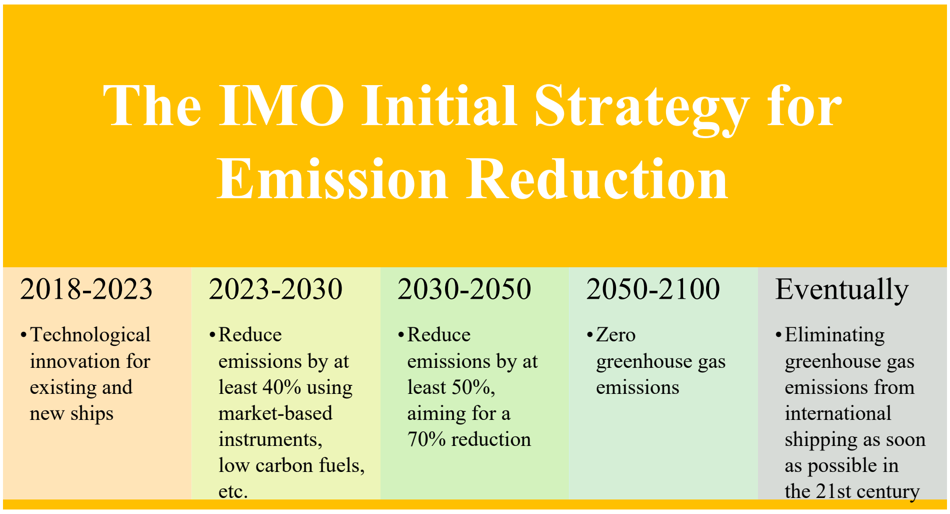

Figure 1. The IMO Initial Strategy for Emission Reduction

Emissions from shipping reached 961 million tonnes of CO_2 in 2012, compared to 816 million tonnes in 2007, an increase of around 18% in five years. And on 4 August 2020, the IMO released its GHG4 (Fourth Greenhouse Gas Study 2020) report, stating that while the global carbon intensity of maritime transport fell by about 11% between 2012 and 2018, annual GHG emissions, at 1,076 million tonnes, are still on an upward trend, with CO_2 emissions expected to rise by 50% by 2050 compared to 2018 and about one times higher than in 2008. [8]

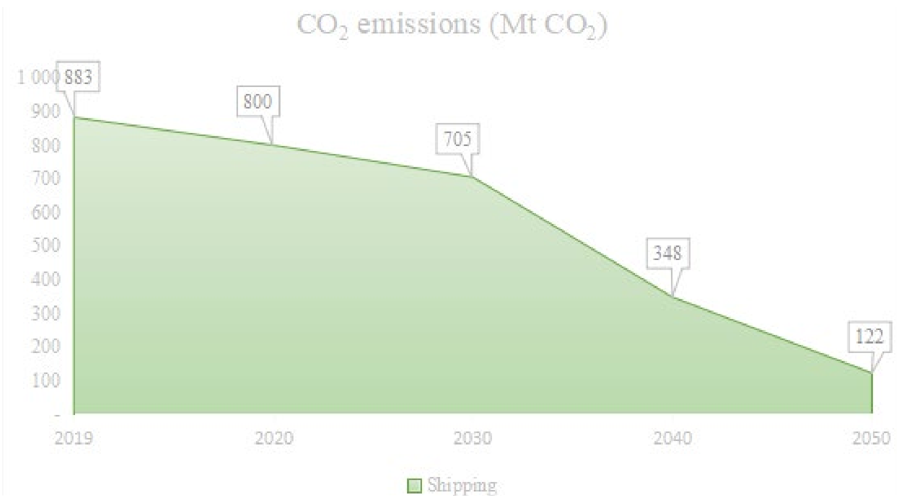

Figure 2. Carbon Emissions Projections for The Shipping Industry (Source: IEA)

According to an analysis by the IEA (International Energy Agency), shipping is expected to reduce its carbon emissions to 122 million tonnes in 2050, representing approximately 9% of the combined emissions of industry, transport and construction.

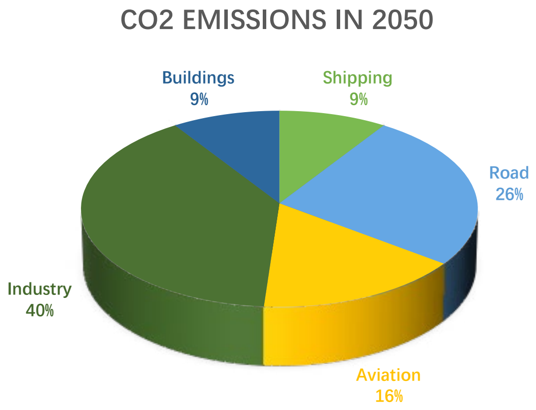

Figure 3. Carbon Emissions from Shipping, Industry and Building in 2050 (Source: IEA)

3. LNG

A ship's bunker type, power type, engine type and engine efficiency all have an impact on GHG emissions. Shipping accounts for 3% of global GHG emissions and is expected to improve the greenhouse effect by limiting GHG emissions. Low or zero carbon technologies for ships are proliferating, but large-scale applications are not yet clear. Current low or zero carbon power technologies are divided into three main groups:

a) LNG and methanol, with mature technology and competitive costs.

b) Biofuels and power cells, with mature technology and high costs.

c) Helium, hydrogen and nuclear power, with exploratory technology and expected lower costs.

3.1. LNG meets the MARPOL

LNG is recognized as the cleanest fossil energy source on the planet, with very little air pollution after combustion [9], while the energy released is high and is gradually being used for power generation, heating in small and medium-sized towns, and as a fuel for vehicles.

Table 1. according to [6,9], CO_2 emissions reduction by using alternative fuels

Types of alternative fuels	CO_2 emissions reductions
LNG	0-20%
Wind	1-32%
Solar	0-12%
Electricity	0-100%
Hydrogen	0-100%
Nuclear	0-100%

In July 2011, the IMO adopted Annex VI to the MARPOL Convention, which increases the standards for NOx and SOx emissions from ships. The ships entering the ECAs (Export Control Areas) must have less than 0.1% sulphur in their bunker by 2015, and all ships entering the ECAs will have implemented the NOx Tier 3 standard by 2016, reducing emissions by 80% compared to Tier 1.

The new MARPOL requirements, combined with the safety and economics of long-term investment, have led to a preference for the use of LNG as a clean energy source to completely solve the SOx and NOx emissions problem. LNG can reduce NOx emissions by 80-90% and achieve zero SOx emissions compared to the same calorific value of traditional bunker.

However, LNG still produces CO_2 during combustion and releases a certain amount of methane (CH_4, a greenhouse gas) due to incomplete combustion. There are already two types of LNG single-fuel engines and LNG-diesel dual-fuel engines. However, as multi-point injection LNG supply systems have not yet been developed, most LNG-fueled ships currently use mixed intake fade-point injection engines.

3.2. LNG vs. other bunkers

For bunkers, converting conventional bunkers such as MDO (Marine Diesel Oil), MFO (Marine Fuel Oil), and HFO (Heavy Fuel Oil) are examples of bunkers [3], to natural gas can be more effective in reducing greenhouse gas emissions. However, the effect will be counterproductive if the use of LNG causes leakage.

3.3. LNG carrier

LNG carriers are specialized vessels for the transportation of natural gas. The current LNG carriers are all fully refrigerated, i.e. the pressurised LNG is filled in a pressure vessel and transported at atmospheric temperature, and there are two types of vessels: Moss Spherical type and Membrane type.[10] When the LNG carrier is sailing in the ocean, as the outside temperature is higher than the container temperature, the LNG vaporizes into natural gas, causing the pressure of the container to rise. The LNG carrier will lead the generated natural gas into the main engine, avoiding the pollution caused by the direct discharge of natural gas into the atmosphere and enhancing the economic efficiency of the voyage.

3.4. Non-LNG carriers

For non-LNG carriers on long voyages, the loading of LNG will be a problem because there are no special pressure containers. In addition, LNG is a hazardous chemical in the liquefied gas category, and its fire protection requirements for ships and ports are greatly increased. Therefore, it is not easy to convert diesel consuming vessels to LNG consuming vessels and likewise some private ship owners are not very motivated to convert their vessels and remain on the fence. This fuel transition is more easily achieved on inland waterway vessels, which are smaller in comparison to ocean-going vessels, and likewise inland waterway vessels are more likely to meet the requirements of LNG-powered vessels in terms of range. In 2020, China's inland waterway transport has built 20 LNG refueling stations and 290 LNG-powered vessels.[11]

4. Hydrogen powered ships

4.1. Hydrogen in bunker

When hydrogen is added to the bunker, the reaction equation is:

$C_{m+n}H_{2x}+\left(m+\frac{n+x}{2}\right)O_2=mCO_2+nCO+xH_2O$ (1) Burning of bunkers

$2H_2+O_2=2H_2O+\text{energy}$ (2) Burning of hydrogen

Compared to burning MDO, MFO and HFO as bunker, the hydrogenation results in less CO_2 in the combustion products.

4.2. Hydrogen direct combustion

When hydrogen is burned directly in the main engine, the reaction equation is: $2H_2+O_2=2H_2O+\text{energy}$.

When it is burned directly, only H_2O is produced in the combustion products and there is no CO_2, which reduces carbon emissions by 50-70%. The thermal energy generated through the reaction is converted into mechanical energy to drive the piston to do work, but there is a large energy loss in this conversion process, with an energy conversion rate of up to 40%.[12]

4.3. Hydrogen fuel cells

Fuel cell ships are also expected to decarbonize the shipping industry.

In ship power generation, fuel cell systems are cleaner and more efficient than traditional power units such as diesel engines, while possessing features such as low noise, low vibration and less heat radiation, which can improve the living and working environment on ship. At present, it also has a number of disadvantages such as a high initial investment cost, a short service life and the difficulty of meeting the requirements of ocean voyages. PEMFCs (Proton Exchange Membrane Fuel Cells) are used directly as a power source on short-haul passenger ships, small yachts and ro-ro ships with relatively short voyage cycles, but are less commonly used on ocean-going transport vessels and are only used as auxiliary power units on board. [13]

The hydrogen fuel cell is a power generation device that converts chemical energy from Hydrogen at the anode and oxygen at the cathode into electrical energy through a redox reaction. The reaction equation is:

$H_2 \rightarrow 2H^+ + 2e^-$ (3) Cathodic reaction equation

$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (4) Anodic reaction equation

$H_2 + \frac{1}{2}O_2 = H_2O$ (5) Total reaction equation

In the hydrogen fuel cell reaction process, there is no CO_2 emission and the energy loss during the reaction is minimal, with a theoretical conversion efficiency of over 80% and in practice over 60%. Hydrogen fuel cells are therefore expected to be widely used in ships in the future.

Picture 1. China's first hydrogen energy fuel cell yacht sailing in Dalian port
(Source: DMU, Dalian Maritime University)

5. Nuclear propelled ships

Nuclear propulsion ships have existed since 1955, mainly for use by naval forces. The advantages of nuclear energy focus on high power density, low greenhouse gas emissions and the ability to operate for long periods of time without additional bunker[2, 15], making the ship less constrained by endurance factors and increasing its independence.

5.1. Technical limitations

Although it has advantages that are unique to other types of bunkers, the disadvantages of nuclear propulsion for ships are also obvious. From a technical point of view, nuclear power is a cutting-edge technology compared to other ship technologies, mastered by only a few countries in the world and kept strictly secret. In the absence of technology disclosure, other countries can often only achieve results through lengthy and costly project development. The high costs often exclude developing countries from the program.

5.2. Safety restrictions

Nuclear propulsion is achieved by creating a fission reaction in an on-board nuclear power reactor, releasing huge amounts of energy which is absorbed and heated by circulating cooling water to produce steam which drives steam turbines and generators. However, many port authorities refuse to allow foreign nuclear-powered ships into their ports because of concerns about radioactive contamination of shipping lanes, ports and coastal cities, or even the hijacking of nuclear-powered ships by unscrupulous elements to attack ports. The certification and licensing of nuclear-powered ships, safety regulations and the suppression of terrorist acts are obstacles that cannot be ignored.

5.3. Management constraints

As carbon neutrality continues to progress, nuclear power is expected to be used in commercial vessels.

Nuclear-powered ships require experienced technicians with knowledge of both nuclear reaction principles and engineering to maintain the ship's main engine, which undoubtedly raises the shipowner's recruitment standards and personnel costs. In addition, the impact of the radioactivity of natural uranium on the health of the crew, drinking water, etc. should be considered in detail. Used nuclear waste will also need to be properly stored or disposed of to avoid significant environmental impacts from leaks.

6. Navigational efficiency

The use of bunkers can be reduced by improving navigational efficiency, for example by optimizing the navigation route, reducing resistance to sailing, improving propulsion efficiency and keeping the ship clean.

This requires the 2/O to keep the ship on the best possible course that satisfies both the shortest route and safety. The OOW should be aware of situations that will reduce the ship's navigational efficiency and try to avoid them, such as the shallow water effect which reduces the ship's navigational efficiency and increases the ship's bunker consumption.

The following disadvantages will occur when a ship is sailing in shallow water:

a) According to Bernoulli's law, the current around the ship accelerates while the pressure around the ship decreases, causing the ship to sink, the draft to increase, the contact area between the ship and the water to increase, and the frictional resistance of the ship to increase, reducing the navigational efficiency. [14]

b) In shallow water the wave is enhanced and the wave resistance increases.

c) Stern eddies are enhanced and propeller efficiency is reduced.

d) In addition, marine sinister organisms growing on submerged hulls, such as barnacles and oysters, can also reduce the efficiency of ship propulsion and consume additional bunker. Where permissible, reduce the time spent at anchor and clean the hull in time to improve energy efficiency and reduce emissions.

7. Summary

Ocean-going vessels will have to use higher energy density bunkers and more powerful engines. As vessels become larger, with more and more 200,000 to 300,000 DWT vessels such as VLCCs (Very Large Crude Carriers), the energy density of the bunker carried and the power of the main engine used for a given volume have also increased. In order to meet the requirements of low-carbon navigation and at the same time save the cost of shipowners to retrofit their ships to a certain extent, ships should focus on encouraging the development and application of biofuel ships such as LNG and methanol on a pilot basis before 2030 when the age of the ships is relatively small and the replacement cost is high. Ships are expected to be commercially available after 2030, when the age of in-service ships generally reaches 15 years or more and replacement costs are significantly lower, when ammonia, hydrogen, and even nuclear-powered ships are expected to be commercially available. [15]

Retrofitting of ships to reduce emissions in the manner described above, to a large extent to ensure the implementation of IMO shipping industry GHG emissions reduction strategy. The transformation of ships in accordance with the above-mentioned program has largely ensured the implementation of the IMO Shipping Industry GHG Reduction Strategy and the Global Carbon Neutral Plan.

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Abbreviations

IMO, International Maritime Organization; LNG, Liquefied Natural Gas; GHG, Greenhouse Gas; MARPOL, International Convention for the Prevention of Pollution from Ships; CO_2, Carbon Dioxide; NOx, Nitrogen Oxides; SOx, Sulfur Oxides; UN, United Nations; SOLAS, International Convention for the Safety of Life at Sea; STCW, International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers; MLC, Maritime Labour Convention; GHG4, Fourth Greenhouse Gas Study 2020; IEA, International Energy Agency; ECAs, Export Control Areas; MDO, Marine Diesel Oil; MFO, Marine Fuel Oil; HFO, Heavy Fuel Oil; O_2, Oxygen; CO, Carbon Monoxide; H_2O, Water; H_2, Hydrogen; PEMFCs, Proton Exchange Membrane Fuel Cells; DMU, Dalian Maritime University; 2/O, Second Mate; OOW, Officer of the Watch; DWT, Dead Weight Tonnage; VLCCs, Very Large Crude Carriers.