# UNIVERSITY OF PIRAEUS

## DEPARTMENT OF MARITIME STUDIES

## M.SC. IN SHIPPING MANAGEMENT

# ECONOMIC EFFECT IN SHIPPING COMPANIES DUE TO DECARBONIZATION

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## ABBREVIATIONS

AFOLU: Agriculture, Forestry and Other Land Use

CAPEX: Capital Expenses

CH4: Methane

CII: Carbon Intensity Indicator

CO2: Carbondioxide

DCS: Data Collection System

ECAs: Emission Control Areas

EEDI: Energy Efficiency Design Index

EEOI: Energy Efficiency Operational Indicator

EEXI: Efficiency Existing Ship Index

ETS: Emissions Trading System

EU: European Union

GHG: Greenhouse Gas

GT: Gross Tonnage

HFC: Hydrofluorocarbons

ICE: Internal Combustion Engines

IEEC: International Energy Efficiency Certificate

IMO: International Maritime Organization

LNG: Liquefied Natural Gas

LPG: Liquefied Petroleum Gas

MARPOL: The International Convention for the Prevention of Pollution from Ships

MBM: Market Based Measures

MEPC: Marine Environmental Protection Committee

MRV: Monitoring, Reporting and Verification

N2O: Nitrous Oxide

NECP: National Energy and Climate Policy

NF3: Nitrogen Trifluoride

NOx: Oxides of Nitrogen

OECD: Organization for Economic Co-operation and Development

PFC: Perfluorinated Compounds

PM: Particulate Matter

SEEMP: Ship Energy Efficiency Management Plan

SF6: Sulphur Hexafluoride

SOx: Sulphur Oxides

UNCTAD: United Nations Conference on Trade and Development

UNFCCC: United Nations Framework Convention on Climate Change

# ABSTRACT

During the last years, many organizations have raised awareness and underlined the need to protect the environment. The International Maritime Organization (IMO), as the global regulator of the shipping industry, has attempted over the years to enact regulations that will help reduce environmental pollution from shipping. For this reason, the IMO Marine Environment Protection Committee (MEPC) has decided to aim to reduce the emission of gaseous pollutants, in particular carbon, by 40% by 2030 and by at least 50% by 2050, making those involved wanting to find a long-term solution rather than something temporary.

The process of carbonization is a complex process that affects all involved and not just shipowners, as producers and suppliers are responsible for their fuel and quality, manufacturers and for the new technologies the manufacturers and the shipyards are responsible. Without significant investment in research and development by these stakeholders, the shipping industry will remain carbon dependent.

In summary, shipping companies are called upon to choose the best solution, in their opinion, in order to achieve this goal. This dissertation aims to analyze the carbon footprint of shipping and will analyze some of the available options available to shipowners such as LNG, hydrogen and ammonia.

Keywords: IMO, carbon dioxide, LNG, ammonia, hydrogen, GHG

# ΠΕΡΙΛΗΨΗ

Τα τελευταία χρονιά πολλοί οργανισμοί έχουν ευαισθητοποιηθεί και έχουν τονίσει την ανάγκη που υπάρχει για προστασία του περιβάλλοντος. Ο Διεθνής Ναυτιλιακός Οργανισμός (IMO), ως παγκόσμιος ρυθμιστή της ναυτιλιακής βιομηχανίας, έχει προσπαθήσει να θεσπίσει κανονισμούς, οι όποιοι θα βοηθήσουν στη μείωση ρύπανσης του περιβάλλοντος από τη ναυτιλία. Γι' αυτό τον λόγο, η Επιτροπή Προστασίας Θαλασσίου Περιβάλλοντος (MEPC) του IMO αποφάσισε να θέσει ως στόχο τη μείωση της έντασης των εκπομπών αερίων ρύπων, συγκεκριμένα του άνθρακα, κατά 40% έως το 2030 και κατά τουλάχιστον 50% έως το 2050 κάνοντας τους εμπλεκόμενους να θέλουν να βρουν μια μακροπρόθεσμη λύση και όχι κάτι προσωρινό.

Η πορεία προς την απανθρακοποίηση είναι μια σύνθετη διαδικασία που επηρεάζει όλους τους εμπλεκομένους και όχι μόνο τους εφοπλιστές, καθώς για τα καύσιμα και την ποιότητα τους υπεύθυνοι είναι οι παραγωγοί και προμηθευτές, για τις μηχανές και τις νέες τεχνολογίες την ευθύνη έχουν οι κατασκευαστές και τα ναυπηγία. Χωρίς σημαντικές επενδύσεις στην Έρευνα και Ανάπτυξη από αυτούς τους εμπλεκόμενους φορείς, η ναυτιλιακή βιομηχανία θα παραμείνει εξαρτημένη από τον άνθρακα

Συνοψίζοντας, οι ναυτιλιακές εταιρίες καλούνται να επιλέξουν τη βέλτιστη , κατά τη γνώμη τους λύση, ώστε να πετύχουν αυτό το στόχο. Η παρούσα διπλωματική εργασία έχει σαν σκοπό την ανάλυση του αποτυπώματος του άνθρακα της ναυτιλίας και θα αναλυθούν κάποιες απ' τις διαθέσιμες επιλογές που έχουν οι πλοιοκτήτες όπως το LNG , το υδρογόνο και η αμμωνία.

Λέξεις Κλειδιά: IMO, Διοξείδιο του άνθρακα, LNG, αμμωνία , υδρογόνο, αέρια του θερμοκηπίου

## 1. INTRODUCTION

Shipping is experiencing increasing pressure to decarbonize its operations and to reduce emissions to air.[1]The industry currently accounts for around 2.7% of global $CO_2$ emissions, but emissions are geographically concentrated across East-West trade routes and a relatively small set of vessel types[2] . Bulk carriers, oil tankers and container ships account for around 85% of all shipping activity, while around 45% of international maritime trade passes through the 20 largest global ports[3] .

The necessity of tackling decarbonization obstacles is projected to grow as shipping emissions continue to rise. The International Maritime Organization (IMO) has established the goal of decreasing greenhouse gas emissions in the shipping industry.

In April 2018, the International Maritime Organization took an important early step in addressing the carbon footprint of the shipping industry, setting for the first time a greenhouse gas (GHG) reduction target. IMO has set the ambition of reducing the shipping industry's greenhouse gas emissions by at least 50% by 2050 compared to 2008, and reducing the carbon intensity of emissions by 40% by 2030, and 70% by 2050 compared to 2008 levels. Key stakeholders such as banks and cargo owners are increasingly concentrating on decarbonization. All of this suggests that the commercial environment for vessels will change in the near future. It will have a significant impact on the future fleet, notably in terms of fuels and technology. This will most likely have a greater influence on expenses, asset prices, and earning potential than in the past.

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[1] Decarbonisation in shipping - DNV(Accessed 10/7/2021)

[2] International Council on Clean Transportation (2017), Greenhouse gas emissions from global shipping, 2013-2015

[3] Deloitte analysis based on UNCTAD (2019), Review of Maritime Traffic; Shanghai International Shipping Institute (2019), Global Port Development 2018, April

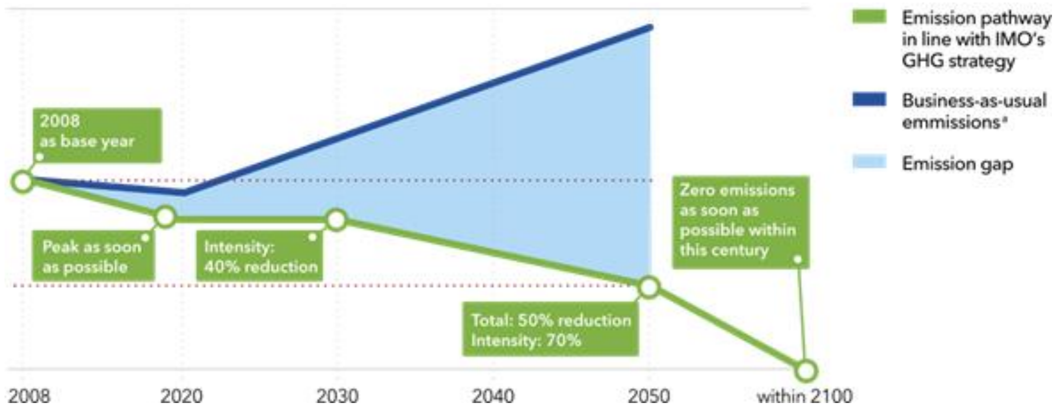

**Image 1 : GHG emissions**

**Source: DNV GL**

Given the milestones in 2030 and beyond, shipping companies must move towards lower carbon intensity and adopt the proper technology in the most technological and economical feasible way.

How will the energy transition change the shipping industry? Which new rules will determine the commercial viability of future naval operations? How can existing vessels be adapted at minimal cost to reduce greenhouse gas emissions? And which alternative fuel is most commercially viable to meet the need for decarbonization?

These are among the myriad questions facing shipowners as they seek to navigate a new market reality dictated by an array of environmental regulations and reporting requirements that will have serious implications for their fleet operations going forward.

To assist shipowners in answering these concerns, Chapter 3 of this research covers regulations and incentives for decarbonization and in Chapter 4 we will see all of the existing measures that have been set by IMO in order to reduce GHG emissions. Then, in Chapter 5, we will look at alternative decarbonization paths as long term solution and possible fuel and converter solutions. Shipping will undoubtedly require new technologies to meet GHG targets, as we will see in Chapter 6. Finally, we will investigate the financial possibilities available in the maritime industry. And how the Greek shipowners intend to adopt these regulations and achieve the IMO goal.

## 2. EMISSIONS FROM SHIPPING

To avoid severe climate change, we must cut global greenhouse gas emissions as soon as possible. Every year, the globe emits around 50 billion tonnes of greenhouse gases (measured in carbon dioxide equivalents).

To determine how to further efficiently cut emissions and which emissions can and cannot be removed using existing technology, we must first identify where our emissions originate.

Since the beginning of the industrial revolution, carbon dioxide emissions, mainly from the burning of fossil fuels, have increased considerably. Most of the world's greenhouse gas emissions come from a relatively small number of countries.

China, the United States and the countries that make up the European Union (EU) are the three largest emitters in an absolute sense. The United States and Russia have the highest per capita greenhouse gas emissions.[4]

Below it’s a chart which shows the breakdown of global greenhouse gas emissions in 2016, by sector, published by Climate Watch and the World Resources Institute.

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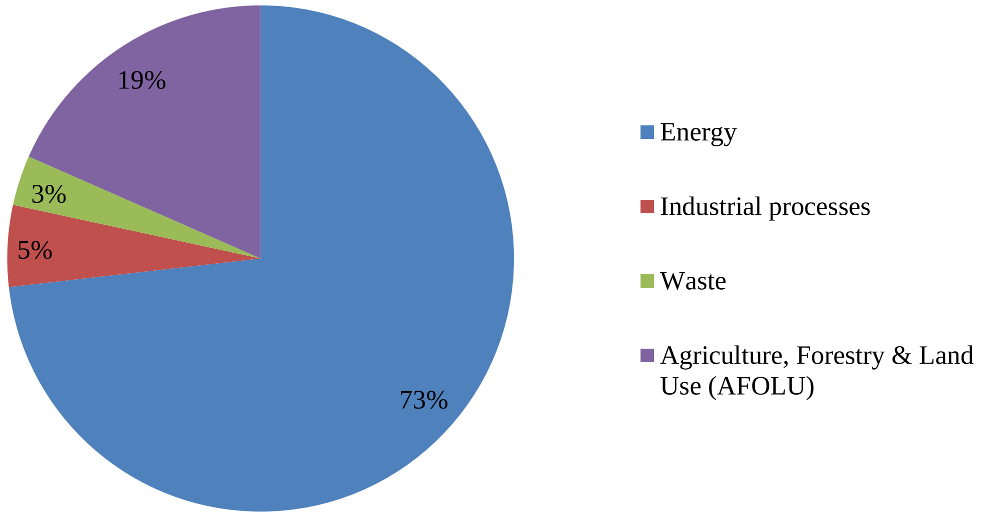
[4] Center for Climate and Energy Solution, Global Emissions

**Figure 1: Share of global greenhouse gas emissions (%)**



**Source: Climate Watch and the World Resources Institute, 2016**

From this chart, almost three-quarters of emissions come from energy use; nearly one-fifth comes from agriculture and land use, and the remaining 8% comes from industry and waste.

Energy consumption is by far the largest source of man-made greenhouse gas emissions, accounting for 73% of the world's total. The energy sector includes transportation, electricity and heat, buildings, manufacturing and construction, fugitive emissions and other fuel combustion.

Transportation sector includes road transportation, aviation, shipping, rail and pipeline.

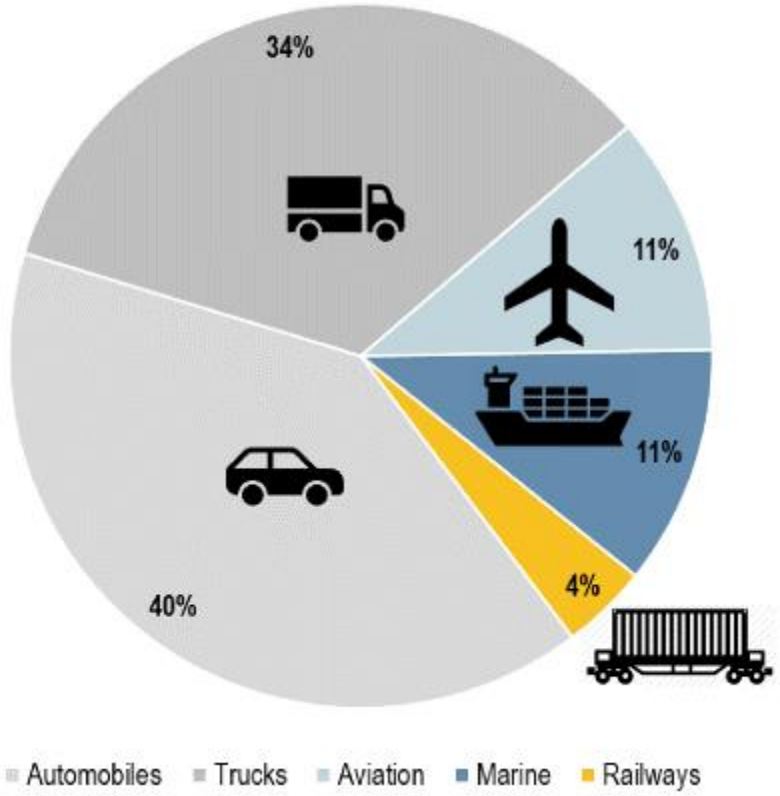


**Image 2: Global CO2 Emissions by the Transport Sector in 2018, in %**

**Source: Oilman Magazine**

Road transport contributes the most to overall transport emissions (around 74 percent in 2018), but this is expected to decrease as road transport decarbonizes faster than other modes (to 67 percent and 63 percent under the ‘with existing measures' and ‘with additional measures' scenarios, respectively).

The aviation industry is expected to have the greatest increases up to 2030, followed by international sea transport. As a result, these sub-sectors are anticipated to account for a greater share of transportation sector emissions in the future years. Recent statistics show even higher rises than predicted for aviation, however due to COVID-19 there was a decrease in 2020.

Shipping is the global economy's backbone. According to the United Nations Conference on Trade and Development (UNCTAD), it is by far the most efficient form of freight transport, transporting roughly 80% of the world's trade volume.

However, as the business develops, it creates more carbon emissions from shipping. Commercial ships burn fuel for energy and emit several types of air pollution as by-products. Ship-source pollutants most closely linked to climate change and public health impacts include carbon dioxide (CO2), nitrogen oxides (NOx), Sulphur oxides (SOx) and particulate matter (PM).[5]

Image 3: Pollution Types from Marine Shipping

Source: Clean Seas

The great majority of greenhouse gas emissions from the sector are carbon dioxide (CO2), but minor amounts of methane (CH4) and nitrous oxide (N2O) are also produced. These gases are produced when fossil fuels such as coal, oil, and natural gas are burned to generate power. Less than 1 percent of greenhouse gas emissions from the sector come from sulphur hexafluoride (SF6), an insulating chemical used in electricity transmission and distribution equipment.

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[5] World Health Organization. (2018). Ambient Air Pollution: Health impacts. Health risks.

The main gases and their effects on both the environment and humans are listed below.

### Carbon Dioxide ($CO_2$)

Carbon dioxide ($CO_2$) is a colorless, odorless, and non-poisonous gas that is generated by the combustion of carbon and the breathing of living creatures. It is a kind of greenhouse gas.

It is a major greenhouse gas that contributes to climate change and ocean acidification.

Carbon dioxide is released into the atmosphere when fossil fuels such as coal, natural gas, and oil are burnt. When other biological materials, such as solid waste and trees, are burnt, they emit carbon dioxide. When massive volumes of carbon dioxide are released into the atmosphere, it has an effect on the entire world.

Rising acidity has a detrimental influence on marine life and ecosystems.

Climate change is possibly the most significant manner in which carbon emissions influence the world. As the world average temperature increases, our climate changes inevitably – it heats. Global warming is the cause of extreme weather events such as tropical storms, wildfires, severe droughts, and heat waves.

### Nitrogen Oxides ($NO_x$)

Nitrogen oxides ($NO_x$) are gaseous products produced by the combustion of fuel, when it’s burned in high temperatures in the main and auxiliary engines.

These nitrogen oxides consist mainly of two molecules, nitric oxide (NO) and nitrogen dioxide ($NO_2$). Nitrous oxide ($N_2O$), is a significant greenhouse gas that plays a role in global climate change.

$NO_x$ pollution is emitted by automobiles, trucks and various non-road vehicles (e.g., construction equipment, vessels, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines Oxides are extremely toxic, especially when they react with other substances in the environment. Nitrogen oxides are produced in considerable quantities by diesel engines in particular. This is owing to the combustion characteristics of this type of engine, including as high operating pressures and temperatures, which are notably noticeable when contrasted to gasoline engines. Furthermore, diesel engines enable extra oxygen to escape the cylinders, reducing the efficiency of catalytic converters, which in gasoline engines prevent the production of most NOx emissions.

NOx gases play an important role in the formation of smog, producing the brown haze often observed over cities, particularly during the summer. As a result, even short-term exposure can irritate the lungs of healthy people.[6]

## Sulphur Oxides (SOx)

It's a collection of gases, colorless non-flammable gas but with a strong irritating odor in many high concentrations. In wet conditions, SOx dissolves in air and converted to sulphuric acid, while oxidized and converted to sulphuric acid in dry conditions, which together with nitric acid is the main component of acid rain.
Typically, Sulphur dioxide is emitted when sulphur-containing fuels or other materials are combusted or oxidized. It's a contaminant that adds to acid deposition, which can affect the quality of soil and water. Acid deposition can have serious consequences, including harm to aquatic ecosystems in rivers and lakes, as well as damage to forests, crops, and other vegetation. Asthma is aggravated by SO2 emissions, which can impair lung function and inflame the respiratory system.

## Particulate Matter (PM)

Particulate matter is collection of solid and liquid particles suspended in air many of which are hazardous. This complex mixture includes
both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets. These particles vary greatly in size, composition, and origin.

Particles in air are either directly emitted, for instance when fuel is burnt and when dust is carried by wind, can be inhaled into people's lungs and then absorbed into the bloodstream, which has been linked to many negative heart and lung health outcomes,

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[6] Moderate Increases in Ambient PM2.5 and Ozone Are Associated... : Journal of Occupational and Environmental Medicine (lww.com)(Accessed 6/9/2021)

including cancers or indirectly formed, when gaseous pollutants previously emitted to air turn into particulate matter[7].

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[7] "Health Aspects of Air Pollution" (2003), Chapter 5 Particulate matter (PM), Section 5.1 Introduction

## 3. REGULATORY FRAMEWORK

International maritime transport is the backbone of the global economy. However, vessels release emissions that pollute the air and contribute significantly to global warming, as inferred from the above chapter. As shipping is forecast to grow, reducing these emissions is urgent, in order not to undermine emissions-reducing efforts in other areas, to keep humans healthy, preserve the environment and limit climate change.

This chapter examines future policy initiatives and regulations that will have an immediate impact on businesses, as well as their potential short- and long-term implications on the decarbonization trajectory.

All regulations are based on the concept that they should apply to all ships, regardless of flag state. The International Maritime Organization (IMO) and the European Union are the two main bodies that set emission standards (EU). In most cases, the IMO norms are incorporated into EU legislation.

Regulators all across the world have begun to take steps to mitigate the environmental and social dangers connected with these emissions. The International Maritime Organization (IMO) has approved necessary steps to minimize greenhouse gas emissions from international shipping. In comparison to 2008, the initial greenhouse gas reduction strategy seeks to lower average carbon intensity (CO2 per tonne-mile) by at least 40% by 2030 and 70% by 2050, as well as reducing overall emissions by at least 50% by 2050.[8]

Efforts to implement an international emissions limit have started in 1973, when the IMO issued the1973 the International Convention for the Prevention of Pollution from Ships (MARPOL).

In 1975, a second body named the Marine Environment Protection Committee (MEPC) was created to deal with environmental issues within the IMO's area of responsibility.

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[8] UN body adopts climate change strategy for shipping (imo.org)(Accessed 28/7/2021)

MARPOL, being the main international convention that covers pollution and marine environmental issues, consists of six Annexes[9]:

- Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983)

- Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk  (entered into force 2 October 1983)

- Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)

- Annex IV Prevention of Pollution by Sewage from Ships  (entered into force 27 September 2003)

- Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)

- Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)

IMO's MARPOL Annex VI was adopted at a Conference in September 1997, through a Protocol to the MARPOL Convention, which included the new Annex.

This resolution invited the MEPC to consider what CO2 reduction strategies might be feasible in light of the relationship between CO2 and other atmospheric and marine pollutants.

Under the amended MARPOL Annex VI, the global sulphur cap in bunker fuels was reduced from 4.50 percent to 3.50 percent m/m as of 1.1.2012. This was further reduced to 0.50 percent m/m on 1.1.2020, after an IMO decision (MEPC 70) based on

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[9] International Convention for the Prevention of Pollution from Ships (MARPOL) (imo.org)(Accessed 28/7/2021)

the final report of CE Delft's "Assessment of fuel oil availability"[10]and also set Emission Control Areas (ECAs).

On 1 January 2020, the new limit on the sulphur content in the fuel oil used on board ships came into force, marking a significant milestone to improve air quality, preserve the environment and protect human health.

Known as “IMO 2020”, the rule limits the sulphur in the fuel oil used on board ships operating outside designated emission control areas, as previously stated to 0.50% m/m (mass by mass).Within specific designated emission control areas the limits were already stricter (0.10%). This new restriction was enforced after amendments to Annex VI of the International Convention for the Prevention of Pollution from Ships.[11]

Currently in the European ECA vessels must use distillate fuels with less than 0, 10% of sulphur, as mentioned above. In the American ECA the rule is the same but the vessels must also achieve the Tier III[12]stage for NOx emissions.

The current ECA are located in Northern Europe, along with the American coasts (including American Islands and Territories), and in the estuaries of the great Chinese rivers.[13]

The North American area comprises:

- The sea area located off the Pacific coasts of the United States and Canada
- The sea areas located off the Atlantic coasts of the United States, Canada, and France (Saint-Pierre-et-Miquelon) and the Gulf of Mexico coast of the United States
- The sea area located off the coasts of the Hawaiian Islands
- The Baltic Sea area

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[10] Assessment of fuel oil availability – final report, July 2016, doc. MEPC 70/INF.6.

[11] IMO 2020 – cutting sulphur oxide emissions(Accessed 28/7/2021)

[12] Progressive reductions in NOx emissions from marine diesel engines installed on ships is included in MARPOL Annex VI, with a “Tier II” emission limit for engines installed on or after 1 January 2011. NOx “Tier III” is more stringent emission limit for engines installed on or after 1 January 2016 operating in ECAs.

[13] What and where are the Emission Control Area (ECA) zones? | Total Lubmarine(Accessed 28/7/2021)

- The North Sea area

The China ECA zone comprises:

- The Pearl River Delta
- The Yangtze River Delta
- The Bohai Bay

**Image 4: IMO Emission Control Areas**

**Source: The Shipowners' Club - Protection and Indemnity (P&I) (shipownersclub.com)**

## 3.1 ENVIRONMENTAL MEASURES

Though two of the most important sectors, international aviation and shipping, were not included due to a disagreement in the approach for determining country responsibility, the Kyoto Protocol remained the most important initiative in implementing binding targets and setting obligatory limits for GHG emissions.

The Kyoto Protocol was an international treaty which extended the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits state parties to reduce greenhouse gas emissions, based on the scientific consensus that (part one) global warming is occurring and (part two) that human-made CO2 emissions are driving it. The Kyoto Protocol was signed on December 11, 1997, in Kyoto, Japan, and went into effect on February 16, 2005.

In 2020, the Protocol had 192 parties (Canada had withdrawn from the protocol in December 2012).[14]

The Kyoto Protocol applied to the seven greenhouse gases listed in Annex A: carbon dioxide (CO2), Methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), per fluorocarbons (PFCs), and sulphur hexafluoride (SF6), Nitrogen trifluoride (NF3).[15]

The Kyoto Protocol included the creation of flexible market mechanisms based on the trading of emission allowances as one of its key components. Countries must fulfill their objectives largely through domestic methods, according to the Protocol.

## 3.2 EU STRATEGIES

The European Union has been in the forefront of global efforts to combat climate change.

In 2005, the EU introduced the EU Emissions Trading System (EU ETS) to guarantee that EU nations met the Kyoto Protocol's GHG emission reduction objectives. Since then, the EU ETS has been a critical instrument in reaching EU GHG emissions reduction objectives set both globally and at the EU level. It was the first emissions trading system in the world and remains the largest greenhouse gas emissions trading system across multiple countries and multiple sectors.

As the UK has now left the EU, the UK’s participation in EU ETS has ended. Instead, the UK has introduced its own emissions trading scheme, the UK ETS, although at present this only covers the power and aviation industries. However, the Department

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[14] Kyoto Protocol to the United Nations Framework Convention on Climate Change". UN Treaty Database.

[15] Overview of greenhouse gases - NAEI, UK (beis.gov.uk)(Accessed 2/8/2021)

for Transport has indicated that they are considering expanding the UK scheme to include shipping, although no firm decision has been taken on this.

Unlike the Kyoto Protocol, which set specified emission objectives for industrialized countries alone, the Paris Agreement expects all parties to address all emissions. Parties must set "economy-wide" emission reduction objectives, and shipping is clearly an important sector of the economy.

The Paris Agreement, which was adopted by 196 Parties at COP 21 in Paris on December 12, 2015, and took effect on November 4, 2016, aims to keep global warming well below 2 degrees Celsius, preferably 1.5 degrees Celsius, compared to pre-industrial levels.

Although shipping is not included in the Paris Agreement, the International Maritime Organization (IMO) is committed to decreasing greenhouse gas emissions from international shipping.[16]

In response to the Paris Agreement in 2015, the International Maritime Organization (IMO) established an Initial Strategy for Reducing GHG Emissions from Ships in April 2018. This Initial Strategy seeks to cut overall annual GHG emissions by 50 percent by 2050 compared to 2008, and to lower the carbon intensity (CI) by 40 percent by 2030, and by 70 percent by 2050, in order to decarbonize as quickly as feasible this century, as stated at the begging of this paper . To build a coordinated response plan for the IMO regulation of GHGs, a number of initiatives involving industry have been devised and implemented, as have different research efforts amongst member states.

The Commission published a strategy for reducing GHG emissions from the maritime industry in 2013, which contains a reference to "a pathway of CO2 emissions reduction consistent with the Paris Agreement temperature goals."

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[16] Initial IMO GHG Strategy(Accessed 6/9/2021)

The strategy is made up of three steps:

- CO2 emissions from large ships visiting EU ports are being monitored, reported, and verified.
- Greenhouse gas reduction targets for the maritime transport industry.
- Additional medium- to long-term measures, including market-based measures.

Countries leading the IMO GHG Reduction Strategy, such as Europe, are predicting the amount of CO2 generated by the international shipping industry, determining if the IMO's proposed GHG reduction objectives are achievable with current technology, and planning countermeasures. In response to the IMO GHG Reduction Strategy, the EU has decided to cut the volume of GHGs emitted by ships by less than 80% by 2025 compared to 1990, with the goal of decarbonization. As an intermediate goal, it is said that it will be reduced by 40% by 2030 and 60% by 2040.

Notably, the EU shipping industry has been using the system of monitoring, reporting, and verifying about ships in operation (EU MRV) since 2018. This is the foundation for the EU Regional Emission Trading System (ETS), which will be implemented in the area if the IMO does not take sufficient measures to execute the GHG reduction strategy.[17]

The MRV Regulation establishes standards for the monitoring, reporting, and verification of carbon dioxide (CO2) emissions from ships entering, transiting, or exiting EU and/or EEC ports. The MRV Regulation is part of Europe's attempts to reduce greenhouse gas emissions, and it applies to ships larger than 5000GT, regardless of flag. The purpose of this advice is to enlighten members on the scope and application of the MRV Regulation.

Emission trading systems improve economic efficiency by facilitating emission reductions where they are most cost-effective. It is a cornerstone of the EU's climate change strategy and a crucial instrument for lowering greenhouse gas emissions in a cost-effective manner. It was the world's first significant carbon market and continues to be the largest.

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[17] DNV-GL, 2019

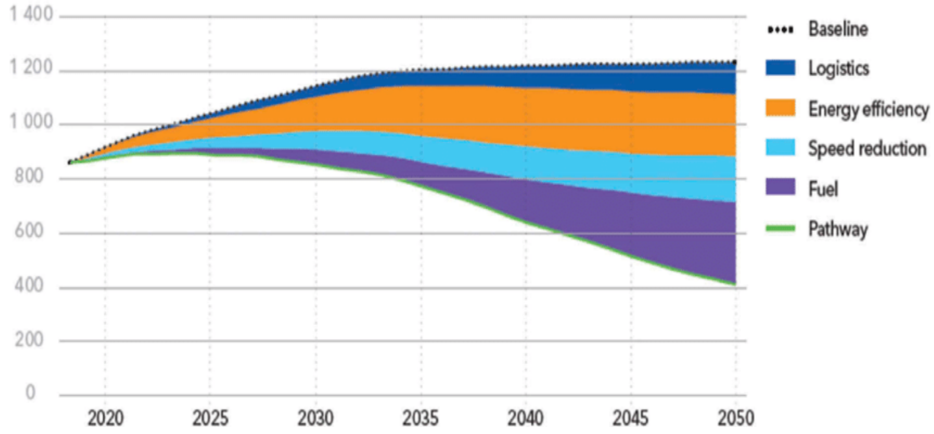

**Image 5 : Emission pathway 2015–2030**

**Source: DNV-GL, 2019**

The only way to meet the IMO's GHG reduction objective by 2050 is for global rules to be implemented in a timely manner, which will stimulate the development of fuels and technologies. There are two choices that are not mutually exclusive: Implementing technical and operational requirements, such as the current Energy Efficiency Design Index, and/or a ban on carrying and using energy carriers with more than a certain carbon content, similar to the 2020 "sulphur cap," and/or implementing market-based measures, such as a CO2 tax, which essentially puts a price tag on CO2 or all GHG emissions.

## 4. GHG REDUCTION MEASURES

The International Maritime Organization (IMO) is dedicated to reacting to the rising climate catastrophe and ensuring that the shipping industry contributes to global greenhouse gas (GHG) emissions reductions. The IMO is striving to accomplish these goals using a combination of existing energy efficiency measures as well as new measures that will be implemented in the short, medium, and long term. [18]

MEPC may complete and agree on short-term steps between 2018 and 2023; but, the dates on which these measures take effect and begin decreasing GHG emissions may fall outside of this specified timeframe. The IMO, on the other hand, plans to prioritize short-term initiatives that might reduce emissions before 2023. Mid-term plans might be created and agreed upon between 2023 and 2030, with long-term policies finalized after that date. Establishing a program for adopting alternative low- and zero-carbon fuels, operational energy efficiency measures for new and existing ships and market-based measures are among the mid- and long-term objectives.

**Image 6: IMO agreement on technical regulations to reduce ships' CO2**

**Source: https://www.ics-shipping.org/**

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[18] Environmental Performance: IMO Agreement on Technical Regulations to Reduce Ships' CO2 | International Chamber of Shipping (ics-shipping.org)(Accessed 9/8/2021)

The MEPC proposed operational and technical measures, and the IMO decided to include a new "energy efficiency" chapter in MARPOL Annex VI. These days, energy efficiency is a huge concern. When we use less energy, not only do we save energy but also we contribute to reducing pollution. For a long time, ship energy efficiency was voluntary, and shipowners were expected to understand their role in energy efficiency. However, the IMO saw the necessity to make the notion of "energy efficiency" essential, and so Annex VI of the MARPOL was changed to add Chapter IV for ship energy efficiency. [19]

Ship energy efficiency is defined by four terms: the energy efficiency design index (EEDI), the ship energy efficiency management plan (SEEMP), the energy efficiency operation index (EEOI), and the international energy efficiency certificate.

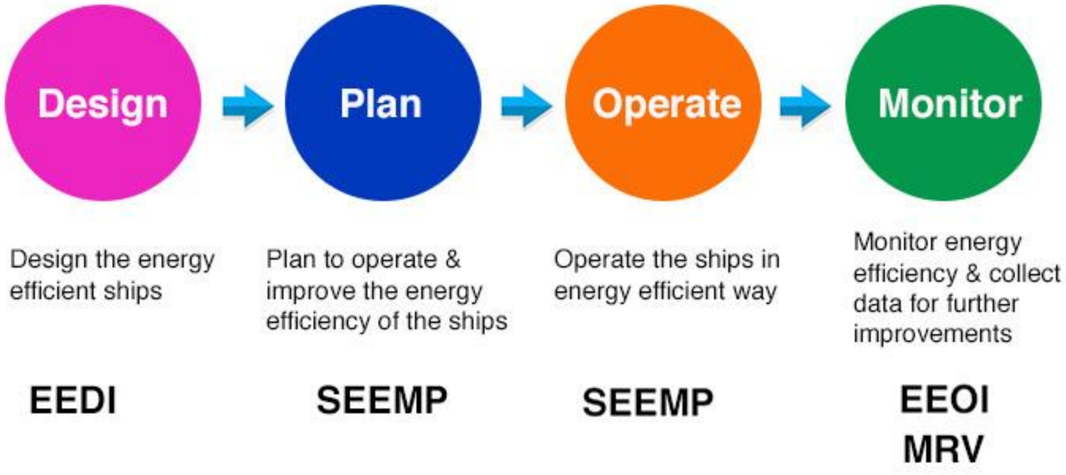

**Image 7 : Ships Energy Efficiency**

**Source**: **Ship Energy Efficiency: Here is All You Need to Know - MySeaTime**

The Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships were made required at MEPC 62 in July 2011 with the approval of changes to MARPOL Annex VI (resolution

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[19] Energy Efficiency Measures (imo.org)(Accessed 28/7/2021)

MEPC.203 (62)) by MARPOL Annex VI Parties. Since the Kyoto Protocol, this was the first legally binding climate change treaty.

In 2016, the IMO introduced the mandatory IMO Data Collection System for ships above 5,000 gt to collect and report fuel oil usage data.

In June 2021, the IMO established substantial new CO2 standards for existing ships. The Energy Efficiency Existing Ship Index (EEXI) measures ship technical efficiency, the Carbon Intensity Indicator (CII) measures operational efficiency, and the improved Ship Energy Efficiency Management Plan (SEEMP) measures management system.

## 4.1 ENERGY EFFICIENCY DESIGN INDEX

Energy Efficiency Design Index (EEDI), formulated for new ships, is an index that estimates grams of CO2 per transport work (g of CO2 per tonne-mile).

The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines.

It can be expressed as the ratio of “environmental cost” divided by “transport work”.

$$\textbf{EEDI} = \textbf{CO}_2 \textbf{ Emissions/ Transport Work}$$

The concept behind EEDI is that its computation should be simple and relevant to a wide variety of users, and that it should motivate all stakeholders to reduce CO2 emissions by reflecting a ship's energy efficiency in real-world usage.

The primary goal is to enhance the hull design and machinery. It promotes continuous technological advancement of all components that impact a ship's fuel economy. It also differentiates between technical and design measures, as well as operational and commercial measures.

The EEDI specifies a minimum energy efficiency level per capacity mile for certain ship types and size segments (e.g. tonne mile). Following a two-year phase zero, new ship designs must now meet their ship class's reference standard by January 1, 2013.

While the EEDI only applies to new ships, meeting the IMO's 2050 target would need improving the efficiency of the existing fleet. As EEDI is for new buildings, EEXI is for operational ships.

The IMO accepted modifications to MARPOL Annex VI during MEPC 76 in June 2021, establishing new short-term measure, the Energy Efficiency Design Index for existing ships (EEXI). The regulations will go into effect on January 1, 2023.

The Energy Efficiency Existing Ship Index (EEXI) measures the energy efficiency of existing ships. However, various proportions apply to different types of ships. It must be calculated for all cargo and cruise vessels above 400 GT that are subject to MARPOL Annex VI.

The EEXI technical file contains the EEXI calculation as well as accompanying documentation and must be submitted to a class society prior to the International Energy Efficiency (IEE) survey.[20]The IEE Certificate will be issued once for each ship and shall be valid throughout the lifetime of the ship.

## 4.2 SHIP ENERGY EFFICIENCY MANAGEMENT PLAN & ENERGY EFFICIENCY OPERATIONAL INDICATOR

As the new EEDI concept has been adopted for newly constructed vessels, the IMO has created and organized a unique instrument known as the Ship Energy Efficiency Management Plan (SEEMP) which is a management plan that is applicable to new and existing ships to assess and manage GHG emissions.

The Ship Energy Efficiency Management Plan (SEEMP) is a cost-effective operational measure that creates a mechanism to improve a ship's energy efficiency. The SEEMP also provides a method for shipping companies to manage ship and fleet efficiency performance over time by utilizing tools such as the Energy Efficiency Operational Indicator (EEOI).

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[20] There will be a NEW certificate: International Energy Efficiency Certificate (IEEC), which shall be issued for both new and existing ships to which chapter 4 of MARPOL Annex VI applies.

The unit of EEOI is determined by the kind of cargo transported or the amount of transport work performed, for example, ton CO 2 / (tons/nautical miles), tons CO 2 / (TEU/nautical miles), or tons CO 2 / (person/nautical miles), etc.[21]

The EEOI allows operators to assess the fuel efficiency of a ship in operation and the impact of any operational improvements, such as enhanced voyage planning or more regular propeller cleaning, or the implementation of technological solutions such as waste heat recovery systems or a new propeller.

This index will be updated after the ship completes each journey owing to external variables such as navigation environment condition, sea-going area, weather, environment temperature, carrying-cargo weight, and so on.

When attempting to optimize a ship's performance, the SEEMP encourages the ship owner and operator to explore new technologies and techniques at each phase of the plan.

SEEMP is a ship-specific strategy that must be implemented in line with the ship type, products delivered, ship itineraries, and other relevant parameters. As a result, SEEMP cannot be deployed at the corporate or fleet levels. Vessels will be operating in various conditions, so even two sister ships will require their unique Ship Energy Efficiency Management plan.

This approach seeks to improve a ship's energy efficiency through four steps:

- Planning
- Implementation
- Monitoring
- Evaluation

Before implementing any technique, it is necessary to "plan" how the process will be carried out. The most important stage in adopting SEEMP is planning; it simply outlines the present state of the ship's energy consumption and how the current energy consumption may be lowered further by developing and implementing an effective plan. Depending on the owner's aims, they can be done to various levels of detail. The

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[21] IMO, Guidelines for voluntary use of the ship energy efficiency operational indicator (EEOI), MEPC.1/Circ.684, 17 August 2009.

goal-setting process and the plan document's drafting take less time. The shipping management firm must compile the ship's energy consumption in many ways, such as fuel use, machinery installed, the efficiency of the machinery and systems, the state of the ship's hull and paint, the latest dry-dock record, and so on. Once the data has been collected, the company's Broader Corporate Energy Management Policy is used to develop the SEEMP for the vessel.

When the SEEMP planning is complete, the next critical step is to identify various methods of executing the measures that were chosen during the planning. The Ship Energy Efficiency Management Plant will include implementation techniques as well as the roles and responsibilities of the stakeholders (Company representative, Ship operator, Seafarers etc.).

Increased energy efficiency awareness throughout the organization is an important aspect of the implementation and training. Employees at all levels should be aware of the efficiency targets and take part in the continuous improvement process. This is especially important for the onboard crew who are in charge of the ship's and machinery's day-to-day operations.

Again, the implementation mechanism must be designed at the planning stage to guarantee that SEEMP is implemented on the ship as soon as possible.

If the implementation techniques are stated in the company's corporate energy management policy, it can be highly useful. This predefined way of implementation can be utilized for establishing SEEMP on a single ship. Record keeping should be a component of all stages following the planning stage, since the records collected during the implementation stage may be utilized for the later step of self-evaluation, which will aid in the plan's improvement.

Once the SEEMP is deployed on a ship, the plan will be monitored to determine the efficacy of the installed SEEMP.

Continuous data collecting is what monitoring entails. During the planning phase, a monitoring strategy is devised. The monitoring phase includes efforts made during operations as well as for the duration of the vessel's life. It should be a hybrid of automatic data capture and manual documentation to save time for shipboard personnel. The company should put in place a monitoring system and process that includes reporting and data analysis and is well-documented.

Finally, the results of the Monitoring phases must be reviewed in order to understand the efficacy of the SEEMP, which will be done in the end. This stage is heavily reliant on constructive input, which may be used to improve the plan if necessary, and it is also utilized to improve the planning, implementation, and monitoring phases.

The four essential phases for implementing SEEMP are displayed in Figure 2[22].

These four stages below operate in a cycle and are interconnected in order to evaluate and evolve the whole SEEMP. It is the ship operator's obligation to ensure that feedback, results, and reports from all phases of the SEEMP cycle are recorded and analyzed, and that the output from them is used to improve the plan.

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[22] ABS SHIP ENERGY EFFICIENCY MEASURES advisory

**Figure 2: Four-step Continuous Improvement Process**

| PLANNING | |
|---|---|
| Ship specific | Current energy use<br>Current energy-saving measures<br>Identify new measures<br>Define implementation plan |
| Company specific | Fleet management<br>Stakeholders policy |
| Human Resources | Training<br>Awareness |

↓

| IMPLEMENTATION | |
|---|---|
| Execute Plan and Procedures | How should measure be implemented?<br>Who is responsible?<br>What is the implementation period? |
| Recordkeeping | Encouraged for each measure<br>Beneficial for self-evaluation |

↓

| MONITORING | |
|---|---|
| Tools | Obtain quantitative indicators<br>EEOI or other appropriate measure |
| System | Continuous and consistent data collection<br>Clear procedure and assignment |

↓

| EVALUATION | |
|---|---|
| Evaluate Effectiveness | Review measure and implementation<br>Deepen understanding |
| Feedback | Develop improvements for next cycle |

### 4.3 CARBON INTENSITY INDICATOR

The Carbon Intensity Indicator (CII) measures how effectively a ship moves products or passengers and is expressed in grams of CO2 emitted per cargo-carrying capacity and nautical mile. The ship is then assigned a yearly rating ranging from A to E, with the rating standards becoming increasingly severe as we approach 2030. The CII applies to all cargo, RoPax, and cruise ships with a gross tonnage of more than 5,000 GT.

The actual annual operational CII obtained (attained annual operational CII) would have to be documented and confirmed in comparison to the necessary annual operational CII. This would allow us to calculate the operational carbon intensity rating. The rating would be given on a scale showing a major superior, minor superior, moderate, minor inferior, or inferior performance level (operational carbon intensity rating A, B, C, D, or E). The degree of performance would be documented in the ship's Ship Energy Efficiency Management Plan (SEEMP).[23]

A ship rated D for three consecutive years, or E, would be forced to submit a corrective action plan outlining how it would attain the requisite index (C or higher). Administrations, port authorities, and other stakeholders are urged to give incentives to ships graded A or B, as appropriate.

### 4.4 DATA COLLECTION SYSTEM

In 2016, IMO adopted the mandatory IMO Data Collection System for ships to collect and report fuel oil consumption data from ships over 5,000 gt. The first calendar year data collection was completed in 2019.[24]

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[23] IMO working group agrees further measures to cut ship emissions(Accessed 28/7/2021)

[24] Data collection system for fuel oil consumption of ships, IMO

As previously stated, the EU adopted the ‘EU MRV Regulation,' therefore the IMO implemented a comparable Data Collection System as part of the MARPOL Convention, and data collection commenced on January 1, 2019. Both schemes aim to collect accurate data on GHG emissions from ships, to analyze it and then determine whether and what further energy efficiency measures should be implemented for ships.

Fuel oil, including gas, distillate, and residual fuels, is defined by Annex VI as any fuel provided to and intended for combustion purposes for propulsion or operation on board a ship. Both the European Union (EU) Monitoring, Reporting and Verification (MRV) and IMO’s (DCS ) requirements have been mandatory since 2017 (MRV) and 2018 (DCS)and are intended to be the first steps in a process to collect and analyze emission data related to the shipping industry[25].

The DCS was suggested by the International Marine Organization (IMO) during the 70th MEPC conference in October 2016 with the goal of increasing energy efficiency in the maritime transportation industry. This was seen as a significant step in reducing shipping's environmental impact and improving the transparency and effectiveness of other energy conservation efforts.

The objective of the IMO's DCS is to create a worldwide fuel consumption database, which necessitates a reliable/continuous flow of data as well as the development of an unbroken relationship between all parties engaged in the process.

As a result, preserving the quality of linked data and ensuring effective engagement from all stakeholders are clearly issues that need to be addressed.

## 4.5 MARKET-BASED MEASURES

Given the shipping industry's projected growth, it is believed that operational and technical measures will be insufficient to satisfactorily reduce GHG emissions. the above suggested short-term actions- EEDI, EEXI, SEEMP- should suffice to meet the 2030 targets, further measures, or greater stringency of the short-term measures, are

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[25] MRV and DCS - DNV(Accessed 20/7/2021)

required to meet the 2050 targets. MEPC 76 acknowledged the critical need to move on with the implementation of mid- and long-term measures and agreed on a work plan to that purpose.

Mid-term measures such as, new/innovative emission reduction mechanisms, possibly including Market-based Measures (MBMs) directly reduce GHG emissions from ships. There is a general consensus that market-based measures as part of a general comprehensive package of measures will help achieve the IMO's targets.[26]However, like with CO2 emission reduction strategies, the talks have been hindered by divergences of opinion among stakeholders.[27] MBM discussions began in 2006 at MEPC 56, but have not proceeded since MEPC 65 in 2013.

The interest in MBMs faded when many developing countries, including Brazil, China, India, Peru, South Africa, and Saudi Arabia, strongly opposed MBM discussions until developed countries adopted a resolution on financial, technological, and capacity-building support from developed countries in order for developing countries to implement regulations on energy-efficiency for ships. MEPC 64/5/9/2012

However, the IMO took this discussion forward at MEPC 69 in 2016, particularly debating strategies to further implement such MBMs, but member states were unable to reach an agreement. Nonetheless, others have proposed that such MBM methods might be more effective after 2016.

A market-based measure is a regulation or legal framework that encourages desirable behavior through monetary incentives. In this situation, the shipping sector should be pushed to utilize low or zero carbon fuels in order to reduce CO2 emissions.

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[26] Market-Based Measures (imo.org)(Accessed 28/8/2021)

[27] Hirdaris, S.; Fai, C. Keynote Paper: The role of technology in green ship design. In Proceedings of the 11th International Marine Design Conference, Glasgow, UK, 11–14 June 2012.

# 5. MEETING IMO DECARBONIZATION GOALS

Chapter 4 illustrates that emission reductions may be achieved through international laws and regulations. This chapter examines potentials for reducing GHG and other related substance emissions from an operational and mostly technological perspective.

The IMO Initial Strategy established decarbonization targets that are currently unattainable given the existing alternative fuels and technology, as are discussed in the following sections.

Moreover, it is not the shipping sector that can create and implement these, but other stakeholders, such as fuel and energy providers, engine manufacturers, and shipyards and so on.

In continuation of the previous chapter, short-term actions, include improving the EEDI, encouraging early adoption of low-carbon technologies, encouraging speed reduction/optimization, setting carbon intensity recommendations for all maritime fuels, and conducting research into novel zero-carbon technologies and fuels.

As stated before, the adoption of the EEXI and EEDI amendments should allow the IMO to meet its 2030 carbon intensity objective. Meeting the 2050 objective, however, will need the implementation of stringent new fuel efficiency requirements.

The maritime industry is under pressure to enhance its sustainability, particularly its air emissions. The IMO anticipates total yearly greenhouse gas emissions from shipping to be cut in half by 2050 as part of a push toward full decarbonization.

Shipping companies are having difficulty meeting these limitations since everything is still in the early stages, and nothing guarantees that those alternatives will allow them to achieve those goals, so they are turning to emissions reduction potentials, both technological and operational.

The numerous technical measures to reach emissions objectives, as well as the political and infrastructure means to accomplish them, are discussed in the following chapters.

## 5.1 TECHNICAL AND OPERATIONAL MEASURES

According to the preceding chapter, the EEDI strives to make new building vessels more energy efficient, whereas the SEEMP supervises energy-efficient operational activities on board vessels.

Improved energy efficiency implies doing the same amount of productive work with less energy. As a result, less fuel is burnt, and emissions of all exhaust gases are reduced. There are several possibilities for improving the energy efficiency of ship design and operation.

Bouman, Lindstad, Rialland and Strømman discuss six main groups for maximum possible CO2 emission reductions, namely, these are[28]:

1. Hull design,
2. Economy of scale,
3. Power and propulsion (including energy-saving devices),
4. Speed,
5. Fuels and alternative energy sources, and
6. Weather routing and scheduling

Bouman, Lindstad, Rialland, and Strømman present annual CO2 emissions for business-as-usual (BAU) and the aforementioned reduction scenarios until 2050. According to their results, all six reduction scenarios must be executed in order to attain nearly net-zero CO2 emissions in the maritime industry. In addition, they noted "some overlap between BAU and reduction scenarios in 2020 and 2030, suggesting uncertainty in the scenarios as well as varying assumptions on the rate of adoption of emission mitigation measures and global maritime transport growth rates."

The options listed above were identified as a significant way of reducing GHG emissions from ships. The cost-effective CO2 emission reduction range for technical and operational measures, excluding alternative fuels, is 20-30%, up to 50-60% with

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[28] Bouman, E.A.; Lindstad, E.; Rialland, A.I.; Strømman, A.H. State-of-the-Art technologies, measures, and potential for reducing GHG emissions from shipping—A review. Transp. Res. Part D 2017, 52, 408–421

more expensive new technologies. As a result, simply one measure is insufficient to accomplish the objectives of the IMO Initial Strategy, and each measure should be adequately integrated, as indicated in the figure below.

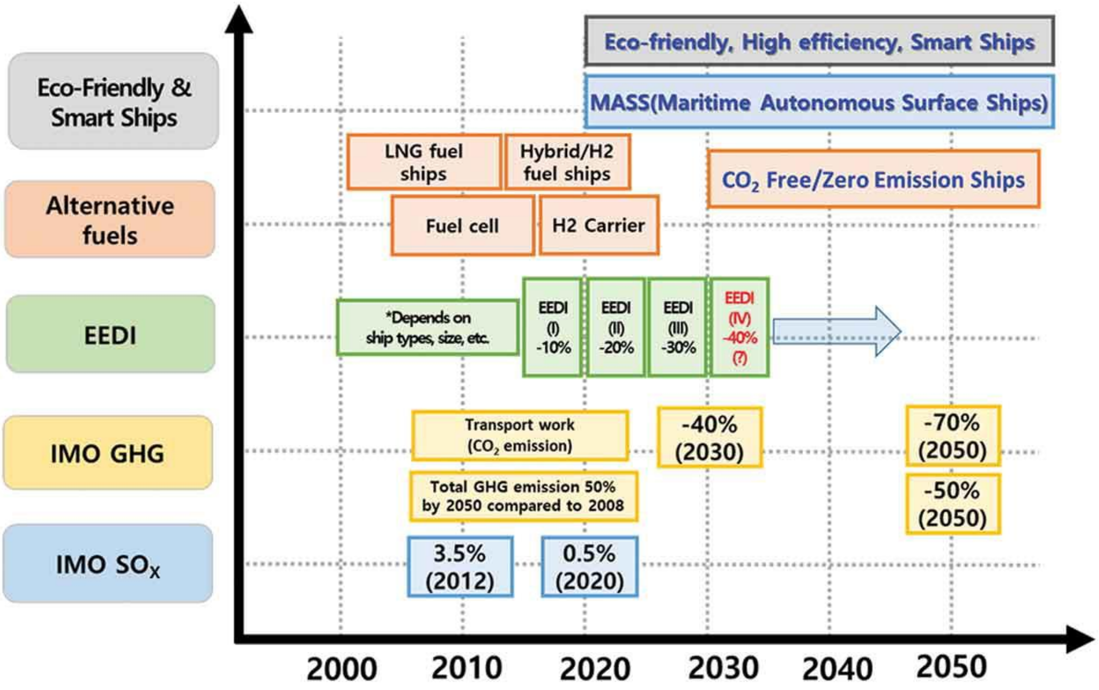

Image 8: IMO regulation and ship technology trend

Source: Joung, 2019

Assuming that these rules and regulations for accomplishing GHG mitigation are effectively planned, a combination of existing technologies is anticipated to cut GHG emissions by up to 75 percent by 2050.

The emissions from the shipping sector are directly proportional to the amount of fuel used. As a result, shipping firms are looking for ways to reduce emissions, both technologically and operationally.

### 5.1.1 DESIGN

The majority of design changes are generally appropriate for newbuildings.

Hull form optimization is regarded as a rising subject within the maritime world as a way to enhance ship energy efficiency.

When evaluating hull form optimization, the owner has three choices to evaluate.[29]

First option has the lowest capital outlay - significant savings in vessel building expenses are sometimes obtained by using a shipyard's standard design. Many of these conventional ships feature well-optimized hull forms and propulsions; however they are often optimized only at the design condition and to a lesser extent at the normal ballast condition or other service circumstances. Changes in draft and ship speed have a major impact on hydrodynamic performance; yet, these operating circumstances may not have been adequately anticipated in the original design.

Second option, allows for design optimization for specified service circumstances, for example, a number of predicted operational draft, trim, and speed combinations with corresponding service periods. This optimization procedure typically entails changes to the forebody design and may entail changes to the stern form, especially when excessive transom immersion is experienced under heavy load circumstances.

Last but not least, third option allows for optimization of vessel hull specifics to work in tandem with the propulsor and power plant, but this increases the vessel's capital cost. Option 3 is generally justified only when a particularly big series is being ordered, the shipyard under consideration does not offer a suitable standard design, the recovery is obtained through reduced operational costs, or the ship requires unique features to serve a specialized service.

It is critical to keep the hull and propeller clean in order to maximize fuel efficiency. Many shipowners have saved money by increasing the frequency of cleaning operations on the hull and propellers, or by introducing condition-based cleaning. The use of more effective hull coatings may minimize resistance and result in longer dry-

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[29] ABS Advisory on Ship Energy Efficiency Measures

docking periods. Surface polishing, hull coating, and friction reduction are all critical factors in resistance. The proper choice of hull coating and hull maintenance can result in a 5% difference in energy needs.

### 5.1.2 ECONOMIES OF SCALE

Economies of scale are another means of reducing emissions, since larger ships and cargoes tend to be more energy-efficient per freight unit. In shipping, economies of scale (EOS) usually refer to benefits obtained when smaller vessels are replaced by larger ones. To make qualified suggestions about the effect of increasing average vessel size, knowledge of the current situation is a prerequisite. the existing maritime fleet consists of vessels of many types and sizes ranging from a few hundred tons to up to hundreds of thousands of tons, while their maximum speed ranges from less than 10 knots (18 km/h) to more than 30 knots (55 km/h), and distances ranges from a few nautical miles (nm) to more than 10,000 nm (18,000 km). Some vessels can only transport one specific product, such as crude oil or LNG.

Typically, when cargo-carrying capacity is doubled, the required power and fuel consumption increases by about two-thirds, thus reducing fuel consumption per freight unit.

The potential of economies of scale to reduce greenhouse gases and costs can be evaluated by calculating the average for existing vessels and comparing it with what can be achieved by replacing the existing fleet with larger vessels. The rise in vessel size is an ongoing process, which gradually increases the average vessel size by introduction of new vessels which are larger than the existing ones and by replacing old vessels which are being scrapped with similar or a larger size one.

All ships may save energy during the operational period. New vessels, on the other hand, may have greater flexibility to capitalize on future operational advances, such as improved cargo-handling gear, the ability to cruise effectively at varied speeds, and so on. As highlighted in the previous chapter, the MEPC is now addressing energy conservation at the operational stage through the creation of the Energy Efficiency Operational Indicator (EEOI) and the Ship Efficiency Management Plan (SEMP).

### 5.1.3 VOYAGE OPTIMIZATION

Additionally, voyage optimization has the potential to enhance energy efficiency. Typically, voyages are planned by the master in collaboration with the commercial operations team, and the weather routing partner aids with route planning.

These organizations often employ broad speed-and-consumption assumptions as inputs, and they are particularly concerned in results that minimize blunders like routing into poor weather or missing laycans.

To achieve optimal voyage performance, a variety of weather routing systems, technical support systems, performance monitoring systems, and other systems can be employed. These systems must be utilized and understood, and the crew's abilities and motivation are important. Incentive systems, in which crew members benefit from effective operation, are one method of increasing motivation.

In terms of weather routing, there have been no notable incidents in recent years involving ship damage or sinking due to storms and bad weather since weather routing today employs modern technology to forecast impending weather and modify the path of the ship.

This technique is highly important and increases the ship's energy efficiency since severe weather can slow down a ship and need the engine to exert more force to drive against the tide or wind, resulting in increased fuel consumption. With weather routing, a changed route may alleviate this problem, making the ship's crew and cargo safer while simultaneously conserving fuel and boosting the ship's energy efficiency.

### *5.1.4 SLOW-STEAMING*

Slowing down ships is one approach to enhance operational efficiency. Reduced speed decreases ship energy use and fuel consumption in all but the most severe circumstances.

Regulated speed reduction is a cost-effective and practical way to reduce greenhouse gas emissions and air pollution from shipping. Slow steaming has been proved to minimize ship fuel use, saving the owner hundreds of dollars in fuel costs. At the IMO's Marine Environment Protection Committee (MEPC 61) in September 2010, the IMO considered a proposal from the Clean Shipping Coalition (CSC) to apply speed restrictions to ships in order to reduce CO and other pollutant emissions.

Slow steaming, which was originally performed in the 1970s, is a relatively new phenomenon, having gained popularity in reaction to the drop in demand and overstock of ships that preceded the onset of the present economic crisis. Since 2008, the technique has been expanded and has given significant benefits to shipping firms, which have now accepted it as a helpful operational strategy to save fuel expenditures.

Regulated slow steaming has the potential to generate emission reductions that rival any other alternative under consideration at the IMO or EU level by 2030 and 2050. And it can do so while making a sizable financial profit. Slow steaming offers several environmental benefits, as shown in the CE Delft study. Even after accounting for the emissions of extra ships required to deliver the same amount of cargo and the emissions associated with building the necessary additional ships, a 10% drop in fleet average speed results in a 19% reduction in CO2 emissions.

The economic benefits of slow steaming are substantial. Taking into consideration both direct costs (fuel consumption, personnel, ship capital costs), indirect costs (extra inventory costs, logistical chain adjustments), and external costs (emissions impacts on human health and ecosystems, climate impacts), the advantages of slow steaming outweigh the costs. This conclusion holds up under a variety of gasoline pricing assumptions and discount rates. Regulated slow steaming, when properly implemented, is cost-free to the shipping industry as a whole and incurs negligible extra logistic and supply chain expenses for customers.

There are few, if any, obvious technical barriers to slow steaming. In recent years, several shipping firms have gained expertise in slow steaming. They have only experienced a few issues even at extremely low engine loads, and these problems may be overcome with minor adjustments to operational methods. As a result, there appear to be few technological restrictions to slow steaming.

Both technological and operational techniques can be used to reduce speed.
In general, operational measures are easier to execute among the many potential fuel reduction measures since they do not need substantial expenditures, are easily implemented, and can provide considerable advantages in a short period of time.

Although it is one of the short-term measures identified by the Initial IMO Strategy and there is widespread agreement that it is beneficial to reducing emissions, it poses significant challenges in terms of optimal speed design, commercial considerations for just-in-time delivery, transparency, shipping market competition, safety, and so on. Furthermore, slower ships require more time and money for each voyage. Also, if a voyage takes too long, it can interrupt supply chains and damage perishables, but some ships are likely to be exempt from a speed limitation regulation for practical, safety, technical, or economic reasons. Ships subject to a speed decrease that refit may be able to outcompete their competitors by lowering fuel usage, allowing them to improve earnings or charge a reduced freight rate.

While slow steaming is already widely utilized, its potential for future emission reduction is believed to be very restricted.

## 5.2 ALTERNATIVE FUELS

A variety of renewable fuel sources such as LNG, LPG, methanol, and biofuels, as well as less advanced options like hydrogen and ammonia, are all possibilities.

During a webinar hosted by the International Chamber of Shipping on April 14, Louise Nevill, CEO of Marsh JLT Specialty's UK Marine & Cargo business[30], said that there has been significant interest in LNG as a future fuel, however considering that methane is 84 times more potent greenhouse gas than CO2, ammonia, hydrogen, and battery cells are more feasible paths to pursue.

According to S&P Global Platts Analytics, alternative shipping fuels are in the early stages of research, and oil-based fuels may remain the dominating choice for many years to come.

Moreover, as stated by the International Energy Agency, ammonia, biofuels, and hydrogen may supply more than 80% of shipping fuel demands by 2070 while consuming just around 13% of the world's hydrogen output.

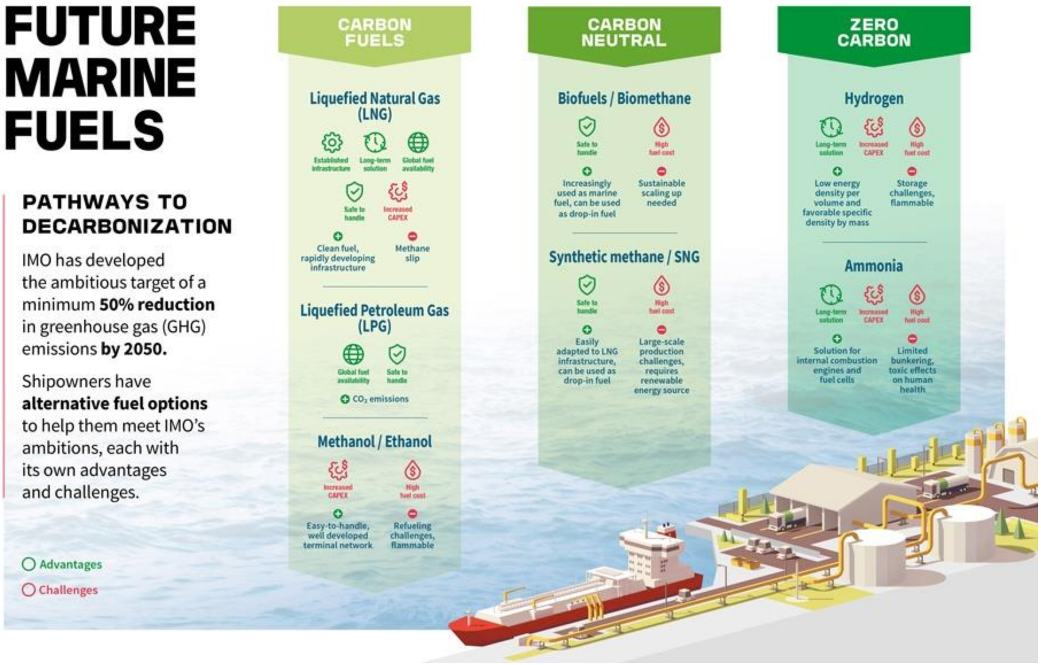

**Image 9: Future Marine Fuels**

**Source:** Future marine fuels: pathways to decarbonization | Marine & Offshore (bureauveritas.com)

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[30] What's happening to the supply and demand balance for road fuels in Europe? | S&P Global Platts (spglobal.com)(Accessed 28/8/2021)

These are just some of the conjectures that are expressed after the announcement for reducing greenhouse gas emissions.

Each option has advantages and disadvantages, but fuel flexibility, or the ability to change an engine to utilize a different fuel, will be critical. Each shipowner will have to make crucial fleet investment decisions multiple times over the next few decades, given that the typical ship's life expectancy is 25-30 years. Some vessels will be refitted with entire new propulsion systems; others will be scrapped and replaced.

DNV GL[31] depicts the varying energy densities for several fuels. The energy density demonstrates “how suitable the fuel is for specific ship types and ship operations.” According to DNV GL, LNG has a “40% lower volumetric energy density than diesel, about the same as LPG.” However, when the storage system is included, LNG has about one-third the volumetric energy density of diesel. According to DNV GL, the volumetric energy density of liquid hydrogen, ammonia, and methanol is considerably lower, 40–50 percent that of LNG. It is worth noting that biodiesel “is the only fuel that comes close to matching the energy density of diesel.”

DNV GL compares fuel cost/technology paths in the same study. The key takeaways are as follows:

- LNG, methanol and LPG are competitive in terms of energy costs, while HVO is significantly more expensive.
- Hydrogen and ammonia are also far more expensive.
- The large cost range indicates a significant uncertainty in terms of pricing

Taking into consideration numerous factors which will be presented and analyzed thoroughly later, shipowners are already under the process of contemplating which method of compliance will be followed, the benefits and the challenges that they will encounter and what prevails the most.

To decarbonize shipping, low- and zero-carbon fuels will be required. For various fuel options, factors such as safety, regulation, pricing, infrastructure availability, lifecycle emissions, supply chain constraints, adoption hurdles, and more must be considered.

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[31] DNV GL. Comparison of Alternative Marine Fuels; DVN GL: Høvik, Norway, 2019

### 5.2.1 LIQUEFIED NATURAL GAS

Since last year, with the Sulphur Cap 2020, maritime companies in order to deal with the Sulphur cap have turned to low-sulphur heavy oil. However, the use of low sulphur heavy oil does not change CO2 emissions. An increasing number of shipping companies have already turned to LNG as an alternative fuel.

Liquefied Natural Gas (LNG) is natural gas that has been cooled to -163°C to liquid form, resulting in a volume reduction of around 625 times as compared to its gas condition. This makes transporting and storing it simple and secure LNG is converted back into a gas by regasification plants once it arrives at its final destination. It's then pumped to people's homes and businesses, where it's burned for heat or electricity. LNG is increasingly gaining traction as a cost-effective and environmentally friendly transportation fuel, particularly for shipping and heavy-duty trucking.[32]

LNG, in conjunction with efficiency measures being developed for new ships in response to the IMO's Energy Efficiency Design Index (EEDI), provides a method to fulfill the IMO's decarbonization objective of a 40% reduction in international shipping emissions by 2030.

Switching to LNG as a fuel has a number of benefits, including meeting regulatory requirements, increasing competitiveness, improving overall air quality, and lowering GHG emissions.

According to an independent study report commissioned by SEA LNG and SGMF which published in April 2019, LNG fuel can effectively remove almost all sulphur oxide (SOx) and particulate matter (PM) emissions while decreasing nitrogen oxide (NOx) emissions by up to 80% and greenhouse gas (GHG) emissions by up to 30%.

Since 2010 the number of vessels fueled by LNG has grown consistently by between 20% and 40% per annum. At present, there are 198 liquefied natural gas (LNG) fueled ships in operation in the world, and further 277 in order.33

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[32] Liquefied natural gas (LNG) | Shell Global(Accessed 2/8/2021)

[33] Global fleet - SEA-LNG(Accessed 2/8/2021)

Ship operators may realize immediate GHG reductions by investing in LNG-fueled vessels today – up to 28 percent on a Tank-to-Wake basis, including the impact of methane emissions.

Whatever the benefits of LNG as a fuel, it confronts a number of challenges. LNG is still a fossil fuel, and it carries the risk of gas leakage. Due to methane slip (the leakage of methane gas into the atmosphere), which varies between engine types, LNG can provide minor environmental advantages[34]. The methane slip in current LNG engines is 2–5%[35]. As a result, LNG may have short-term potential with only little policy intervention. Several lifecycle studies have been conducted to evaluate the GHG emissions per kWh of LNG as a transportation fuel. Balcombe examined several lifecycle studies and concluded that the average total GHG emissions, including combustion and upstream, are 650 gCO2e/kWh.[36] This is a critical area for technical advancement, with specialists trying to enhance engine design to reduce methane slip.

Secondly, gas availability is regarded as a critical problem; if ships cannot bunker LNG where and when it is required, there will be little reason to pursue this alternative.

However, Lloyd’s Register’s study illustrates that many of the main oil fuel bunkering facilities are conveniently adjacent to LNG ports. As a result, the physical aspects of LNG supply may not be as serious as some worry. Global LNG bunkering consumption is expected to increase from 0.4MT in 2017 to 10MT in 2025.

The infrastructure for LNG bunkering is constantly developing, and fuel is now accessible in the majority of major marine terminals. It can currently be delivered to boats in 96 ports, including the majority of the major bunkering ports, with a further 55 ports supporting LNG bunkering investments and operations. The ports of Rotterdam, Amsterdam, Zeebrugge (Belgium), Barcelona, and other large ports can

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[34] Balcombe, P.; Brierley, J.; Lewis, C.; Skatvedt, L.; Speirs, J.; Hawkesa, A.; Staffell, I. How to decarbonise international shipping: Options for fuels, technologies and policies. Energy Convers. Manag. 2019, 182, 72–88

[35] Jafarzadeh, S.; Paltrinieri, N.; Utne, I.B.; Ellingsen, H. LNG-Fuelled fishing vessels: A systems engineering approach. Transp. Res. Part D 2017, 50, 202–222

[36] Schuller, O.; Reuter, B.; Hengstler, J.; Whitehouse, S.; Zeitzen, L. Greenhouse Gas Intensity of Natural Gas; Final Report; Thinkstep AG: Stuttgart, Germany; Natural & Bio Gas Vehicle Association (NGVA) Europe: Brussels, Belgium, 2017.

handle LNG bunkering. As of February 2020, 12 LNG-bunkering boats were in service, with a further 27 on order.

The AIDAnova is the world's first LNG-powered cruise ship. Shell LNG collaborated with Carnival Corporation PLC to achieve lower emissions, quieter engines, and no visible emissions, and this is an example of a successful LNG-powered project. The AIDAnova has achieved a 95–100% reduction in SOx, up to 85% reduction in PM and NOx and up to 22% tank to wake greenhouse gas emissions reduction compared to marine diesel oil. “LNG is now the most cost-effective alternative that delivers emission reductions today,” said Tom Strang, Senior Vice President Maritime Affairs at Carnival. What we can do today with fossil LNG, combined with an increasing amount of renewable liquefied methane—either from bio or synthetic sources—could result in ships becoming carbon-neutral in the future.[37]

The use of LNG as a marine fuel outside of the LNG carrier sector, as well as gas-only and dual-fuelled engines, is a relatively recent use of the fuel. LNG-fueled vessels and accompanying bunkering activities, on the other hand, have had an excellent safety record since its introduction as a maritime fuel at the turn of the century.

**Table 1: Advantages and Disadvantages of LNG**

| Advantages | Disadvantages |
|---|---|
| GHG Benefits/ Meet The Imo’s Regulations | The Risk Of Gas Leakage |
| Strong Returns On Investment | May Be A Short-Term Potential |
| Can Be Bunkered At Most Key Ports | Massive Investment Required |
| Proven Safety Record | |

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[37] Shell. Decarbonising Shipping: Setting Shell’s Course; Shell: The Hague, The Netherlands, 2020.

### *5.2.2 LPG*

LPG has made its way into the shipping industry and is expected to hold over the marine fuel market. LPG is a cost-effective, environmentally friendly, and energy-efficient fuel. LPG will play a key role in the IMO's 2050 regulation, which targets for a 50% decrease in greenhouse gas emissions.

Liquefied Petroleum Gas (LPG) is a term used to describe a mixture of light hydrocarbons that may be liquefied at room temperature under moderate pressure but are gaseous under normal air conditions. Propane and butane (regular butane and iso-butane), propylene, and other light hydrocarbons make up the majority of its chemical composition, which might vary. In other nations, the mix also changes with the seasons. LPG is easier to store and transport than other gaseous fuels because it may be liquefied at low pressures at room temperature. It's kept in tanks or cylinders under pressure. LPG is made mostly from natural gas processing, but it can also be made from oil refining. Both of these procedures produce LPG as a by-product. Natural gas processing plants currently provide more than 60% of worldwide LPG supply, however the percentage varies greatly between areas and countries. It is not only readily available and plentiful, but it is also cost-effective and environmentally friendly.

LPG is now sourced mostly from natural gas and oil extraction activities, but if new technologies and techniques emerge, it may be possible to create it from renewable sources.

LPG's environmental performance is comparable to LNG's, with some advantages, despite the fact that both are fossil fuels.

For the large existing fleet of LPG carriers, LPG is the best dual fuel alternative. Furthermore, one of the major advantages of LPG is bunkering, with import/export ports and LPG carriers providing a vast network of outlets, enhancing LPG's usefulness as a maritime fuel.

More specifically, there are currently over 1000 storage facilities and terminals, as well as over 700 small carriers providing ship-to-ship bunkering services.There are already four LPG-powered ships, and more than 71 ships will be retrofitted or built to accommodate LPG in the future.

LPG has a compelling economic argument because to its cheap energy prices and low capital expenses. However, because operating experience is limited, the maturity level is medium. Furthermore, the absence of bunkering infrastructure makes utilizing LPG as an alternative maritime fuel difficult. Furthermore, one of the primary drawbacks of LPG as an alternative fuel is its environmental performance when derived from fossil sources.

Nonetheless, because LPG is still in its infancy, the regulations that govern it are crucial. There is a legitimate danger associated with LPG fuel storage tanks, fuel system leaks, and spills. Furthermore, LPG is a very flammable gas. Finally, the financing and incentives for LPG are less than those for LNG, which might have made a significant difference.

**Table 2 : Advantages and Disadvantages of LPG**

| Advantages | Disadvantages |
|---|---|
| Supports IMO 2050 GHG Strategy | LPG Fuel System Leakages And Spills |
| Affordable Price Tag | Risks Associated With LPG Fuel Storage Tanks |
| Can Be Bunkered Globally | Few Funding And Incentives |

### *5.2.3 METHANOL*

Methanol, having the molecular formula CH3OH, is the simplest alcohol, containing the least carbon and the most hydrogen of any liquid fuel.

Methanol may be made from a variety of feedstocks, the most common of which are natural gas or coal, but also renewable resources like as black liquor from pulp and paper mills, forest thinning or agricultural waste, and even directly from CO2 collected in power plants or from the atmosphere. When generated from natural gas, a mixture of steam reforming and partial oxidation is commonly used, resulting in an energy efficiency of up to 70%. Methanol generated by coal gasification is based on a low-cost, widely available resource, but its greenhouse gas (GHG) emissions are almost twice as high as those from natural gas.

Methanol is a potentially viable solution for reducing ship emissions and carbon footprint. Because it is sulphur-free, it complies with the European Commission's Sulphur Directive.

The main upside for methanol is its relatively high performance in terms of application, the possibility to use current converter technology, and cheap tank costs, which translates into low capital expenditures. Methanol is a desirable fuel since it contains no sulfur and has a low carbon content. It offers a substantial environmental benefit over traditional fuels since it burns cleanly, has no sulphur, and can be produced from renewable feedstocks.

In terms of the fuel itself, the dual fuel engine, and the shoreside storage and bunkering infrastructure, methanol is a cost-effective alternative maritime fuel. The cost of building new vessels and converting existing vessels to run on methanol is substantially lower than the cost of other fuel conversions. Furthermore, methanol is available globally through existing global infrastructure and is one of the top five chemical commodities exported globally each year.

One disadvantage of alcohol fuels, such as methanol, is that their energy levels are lower than those of conventional fuels. Given similar energy density, the area required in a tank for storing methanol will be around double that of standard diesel fuels. In terms of energy density, methanol and LNG are comparable. It is, of course, a dangerous chemical even when in touch with the skin and must be handled carefully, therefore extra precautions must be taken while utilizing methanol as a fuel.

**Table 3 : Advantages and Disadvantages of Methanol**

| Advantages | Disadvantages |
|---|---|
| Low Emission Fuel | Low Energy Content |
| Available Worldwide | Safety |
| Economical | |

### *5.2.4 HYDROGEN*

Hydrogen fuel can be used in place of conventional transportation fuels. There are several techniques for producing hydrogen from various sources. It may be made from natural gas via steam methane reforming. After being heated, compressed methane is combined with water.[38]

Hydrogen is usually found in nature as a combination of water or methane. The element must be removed from these compounds in order to get pure hydrogen. Hydrogen is a colorless, odorless, tasteless, non-toxic, largely nonreactive, and highly combustible gas having a wide flammability range under normal circumstances.

When compared to other marine fuels, hydrogen has the greatest energy content per mass of all chemical fuels at 120.2 MJ/kg. In terms of mass energy, it outperforms MGO by 2.8 times and alcohols by 5–6 times. As a result, hydrogen fuel can enhance an engine’s efficiency while also assisting in the reduction of specific fuel usage.

As previously stated, combustion of LNG reduces SOx and particle emissions by nearly 100 percent, and NOx emissions by 85 percent to 90 percent, when compared to conventional fuel oils. However, if hydrogen becomes the preferred maritime fuel in the future, emissions from the maritime industry can be further reduced or eliminated.

Energy Observer, launched in April 2017, is the first vessel in the world to both generate and be powered by hydrogen.[39] In 2021/2022, a ferry using liquid hydrogen

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[38] Exergoenvironmental analysis of a steam methane reforming process for hydrogen production,lA.BoyanoaA.M.Blanco-MarigortabT.MorosukcG.Tsatsaronisa,2010

[39] Energy Observer (energy-observer.org)(Accessed 13/8/2021)

(LH2) in combination with fuel cells and batteries is planned for Western Norway. If everything goes according to plan, this will be the first time LH2 has been utilized as a fuel aboard a ship, as there are currently no LH2-fueled maritime vessels in service. As a result, there is no actual experience with LH2 systems onboard ships.[40]

According to Shell[41], liquid hydrogen LH2 offers several benefits over other possible zero-emission fuels for transportation, making it more likely to succeed. LH2 storage, on the other hand, is difficult and expensive, with a slew of safety concerns owing to the necessity for cryogenic storage. Another significant difficulty with LH2 is the fueling process, which happens at low temperatures. To minimize evaporation of LH2 and hence high heat fluxes into the tank, certain insulating materials are necessary for the tank components.[42]Studies, such as the one presented by Zheng et al., on new cryogenic insulation methods, can assist the shipping sector if LH2 is the way forward.

The main advantage of hydrogen is the possibility of being a zero emissions fuel if produced from renewables. Furthermore, future hydrogen production capacity fits well with the anticipated energy transition to renewable power production on land. It is a non-toxic chemical that is uncommon for use as a fuel source. This indicates that it is favorable to the environment and does not hurt or destroy human health. Hydrogen is thought to be more beneficial than other fuels because of its high energy content per unit of mass, as well as the availability of its primary source (when generated from water)[43].

The most prominent challenges for hydrogen are the costs and the lack of bunkering infrastructure. The cost of hydrogen bunkering facilities is projected to be greater than that of LNG facilities, owing to the higher cryogenic storage need of liquid hydrogen and the materials required for tanks, pipelines, and seals. Hydrogen is kept as a compressed gas at 350-700 pressure or as a cryogenic liquid at -253 C, whereas LNG

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[40] Norse Group Announces Launch Of MF Hydra, World's First LH2 Driven Ferry Boat - FuelCellsWorks(Accessed 13/8/2021)

[41] Shell. Decarbonising Shipping: Setting Shell's Course; Shell: The Hague, The Netherlands, 2020

[42] Zheng, J.; Chen, L.; Xu, X.; Guo, L.; Zhou, Y.; Wang, J. A novel insulation system based on active cooling without power input for liquid hydrogen storage. Energy 2019, 182, 1–10

[43] Hydrogen as aviation fuel: A comparison with hydrocarbon fuels, Contreras et al., 1997

is stored at -163 C. The primary cost components are therefore storage and bunker boats, which must be scaled dependent on the number of ships serviced.

Another key challenge for hydrogen is its applicability. This limits the ship segments for which hydrogen can be used significantly. With current technology, hydrogen seems limited to shortsea shipping when considering current costs of tanks and fuel cells and range limitations due to its low density. It should also be noted that costs for required safety systems and mitigating measures is not quantified explicitly in the literature and may represent additional costs compared to what is presented in this report.

**Table 4 : Advantages and Disadvantages of Hydrogen**

| Advantages | Disadvantages |
|---|---|
| Zero Emissions Fuel | Cost |
| Non-Toxic | Lack Of Infrastructure |
| High Energy Content | Safety |

### *5.2.5 AMMONIA*

Ammonia is a chemical that may be utilized in a variety of industries and for a variety of purposes. It is mostly manufactured utilizing liquefied natural gas as a feedstock. Also, it may be made from an increasing range of renewable resources, such as biomass, making the ammonia manufacturing cycle more flexible. It can be considered a carbon-neutral fuel if generated through biomass gasification. By incorporating front-end electrolysis into existing ammonia facilities, hybrid green ammonia may be generated. Green ammonia is zero-carbon ammonia that may be generated using sustainable power, water, and air. It will be more expensive to produce than ordinary ammonia. On an industrial scale, the generation of green ammonia by electrolysis is not yet economically possible.

There have been several attempts across the world to use ammonia as a carbon-free fuel. Many nations have launched many ammonia-related projects for power generation, off-grid applications, internal combustion engines, and other purposes.

Furthermore, because ammonia is an excellent hydrogen transporter, it is projected to rise as the number of hydrogen-powered devices grows.

Currently, 80 percent of ammonia generated is used solely in the fertilizer sector. If 30% of shipping shifted to ammonia as a fuel, present output would have to almost double.

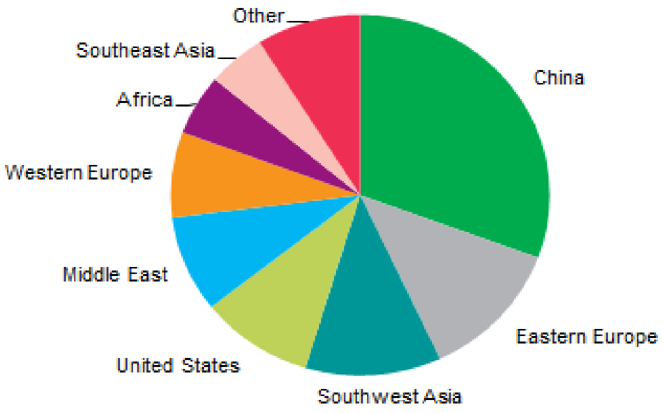

**Image 10: World Consumption of ammonia**

**Source: IHS Markit, 2020**

Until the outbreak of the COVID-19 crisis, the global ammonia market had been stable. In major producing locations, there were little limitations related to feedstock natural gas supplies. From 2016 to 2018, Mainland China witnessed a significant increase in coal costs as well as increased competition in its urea export market, resulting in a severe decrease in ammonia output. However, output in the Middle East and the United States rose in 2019, with just a small reduction in overall global production.

The overall apparent consumption of ammonia is expected to rise by roughly 12.9 percent between 2020 and 25. As future capacity additions continue to outstrip consumption, the global ammonia supply/demand balance is anticipated to shift toward a surplus. Ammonia capacity is growing largely in places with lower natural gas supply and costs, such as the United States and the Middle East.

With an energy transition to renewables, ammonia will have the potential to become a carbon free energy carrier with higher density than hydrogen, and in principal technically feasible for deep sea. However, the current maturity is low and green ammonia is expensive, limiting the feasibility for use as an alternative fuel.

Ammonia is a nitrogen-hydrogen compound. Because ammonia contains no carbon, it produces no CO2 when used to power an internal combustion engine. This opens up the possibility of totally zero-carbon propulsion. However, a tiny amount of pilot fuel is necessary for combustion, which should also be carbon-free.

It must also be created using renewable energy; otherwise, a large amount of energy will be required. It can be used in both fuel cells and internal combustion engines. It does not require the use of high-pressure tanks or cryogenic dewars, unlike hydrogen. It also has a 10 times higher energy density than a lithium-ion battery.

A barrier for using ammonia as an alternative marine fuel is the lack of a bunkering. According to a 2020 research conducted by University Maritime Advisory Services (UMAS) and the Energy Transitions Commission, USD 1-1.4 trillion is required to meet the IMO's carbon reduction ambitions by 2050. According to the report, about 87 percent of total investment is required in land-based infrastructure and low-carbon fuel producing facilities. In many situations, the upstream problems are much more difficult to address since they include many more parties, and these massive infrastructure investments might have serious consequences for people and the environment.

While ammonia is not particularly combustible, concentrations as little as 0.25 percent in the air can cause deaths, making the fuel extremely hazardous to humans. Today's residual and distillate fuel oils - as well as natural gas- all pose fewer hazards than ammonia. To guarantee the safety of ship crews, port personnel, and fuel providers, fuel systems must be developed, produced, operated, and maintained. Handling ammonia aboard ships will need a completely new set of expertise and safety precautions.

Ships today are designed in conventional designs, with engines and fuel systems frequently located in restricted areas on lower decks. The various ammonia needs may cause ship plans to change or even full redesigns.

Despite the challenges, ammonia seems to be one of the most widely available and promising fuels for the future, which are zero carbon emissions. For this reason, Avin

International LTD, a Greek shipowning company, has ordered a Suezmax tanker from the Chinese shipbuilder New Times Shipbuilding Co. that will be the first ammonia-fuel ready vessel in the world the vessel complies with the ABS Ammonia Ready Level 1 requirements, indicating it is designed to be converted to run on ammonia in the future.[44]

**Table 5: Advantages and Disadvantages of Ammonia**

| Advantages | Disadvantages |
|---|---|
| Produces No CO2 | Lack Of Bunkering |
| Produced By Renewable Energy | Safety |
| | Full Redesign Of The Vessel |

### *5.2.6 BIOFUELS*

Biofuels (biodiesel, liquefied biogas, etc.), have the potential to help reduce GHG emissions while also having the advantage of being quickly biodegradable. Biofuels are versatile fuel options since they may be combined with conventional fuels or utilized as drop-in fuels in existing systems without requiring major technological changes. While multiple demonstration projects have been carried out to assess the technological feasibility of various biofuels[45], the fundamental barrier to their widespread adoption is the ability to obtain the required production volume.[46] There are also some doubts about their ability to reduce GHG emissions. According to several studies, biofuels have the potential to pollute the air during growing and are not totally carbon-neutral due to the forest destruction required for their production.[47]

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[44] Avin International orders ‘ammonia-ready’ suezmax tanker in decarbonisation drive | TradeWinds (tradewindsnews.com)(Accessed 2/8/2021)

[45] Master Plan for CO2 Reduction in the Dutch Shipping Sector: Biofuels for Shipping. May 2018.

[46] IEA. Biofuels for the marine shipping sector: An overview and analysis of sector infrastructure,
fuel technologies and regulations. IEA Bioenergy, 2017(Accessed 2/8/21).

[47] Balcombe, P.; Brierley, J.; Lewis, C.; Skatvedt, L.; Speirs, J.; Hawkes, A.; Stael, I. How to decarbonise

The issue with biofuels in the maritime industry is that there is limited experience and understanding "on how to handle and deploy biofuels as part of their fuel supply." Another issue is the massive volumes of biofuels required to feed the shipping industry." As a result, sustainable biofuel production is constrained by food prices, natural resources (such as land availability), and societal factors. There are also worries about the storage and oxidation stability of biofuels, which necessitates more investigation.[48]

## 5.3 RENEWABLE ENERGY

Wind and solar energy have the potential to minimize carbon emissions and can be used to enhance existing power generation systems. The potential CO2 reduction for onboard solar energy generation is predicted to be between 0.2 and 12%, while wind-solar hybrid systems may reach up to 40% fuel savings. Despite their potential for GHG reduction, they are not currently seen as a viable alternative for commercial shipping, and it is widely agreed that the transition from fossil fuels to renewable fuels is still a long way off.

The use of big kites to enhance propulsion efficiency in navigation while decreasing fuel consumption and related pollutants is an intriguing new trend in the modern maritime industry. Especially

Kites can save a lot of fuel on the high seas, where the winds are typically stronger. While remaining at full speed this approach has the ability to save gasoline and is distinguished by because of the extremely cheap installation costs.

Renewable energy is a great step forward for 2020, but it is insufficient for 2050.

By fully implementing national climate and energy plans for 2030, the EU would be able to outperform its existing climate and renewable energy objectives for 2030.

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International shipping: Options for fuels, technologies and policies. Energy Conv. Manag. **2019**, 182, 72–88.

[48] Bicer, Y.; Dincer, I. Clean fuel options with hydrogen for sea transportation: A life cycle approach. Int. J. Hydrogen Energy 2018

Such achievements, however, would be inadequate for the EU to fulfill a greater objective of 55% reduction in greenhouse gas emissions by 2030, or to attain climate neutrality by 2050. [49]

To fulfill these higher promises, renewable energy should account for almost 70% of total EU generation by 2030 and more than 80% by 2050 allowing sectors that are more difficult to decarbonize to cut emissions through electrification. To reach such objectives and accelerate the energy transition, investments in renewable electricity supply must be increased. Furthermore, increased carbon costs under the EU Emission Trading Scheme would increase the competitiveness of renewable energy sources.[50]

Expanding renewable power generation across the EU gives many potential to enhance human health and the environment while reducing climate change by substituting more polluting fossil fuels. However, robust monitoring and policy implementation, as well as perhaps additional targeted actions, will be required to accompany these trends in order to prevent environmental problems from moving, especially in regions not examined by this study. Other important tools for policymakers will include advances in cross-sectoral energy and resource efficiency, as well as paying special attention to project planning, design, selection, and siting based on the habitats, species, and ecosystems that may be affected.

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[49] Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions Powering a climate-neutral economy: An EU Strategy for Energy System Integration(COM (2020) 299 final).

[50] EEA, 2020c, ‘Greenhouse gas emission intensity of electricity generation in Europe (ENER 038)’, European Environment Agency, accessed 15 December 2020.

# 6. TECHNOLOGY

Technology has had a transformative influence on all aspects of shipping, optimizing technical and operational performance - lowering costs, boosting efficiency and communications, increasing safety and security, and more.

To reach GHG objectives, shipping will definitely require new technology, new fuels, and creativity. R&D, infrastructure, and testing must all be funded.

The characteristics of most new and alternative fuels differ from those of traditional fuel oils, creating various safety issues. This necessitates the creation of legislation and technical norms for safe ship design and usage in tandem with the technology advancement required for their adoption. Many low-carbon alternative fuels need the transport of pilot fossil fuels. Except for sustainable biofuels, personnel expenses and training are important factors for all alternative fuels.

Alternative fuels such as ammonia, methanol, or hydrogen need a new generation of internal combustion engines and technological breakthroughs not yet established for ocean-going ships, and will need to be developed by other sector players as mentioned before like energy providers, engine manufacturers, and shipyards.

Today's global fleet is mostly powered by internal combustion diesel engines fueled by VLSFO, MGO, and HFO in combination with a scrubber. Some 120 ships have dual-fuel gas engines that run on LNG, 10 boats run on methanol, and approximately 120 car/passenger ships are powered by batteries.[51]

Beneath, the existing engine types and technologies are presentedbut also what changes and retrofits are needed so that engines can be compatible with alternative fuels.

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[51] Alternative Fuels Insight platform (AFI), afi.dnvgl.com

## 6.1 INTERNAL COMBUSTION ENGINES

Internal combustion engines (ICE) supply power to a ship (for auxiliary and ancillary uses) as well as propelling power. These technologies can be used with alternative fuels to minimize fuel usage and eliminate pollutants (either GHG or pollutant emissions).[52]

Marine ICEs hold a dominant position in the worldwide merchant fleet, accounting for about 98 percent of the merchant fleet today. ICE engines are now the most efficient in transportation. Furthermore, the lower cost of energy due to the use of heavy fuel oil has made the ICE highly appealing for shipping. Furthermore, the transition of the gas and gas-diesel cycles, have significantly enhanced their environmental performance, as well as the introduction of new control system technologies.

## 6.2 TYPE OF ENGINES

There are numerous types of ICE and engines available today, as well as numerous ICE manufacturers. Four-stroke engines, gas and gas-diesel four-stroke engines, two-stroke ship low-speed crosshead engines, and gas-diesel two-stroke low-speed engines are the most common types of marine engines.

### *6.2.1 FOUR STROKE ENGINES*

Four-stroke engines are the most prevalent engines used on vessels of various sizes in the maritime industry. Four-stroke engines are lower in size, weight, and cost of manufacturing than two-stroke engines. The cylinder heads of four-stroke engines, on the other hand, have a more sophisticated design due to the existence of camshafts, valves, and so on. High-pressure fuel injection, improved mixing air and fuel in the

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[52] Bilousov, I.; Bulgakov, M.; Savchuk, V. Modern Marine Internal Combustion Engines: A Technical and Historical Overview; Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping 8; Springer: Cham, Switzerland, 2020.

combustion chamber and innovative techniques in the control of medium- and high-speed engines have made four-stroke engines more ecologically friendly, particularly in terms of NOx emissions. As a result, four-stroke engines are appealing for technical fleet vessels, passenger and cargo vessels, and cruise ships operating in regions with existing limits on hazardous material emissions, such as emission control area (ECA) zones.[53]

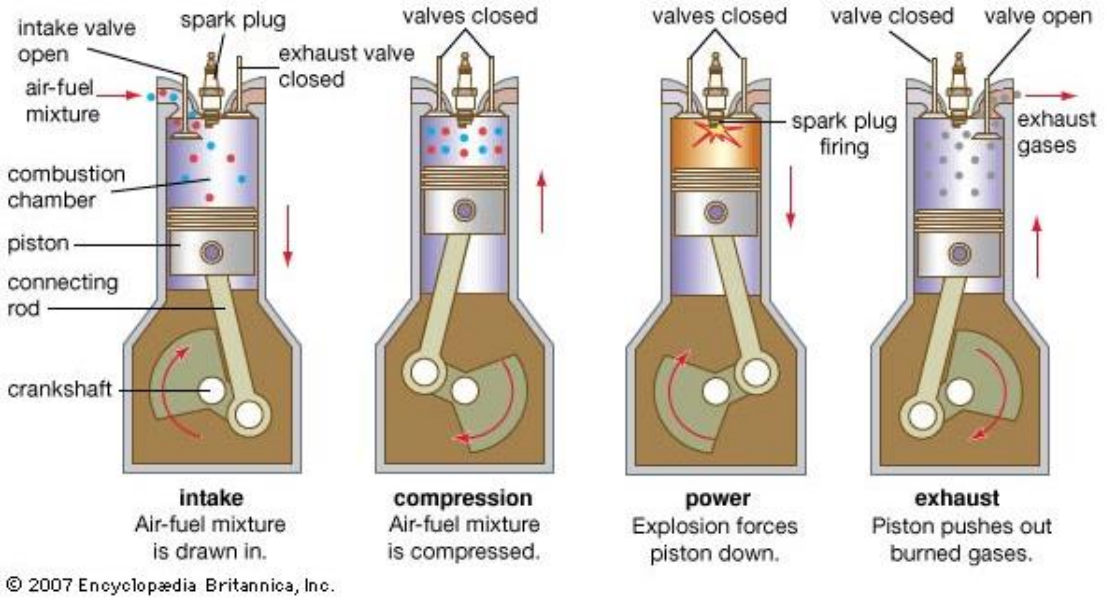

**Image 11: Four Stroke Engine**

### 6.2.2 TWO STROKE ENGINES

The benefit of two-stroke engines over four-stroke engines is their capacity to enhance power output for the same operating volume. To obtain a high stroke to bore ratio, low speeds are necessary to restrict the maximum piston speed, necessitating the use of a crosshead design and the uniflow-scavenging idea. For more than a century, commercial ships have relied on the marine diesel engine, which is today mostly a low-speed, two-stroke, crosshead-type, reversible, uniflow-scavenged, turbocharged,

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[53] Bilousov, I.; Bulgakov, M.; Savchuk, V. Modern Marine Internal Combustion Engines: A Technical and Historical Overview; Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping 8; Springer: Cham, Switzerland, 2020

electronic engine. Two-stroke engines are the most thermally efficient and dependable engines due to their smaller size and fewer moving components.[54]

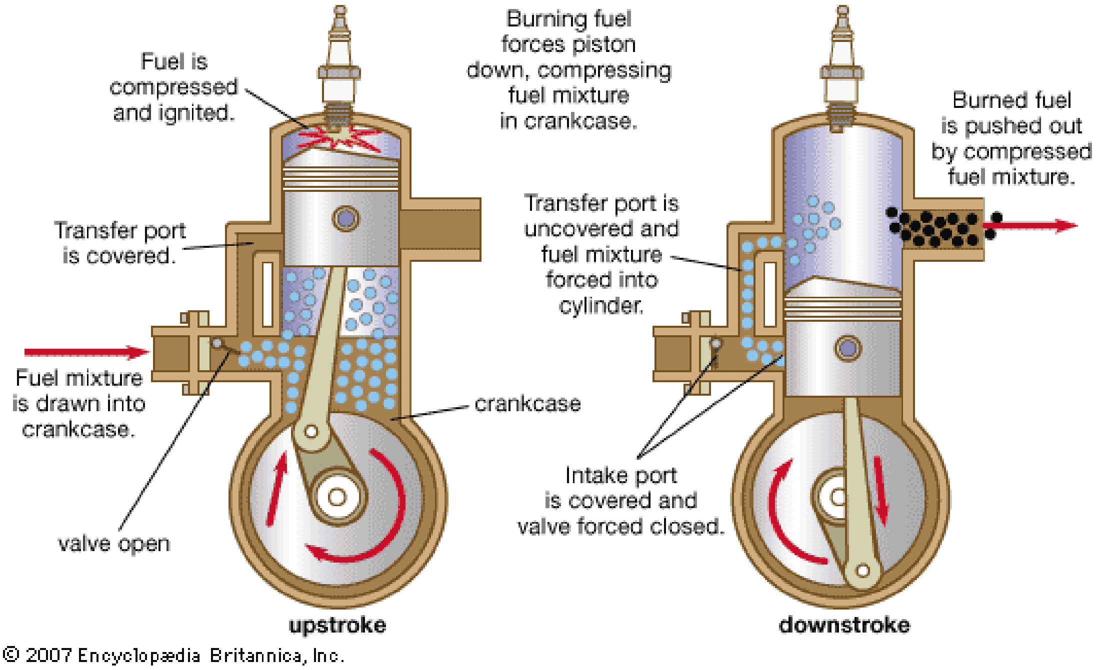

**Image 12 : Two Stroke Engine**

### 6.2.3 DUAL FUEL ENGINES

The use of gas as a fuel is the most promising approach to reach low emissions levels, particularly in ECA zones. In compared to heavy fuel oil, gas fuels have lower emissions: SOx emissions are non-existent (due to the lack of sulphur in the fuel), NOx emissions are decreased by 90%, and PM and CO2 emissions are reduced by 30%. Methane, propane, and butane are the most promising gas fuels. On board a ship, methane is kept in cryogenic tanks as LNG, whilst propane-butane mixes are stored in tanks at ambient temperatures and high pressures as LPG.

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[54] Kyrtatos, A.; Spahni, M.; Hensel, S.; Züger, R.; Sudwoj, G. The Development of the Modern Low-Speed Two-Stroke Marine Diesel Engine. In Proceedings of the 28th CIMAC World Congress, Helsinki, Finland, 6–10 June 2016.

When using gas fuels in two- or four-stroke engines, there are three approaches:

- Convert diesel engines to the Otto cycle, i.e., mix the air-fuel mixture externally to the combustion cylinder and ignite the air-fuel mixture using electric spark ignition.
- Mix the air-fuel combination externally to the combustion chamber and ignite the air-fuel mixture in the combustion cylinder with electric spark ignition coupled with liquid fuel injection: DF engine.
- In the combustion chamber, mix the air-fuel combination and ignite it by electric spark ignition coupled with liquid fuel injection: DF engine

The first two methods are utilized in four-stroke engines for a variety of purposes, whereas the last is employed in low-speed two-stroke engines.

The first method is more commonly employed in stationary power applications, such as providing electricity to offshore facilities, but it is less frequent in ships.

The second method is employed in medium- and high-speed engines. Combination of electric spark ignition and liquid fuel injection into the combustion chamber: DF engine.

Most engines nowadays operate on a dual-fuel (DF) basis, either two- or four-stroke.

To account for fluctuations in the ship's operating circumstances, offer cargo type and size independence, and keep the engine's ability to run only on liquid fuels or a gas-liquid fuel mix As a result, DF four-stroke engines can function. On gas, liquid, or a mixture of the two, in various quantities The DF engine performance and emissions vary based on operating circumstances and the control system's level of sophistication.

In general, DF engines operate best under moderate to high load circumstances, and they may frequently have the same or higher fuel economy as a pure diesel engine under the same conditions.[55]

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[55] Weaver, C.S.; Turner, S.H. Dual Fuel Natural Gas/Diesel Engines: Technology, Performance, and Emissions; SAE Technical Paper 940548; SAE International: Warrendale, PA, USA, 1994

DF engines have proved to be a viable choice for attaining environmental performance, future energy transformation, and marine engine dependability.

However, there are unresolved issues and technological hurdles that must be overcome before DF engines can become a primary engine for maritime applications.

## 6.3 ALTERNATIVE FUELS IN ICE

Nowadays, the production of hazardous emission gases is one of the most serious issues with the usage of internal combustion engines. For the purpose of reducing emissions, more and more people involved in maritime industry are focused on the using of alternative fuels, like those mentioned in previous chapters.

The energy shift presents significant cost and technological hurdles. In this chapter, it will be presented the use of alternative fuels in ICE, namely LNG, hydrogen, methanol and ammonia.

### *6.3.1 LNG*

LNG is used in dual-fuel engines, either in low-pressure or high-pressure configurations. Methane slip occurs more frequently in low-pressure engines than in high-pressure engines. However, NOx levels in low-pressure engines are lower than in high-pressure engines, necessitating the adoption of selective catalytic reduction (SCR) in the latter situation. CO and unburned HC levels may rise depending on engine conditions.[56]

The technology needed to use LNG as a ship fuel is easily available. Low and high-pressure 2-stroke piston engines, as well as low-pressure 4-stroke piston engines, are examples of piston engines. Several types of LNG storage tanks, as well as process equipment, are commercially available. At 1 bar absolute pressure, the boiling point of LNG is about –163°C. As a result, LNG must be kept in insulated tanks for

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[56] Lindstad, E.; Eskeland, G.S.; Rialland, A.; Valland, A. Decarbonizing maritime transport: The importance of engine technology and regulations for LNG to serve as a transition fuel. Sustainability 2020, 12, 8793.

cryogenic applications, which are expensive in comparison to typical petroleum-based fuel storage and supply systems.[57]

LNG DF engines can now provide a transitional solution for some parts of the industry, assuming that LNG bunkering infrastructure is developed at important ports of call around the world. Drop-in fuels, which are compatible with all vessel types regardless of trade and can burn biofuels without needing technical, safety, or design changes, can also be a partial answer to oceangoing bulk transport.

Dual-fuel technology's strength is its "fuel flexibility": dual-fuel systems allow for the use of MDO in transfers and LNG while operating in port, near to shore, or in an emissions control region (ECA). Using LNG as fuel can help lower a vessel's running expenses since owners and operators can choose the most appropriate fuel.

### *6.3.2 METHANOL*

There are two main options for using methanol as fuel in conventional ship engines: in a two-stroke diesel-cycle engine or in a four-stroke, lean-burn Otto-cycle engine.

Methanol may be used as a fuel in both maritime spark-ignition (SI) and compression ignition (CI) engines, with the latter operating in dual-fuel mode.

When compared to LNG refit costs, the use of methanol in existing boats offers significantly cheaper retrofit costs. Methanol refit expenses, in particular, vary from 25% to 35% of the comparable LNG conversion costs for 10–25 MW engines.[58]

Methanol may be used as fuel in traditional ship engines in two ways: in a two-stroke diesel-cycle engine or in a four-stroke, lean-burn Otto-cycle engine. There is presently just one commercially produced two-stroke diesel engine type, the MAN ME-LGI series, which is now in use on methanol tankers.[59]

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[57] SEA-LNG-DNV-GL-Comparison-of-Alternative-Marine-Fuels-2019_09

[58] Yfantis, E.A.; Katsanis, J.S.; Pariotis, E.G.; Zannis, T.C. Methanol as a Low-Carbon and Sulphur-Free Alternative Fuel for Shipping:
Prospects and Challenges; Hellenic Institute of Marine Technology: Piraeus, Greece, 2018

[59] SEA-LNG-DNV-GL-Comparison-of-Alternative-Marine-Fuels-2019_09

### *6.3.3 HYDROGEN*

Green hydrogen is a good contender for the maritime industry's deep decarbonization. However, there are numerous obstacles to hydrogen's usage as a fuel in ICE. However, because hydrogen has a high auto ignition temperature, it is more suited as a fuel for a spark-ignition engine than a compression-ignition engine, which might be a concern in the shipping industry (because ICEs are mainly compression-ignition engines). However, the use of hydrogen as a secondary fuel in compression-ignition engines is favored since it produces reduced emissions while incurring no penalty in engine performance.[60]

There are examples of hydrogen-powered ships, such as the CMB Hydroville, a 16-passenger shuttle. The technology is a hybrid engine that can run on both diesel and hydrogen. Furthermore, the CMB technology is constructing a number of hydrogen-powered vessels. “The economic and environmental advantages of low-carbon solutions in marine transport give the possibility to compete in the maritime market while essentially eliminating pollution at the point of use.”[61]

### *6.3.4 AMMONIA*

Conventional ammonia (NH 3) is the most abundant chemical on the planet. Ammonia is not a “drop-in” fuel, and there are no marine engines that can burn it. As a result, in order for ammonia to become the primary fuel, a significant portion of shipping's operating infrastructure will have to be demolished and replaced with new infrastructure across the world.

Despite its toxicity and strict handling requirements, ammonia engines have previously been created, and maritime engines are now being developed by adapting existing dual-fuel (DF) engine technology to ammonia.

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[60] White, C.M.; Steeper, R.R.; Lutz, A.E. The hydrogen-fueled internal combustion engine: A technical review. Int. J. Hydrogen Energy 2006, 31, 1292–1305.
[61] CMB.TECH. Projects 2020. (Accessed 30/8/21).

Nevertheless, the market has lately expressed interest in using ammonia as a fuel in ICE both the shipping sector and the automotive sector. Ammonia can be used in conjunction with internal combustion engines aboard ships. Ammonia has an energy density that is roughly 43% that of MGO (42.7 MJ/kg vs. 18.6 MJ/kg)[62]. Ammonia engines are also still under development due to their toxicity and more rigorous storage and handling regulations. The ammonia leak from the combustion process will also need to be handled, and ships will need to be outfitted with combustion after treatment equipment to prevent possibly significant NOx production.

Wärtsilä, in collaboration with Knutsen OAS Shipping AS, Repsol, and the Sustainable Energy Catapult Centre, is intending to test ammonia in a marine four-stroke engine under the Norwegian Research Council's DEMO 2000 initiative.[63]

Wärtsilä has already conducted some preliminary ammonia experiments in dual-fuel and spark-ignited gas engines, which "will be followed by field testing in partnership with shipowners from 2022, and perhaps also with energy consumers in the future," according to the company.[64]

Given the aforementioned restrictions and issues, in the coming years, industry tests will establish if ammonia holds promise as the next generation of fuel for ICE applications (either as a single or dual fuel).

## 6.4 UPGRADING THE FLEET

Shipping companies and ship owners have begun upgrading their fleets by investing in new hybrid and electric vessels, as well as retrofitting current ships with revolutionary smart ship technology, in order to stay relevant in a shipping industry unified by a shared ecological purpose.

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[62] Niels de Vries, TU Delft, Report: Safe and effective application of ammonia as a marine fuel, 2019.

[63] Wärtsilä. World's First Full Scale Ammonia Engine Test—an Important Step Towards Carbon Free Shipping. 30 June 2020. (Accessed 30/8/21).

[64] Wärtsilä Advances Future Fuel Capabilities with First Ammonia Tests.(Accessed 30/8/21)

Ship owners and system integrators should consider the long term while planning and implementing a smart ship solution, concentrating on system dependability and cost efficiency during the vessel's 25-year tenure.

To meet the IMO 2030 targets and cut carbon emissions, the shipping sector is deploying smart ship technology. These technological improvements result in an exponential increase in data volumes and processing requirements, emphasizing the necessity for data infrastructure and hardware components to be consistent and reliable.

Improved data (i.e. better weather data, navigational data, sonar, and radar) gives greater control of ship's systems, which leads to more energy-efficient decision making and a reduction in carbon and GHG emissions.

Electronics evolve every seven years on average. Lifecycle management, form-fit, and backward compatibility are key ideas that ensure that all systems and hardware are capable and prepared to satisfy data volume and processing requirements seven years in the future, as well as providing a smooth transition when changes are required.

## 7. CHALLENGES

Even before 2030 and 2050, the maritime industry has an unprecedented challenge in meeting the IMO's decarbonization standards, since owners and charterers must demonstrate that the vessels they acquire and manage are high performers, with less efficient ships undergoing performance enhancements. The importance of thorough decarbonization has piqued the interest of the maritime industry's key stakeholders. It was shown that the majority of stakeholders regarded decarbonization as a critical or top priority for their businesses.[65] As a result, this indicates that the market and industry are contemplating decarbonization as a business strategy.

Unlike earlier environmental regulations, attaining GHG objectives for shipping necessitates substantially more difficult technological and operational adjustments. The shift to new and alternative zero-carbon/carbon-neutral fuels and unconventional technologies is one of the difficulties. Furthermore, ship energy efficiency must be rethought, with the adoption of proven energy-recovery and energy-efficiency technology accelerated

These challenges also impose a renewed emphasis on system-level thinking and the integration of all available technologies. While the industry has been debating how to reduce emissions for many years, all of the most plausible options encounter problems and impediments. Meanwhile, shipowners are deferring investment in new vessels for fear of ordering a vessel that would be in violation of future GHG rules.

Given the maritime sector's 3% contribution to GHG emissions, deep decarbonization will need worldwide and regional financial incentives and regulations. Shipyards will also need to emphasize more efficient boats, and standard designs may need to be updated to meet the minimum acceptable Carbon Intensity Indicator (CII) requirements. The Energy Efficiency Existing Ship Index (EEXI) has garnered the most attention thus far; but, the CII, which provides a market mechanism for charterers, financiers, and regulators to grade performance, may have a substantial impact on vessel market ability. Regarding the adoption of MBMs, political barriers

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[65] Shell; Deloitte. Decarbonising Shipping: All Hands on Deck; Shell: The Hague, The Netherlands, 2020

owing to needless fragmentation and complexity of the international scene, along with elements that are purely political in nature, are thought to stymie the maritime decarbonization process. Removing these barriers is seen to be critical for bringing the decarbonization process ahead.

In Chapter 5, we looked at alternative fuels for shipping. The advantages and disadvantages of alternative fuels in terms of cost, technical complexity, and maturity were examined. Based on the data provided above, LNG is a promising short-term decarbonization strategy, with current ships already utilizing LNG. We conclude that other energy options are not now widely available, and LNG looks to be the only green fuel that is financially and globally scalable for the deep-sea portion in the short term. However, despite its benefits for lowering SOx emissions, many researchers concur that because it cannot achieve the necessary IMO GHG reductions, its position as a marine fuel will be transitory. The primary constraint to the move from conventional fuels to LNG over the period it will stay in demand is the lack of availability of bunkering facilities at ports.

On the one hand, bunker suppliers are hesitant to invest in bunkering stations until there is adequate demand for LNG as a marine fuel, while shipowners are hesitant to invest in LNG vessels if LNG refilling possibilities are difficult to come by. Another technological obstacle to various alternative fuels is storage capacity. LNG fuel tanks, for example, require two to three times the capacity of fuel-oil tanks with the same energy content. In compared to gaseous fuels, liquid fuels need storage tanks that are more readily integrated aboard. Storage tanks for gas fuels, on the other hand, are generally more expensive, take up more room, and are more difficult to incorporate onboard.

Despite their great potential to reduce CO2 emissions, clean alternatives (biofuels, methanol, hydrogen, and so on) are unlikely to become widely available in the near future due to a variety of technological, economic, and safety challenges. Hydrogen and ammonia fuels appear to be a realistic alternative for deep decarbonization, there are still challenges to solve before they can become an economically viable option. Storage, transportation, safety, toxicity, and cost are the major problems for these alternative fuels.

Biofuels tend to be marginally less expensive than renewable energy or natural gas with carbon capture and storage. Biofuels, on the other hand, suffer sustainability and supply difficulties, and as a result, they may become uncompetitive in the mid–long term due to price volatility and sustainability restrictions. Because fuel price is the most important factor in determining total operating costs, a fuel derived from natural gas or a renewable energy source may provide longer-term benefits than biofuels, especially when future global energy demand growth is considered, as well as the aforementioned sustainability and availability issues with biofuels.

In terms of renewable energy, existing ships and promising technologies are available to aid the shipping sector in lowering CO2 emissions, but the technologies are not yet mature enough to accomplish profound decarbonization on their own.

The transition in fuel and fuel-converter technology is quite sudden when it comes to newbuildings and "Design Requirements" (DR).

As previously stated, ammonia contains no carbon, thus emission reduction objectives can be reached by inventive design that use ammonia as an alternative fuel.

The figure below shows the evolution of the maritime fuel mix over the next three decades, as well as the projected market penetration of ammonia in 2050.
Only in 2037 does a considerable number of ammonia-fueled ships begin to be launched. The tipping point, on the other hand, comes rapidly. By 2042, more than half of all new buildings will be powered by ammonia. Ammonia is used in nearly all

new structures just two years later, in 2044.

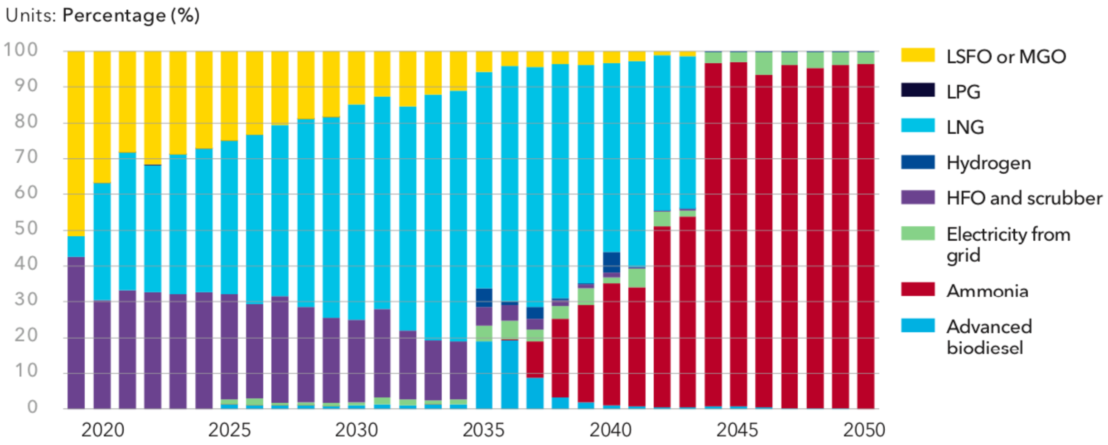

**Image 13: Share of fuels (% of energy bunkered) for newbuildings for the IMO ambitions DR pathway (2018–2050)**

**Source: DNV GL, Maritime Forecast to 2050, September 2019.**

Shipping companies are spending significantly to extend their fleets with newly-built ships, encouraged by the increase in demand. As a result, according to a recent projection from marine brokerage Banchero Costa, new shipping capacity would reach a record-breaking level by 2023.

Bud Darr, executive vice president, maritime policy and government affairs of MSC Group, the world's second largest cargo liner carrier, stated that the climate change objective confronting the shipping industry is the most difficult issue the business has ever faced.[66]

To meet that challenge, MrDarr stated that the industry must collaborate with energy and supply chain providers involved in the delivery of sustainable fuels, and that government intervention is required to accelerate the transition, as well as support from academia to help us figure out what the solution set can look like and how to get there.

The aims of the IMO will be achieved through a fundamental shift in technology, as well as societal pressure, financial incentives, and regulatory and legislative reforms

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[66] THE REPORTthe Magazine of the International Institute of Marine Surveying ‘COP26 and the road to global net zero. What's the buzz?’ ,September 2021,Issue 97

at the local, regional, and international levels. Time and preparation are required for the implementation of green projects.

## 8. ECONOMIC FACTOR

Shipping is still a fragmented industry with a high capital need that necessitates constant access to equity and loan financing.

Previous chapters have highlighted technical and operational options for reducing CO2 emissions from ships. Depending on the fuel price, several actions may be cost-effective for the operator. These steps are expected to be performed based on business-economic considerations by shipping sector participants. Other options are unlikely to be cost-effective, even if gasoline prices continue high. Shipowners are now faced with major investment considerations.

According to estimates from industry analysts, the new IMO standards would cost the shipping sector $60 billion USD each year. MGO is now around 60% more costly than regular HFO. Given that bunker expenses account for about 47 percent of a vessel's operational costs, IMO rules will result in considerably higher costs for the shipping sector. This greater cost will result in a 10% rise in transportation rates per TEU for consumers, and the question of who will pay these higher expenses is not minor.[67]

However, fuel prices are not the only major expenses to consider when assessing alternative energy alternatives; capital and operational costs must also be addressed.

Access to finance markets is commonly acknowledged as a barrier to investing in emission reduction measures. Most shipping companies are small and have limited resources to engage in retrofitting; therefore the payback period of various solutions is an important consideration in shipowners' decision-making.

Furthermore, ships have a resale value that does not reflect expenditures in energy-saving technology. For those interested in utilizing LNG as a maritime fuel, the shift to LNG requires not just significant expenditures to create the requisite refueling stations, but also the acquisition of new powered LNG ships, which cost 10%–30% more than similar diesel-fueled conventional ships. Retrofitting can also be

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[67] How the new fuel regulations change the entire shipping industry - Hapag-Lloyd.(Accessed 16/9/21)

prohibitively expensive due to the large amount of space required to add larger fuel tanks. The cost of adapting conventional engines to run on methanol is expected to be cheaper.

## 8.1 FINANCING

Shipowners, engine manufacturers, and shipbuilders must collaborate to design modular or flexible propulsion systems that can run on a variety of future fuels or be easily replaced. These technologies would lower the risk and cost of any future fuel change, although being more expensive at first.

The maritime sector will continue to have difficulties in obtaining cost-effective, flexible financing to fulfill its goals. These obstacles include challenging market circumstances, including the effect of Covid-19, poor historical investor returns, low corporate valuations, a limited supply of attractive bank loans, and a diverse range of rival public stocks that are more liquid and less volatile. Companies will need to be opportunistic, agile, and innovative in order to take advantage of a diverse range of debt and equity instruments made accessible by various capital sources and markets throughout the world.

Regardless of the fuel that will emerge as the main choices along the way for the carbonization of various types of ships by the middle of the century, the total capital expenditure (CAPEX) for the necessary technologies on board will be huge.

Maritime Forecast to 2050 predicts that in the 2020-2050 period, such a CAPEX could range from $ 250-800 billion, depending on greenhouse gas reduction targets. He estimates that the maximum investment each year ranges from 20-60 billion dollars.

As emissions requirements evolve, bankers will play an important role in enabling investments and minimizing vulnerability to high retrofitting costs. If classification societies provide confidence, risk-averse bankers may find it simpler to make such judgments. Lifecycle contracts may also assist to decrease the risk of future investments in low-carbon technology, particularly when the cost of an engine is combined with the cost of future retrofitting, splitting the risk between engine manufacturers and shipowners.

### *8.1.1 RESEARCH AND DEVELOPMENT FUND*

The international shipping community has established the first collaborative shipping Research and Development (R&D) Fund, with the goal of reducing CO2 emissions from international shipping. The idea involves USD 5 billion in core investment from shipping firms throughout the world over a 10-year period. To date, ten nations have contributed to the $5 billion R&D fund, including Japan, Malta, Nigeria, Singapore, Switzerland, and Denmark. Greek shipowners, also, completely endorse the idea made by the global shipping industry.

The Fund, which may be operational by 2023, would be controlled by an International Maritime Research and Development Board (IMRB), a non-governmental organization governed by UN IMO Member States.

The $5 billion R&D plan, which is now endorsed by a broad spectrum of nations, will be revisited by the IMO Marine Environment Protection Committee, which will convene two weeks after the Cop26 event in November[68].

### *8.1.2 THE POSEIDON PRINCIPLES*

So far, shipping has been able to avoid the upheaval that ESG may be about to bring to the key stakeholders. However, in the coming years, shipping will be obliged to give more openness through ESG reporting. The Poseidon Principles, which provide a framework for responsible ship financing, place sustainability at the core of the Poseidon Principles; banks and financial institutions will monitor and publicize whether their shipping portfolios are in accordance with IMO's climate targets. This

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[68] The UK will host the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow on 31 October – 12 November 2021. The COP26 summit will bring parties together to accelerate action towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change.

entails cutting greenhouse gas emissions by 40% by 2030 and 70% by 2050, compared to 2008 levels. Compliance with these standards necessitates a drastic, market-wide shift.

The Poseidon Principles, which were launched in New York on June 18, 2019, are an agreement established between the banking sector and the shipping industry to incorporate the IMO's climate change regulations into ship financing decision-making processes. They apply internationally, and signatories to the Principles must guarantee that their ship financing portfolios are linked with the IMO's Initial GHG Strategy. It is believed that making access to credit conditional will push the industry to build "greener" ships.[69]

### *8.1.3 ALTERNATIVE FINANCING*

Traditionally, the most popular ways for shipping firms to generate funds were through debt financing through banks and equity financing. However, traditional means of finance are rapidly being supplanted by new sources of capital such as convertible debt, private equity, and sale-and-leaseback transactions.

Sale-and-leaseback transactions have lately grown in favor. A sale-and-leaseback agreement occurs when the original ship owner sells a vessel to another firm and then leases it back from them. The original ship owner becomes a lessee, while the new purchase becomes a lessor. Occasionally, the deals will contain a buy option, under which the lessee has first refusal to repurchase the vessel at the conclusion of the lease. BIMCO launched SHIPLEASE, a standardized term sheet for use in sale and leaseback agreements, in 2020 as a result of the growing popularity of sale-and-leaseback arrangements.[70]

When the original shipowner receives revenue from the sale of their ships, the sale-and-leaseback agreement allows them to raise cash and free up capital, therefore

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[69] Home - Poseidon Principles.(Accessed 26/9/21)

[70] SHIPLEASE (bimco.org).(Accessed 26/9/21)

increasing liquidity. The funds collected by the lessee might be utilized to invest in other businesses or to cover operational expenditures. Such arrangements may be utilized by shipping companies for new builds or second-hand vessel purchases to facilitate vessel delivery without increasing the company's debt or diluting its equity.

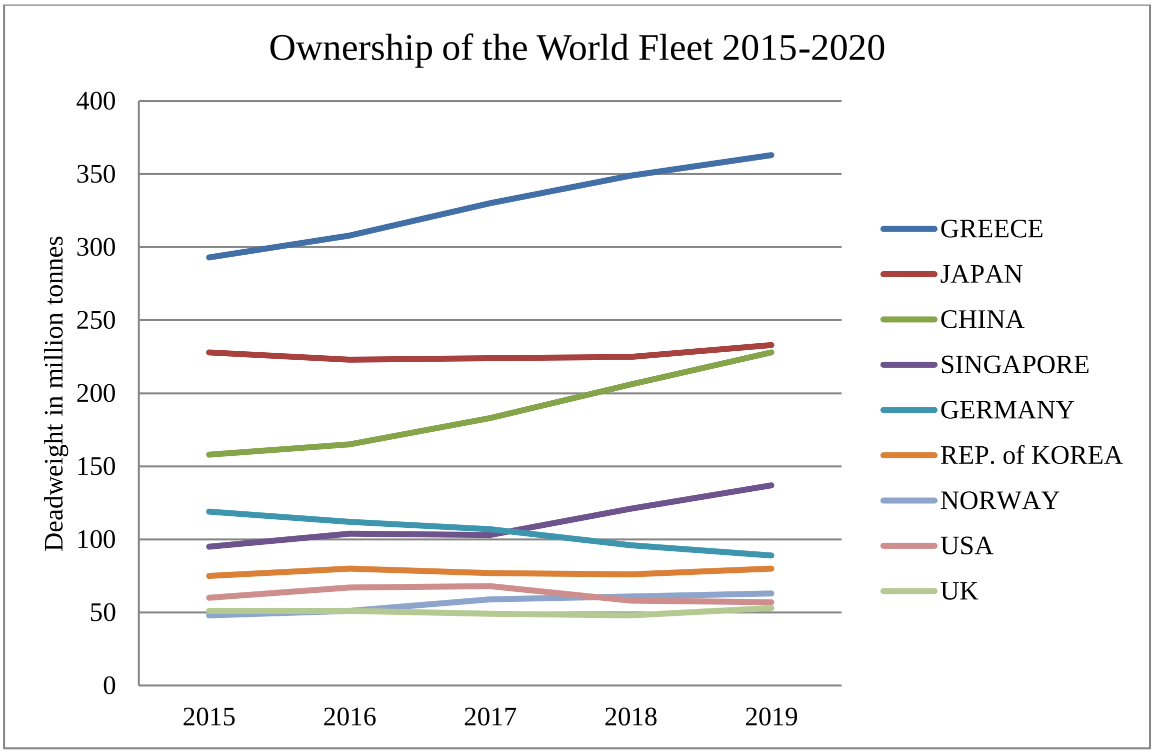
## 9. GREEK SHIPPING

Shipping is one of the most significant businesses on the planet. Greek shipping is the backbone of the EU-controlled fleet, a crucial facilitator of international trade, and an essential component of the Greek economy.

Greek shipping has contributed significantly to the economy and development not only of Greece but also of many other countries, as Greek shipowners have always been the main customers of large shipyards and other companies around the world.

Greece is the world's largest shipowner, with a fleet of 4,901 ships accounting for 19.42 percent of global deadweight tonnage (dwt). The Greek-owned fleet expanded by more over 4% in 2020, to around 364 million dwt, as indicated in the figure below.

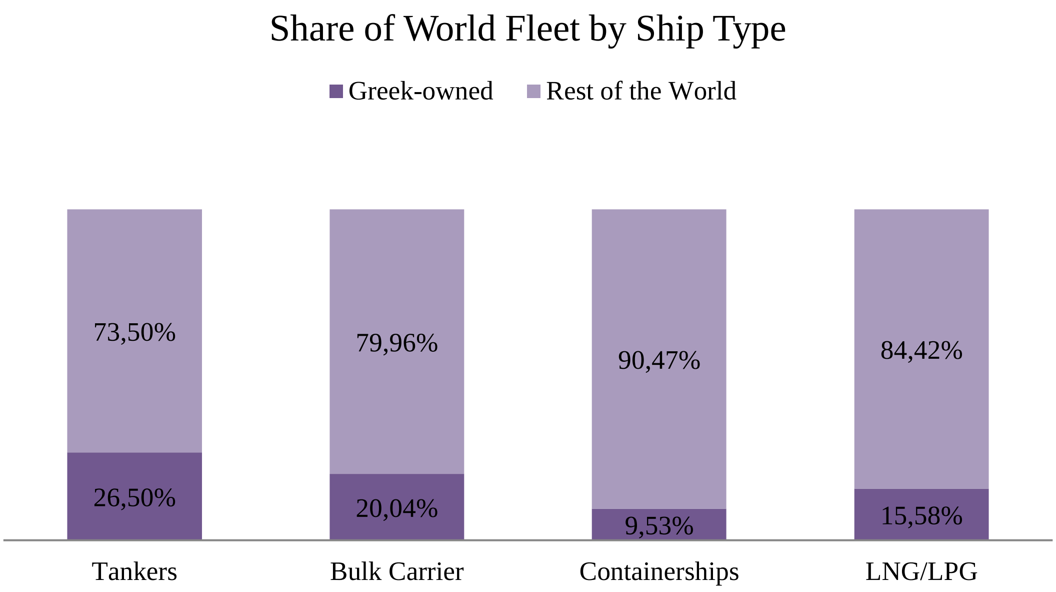
**Figure 3 : Ownership of the World Fleet, 2015-2020 (in dwt, ships > 1000 gt)**



**Source: UNCTAD, Review of Maritime Transport, 2015-2020**

Greek-owned ships account for 58% of the EU-controlled fleet. Greek shipowners own 30.25 percent of the world's tanker fleet, 14.64 percent of the world's chemical and product tankers, 15.58 percent of the world's LNG / LPG carriers, 20.04 percent of the world's bulk carriers, and 9.53 percent of the world's containerships.

**Figure 4: Share of Word Fleet by Ship Type**



**Source: IHS Markit, 2021**

According to statistics from consultancy Vessels Value, the active fleet has 4,546 ships worth a total of $117.59 billion. Add to that the 187 vessels under construction, which are valued $14.99 billion. The increase in value is mostly due to increased fees for container and dry cargo ships, but there has also been a considerable gain in value for tankers, despite lower fees.

The value of dry cargo ships, including operating and under construction, is $46.7 billion, while tankers are $39.1 billion. Container ships, commonly known as boxships, are worth $23.46 billion. There are 441 Greek-owned boxships, compared to 1,458 tankers and 2,326 dry cargo ships.

Despite having a significant market share in comparison to the rest of the globe, Greek shipowners also have the newest fleet. The Greek fleet's average age in terms of ships is presently 12.1 years, compared to 14.5 years for the global fleet. This is due to the fact that they continue to invest in new structures. In 2020, Greek interests ordered 104 vessels (above 1,000 gt), representing for 10.99 percent of global tonnage on order.

Investing in new, advanced, and energy-efficient vessels is part of the Greek shipping industry's plan to comply with the new standards (Sulphur cap, GHG reduction etc.)

In light of the 2030 milestone and beyond, a shipping company should transit to reduce carbon intensity and use the most techno-economically viable technology.

Utilizing new operational techniques or technological improvements in ship technology to reduce carbon footprint should be assessed against the performance of each specific vessel.

There are also concerns that most low-carbon energy sources will be unable to provide the base load electricity required for international transportation. Furthermore, as discussed in previous chapters, it is not currently assured that an appropriate supply of any fuel will be available on time.

As we approach the next decarbonization milestone of 2030 and beyond, it is clear that a company should transition to lower carbon intensity.

Given the necessity for decarbonization and the ever-changing environment of requirements, a shipowner's most challenging duty is choosing how to reform his strategy and keep it continually updated with trustworthy, science-based knowledge. The regulatory landscape is presently in upheaval, but long-term ambitions are ambitious and need quick action.

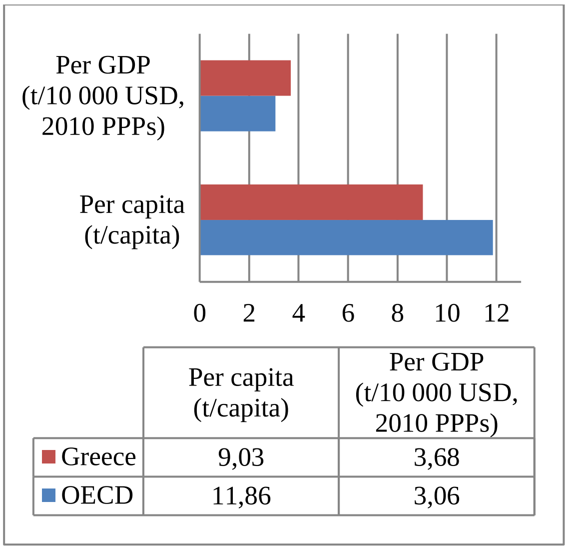
## 9.1 GREECE TRANSITION TO 2030

Greece's greenhouse gas emissions have decreased considerably during the last decade, owing mostly to the recession and a shift toward cleaner energy. Greece met its Kyoto Protocol obligation and is on pace to meet its 2020 and 2030 mitigation objectives as a result of this drop. In 2002, Greece accepted the Kyoto Protocol, and in 2016, it ratified the Paris Agreement. However, the economy's GHG intensity has only modestly improved and remains one of the highest in the OECD (Organization for Economic Co-operation and Development), indicating that further climate action is needed. The government set high objectives for 2030 and created a long-term mitigation strategy. Additional efforts, however, will be required to attain carbon neutrality by 2050.

As previously stated, in most nations, energy usage accounts for the majority of emissions (three-quarters in 2017), with industrial activities, agriculture, and waste accounting for the balance. While GHG emissions have decreased in all sectors since 2005, the decrease has been primarily driven by lower emissions from power generation and, to a lesser extent, the residential, transportation, manufacturing, and construction sectors.

As seen in the graph below, per capita emissions have gradually decreased over the last decade and are now substantially lower than the OECD average.

**Figure 5: GHG Emission intensity and percentage change since 2005**



| | Per capita (t/capita) | Per GDP (t/10 000 USD, 2010 PPPs) |
|---|---|---|
| 🟥 Greece | 9,03 | 3,68 |
| 🟦 OECD | 11,86 | 3,06 |

**Source: MoEE (2020), Long-term Strategy to 2050; OECD (2019), "Air and climate: Greenhouse gas emissions by source", OECD Environment Statistics (database).**

Greece exceeded its objective for the first Kyoto Protocol commitment period of limiting GHG emissions increases to 25% by attaining a 17% increase from 1990 levels between 2008 and 2012. It is also on pace to fulfill the European Union (EU) rules' 2020 and 2030 objectives for non-EU Emissions Trading System emissions (EU ETS). Non-EU ETS emissions were 28 percent lower in 2018 than in 2005, greatly exceeding the objective of 4 percent reduction from 2005 to 2020 and 16 percent reduction from 2005 to 2030.

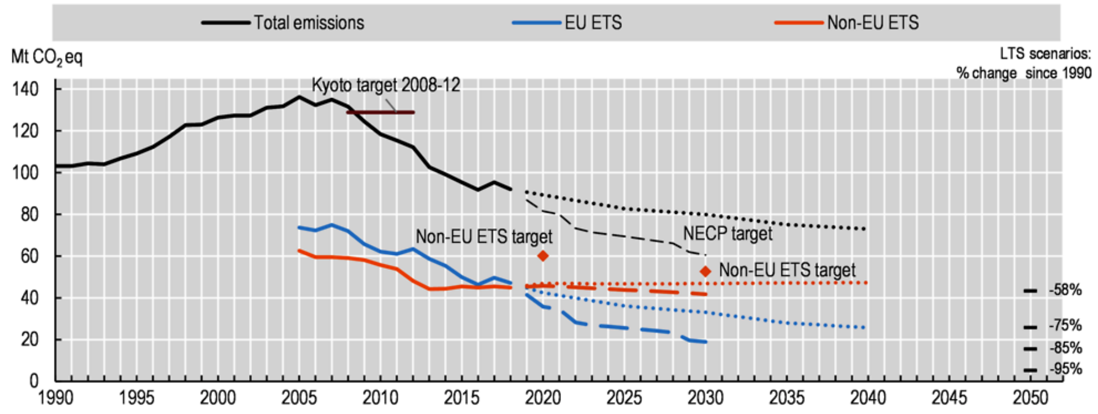


**Image 14: GHG emissions, projections and targets**

**Source : EEA (2019), Country Profiles: Greenhouse Gases and Energy 2019 (database); MoEE (2019), Climate Change Emissions Inventory: Submission of the Information under the Articles 12, 13 and 14 of the Monitoring Mechanism Regulation (EU) 525/2013; MoEE (2019), National Energy and Climate Plan;**

In order to meet the objective of Kyoto's first commitment period (2008-12), Greece established the Second National Climate Change Programme 2000-10 in 2002 (and modified it in 2007).For the second commitment period, it did not have a comparable comprehensive, economy-wide policy (2013-20). Greece has established a National Energy and Climate Policy (NECP), which defines an evolution scenario for the energy system and recommends policies and actions to achieve the national energy and climate objectives for 2030.

Greece, like the majority of EU members, supports a carbon neutrality target for 2050. It has not yet set a mitigation target for 2050, but it has established a Long-Term Strategy through 2050 that includes decarbonization possibilities.

Greece's plan, which builds on an existing proposal supported by the International Chamber of Shipping and IMO Member States, complements the enhanced Ship Energy Efficiency Management Plan in such a way that the UN IMO 2030 target is met. This is because establishing a single necessary need for every ship in a certain sector ensures that there will be no purposeful or inadvertent circumventions of specified technical requirements, which might otherwise be conceivable, for example, by offering multiple goal-based alternatives.

The proposed policy specifies the maximum main engine power that ships over 5,000 GT can use under normal conditions to keep CO2 emissions from ships at a historical low (2012) throughout a three-year phase-in period beginning before 2023. The sectoral prescriptive approach it adopts mandates that bulk carriers and tankers lower their main engine power by 50% and containerships drop their main engine power by 66%. The proposal includes a review provision that allows the UN IMO to take corrective measures if necessary.

The proposal is primarily compatible with the mode of operation of bulk/tramp shipping, in which charterers play a determining role in the ship's operation, and this is why shipowners' commitment to a ship's operational efficiency through goal-based measures, KPIs, and so on may not be sufficient to affect a change in the ship's carbon footprint. Charterers should be clearly obligated to follow any measures put in place to decrease GHG emissions from ships.

According to Mr. Theodore Veniamis, President of the UGS, Greece is in the forefront of real attempts to develop efficient and practical climate change mitigation measures. Furthermore, Greece's plan is straightforward, open, and readily enforced, and it accommodates sectoral specificities without distorting competition, which is critical. Furthermore, it provides for early action and the start of implementation prior to 2023, which leads to direct absolute GHG emissions reductions, SOx, NOx, and underwater noise reductions, while also factoring in safety and rewarding more efficient ships.

## 9.2 THE PERSPECTIVES OF THE GREEK SHIPOWNERS

As large shipowners with active participation in shipping, Greek shipowners have a Leading Thought, being at the forefront, and leading the market.

In this chapter we will analyze some of the views, concerns and attitudes of Greek shipowners.

Greek shipping companies have made new investments of $ 1.35 billion to renew their fleet, with significant prospects for future growth in world trade.

The presence of Greek shipowners in the liquefied natural gas (LNG) transport sector is important, which is showing great growth, with the demand for natural gas growing at a rapid pace.

Maran Gas of the Angelikoussi group, implements an investment program for the construction of 22 new vessels, mainly tankers and LNG ships, where it has focused in recent years.

Alexandros Panagopoulos, Founder & CEO of Forward Ships, emphasized that ship emissions data would eventually morph into a new currency that will be used to assess investment acceptability. On the choice of fuel for shipping, he stated that currently he does not see any other realistic and practical option other than LNG and then a mixing of that with biogas since “the infrastructure, the availability, the rules, and the competitive cost of LNG all lead to it.” “We all know that going to absolute zero is the ultimate goal,” he added, “but the fuel and technology that will bring us there have yet to be invented.”

Furthermore, shipowners note that promising alternative fuels, such as ammonia, methanol or hydrogen, need a new generation of internal combustion engines and technological advances that have not yet been developed for seagoing ships. At the same time, regulations and technical rules are required for the safe design and use of new fuels on ships.

According to  Ms Prokopiou CEO of Prominence Maritime, in order to use ammonia as fuel in the future, it’s important to have specializes seafarers in order to handing and operating  it safely.

Dr. Nikos Tsakos, President and CEO of TEN, pointed out that in order to address the issue and the decarbonization of the shipping industry, which is supported by the shipping world as a whole, legislators should look at how the whole chain will work, from the production of alternative fuel to consumption and not just focus on the final recipient who is the shipowner.

Dr. John Coustas, CEO of Danaos, joined the “Shipping – Is it all Glitter & Gold” panel on the 13th Annual Capital Link New York Maritime Forum and commented that at present there is no clear path for the decarbonization of shipping, adding that ammonia and methanol are a choice of marine fuels with an unknown time horizon.

Dr. Ioannis Coustas stressed that is focused on raising funds, improving the energy efficiency of the existing fleet and therefore on compliance with environmental regulations.Also he mentioned that alternative fuels, such as ammonia and methanol, should not emit more carbon dioxide in their production process than ships emit in their use.

During the Greener Shipping Summit[71], about 20 speakers reviewed the progress being made in green shipping, and the technology available to achieve the energy efficiency required to achieve the IMO goals.

Semiramis Paliou, director of Diana's Shipping Inc and president of the Hellenic Marine Environment Protection Association (HELMEPA), was among those who spoke, noting that the shipping industry is currently focusing on the environment, which is being widely addressed under the broad definition of decarbonization, and that as it moves in this direction, "the shipping industry is faced with multiple hurdles." She stated that there are issues to be addressed, such as whether new fuels would result in more expensive ships, higher running costs, more complicated systems, new crew skills, and potential new risks. She emphasized that the way must be approached with caution and collaboratively by all maritime stakeholders.

During the same online conference, there was a lot of discussion on how EEXI and CII work, and it quickly became clear that when it comes to ship operation, the indexes are more of a CAPEX issue than a technical one.

Compliance with EEXI was accepted to be examined in conjunction with CII and, more significantly, assessed in a life cycle assessment mode with consideration of well to wake emissions. There is anticipation that a second wave of EEXI in 2026 will not be required due to reduced speeds and the benefits of fleet renewals as well as the adoption of more environmentally friendly alternative fuels.

Due to the inefficiency of the turbine, some types of vessels, such as steam turbine-driven LNGs, may be compelled to run at substantially lower speeds. If they do not

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[71] Presentations - Digital Greener Shipping Summit 2021

have reliquefaction aboard, the excess boil-off will be discarded rather than utilized for propulsion or energy generation.

When it comes to CII, it was said that Imo and the EU must include charterers in the fight against pollution.

Takis Koutris, Managing Director of Roxana Shipping / Kristen Marine, stated that IMO has a three-step strategy to lowering GHG, the introduction of the carbon intensity, the vision, and levels of ambition, highlighting that the balance for meeting the 2030 objective is 10% for EEOI.

Panos Zachariadis, technical director of Atlantic Bulk Carriers, questioned how much CII will affect a company's legal duties.

As stated by Dimitris Vastarouchas, DCOO & Technical Director Danaos Maritime, the shipping sector will confront new hurdles in order to meet the IMO's intermediate level of ambition for 2030. Compliance with EEXI and a considerable decrease in CII will be the industry's primary emphasis factors. There are several questions that must be answered in order to complete the puzzle and decide the decarbonizationscene.What will be the final form of decarbonization tax (levy or ETS) and who will ultimately bear it, how will this affect future charter party agreements, what penalties will be imposed on low rating vessels, and whether the CII rating will seriously drive the financial institutes' decision making process and gain increased weighting over traditional criteria.

During the 6th Delphi Economic Forum, Mr. Vangelis Marinakis, owner of Capital Maritime& Trading Corp., stated that the International Maritime Organisation (IMO) guidelines to reduce shipping industry emissions until 2050 mean that shipowners must “pay the bill” for new vessels and engines”. Mr Marinakis, recently, made an investment in alternative forms of energy production cause as he stated ‘When you’re in the shipping business you’re obliged to record not only a reduction in your carbon emissions ‘footprint’ but to take other action for the environment.’

In favor of slow steaming is Mr. Prokopiou and explained its importance. As he said, if the speed for the existing ships goes to 10 knots, from the 15 that are in force today, all the emissions (NOx, SOx, CO2 particulates) will be immediately reduced by more than 50%. "I do not understand who and why is against this measure," he continued".

"From now on, for the ships that will be built, after cooperation between the IMO, the shipowners, the engine manufacturers and the shipyards, regulations will be issued with the standards that will apply to the permitted amounts of greenhouse gas (GHG) (emissions), for each ton of cargo carried and for each type of ship (VLCCs, suezmaxes, capes, kamsarmaxes, etc.) ".

And finally, George Melissanidis, Chairman of Aegean Shipping Management S.A., having achieved the creation of a “Green” fleet with an average age of 2.9 years continues to invest in “green” ships and ecological technology attempting to achieve the most advanced and stringent environmental classification criteria, focusing on the nature of the business and the operating profiles of the vessels.

# 10. CONCLUSION

In 2018, IMO adopted an initial strategy on the reduction of GHG emissions from ships. Having crossed the Sulfur Cap reef, the focus is on carbon depletion, pushing for an immediate transition from theory to practice. The whole international shipping sector aspires to produce zero GHGs by the end of this century, which means that new fuels and technologies will be critical in decarbonizing the sector

Despite the fact that the sector is required to meet precise emission reduction targets within specified periods, there is substantial uncertainty throughout the industry. Simultaneously, shipowners must make fleet maintenance and renewal decisions while meeting the demands of regulators, charterers, financiers, and others.

Decarbonizing shipping is a vital, complicated, and expensive endeavor. Regulation is usually regarded as a need and the single most powerful incentive for completing the work. The potential measurements are classified as short-, medium-, and long-term. Short term refers to the period between 2018 and 2023, medium term refers to the period between 2023 and 2030, while long term refers to the period after 2030. As explained in Chapter 4, the IMO has already implemented energy efficiency and operational measures such as the EEDI and SEEMP.

There are several methods for decarbonizing shipping, including fuel switching, technology interventions, operational efforts, and market-based approaches. Not all alternatives have attained their full maturity. Some of the solutions under consideration are already technologically sophisticated, while others are not; some are simple to execute in the short term, while others need significant financial investments and longer timeframes. Furthermore, several solutions that appear to be highly promising for lowering GHG emissions in the initial instance must overcome a variety of hurdles in order to fully utilize their potential on a wide scale. In the short term, many steps may be implemented and combined to help reduce CO2 emissions, but in the long run, comprehensive decarbonization will need a steady shift away from fossil fuels and toward alternative energy sources. Any measure or action has both dangers and possibilities, and it is nearly impossible to predict which solutions will be most effective.

Chapter 7 examined the key problems and constraints to adopting decarbonization solutions. These barriers include not just the sector's typical aversion to change, but also investment opportunities and risk, uncertainty about future regulatory measures, information and time constraints, technological limitations, market challenges, and political obstructions. The fundamental challenge for the future is integrating environmental sustainability, economic sustainability, and transport requirements properly.

Governments and research have an important role as potential facilitators of shipping decarbonization and may help to drive decarbonization projects through an integrated package of measures that includes civil society participation. Institutional interventions may include financial incentives, subsidies, investments in not-yet-ready but promising low-carbon solutions, and other enabling policies.For its part, research can help to resolve some of the issues that are impeding the adoption of decarbonization measures in shipping, therefore creating an environment that supports and encourages the fulfillment of the IMO's objectives.

There is no time to waste if the IMO's carbon reduction objectives are to be met, and shipowners must act today to protect their assets tomorrow. As discussed in Chapter 6, alternative fuels have different physical characteristics than conventional fuels. The future of shipping and decarbonization will be based on strong partnerships in both technical and procurement areas. To decarbonize all enterprises in the long term, massive quantities of energy and cash must be invested in research and development projects to bring alternative fuels and alternative propulsion technologies to market.

As for now, gas appears to be the most viable answer right now. Decarbonization will be aided by the use of LNG in the maritime industry. Unlike other alternative fuels such as renewable hydrogen and ammonia, LNG is already operationally proved, financially feasible, accessible, and scalable. But LNG is only a short term option.

Existing vessels require an amount of money for retrofitting which doesn’t secure them the payback period.  The average age of a vessel is 20-25 years, so investing now in a newbuilding which is running in LNG does not meet IMO target beyond 2030.

Based on the information presented in earlier chapters, we may assume that ammonia will be the primary maritime fuel if the world achieves net-zero emissions by 2050.

Overall, ammonia appears to be a viable alternative fuel with the potential to make a significant contribution to decarbonization as well as a solution for maritime firms wanting to decarbonize their operations.

The industry is not yet confident that there are either defined needs that will aid in long-term planning or that present technology can support it. As a result, given the impending measures required by the 2030 and 2050 objectives, it is critical that technical solutions, as well as the legislative framework to support them, be in place as soon as feasible. Sector stakeholders must now collaborate to create and demonstrate the viability of practical solutions.

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