Toward Achieving Net Zero GHG Emissions from International Shipping by 2050

March 2022

Shipping Zero Emission Project

This document was originally written in Japanese. This English version is provided for reference purposes only.

Foreword

Amid globally growing momentum for decarbonization since the Paris Agreement came into effect in 2016, further reduction of greenhouse gas (GHG) emissions has become an urgent issue in international shipping, which currently accounts for approximately 2% of global GHG emissions and is expected to significantly grow in the future. In April 2018, the International Maritime Organization (IMO) adopted the "Initial Strategy on reduction of GHG emissions from ships", aimed at reducing the GHG emissions from international shipping by at least 50% by 2050 and phasing them out as soon as possible in this century. Currently, in accordance with the Strategy, discussion and consideration on GHG emissions reduction measures are underway at the IMO.

Japan is one of the major players in global shipping and shipbuilding sectors. In order to actively contribute to international actions to address the climate change while ensuring the sustainable growth of maritime transport and related industries, Japan established the "Shipping Zero Emission Project", in collaboration with the industrial, academic, and public sectors, in August 2018. The Japan Ship Technology Research Association (JSTRA) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) are taking the lead in organizing this project with the support from the Nippon Foundation.

This report contains the outcome of the studies conducted by this Project in 2021.

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(Organizer)

(Co-Organizer)

(Supporter)

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Support: The Nippon Foundation

This project has established the Task Force on ship design and the Task Force on ship operation and has been carried out with the participation of more than 50 experts from related industries and organizations.

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Table of Contents

Chapter 1: Introduction

Section 1.1: Background

According to the study on greenhouse gas (GHG) emissions from international shipping conducted by the International Maritime Organization (IMO) in 2020, total CO_2 emissions from international shipping as of 2018 was approximately 920 million tons, around 2.5% of global CO_2 emissions. Demand for maritime transport is forecasted to increase amid the growth of the world economy.

Measures for tackling the climate change in a global manner are being discussed under the United Nations Framework Convention on Climate Change (UNFCCC). However, GHG emissions from international shipping and aviation sectors operating beyond national borders are difficult to be separated and allocated to countries, by nationality of the ship or aircraft, or by the country that operates them. Thus, actions to reduce emissions from these sectors are not compatible with the country-specific reduction measures of the UNFCCC. For these reasons, the Kyoto Protocol states that the control or reduction of their respective GHG emissions will be pursued through activities conducted through the IMO and the International Civil Aviation Organization (ICAO), which are specialized agencies of the United Nations.

The IMO adopted the initial IMO Strategy on Reduction of GHG emissions from Ships (hereafter “the IMO Strategy”) to reduce GHG emissions from ships in April 2018. The IMO Strategy sets GHG reduction targets: (1) to reduce carbon intensity (i.e. CO2 emissions per transport work) of international shipping by at least 40% by 2030 compared to 2008, (2) to reduce the total annual GHG emissions from international shipping by at least 50% by 2050 compared to 2008, and (3) to phase out GHG emissions from international shipping as soon as possible, in this century.

Against this background, in 2018, Japan established the “Shipping Zero Emission Project” (hereinafter referred to as "this project") in collaboration with industry, academia, government, and public sectors. A "Roadmap to Zero Emission from International Shipping" was developed in 2020, mainly summarizing the following.

- Regulatory measures necessary to achieve the 2030 target (40% improvement in average fuel consumption) set in the IMO strategy

- Fuel mix scenarios to achieve the 2050 target (50% reduction in total emissions)

- Roadmap for R&D and practical application required to achieve post-2050 goals

- Conceptual design of zero-emission / ultra-low carbon ships

The IMO strategy is to be revised in 2023. Since the adoption of the strategy in 2018, global interest in combating climate change has been increasing, and international shipping is required to make further efforts to reduce GHG emissions. At the 77^{th} session of the Marine Environment Protection Committee (MEPC 77), the Committee, in view of the urgency for all sectors to accelerate their efforts to reduce GHG emissions as emphasized in the recent IPCC reports and the Glasgow Climate Pact, recognized the need to strengthen the ambition of the strategy during its revision process. In Japan, the Government of Japan and shipping industry announced in October 2021 that they would aim for net zero GHG emissions from international shipping by 2050, and such initiatives to reduce GHG emissions at the government or industry level are spreading worldwide.

As one of the world's leading shipping and shipbuilding countries, it is important for Japan to lead the way in reducing GHG emissions from international shipping, both in terms of establishing an international framework at IMO and in technological development, and to actively contribute to achieving net zero GHG emissions from international shipping in 2050.

Section 1.2: Purpose

Based on the above background, in this report, we collected and organized the latest information on the forecasted diffusion of zero-emission fuels, organized domestic and international technology development trends and issues for the realization of zero-emission ships, conducted GHG emission reduction simulations based on various scenarios, and summarized regulatory developments that are considered necessary to achieve net zero emissions in 2050.

Based on the findings obtained through this review work, Japan will discuss the revision of the IMO strategy and mid- and long-term measures at IMO.

Section 1.3: Outline of the Project

This report outlines the results of the Project in the structure mentioned below.

(1) GHG reduction from international shipping (Chapter 2)
(2) Measures to achieve at least 40% improvement in average fuel efficiency by 2030 (Chapter 3)
(3) Trends in zero-emission fuel supply (Chapter 4)
(4) Organizing technology development issues and trends for zero-emission ships (Chapter 5)
(5) GHG emission reduction simulation (Chapter 6)
(6) Regulatory developments (Chapter 7)

Chapter 2: GHG Reduction from International Shipping

<u>Section 2.1: Targets Set by the Strategy</u>

In April 2018, the Initial IMO Strategy on reduction of GHG emissions from ships ("the IMO Strategy") was adopted at the 72nd session of the IMO's Marine Environment Protection Committee (MEPC 72). Figure 2.1-1 gives an overview of the IMO Strategy. The IMO Strategy sets the following GHG reduction targets[1]:

- To reduce carbon intensity (i.e. CO_2 emissions per transport work) of international shipping by at least 40% by 2030, compared to 2008

- To reduce the total annual GHG emissions from international shipping by at least 50% by 2050, compared to 2008

- To phase out GHG emissions from international shipping as soon as possible, in this century

In addition, the IMO Strategy specifies candidate measures for the reduction of GHG emissions for achieving the targets mentioned above. They are classified into three types as follows:

- Short-tern measures: To be agreed between 2018 and 2023 (e.g. Fuel efficiency regulations for existing ships)

- Mid-tern measures: To be agreed between 2023 and 2030 (e.g. the introduction of market-based measures (MBM))

- Long-tern measures: To be agreed beyond 2030 (e.g. Promoting the introduction of zero-carbon fuels)

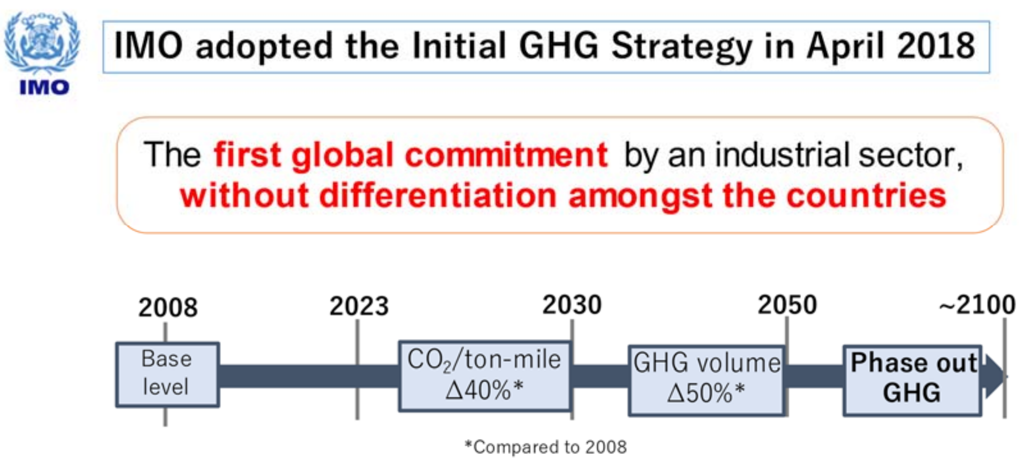

Figure 2.1-1: Overview of the Initial IMO strategy

The IMO Strategy is to be revised in the spring of 2023. Discussions on the revision were initiated at the 77th session of the Marine Environment Protection Committee (MEPC 77) held

[1] International Maritime Organization [IMO]. (2018). Adoption of the initial IMO strategy on reduction of GHG emissions from ships and existing IMO activity related to reducing GHG emissions in the shipping sector. https://unfccc.int/sites/default/files/resource/250_IMO%20submission_Talanoa%20Dialogue_April%202018.pdf

in November 2021, and as a result of the deliberations, the Committee, in view of the urgency for all sectors to accelerate their efforts to reduce GHG emissions as emphasized in the recent IPCC reports and the Glasgow Climate Pact, recognized the need to strengthen the ambition of the strategy during its revision process. Discussions will continue with the aim of agreeing on a revised draft at MEPC80, scheduled to be held in July 2023[2].

Section 2.2: The Movement for Net Zero GHG emissions in 2050

Since the adoption of the Strategy in 2018, global interest in combating climate change has been growing, and international shipping is required to make further efforts to reduce GHG emissions. Around the world, governments, industry groups, and individual private companies have begun to set even more ambitious goals to achieve carbon neutrality and net zero GHG emissions by 2050. One of the main reasons for this is “the Special Report on Global Warming of 1.5°C” compiled by the Intergovernmental Panel on Climate Change (IPCC) released in October 2018. In the report, the following is mentioned[3]:

- At the current rate of progress, global warming will reach 1.5°C in 2030-2050.

- It is not impossible to limit global warming to 1.5°C. However, it will require an unprecedented transition in all aspects of society.

- CO2 emissions must be reduced by 45% by 2030 and reach net zero around 2050.

The 24th session of the Conference of the Parties (COP24: December 2-15, 2018, Katowice, Poland) to the UNFCCC also adopted a decision document that included a request for parties to use the information contained in the Report in all agenda items under the UNFCCC subsidiary bodies[4], which is considered to be the background for each country to become more aware of the net zero goal in 2050.

In April 2021, U.S. President Biden, who took office in the same year, hosted a climate summit, and at this side event, Kerry, the US Special Presidential Envoy for Climate, announced that the US would work with other countries to establish ambitious reduction targets and measures to achieve them in IMO, so that international shipping can achieve zero emissions by 2050[5]. In Japan, in 2020, Prime Minister Suga (at that time) set a goal to be carbon neutral by 2050, targeting all domestic industries, and on October 26, 2021, Minister of Land, Infrastructure, Transport and Tourism Saito expressed that Japan aims to achieve net zero GHG emissions from international shipping by 2050. On the same day, the Japanese Shipowners' Association also announced its "Challenge to achieve net zero GHG emissions by 2050”[6]. In MEPC77, a number of delegations stressed the need for the Organization to send a clear signal on its commitment to reduce GHG emissions from ships to achieve zero emissions by 2050, as stated by many, or net zero emissions by 2050, as stated by others.

In order to achieve net zero emissions by 2050, it is essential to promote the use of zero-emission ships that do not emit GHGs. As a move to establish shipping routes where zero-emission ships operate (called "Green Shipping Corridor" etc.), the Clydebank Declaration was

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[2] IMO. (2021). MEPC 77/16, Report of the Marine Environmental Protection Committee on its seventy-seventh session.

[3] IPCC. (2018). Global warming of 1.5°C.
https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf

[4] United Nations. (2018). Report of the Conference of the Parties on its twenty-fourth session, held in Katowice from 2 to 15 December 2018.
https://unfccc.int/sites/default/files/resource/10a1.pdf

[5] Volcovici, V. (2021, April 21). U.S. to join effort to curb climate-warming emissions from shipping. Reuters.
https://www.reuters.com/business/environment/us-join-global-effort-decarbonize-shipping-industry-kerry-2021-04-20/

[6] The Japanese Shipowners’ Association. (2021). Japanese Shipping Industry Announces “Challenge of 2050 Net Zero GHG.”.
https://www.jsanet.or.jp/e/pressrelease_e/2021/pdf/20211026e.pdf

announced at the 26th Conference of the Parties to the UNFCCC in 2021 (COP26: October 31-November 12, 2021, Glasgow, UK), led by the UK Department for Transport. 22 countries including Japan participated as signatories[7].

<Reference: Signatory countries to the Clydebank Declaration>
Australia, Belgium, Canada, Chile, Costa Rica, Denmark, Fiji, Finland, France, Germany, Ireland, Italy, Japan, Marshall Islands, Morocco, Netherlands, New Zealand, Norway, Spain, Sweden, United Kingdom, United States

On September 24, 2021, a summit of the four countries "QUAD" by Japan, the United States, Australia, and India was held, and the joint statement included a commitment to promote decarbonization of shipping and port operations. The attachment (fact sheet) of the joint statement states that the four Quad countries are in a position to develop green port infrastructure and use of clean marine fuels on their own large scale and have launched a Quad Shipping Task Force and to decarbonize the shipping value chain. It specifies the formation of a network dedicated to greening and decarbonizing and the establishment of two to three low-emission or zero-emission shipping corridors by 2030 as a Quad[8].

In addition to the above, there is Mission Innovation (Zero Emission Shipping Mission) as an international framework to which Japan is not a member. Mission Innovation is a framework established in 2016 under the leadership of the United States and France to promote international cooperation in various fields, and as of March 2022, 13 fields, including the Zero Emission Shipping Mission, have become targets of cooperation. The Zero Emission Shipping Mission is led by Denmark, Norway, and the United States, with 10 other countries including the United Kingdom and South Korea and 2 organizations, as members. The Zero Emissions Shipping Mission is very ambitious, with the goal of having at least 5% (based on fuel consumption) of the world's ocean shipping fleet powered by zero-emission fuels throughout their life cycle by 2030, including green hydrogen, green ammonia, green methanol, and advanced biofuels, and having at least 200 ships primarily using these fuels on major ocean shipping routes. In addition, at COP26 (November 2021), the Prime Minister of Denmark announced the "Declaration on Zero Emissions Shipping by 2050," which was signed by 14 countries, including the United Kingdom and the United States. Signatories to the Declaration are urged to act in the IMO's international negotiations and strengthen international cooperation to achieve zero emissions from international shipping by 2050, so that the IMO's 2050 GHG reduction targets are revised to be more ambitious and the 2040 and 2030 targets are adopted as a path to achieving them.

There are various movements at the private level as well. For example, the Getting to zero Coalition hosted by the Global Maritime Forum has 230 member companies and organizations, including some of the world's leading shippers in global energy development, resource development, grain trading[9]. In September, 2021, the coalition declared “Call to Action for Shipping Decarbonization” urging national governments to do the following[10].

- Commit to decarbonizing international shipping by 2050.

- Support projects to achieve zero-emission shipping.

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[7] GOV.UK. (2021b). COP 26: Clydebank Declaration for green shipping corridors. https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

[8] The Ministry of Foreign Affairs press release: https://www.mofa.go.jp/mofaj/fp/nsp/page4_005424.html

[9] Getting to Zero Coalition. (2021). Ambition Statement. http://www.globalmaritimeforum.org/content/2019/09/Getting-to-Zero-Coalition_Ambition-statement_230919.pdf

[10] Global Maritime Forum. (2021). Call to Action for Shipping Decarbonization. https://www.globalmaritimeforum.org/content/2021/09/Call-to-Action-for-Shipping-Decarbonization.pdf

- Take policy measures to ensure that zero-emission ships are the default option by 2030

From Japan, shipping companies, trading companies, ClassNK, etc. are also participating in Getting to Zero Coalition.

In October 2021, 9 companies including Amazon.com in the US, IKEA, the world's largest furniture company in Sweden, Unilever in the UK, and Michelin, a major French tire company, launched an organization called Cargo Owners for Zero Emission Vessels (coZEV) and announced that it aims to decarbonize international maritime transport by major shippers by 2040 and to achieve net zero GHG emissions by 2050 in order to achieve the goals of the Paris Agreement, and has stated that only ships using decarbonized fuels such as hydrogen and ammonia will be used to transport their goods[11].

Shipping companies are also launching net zero GHG emissions goals one after another. In October 2021, the International Chamber of Shipping (ICS) announced its support for the shipping industry to achieve net zero CO2 emissions in international shipping by 2050[12]. Maersk, the world's largest shipping company, announced in January 2022 its goal of achieving net zero GHG emissions in 2040[13]. Mitsui O.S.K. Lines (MOL), NYK Line, and Kawasaki Kisen Kaisha (K Line), Japan's leading shipping companies, also announced net zero GHG emissions targets by 2050 in June, September, and November 2021, respectively[14][15][16].

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[11] Cargo Owners for Zero Emission Vessels [coZEV]. (2021). Leading Cargo Owners Stand Together for Maritime Decarbonization.
https://www.cozev.org/img/FINAL-coZEV-2040-Ambition-Statement_2021-10-18-144834_uorz.pdf

[12] ICS. (2021). MEPC 77/7/22, Comments on a proposed draft MEPC resolution on zero emission shipping by 2050, and revision of the IMO GHG Strategy.

[13] Maersk. (2021). A.P. Moller - Maersk accelerates Net Zero emission targets to 2040 and sets milestone 2030 targets. https://www.maersk.com/news/articles/2022/01/12/apmm-accelerates-net-zero-emission-targets-to-2040-and-sets-milestone-2030-targets

[14] Mitsui O.S.K. Lines. (2021). - Aiming at Net Zero GHG Emissions by 2050 - Introducing 'MOL Group Environmental Vision 2.1'. https://www.mol.co.jp/en/pr/2021/21052.html

[15] NYK Line. (2021). NYK Announces Target of Net-Zero Emissions by 2050 for Oceangoing Businesses. https://www.nyk.com/english/news/2021/20210930_03.html

[16] Kawasaki Kisen Kaisha, Ltd. (2021). The Challenge of Achieving Net-Zero GHG Emissions. https://www.kline.co.jp/en/news/ir/auto_20211102423677/pdfFile.pdf

Chapter 3: Measures to Achieve at Least 40% Improvement in Average Energy Efficiency by 2030

Section 3.1: Improving the Energy Efficiency of New Ships (EEDI Regulations)

The EEDI regulations impose a standardized energy efficiency index[17] to mandate new ships to ensure that their energy efficiency is equivalent or superior to a predetermined requirement level (the required EEDI). In July 2011, the IMO adopted amendments to MARPOL Annex VI which entered into force in 2013. The required EEDI is set for each ship type, and the Convention stipulates that the required EEDI is basically strengthened by 10% every 5 years, as shown in Table 3.1-1.

Table 3.1-1: The Level of Required EEDI under MARPOL Annex VI

	Year of application (on the basis of the shipbuilding contract)	Required EEDI
Phase 0	2013-	Average EEDI of ships built between 1999 and 2008
Phase 1	2015-	10% better than Phase 0
Phase 2	2020-	20% better than Phase 0
Phase 3	2022- / 2025-	30% to 50% better (determined by ship type and by size) than Phase 0

Section 3.2: Improving the Fuel Efficiency of Existing Ships

In order to achieve the target for 2030 included in the GHG Reduction Strategy (to improve average fuel efficiency by at least 40% by 2030 (compared to 2008)), it is necessary to take measures to improve fuel efficiency for existing ships that are not subject to EEDI regulations (Ships contracted for construction before 2013).

For this reason, a draft amendment to MARPOL Annex VI was adopted in June 2021 to introduce fuel efficiency regulations (EEXI regulations[18]) and Carbon Intensity Indicator ratings (CII ratings[19]) for existing ships, and is expected to be introduced in January 2023 (see Figure 3.2-1).

[17] EEDI: stands for Energy Efficiency Design Index.
[18] EEXI: stands for Energy Efficiency Existing Ship Index.
[19] CII: stands for Carbon Intensity Indicator

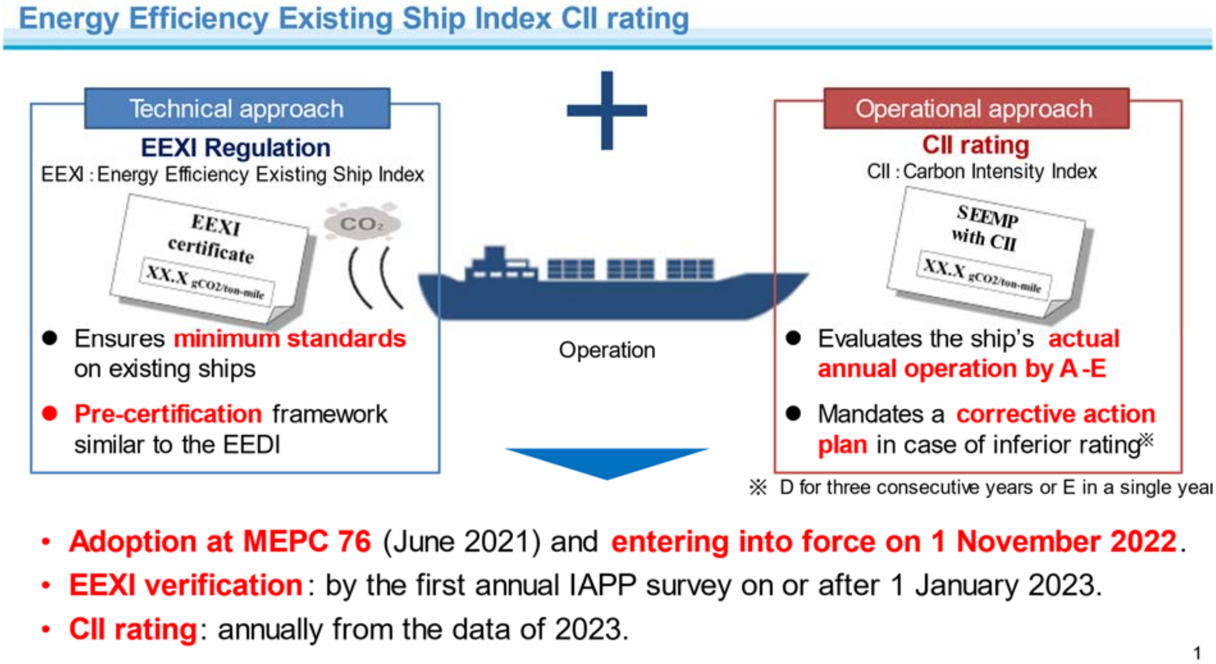


Figure 3.2-1: Fuel efficiency improvement measures for existing ships
(EEXI regulations and CII rating)

Chapter 4: Information on Zero-Emission Fuel Supply

Section 4.1: Future Projections for Achieving Net Zero GHG Emissions

In May 2021, the IEA issued "Net Zero by 2050 A Roadmap for the Global Energy Sector[20]," which presents future projections (NZE scenario) for the entire world to achieve net zero GHG emissions in 2050.
The outlook for primary energy supply under the IEA NZE scenario is shown in Figure 4.1-1. While the share of fossil fuels is expected to decline compared to today, renewable energy is expected to account for two-thirds of the total energy in 2050, a significant change from the current energy mix.

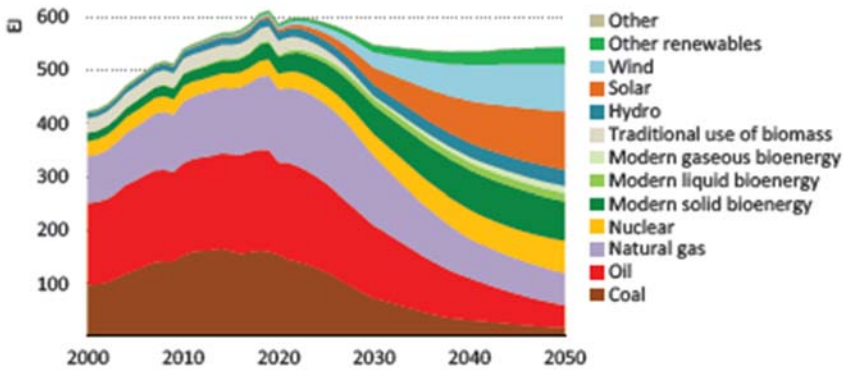


Figure 4.1-1: Primary energy supply outlook under the IEA NZE Scenario

In the IEA NZE scenario, it is expected to be important how electric power produced by renewable energy, which is expected to expand toward 2050, and zero emission fuels to which gaseous hydrogen generated from that electric power be applied, will be deployed in each field. The fuels shown in Figure 4.1-2 can be considered as alternative fuels with the potential to be used more widely in the marine industry.

	Zero-emission fuel		Carbon neutral fuel		
	Hydrogen (LH2)	Ammonia	Carbon Recycled (CR) Synthetic Methane	CR synthetic methanol	Biodiesel (FAME)
Lower Calorific Value (GJ/t)	120.0	18.8	50.0	19.9	37.1
Liquid density (t/m³)	0.0708	0.7	0.422	0.79	0.885
CO2 conversion factor (CO2-t/fuel-t)	0	0	(0＊)	1.375	0
Volume ratio per calorific value (VLSFO ratio, @ liquefied state)	4.42	2.86	1.78	2.39	1.14
CO2 emissions per calorie (CO2-g/GJ)	0	0	(0＊)	(0＊)	0
By-product GHGs and global warming potential (From IPCC AR5)		N2O Global warming potential: 265	Methane (Slip) Global warming potential: 28		
Boiling point (℃)	-253	-33	-161	65	345～354
Storage method on board (liquid state)	Vacuum heat shielded tank	TypeC (low temperature or pressurized) Independent square tank/ Membrane	TypeC (low temperature or pressurized) Independent square tank/ Membrane	Normal temperature and pressure Tank with hull	Normal temperature and pressure Tank with hull
Properties when stored on board (liquid state)	abt.-250℃, 0.5MPa	-30～-10℃, 0.07～0.5MPa	-160～-140℃, 0.07～0.5MPa	Normal temperature Normal pressure	Normal temperature Normal pressure
Point of ignition (℃)	560	630	537	440	256～266
Low-speed marine engine cycle	Diesel / Otto	Diesel / Otto	Diesel / Otto	Diesel / Otto	Diesel
Pilot fuel	Required	Required	Required	Required	Blended with FO

*If the emissions of CO2 as raw material have already been counted on land or are directly captured from the air (DAC)

Figure 4.1-2: Alternative fuel options

The IEA NZE scenario also shows the outlook for energy consumption in each industrial sector,

[20] International Energy Agency (2021), Net Zero by 2050 A Roadmap for the Global Energy Sector

and for the shipping sector, as shown in Figure 4.1-3, hydrogen, ammonia, and biofuels are the main energy sources. In addition, it is analyzed that ammonia and biofuels are considered to be the most promising sources based on energy density and quantity, the development schedule of large engines and so on. As shown in the figure, it is predicted that some fossil fuels will remain used in the shipping sector as of 2050, resulting in 122 Mt CO2 emissions. In the IEA NZE scenario, this CO2 emission is expected to be offset with applications of BECCS (bioenergy with carbon capture and storage) and DACCS (direct air capture with carbon capture and storage).

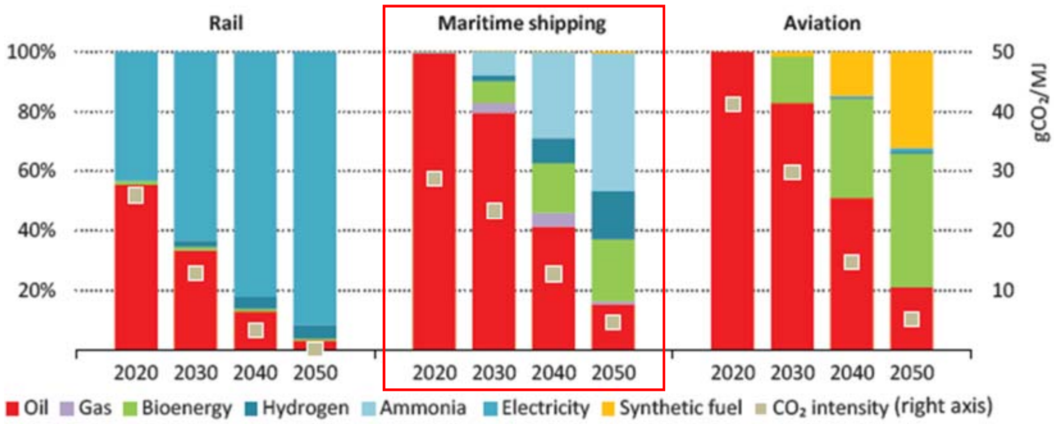


Figure 4.1-3: Energy consumption in the transportation sector under the IEA NZE scenario

According to the IEA, the costs and demand for zero-emission fuels to achieve net zero GHG emissions globally in 2050 are shown in Table 4.1-1 below.

Table 4.1-1: IEA targets for zero-emission fuels[21][22]

		2030 Target (Technology development)	2030 Target (Cost and supply)	2050 Target (Cost and supply)
Hydrogen The amount of hydrogen supplied as gaseous hydrogen. The amount of hydrogen produced as a raw material for ammonia and synthetic fuels are excluded.	Green	【Improvement of efficiency of water electrolysis equipment and reduction of equipment cost】 Alkaline water electrolysis： Efficiency 63～70→65～71% Equipment cost 500～1400→400～850$/kW PEM electrolysis： Efficiency 56～60→63～68% Equipment cost 1100～1800→650～1500$/kW	【Cost】 2.6USD/kg 【Supply】 54 million tons (≒6.5EJ)	【Cost】 2.1USD/kg 【Supply】 180 million tons (≒22EJ)
	Blue	-	【Cost】 1.4USD/kg 【Supply】 46 million tons (≒5.5EJ)	【Cost】 1.4USD/kg 【Supply】 110 million tons (≒13EJ)
Ammonia Including not only fuels but also raw material ammonia		-	【Supply】 250 million ton-NH3 (≒4.7EJ) Breakdown Marine: 33 million tons (≒0.62EJ) Aviation: 0 ton Power generation: 36 million tons (≒0.68EJ) Other industries (fuel): 0 ton Other industries (raw materials): 200 million tons (≒3.8EJ)	【Supply】 610 million ton-NH3 (≒13EJ) Breakdown Marine: 250 million tons (≒4.7EJ) Aviation: 0 ton Power generation: 90 million tons (≒1.7EJ) Other industries (fuel): 40 million tons (≒0.75EJ) Other industries (raw materials): 220 million tons (≒4.1EJ)
Synthetic fuels Including methane, methanol, synthetic jet fuel, etc.		-	【Supply】 5 million ton-H2 equivalent (≒ 0.6EJ) Breakdown Marine: 10,000 tons (≒0.001EJ) Aviation: 1.5 million tons (≒0.18EJ) Other industries: 3.5 million tons (≒0.42EJ)	【Supply】 100 million ton-H2 equivalent (≒12EJ) Breakdown Marine: 450,000 tons (≒0.05EJ) Aviation: 38 million tons (≒4.56EJ) Other industries: 61 million tons (≒7.32EJ)
Biofuels Including liquid and gaseous fuels		-	【Supply】 18EJ Breakdown Marine: 0.82EJ Aviation: 2.1EJ Other industries: 15EJ	【Supply】 28EJ Breakdown Marine: 2.1EJ Aviation: 6.3EJ Other industries: 20EJ

21 Prepared by the secretariat based on the following:
IEA Net Zero by 2050 A roadmap for the Global Energy Sector
IEA Global Hydrogen Review 2021

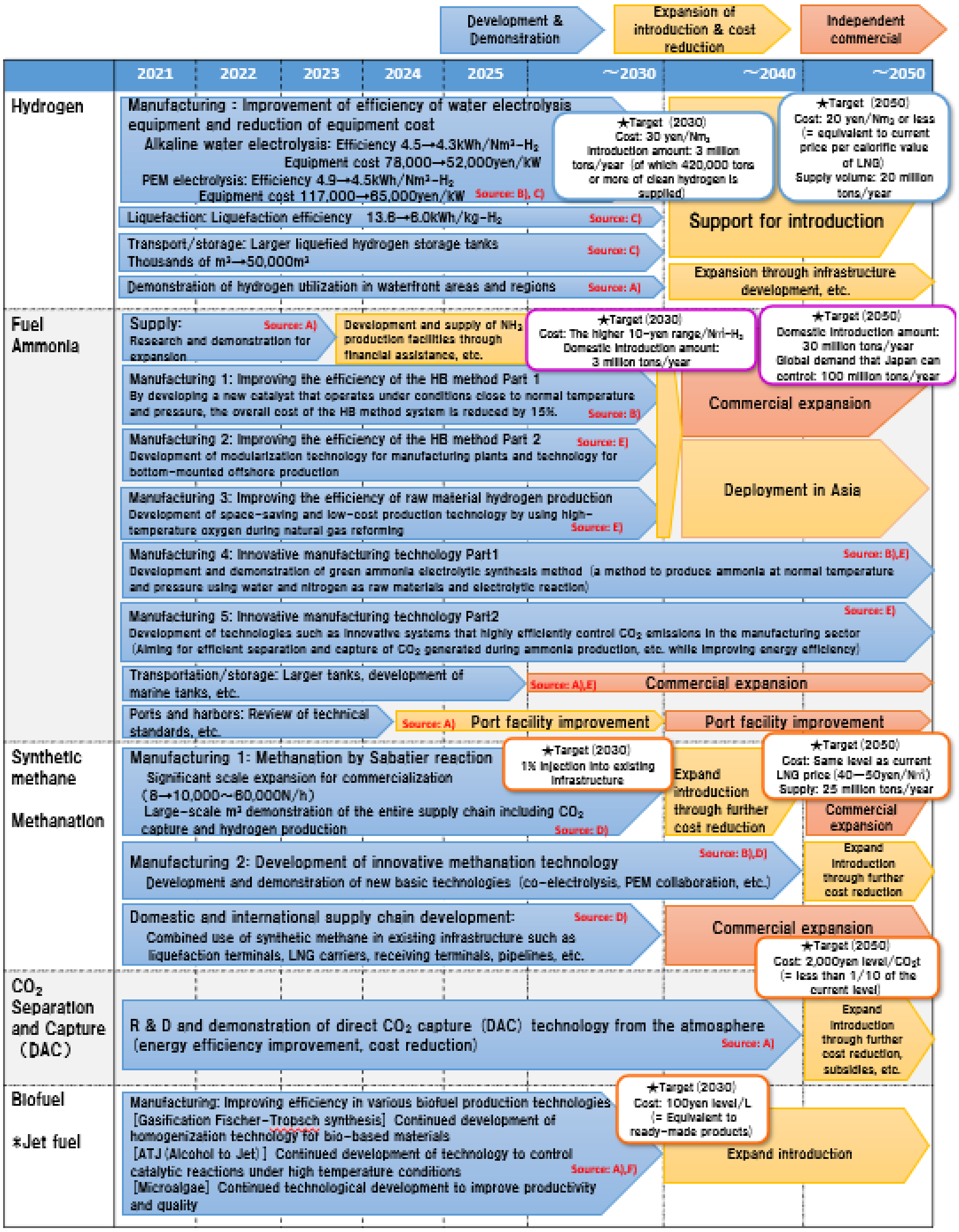
22 Global ship fuel consumption (energy equivalent) in 2050 will be 9.9 EJ, of which 1.5 EJ is expected to remain using heavy oil

Section 4.2: Outlook for Domestic Alternative Fuel Supply

In June 2021, the Government of Japan announced the "Green Growth Strategy Through Achieving Carbon Neutrality in 2050", which lays out its policy for future efforts to achieve carbon neutrality by 2050, as well as a process chart for key technologies in each field by 2050.

In the process chart, specific measures are presented with an awareness of (1) the "R&D phase" that is promoted by the fund established by the government and private R&D investment, (2) the "demonstration phase" that is promoted by the public- and private-sector co-investment on the premise of inducing private investment, and (3) the "introduction expansion phase," in which demand will increase through the development of public procurement, regulations, standardization, and other systems, and costs will be reduced through mass production accompanying this, and (4) the "independent commercialization phase," in which commercialization will proceed independently without public support, based on regulations, standards, and other systems. Table 4.2-1 summarizes the process chart related to the supply of alternative fuels based on the Green Growth Strategy Through Achieving Carbon Neutrality in 2050 and other factors.

Table 4.2-1: Process chart related to alternative fuel supply in the Green Growth Strategy Through Achieving Carbon Neutrality in 2050[23]



23 Prepared by the secretariat with reference to the following
A) Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (June 18, 2021)
B) Information on open call for participants of the Green Innovation Fund
C) Hydrogen Roadmap (Ministry of Economy, Trade and Industry, June 8, 2020)
D) Technology roadmap for the gas sector regarding "Transition Finance" (Ministry of Economy, Trade and Industry, February 2022)
E) Interim Report of the Public-Private Fuel Ammonia Promotion Council (Ministry of Economy, Trade and Industry, February 8, 2021)
F) NEDO Technology Strategy Center (TSC), Report Toward the Development of a Technology Strategy for the Next-Generation Biofuels (Bio jet Fuel) Field

Section 4.3: Trends in Alternative Fuel Production Projects for Marine Use

Table 4.3-1 shows trends in alternative fuel production projects for marine use. In addition to projects related to zero-carbon fuels derived from hydrogen (hydrogen and ammonia), efforts related to carbon-neutral fuels[24] are also underway in the maritime sector.

Table 4.3-1: Trends in alternative fuel production projects for marine use[25]

No.	Fuel type	Producing country	Year production started	Annual production (t-H2)	Project overview
1	Hydrogen	Belgium	2022	11,000	Development of green hydrogen generation facilities.
2	Hydrogen / Ammonia	Australia	2023	10,500	Construct a solar power generation facility and supply the generated green hydrogen to an ammonia production plant.
3	Hydrogen / Ammonia	Norway	2023	800	Green hydrogen is produced and used for fertilizer production and fuel ammonia.
4	Hydrogen	Denmark	2023	Unknown	Produce renewable hydrogen using offshore wind.
5	Hydrogen	Norway	2023	Unknown	Development of green hydrogen generation facilities.
6	Hydrogen / Ammonia	Netherlands	2024	Unknown	Development of 100 MW water electrolysis facility and green ammonia plant.
7	Methanol	Belgium	2024	Unknown	Development of a plant to produce methanol from green hydrogen.
8	Hydrogen	Germany	2025	5,000	Development of a 30 MW electrolysis facility.
9	Hydrogen	Netherlands	2025	86,000	Achieve large-scale production of blue hydrogen in the industrial area of Rotterdam.
10	Hydrogen	Netherlands	2040	800,000	Produce green hydrogen with 10 Gigawatts of wind energy in the North Sea.
11	Hydrogen / Ammonia	Finland	Unknown	Unknown	Build facilities to produce hydrogen and ammonia offshore using offshore wind power.
12	Hydrogen	Germany	Unknown	Unknown	Build the world's largest hydrogen electrolysis plant powered by wind power in the Port of Hamburg.
13	Hydrogen	Oman	Unknown	Unknown	Development of equipment for hydrogen generation from solar power.
14	Hydrogen / Ammonia / Methanol	Oman	Unknown	40,000	Construction of a green hydrogen production plant in Duqm (Oman).
15	Methanol	Norway	Unknown	Unknown	Build a facility to produce methanol from renewable energy and waste CO2 gas.
16	Hydrogen / Methanol	Denmark	Unknown	Unknown	Build hydrogen and e-fuel production facilities.
17	Methanol	Belgium	Unknown	Unknown	Build a plant in Antwerp to produce methanol from CO2 and hydrogen.
18	Methane	Japan	Unknown	Unknown	Methane is produced from CO2 and used as fuel for ships.
19	Methanol	Sweden	Unknown	Unknown	Build a facility to capture and recycle CO2 to produce e-methanol fuel.
20	Hydrogen	Germany	Unknown	Unknown	Build a 700 MW hydrogen production plant by 2030.

24 Carbon Capture and Reuse (CCR), (Project No. 18 in Table 4.3-1), etc.
https://ccr-tech.org/

25 Prepared by the secretariat using Getting to Zero Coalition, Mapping of Zero Emission Pilots and Demonstration Projects
https://www.globalmaritimeforum.org/news/new-mapping-of-zero-emission-pilots-and-demonstration-projects-shows-an-increasing-focus-on-hydrogen-based-fuels

Chapter 5: Information on Technological Development and Related Technical Issues for Zero-Emission Ships

Section 5.1: Technical Development Issues for Zero-Emission Ships

Toward zero-emissions in international shipping, it is necessary to introduce and promote zero-emission ships.

Since zero-emission ships will use new fuels such as hydrogen and ammonia instead of heavy oil, which is the existing marine fuel, there are technical development issues in terms of engines, onboard storage, auxiliary equipment, fittings, bunkering, etc.

In this project, we have summarized the current technical development issues and other issues that can be considered for zero-emission ships (See Table 5.1-1).

Table 5.1-1: Technical development issues for zero-emission ships

		Expected use on board	Combustion	Onboard storage	Auxiliary engine, fittings, etc.	Bunkering	Others	Other than technical issues
Hydrogen fueled ship	Direct combustion	Main and auxiliary engines	• Diesel cycle: High-pressure fuel supply device (30 to 50 MPa or more for direct injection) • Otto Cycle: Control technology for abnormal combustion (knocking and misfire)	• Space efficiency during storage	• Fitting that is resistant to low temperatures and hydrogen embrittlement	• Safety of liquid hydrogen bunkering		Establishment of fuel supply system / Development of ship safety standards / Development of competency requirements of seafarers and international standardization / Recruitment and training of seafarers / Development of technical personnel in shipbuilding and maritime sector.
	Fuel cell	Large ship: Main engine Medium and small size ship: Main and auxiliary engines	• Development of SOFC (Solid Oxide Fuel Cell) with high efficiency (about 60%) similar to that for land use (insulation material resistant to thermal changes corresponding to power generation at 500~1000 ° C)					
Ammonia fueled ship	Direct combustion	Main and auxiliary engines	• Technology to handle unburned ammonia and reduce pilot fuel • Detailed understanding of the actual state of N2O (elucidation of generation mechanism and development of generation suppression method) and reduction measures (post-treatment with catalyst, etc.)		• Onboard power supply and steam supply system using ammonia or ammonia reformed hydrogen • Fitting for corrosion and leakage	• Ammonia fuel bunkering (offshore)	• Corrosion and leakage prevention (including detection sensors, etc.) • Ammonia gas treatment technology (purge gas, leakage gas, BOG)	Establishment of fuel supply system / Development of ship safety standards / Development of competency requirements of seafarers and international standardization / Recruitment and training of seafarers / Development of technical personnel in shipbuilding and maritime sector/ Environmental impact assessment
	Fuel cell (ammonia reforming or direct use)	Large ship: Auxiliary engine Medium and small size ship: Main and auxiliary engines	• Development of SOFC (Solid Oxide Fuel Cell) with high efficiency (about 60%) similar to that for land use (insulation material resistant to thermal changes corresponding to power generation at 500~1000 ° C)					
Methane (bio/synthetic)		Same as LNG fueled ships	• Technology for LNG fueled ships can be converted. • Measures against methane slip (especially for small/medium output 4-stroke engines. Engine				• Determine the amount of methane leaks (emission from low-pressure compressors and	Establishment of the concept that fuel emissions on board are treated as zero at IMO / Establishment of fuel

Table 5.1-1 (Cont.): Technical development issues for zero-emission ships

		improvement, methane oxidation catalyst, etc. are under consideration)				FGSS, and emission during gas-free operation) and take action to address these leaks.	supply system
Diesel oil (bio/synthetic)	Blending with low sulfur heavy oil or dedicated combustion (main and auxiliary engines)	• FAME: Suppression of NOx increase • FAME: Ensure compliance with NOx regulations	• FAME: Corrosion protection for biodiesel oil • FAME: Measures against deterioration during onboard storage			• Suppression of sludge when mixing	
Ethanol (bio/synthetic)	Main and auxiliary engines	Technically established					
Retrofit technology (Retrofit from LNG fueled ships, etc. to alternative fuel ships)	Main and auxiliary engines (direct combustion, fuel cell)	Engine capable of burning new fuel with partial refurbishment	Dual-use tanks, material selection	Auxiliary engine, fittings, and instrumentation equipment that can be partially replaced or concurrently	Bunkering ships that can be dual-purpose or converted	Minimization of modification workload	Seafarer training for multiple fuel types

Section 5.2: Trends in Zero-Emission Ship Technology Development

5.2.1 Initiatives in Japan (Green Innovation Fund)

Japan is promoting the "Development of Next-Generation Ships" project for the world's first practical use of zero-emission ships, by utilizing the "Green Innovation Fund" created by the New Energy and Industrial Technology Development Organization (NEDO), a national research and development agency.

In October 2021, four themes and implementers were selected for the "Development of Next-Generation Ships" project. The details are as follows (See Table 5.2.1-1 and Figures 5.2.1-1 to 5.2.1-4).

Table 5.2.1-1: Projects adopted by the Green Innovation Fund

Theme Title	Implemented by
Development of marine hydrogen engine and MHFS*. *MHFS: Marine Hydrogen Fuel Tank and Fuel Supply System	Kawasaki Heavy Industries, Ltd. Yanmar Power Technology Co., Ltd Japan Engine Corporation
Development of ships with ammonia fueled domestic engines	NYK Line Co., Ltd. Japan Shipyard Co., Ltd. Japan Engine Corporation IHI Motor Co., Ltd.
Integrated project for development and social implementation of ammonia fueled ships	ITOCHU Corporation Japan Shipyard Co., Ltd. Mitsui E&S Machinery, Co., Ltd. Kawasaki Kisen Kaisha, Ltd. NS United Kaiun Kaisha, Ltd.
Development of methane slip reduction technology from LNG fueled ships by catalyst and engine modification	Hitachi Zosen Corporation Yanmar Power Technology Co., Ltd Mitsui O.S.K. Lines, Ltd.

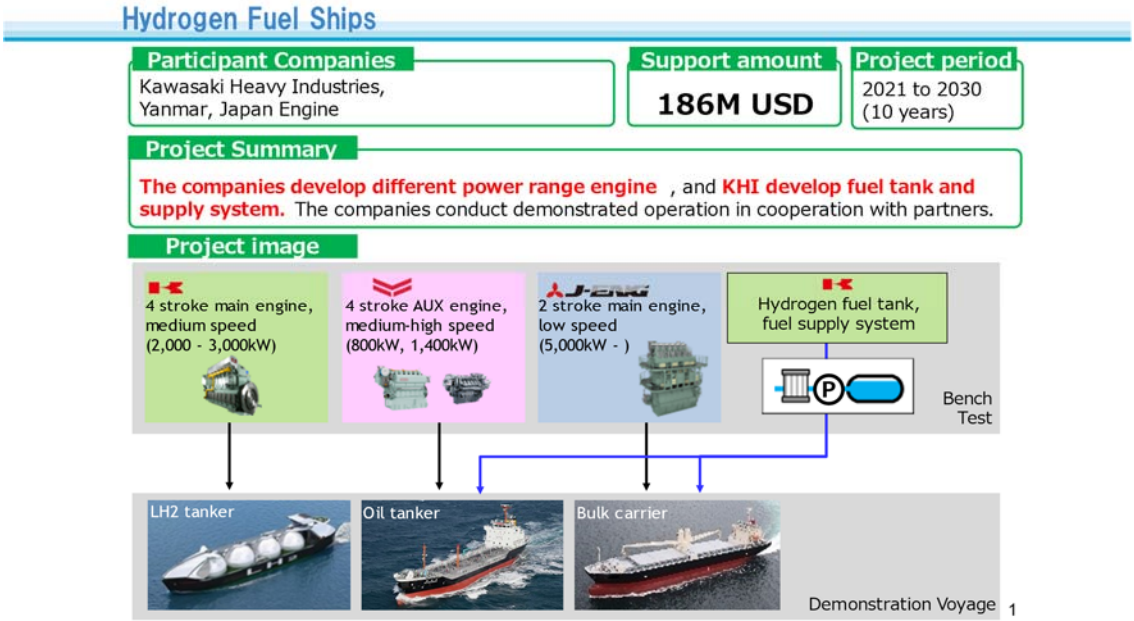


Figure 5.2.1-1: Project adopted by the Green Innovation Fund
(Development of marine hydrogen engine and MHFS)

Figure 5.2.1-2: Project adopted by the Green Innovation Fund
(Development of ships with ammonia fueled domestic engines)

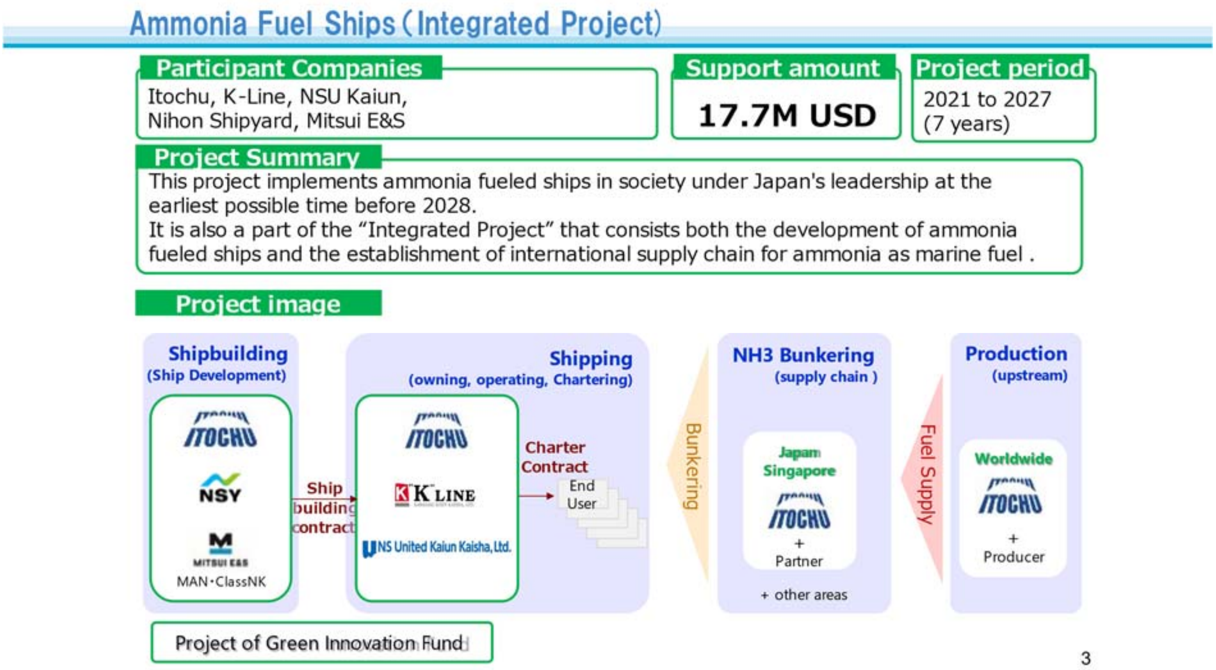


Figure 5.2.1-3: Project adopted by the Green Innovation Fund
(Integrated project for development and social implementation of ammonia fueled ships)

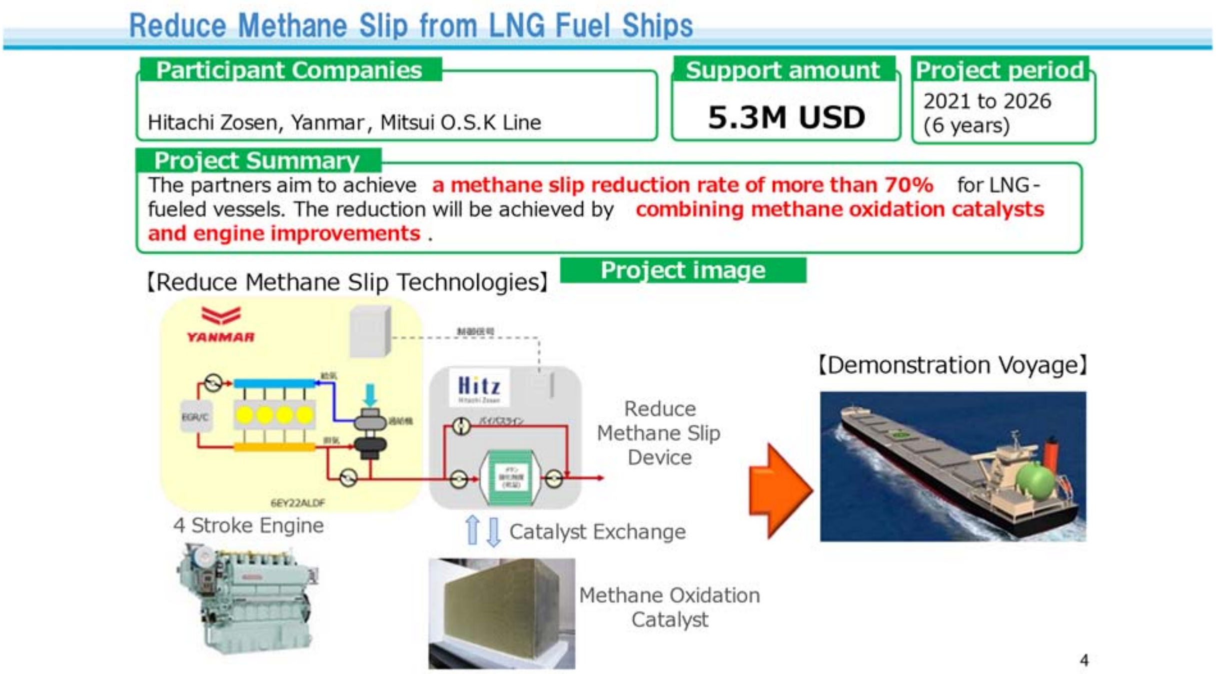


Figure 5.2.1-4: Project adopted by the Green Innovation Fund
(Development of methane slip reduction technology from LNG fueled ships by catalyst and engine modification)

5.2.2 Domestic and International Trends

The following is a summary of domestic and international technology development trends related to zero-emission ships.

5.2.2.1 Hydrogen Fueled Ships

Technology Development related to Hydrogen Combustion:

Engine development is underway for the introduction of hydrogen fueled ships. In the development of engines, the control of abnormal combustion (knocking, misfire, and premature ignition) in the case of the Otto cycle, and the development of high-pressure fuel supply systems in the case of the Diesel cycle are issues to be addressed.

The development status of hydrogen engines by domestic and overseas engine manufacturers is shown in Figure 5.2.2-1. Only one domestic engine manufacturer (J-ENG), the aforementioned Green Innovation Fund recipient, has announced the development of a large output 2-stroke hydrogen engine. On the other hand, many engine manufacturers are developing 4-stroke hydrogen engines with small to medium output.

	Output (kW)	Engine manufacturer	Target year for development	Remarks
2 stroke	5000kW~	J-ENG	FY2026※	GI Fund
4 stroke	1000kW~ 2670kW	ABC, CMB	2020	Mixed combustion (75% hydrogen)
4 stroke	645kW	MAN	2021	Mixed combustion (25% hydrogen) Plan to develop a dedicated combustion engine at the end of the 2020s
4 stroke	776kW~ 2535kW	Rolls Roys, mtu	2023	
4 stroke	Unknown	Wärtsilä	2025	
4 stroke	2000kW~ 3000kW	Kawasaki Heavy Industries	FY2026※	GI Fund
4 stroke	800kW	Yanmar	FY2026※	GI Fund (Engine with output of 1400 kW to be developed in sequence)

※ The target years indicates the completion of onshore testing prior to installation on ship.

Figure 5.2.2-1: Development trends of hydrogen engine in Japan and overseas

Other Technology Development:

Since hydrogen is approximately 4.5 times the volume per calorific value of heavy fuel oil C in its liquefied state, and the tank volume is bulky, it is necessary to develop hydrogen tanks that take into account volumetric efficiency during storage, and development is being promoted by the Green Innovation Fund.

In addition, it is necessary to develop fittings that are resistant to low temperatures and hydrogen embrittlement, and to develop bunkering technology that takes safety into consideration, and these developments must also be promoted in the future.

5.2.2.2 Ammonia Fueled Ships

Technology Development related to Ammonia Combustion:

Engine development is underway for the introduction of ammonia fueled ships. In developing engines, the treatment of unburned ammonia and the development of pilot fuel reduction technologies are issues to be addressed. In addition, since the combustion of ammonia emits more N2O than conventional heavy fuel oil combustion, which has a greenhouse effect about 300 times greater than that of CO2, it is important to understand the actual situation in detail (clarification of the generation mechanism and the amount of N2O generated) and develop technologies to reduce emissions (such as after-treatment using a catalyst).

The development status of ammonia engines by domestic and overseas engine manufacturers is shown in Figure 5.2.2-2. Development is underway with the aim of completing development around 2025.

	Output (kW)	Engine manufacturer	Target year for development	Remarks
2 stroke	Unknown	MAN	2024	4 strokes are planned to be developed (target year etc. are unknown)
2 stroke	8000kW	J-ENG	Middle of FY2025	GI Fund
2 stroke	5000kW~	WinGD	2025	
4 stroke	Unknown	Wärtsilä	2023	
4 stroke	1600kW	IHI Power Systems Co., Ltd	FY2023	GI Fund For main engine (coastal ships)
4 stroke	1300kW	IHI Power Systems Co., Ltd	FY2025	GI Fund For auxiliary engine

Figure 5.2.2-2: Development trends of ammonia engine in Japan and overseas

As for measures to reduce N2O emissions, one Japanese manufacturer (Hitachi Zosen) is currently developing an N2O decomposition catalyst.

Other Technology Development:

Since ammonia is corrosive and highly toxic, it is necessary to develop fittings that take this characteristic into account. In addition, it is necessary to develop treatment technology for leaked ammonia and bunkering technology that takes safety into consideration, and these developments must also be promoted in the future.

5.2.2.3 Fuel Cell Ships

As for fuel cell ships, demonstration projects are already underway in Japan and overseas as shown in Figure 5.2.2-3.

Ship type	Shipping company	Type of fuel cells	Target year for demonstration operation
Experimental ship (12 people)	Toda Corporation, Nagasaki Institute of Applied Science, ClassNK	PEFC (30kW x 2), battery (132kW), motor (220kW x 2) used together	2015
Passenger ship (75 people) Sea Change	SWITCH Maritime	Unknown (360 kW) with battery (100 kWh)	2022 Sea trials underway at All American Marine shipyard
Ro-Ro passenger ship Topeka	Wilhelmsen	PEFC (3MW) with battery (1000kW)	2024
Large ferry	KNUNDE HANSEN	PEFC	2027

Figure 5.2.2-3: Demonstration projects of fuel cell ships in Japan and overseas

Although there has been no activity regarding ammonia fuel cell ships in Japan, a project is underway in Europe to install a 2 MW ammonia fuel cell on the LNG fueled ship "Viking

Energy," with plans to test operate the ship in 2024[26].

5.2.2.4 Other Technologies

Methane (Bio/Synthetic) Fueled Ships:

LNG technology that has already been in practical use can be used, and LNG fueled ships and fuel supply infrastructure can be converted without modification. However, there are concerns about unburned CH_4, which has about 30 times the greenhouse effect of CO_2, leaking (methane slip) during combustion, and methane leaks from compressors, etc., which need to be identified and addressed.

Hitachi Zosen and Yanmar are developing a methane slip reduction technology by combining the development of methane oxidation catalysts with engine improvements as part of a Green Innovation Fund project to reduce methane slip emissions. After completing the onshore test at the end of FY2024, the PJ will move on to the actual ship demonstration with MOL, aiming for completion of the PJ in FY2026.

Diesel Oil (Bio/Synthetic) Fuel Ships:

While it has the advantage of being able to be used directly in existing heavy fuel oil fired ships, it should be noted that the following issues exist among biodiesel oils, particularly with respect to FAME (Fatty Acid Methyl Ester).

1. control of NOx increase
2. ensuring compliance with NOx regulations
3. corrosion preventions
4. measures against deterioration during onboard storage
5. sludge control when mixed with other fuels (* This issue is also common to HVO)

Cases where Retrofit Technology is Utilized to Become Zero-Emission Ships (e.g., from LNG Fueled to Ammonia Fueled Ships):

One possible means of transitioning to zero-emission ships is to retrofit ships that use conventional fuel. In this case, from the viewpoint of minimizing the cost and time required for retrofitting, it is considered necessary to develop engines that can burn the new fuel with only partial conversion, and auxiliary equipment that can be partially converted or used for both.

Section 5.3: Major CO2 Reduction Technologies other than Fuel

Whereas Sections 5.1 and 5.2 focus on alternative fuels, this section summarizes the characteristics of the main CO_2 emission reduction technologies other than fuel, including wind propulsion, battery propulsion, and onboard CO_2 capture, as shown in Table 5.3-1.

[26] https://shipfc.eu/about/

Table 5.3-1: Major CO_2 reduction technologies other than fuel

	Efficiency improvement potential	Pros	Cons
Wind propulsion	Depends on natural conditions, etc.	Zero CO_2 emissions	Not the primary propulsion energy source at this time due to its scale, but contribution rate can be increased
Solar battery	Depends on natural conditions, etc.	Zero CO_2 emissions	Not the primary propulsion energy source due to its scale
Air lubrication	Improved by 2-6%	Can be implemented with existing technology	Effect depends on hull shape, draft, and weather/sea conditions
Low friction paint	Improved by 2-5%	Can be implemented with existing technology	Effect depends on hull shape and speed
Energy saving duct	Improved by 2-5%	Can be implemented with existing technology	Effect depends on hull shape and stern shape
Bow shape change	Improved by 2-5%	Can be implemented with existing technology	Effect depends on hull shape and bow shape
Waste heat recovery power generator	Improved by 1-5%	Can be implemented with existing technology	
Battery propulsion	Depends on the degree and method of utilization	- Zero emissions on board - Proven as a main propulsion engine for some small ships and as an auxiliary propulsion engine for some large ships	- Low weight and volumetric energy density - High-voltage charging infrastructure not yet in place - Longer refueling times (than normal refueling) - Assuming a large oceangoing ship, a significant increase in weight is expected due to the installation of batteries.
Onboard CO_2 capture	Capable of recovering 85% to 95% or more of CO_2 in exhaust gas (theoretical value)	- (Theoretically) regardless of fuel oil - (Theoretically) large reduction rate - Onboard testing is being conducted at a demonstration plant	- Exhaust gas pre-treatment is required for some fuel types (denitration, desulfurization, etc.) - Large volume and weight of CO_2 after capture - CO_2 storage near

			the triple point - Need to improve CO2 capture rate - Need to develop onshore CO2 receiving facilities and to have a business operator to inject and store CO2 in geological formations - Capacity to store CO2 in geological formations must also be considered (according to IEA, in 2050, the demand for storing CO2 in geological formations will be 1.9 Gt, while the amount that can be stored will be 0.9 Gt).

In addition, with respect to on-board CO2 capture, Mitsubishi Shipbuilding Co., Ltd, Kawasaki Kisen Kaisha, Ltd. (K Line), and ClassNK have been working on the "CC-Ocean (Carbon Capture on the Ocean project)," a project to verify CO_2 capture equipment for offshore use, and in August 2021, a small CO_2 capture demonstration plant was installed on a coal carrier. It was installed and successfully captured CO_2 with a purity of more than 99.9%. It is also being considered in other countries, and feasibility studies of similar projects are being conducted by German and Dutch companies[27], and oil companies[28].

Figure 5.3-1: Project by Mitsubishi Shipbuilding, Kawasaki Kisen Kaisha, and ClassNK
View of the CO2 capture system that has been installed on board the ship

<u>Section 5.4: A Summary Table of Domestic and International Technology Development Trends</u>

27 https://www.conoship.com/wp-content/uploads/2020/06/200513-CO2ASTS-Public-Concise-Report.pdf

28 https://www.ogci.com/wp-content/uploads/2021/11/OGCI_STENA_MCC_November_2021.pdf

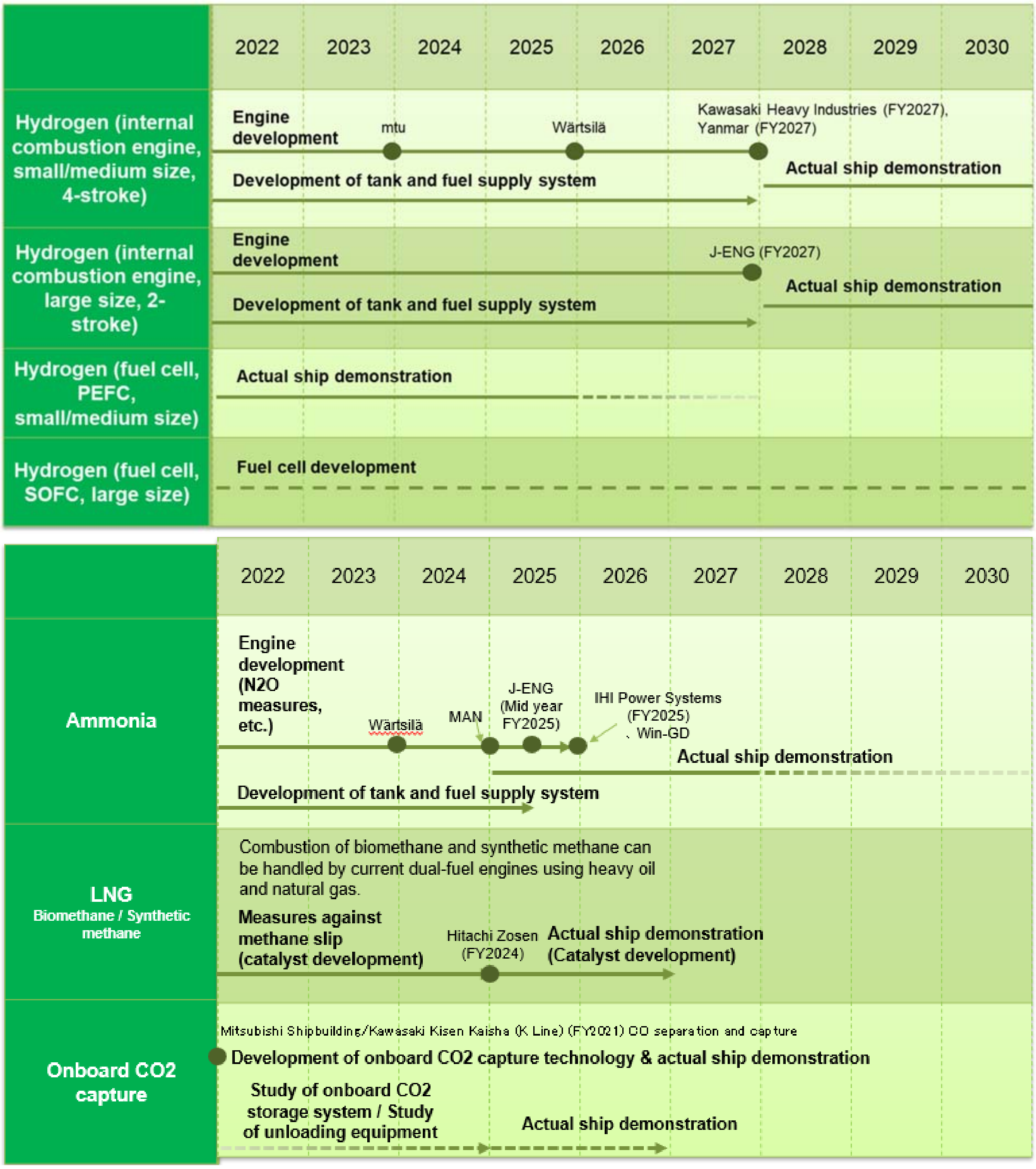
Table 5.4-1 summarizes domestic and international technology development trends.

The "Roadmap to Zero Emissions from International Shipping," compiled in 2020, sets the period from 2028 to 2030 as the start of zero-emission ships, but the Green Innovation Fund is currently developing technologies to complete the demonstration operation of hydrogen fueled ships by 2030 and to achieve commercial operation of ammonia fueled ships as early as possible, by 2028.

In addition, according to media reports, a Japanese company has announced plans to complete the construction of an ammonia fueled ship by the end of 2025[29], and there are also moves to further accelerate zero-emissions.

[29] https://www.sumitomocorp.com/ja/jp/news/release/2021/group/15330

Table 5.4-1: A summary table of domestic and international technology development trends

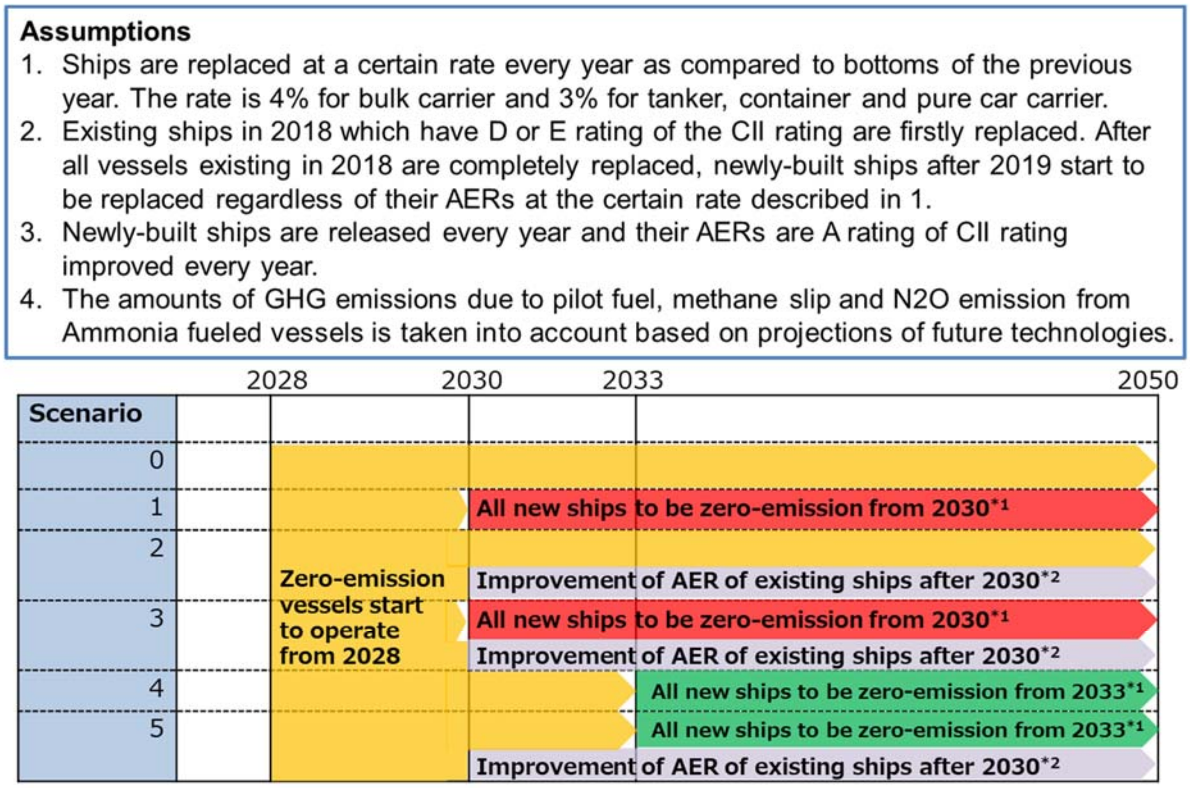


Chapter 6: Simulation for GHG Emission Reduction Pathways towards Net Zero by 2050

Section 6.1: How to Proceed with the Discussion on Simulation for GHG reduction

In this section, we established multiple GHG reduction scenarios with different assumptions, simulate how GHG emission could be reduced towards net zero by 2050, and by comparing the results of the simulation, we assess what kind of measures and regulatory developments are required to achieve net zero GHG emissions by 2050 in the international shipping sector. Simulations were conducted for three ship types, bulk carriers, tankers, and container carriers, which are the three major and representative ship types accounting for 84.77% of the world's shipping tonnage (deadweight tonnage base) as of 2020[30], in addition to these three types, Car Carriers (Ro-Ro cargo ships' for CII category), which is one of representative ship types operated by Japanese shipping companies, was selected as the fourth ship type.

Specifically, six reduction scenarios were set up for each ship type under the assumptions shown in Figure 6.1-1 to calculate how GHG emissions would change by 2050.



*1 "All new ships to be zero-emission from 20XX" means that ships built after 20XX are operated with CII (AER) =0.
*2 "Improvement of AER of existing ships from 2030" means that ships which are rated as D or E of CII rating in the previous year will improve its CII (AER) to the required CII line for the year through operational improvement or use of drop-in fuel, etc.
*3 For Scenarios 0 and 2, all new ships built after 2037 will be zero-emission ships (see 6.4.1 for details).

Figure 6.1-1: Common condition settings for simulations and differences between simulations

Four assumptions were applied for all the ship types: 1. the scrapping rate, 2. assumptions for the retirement of elder ships, 3. assumptions for the performance of new ships, and finally 4. assumptions for future mitigation technology for the other GHGs than CO2. The detail of the four assumptions are discussed in section 6.3. The six reduction scenarios were made with the matrix of two viewpoints, the first viewpoint is when all new built ships will be changed to zero-emission ships (2030 and 2033), which is defined as ships navigating with an Annual

30 United Nations Conference on Trade and Development. (2021). Review of maritime transport 2021. https://unctad.org/system/files/official-document/rmt2021_en_0.pdf

Efficiency Ratio (AER) of zero CO2 emissions per ton-mile per year. The second viewpoint is whether or not the existing ships will improve their AER after 2030. See also section 6.4.

Figure 6.1-2 shows the schematic flow of this simulation.

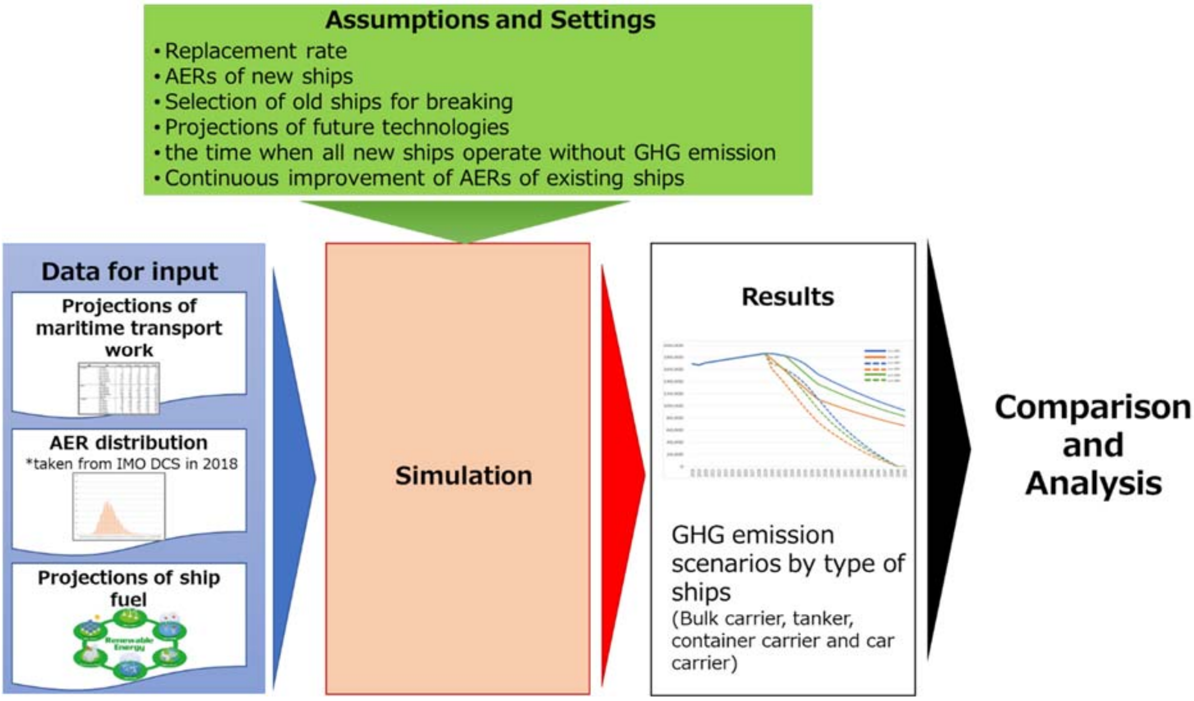


Figure 6.1-2: Simulation implementation flow

Section 6.2: The Data Used for the Simulation

6.2.1 Future Projections of Marine transportation

Future projections of maritime transportation is based on the maritime transportation (ton-miles/year) for each socio-economic scenario presented in the IMO 4th GHG Study[31], RCP2.6 for the Representative Concentration Pathways (RCP), and the Shared Socioeconomic Pathways (SSPs) selected SSP2 (however, the OECD's GDP Growth was selected instead of SSP2 in some GDP projections).

Future projections of the marine cargo volumes for each ship type are shown in Figures 6.2.1-1 through 6.2.1-4. Note that car carriers are not shown in the IMO 4th GHG Study as an individual future projection but are included in the "other dry cargo ships (general cargo ships, RORO ships, and car carriers)" category. Therefore, based on the actual transportation of car carriers in 2018, we estimated the transportation of car carriers in 2019 and beyond, assuming that the ratio of transportation of car carriers to marine cargo volumes of other dry cargo ships in 2018 estimated in the IMO 4th GHG Study will be maintained in the future.

[31] IMO, 4th IMO GHG Study, 2020

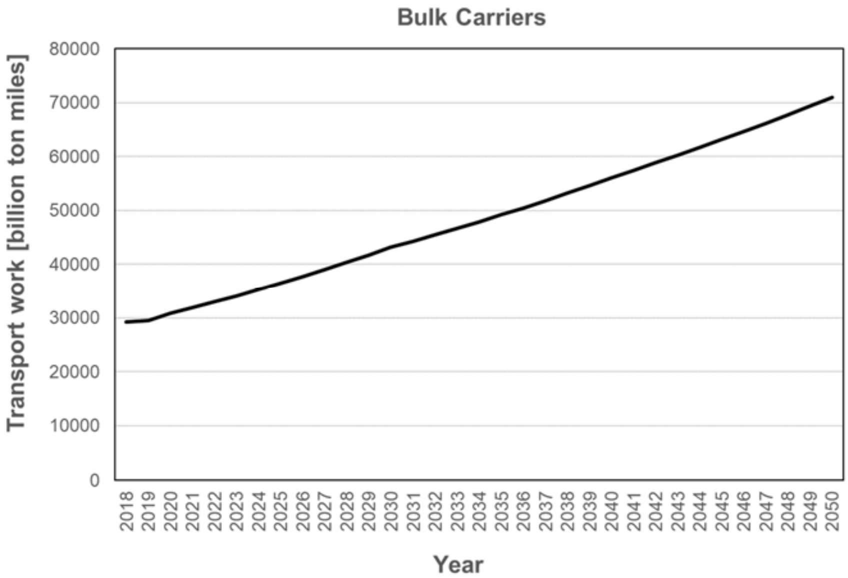


Figure 6.2.1-1 Projection of marine transportation for bulk carriers

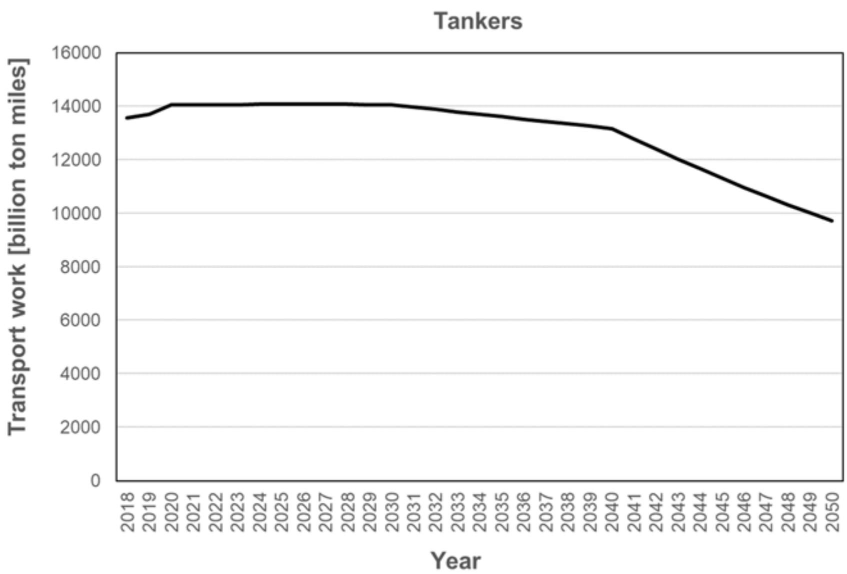


Figure 6.2.1-2 Projection of marine transportation for tankers

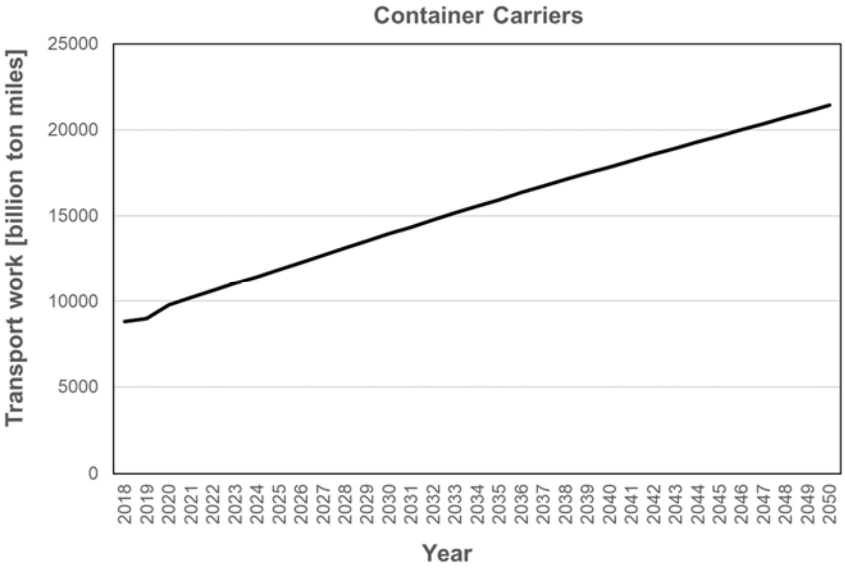


Figure 6.2.1-3 Projection of marine transportation for container carriers

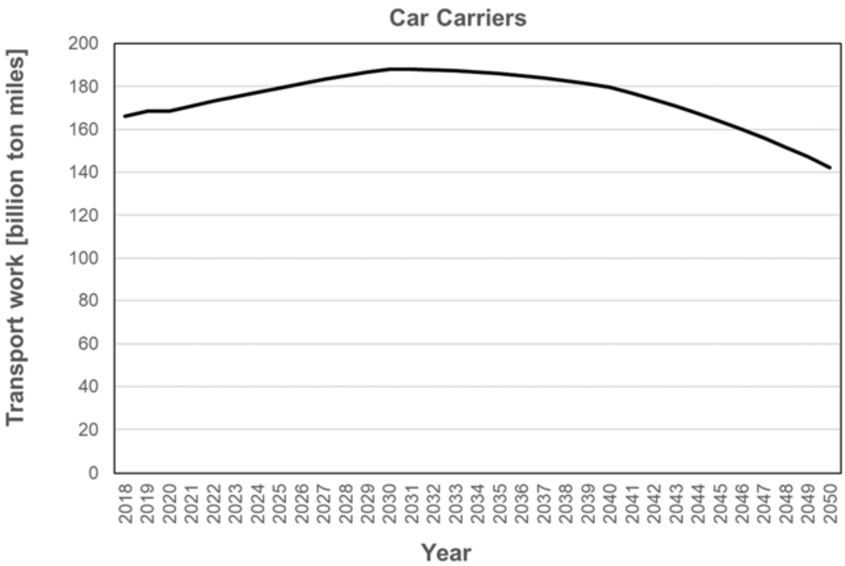


Figure 6.2.1-4 Projection of marine transportation for car carriers

6.2.2 AER Distribution of Global Fleet in 2018

In this simulation, the AER distribution of the global fleet in 2018 was used as the initial value. The figure below shows the schematic AER distribution of the global fleet in 2018. The horizontal axis represents annual CO2 emissions per unit transport volume (ton-miles), and the median value is set to 1 to make the size of the ship (deadweight tonnage) dimensionless by using the AER reference line of each ship type.

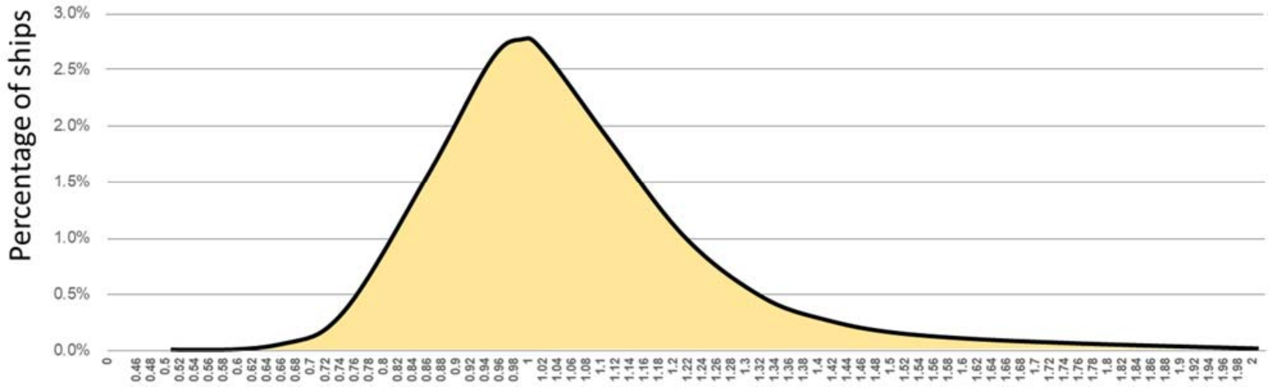


Figure 6.2.2-1 AER distribution of global fleet in 2018 (bulk carriers)

In this simulation, GHG emissions are projected to 2050 by changing the distribution of AER and resulted fleet average of AER, with the assumptions described in following paragraphs.

6.2.3 Fuel Mix for Zero Emission

The fuel breakdown for zero-emission ships was estimated using the energy consumption ratios of ammonia, hydrogen biodiesel/biomethane, and the other energy(total of electricity and synthesised fuels) in the international shipping sector as projected in the IEA NZE report[32]. Specifically, the ratio of ammonia to hydrogen in the total zero emission fuels in the shipping sector is assumed as 45.8 % in 2030, 53.3% in 2040 and 54.9 % in 2050, respectively. For the CO2, all the fuels will result zero emission, however, applying the emission factor stated in table 6.3.4-3, the N2O and CH4 emission were estimated. It is assumed that by use zero-emission fuels other than ammonia no N2O and CH4 emission are expected. IEA only provided the energy mix for each decade, the Linear interpolation was applied for each annual mix.

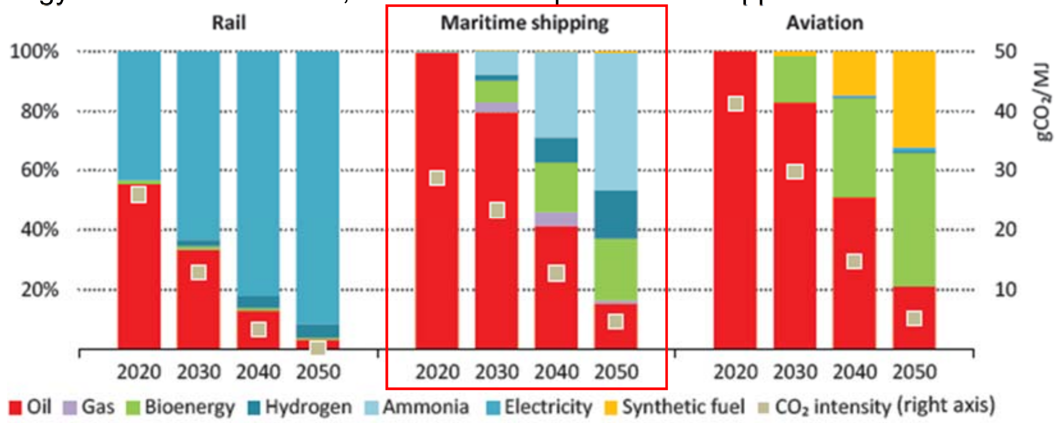


Figure 6.2.3-1 Energy consumption in the transportation sector under the IEA NZE scenario

Section 6.3: Assumption applied commonly for Ship Types

6.3.1 Assumptions about Scrapping Rates

With regard to the rate at which new ships are introduced and old ships are retired, i.e., the speed of replacement , the historical scrapping rate (the ratio of the scrapped ship's tonnage (DWT) to the previous year's tonnage) calculated based on the IHS Markit ship data shown in Table 6.3.1-1.

[32] International Energy Agency (2021), Net Zero by 2050 A Roadmap for the Global Energy Sector

Table 6.3.1-1 Changes in the scrapping rate (%) of bulk carriers, tankers, container carriers, and car carriers (2008-2020)
(The numbers in red indicate the maximum scrapping rate for each ship type.)

Ship type	08	09	10	11	12	13	14	15	16	17	18	19	20
Bulk carriers	1.3	3.3	0.9	3.9	4.6	2.4	1.6	3.2	3.4	1.2	0.5	0.9	1.5
Tankers	1.3	2.3	3.2	1.7	2.8	1.9	1.2	0.5	0.3	1.7	3.3	0.6	0.3
Container carriers	1.0	2.3	0.7	0.5	2.2	2.6	2.1	0.8	3.2	2.1	0.4	1.0	0.9
All ship types	1.3	2.7	2.0	2.5	3.3	2.3	1.6	1.8	2.2	1.5	1.5	0.9	1.1

Specifically, for each ship type, the scrapping rate was set by rounding down to the nearest whole number for the year with the highest scrapping rate in the past. The reason for using the largest annual scrapping rate in the past is that a higher scrapping rate is expected from the perspective of bringing GHG emissions closer to zero as soon as possible by encouraging the replacement of existing fossil fuel ships with newly built zero-emission ships. The scrapping rate was estimated separately and set at 4% (25 years) for bulk carriers and 3% (33 years) for tankers, container carriers, and car carriers (average age of scrapped ships in parentheses). The scrapping rate for car carriers varied widely, due to the small number of ships involved, and therefore the rate was set based on the results for all ship types.

6.3.2 Assumptions about the Retirement of Elder Ships

In general, ships that have been used for a certain period of time after construction lose their economic competitiveness due to aging and obsolescence. And ages ships are to be scrapped. Since ship age is a factor balanced between newbuliding and scrapping, it is most natural to assume that ships over a certain age stated in paragraph 6.3.1 will be scrapped, but the AER distribution of the global fleet in 2018 (see 6.2.2) based on the IMO's DCS does not include information on ship age, therefore such an assumption cannot be implemented. Instead, we assumed that the worse performance (actual AER/CII reference value), the ships should be elder, and we simulated under the condition that the ships with the worst environmental performance (elder ships) will be scrapped.

To discuss the superiority and inferiority of a ship's performance in the AER distribution of the global fleet, it is useful to use the Carbon Intensity Indicator (CII). CII is given a reference value (required annual operational CII) at the median in the AER distribution of the global fleet in 2018, and ships located in the 15% before and after the reference value are given a C rating. Ships distributed in the 20% area with better performance (lower CO2 emissions per ton-mile) than the C rating are given a B rating, and ships distributed in the 20% area with worse performance (higher CO2 emissions per ton-mile) than the C rating are given a D rating. Ships distributed in the top 15% with the best performance are given an A rating, and ships distributed in the 15% with the worst performance are given an E rating (see Figure 6.3.2-1).

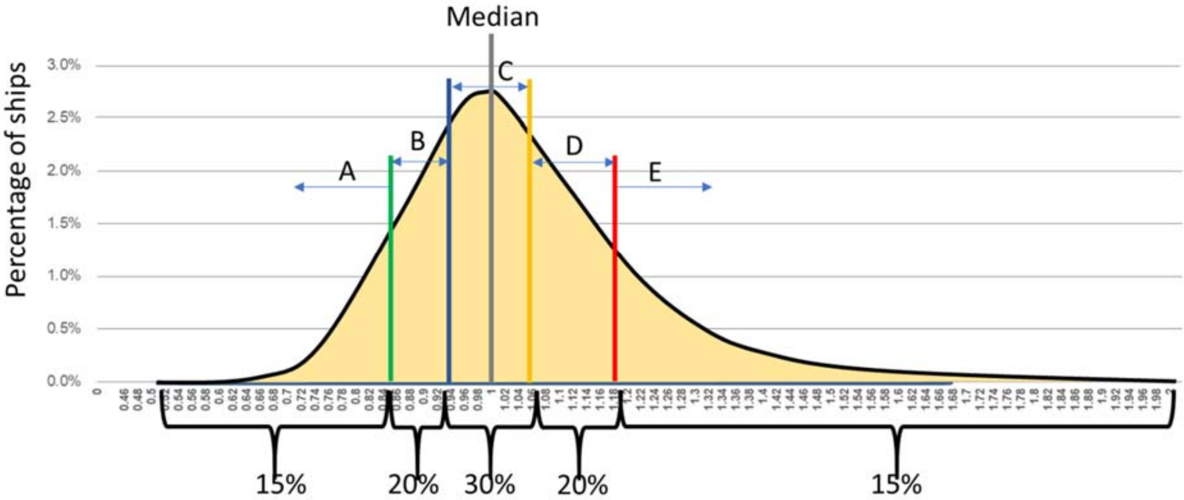


Figure 6.3.2-1 AER distribution of the global fleet in 2018 (bulk carriers)

The CII Reference Line Guidelines (MEPC.338(76)) stipulate that the reference values and each threshold should be improved in the direction of better performance by 2% every year from 2023 to 2026[33]. At this moment, the quantitative reduction factor (Z factor) after 2027 has not been determined, but it is assumed that after 2027 the values for reference line together with those thresholds will decrease uniformly to zero in 2049 (See Figure 6.3.2-2).

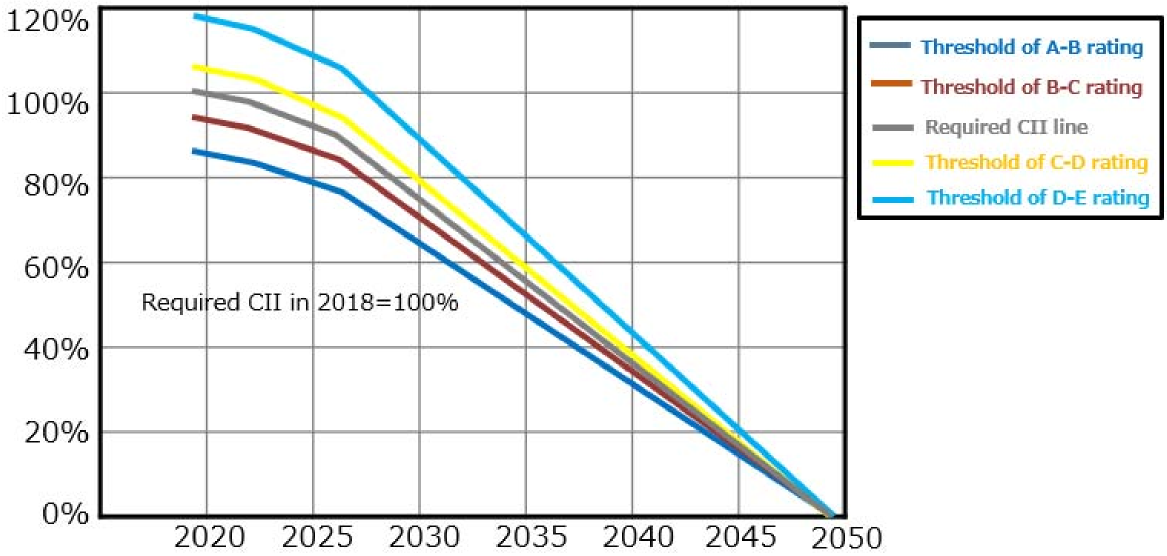


Figure 6.3.2-2 Decrease in CII reference values and thresholds

Under the above assumptions regarding CII, the following assumptions were made for the breakdown of ships to be scrapped each year.

(i) Retirement of existing ships in 2018
Ships existing in 2018 should be scrapped first in the total fleet. In the specific selection of ships to be scrapped, 4% or 3% of the previous year's tonnage will be scrapped, of which 40% will be from CII D-rated ships and 60% from E-rated ships in each year.

33 IMO. (2021). MEPC 76/15/Add.2, 2021 Guidelines on the operational carbon intensity reduction factors relative to reference lines (CII reduction factors guidelines, G3).

(ii) Retirement of ships to be built after 2019
After all existing ships in 2018 have been scrapped, the scrapping of ships built after 2019 will start. In selecting the ships to be scrapped, ships shall be scrapped by 4% or 3% of the previous year's existing tonnage, and the ships to be scrapped shall not depend on the performance (equally scrapped by 4% or 3% each in all CII values).

6.3.3 Assumptions about the Performance of New Ships

For new ships, given that the latest energy-saving technologies can be adopted, it can be assumed that the performance is qualitatively better and improves every year. Under this assumption, the performance (=actual AER/CII reference value) of new ships introduced each year is assumed to be lower than the threshold of the A-rating in CII for each year applying the Z factor assumed in 6.3.2, and the shape of the distribution (probability density function) is assumed to remain the same as the A-rating distribution in 2018. In this simulation, the total number of new ships to be built is assumed to be summed up the amount of ships scrapped each year with the increase or decrease in the fleet resulting from the changes of transportation demand. As CII reference values and thresholds for A-B are improved every year, the lower limit of the performance of new ships will also be improved every year. The improvement rate shall be 2% every year until 2026 and 3.3% every year after that (note that the rate will be merely lower than the Z factor for reference line).

Next, consider the performance limit of the new ships to be introduced. Since the IMO 4th GHG study estimates that up to 55~60% GHG reduction is possible without using zero-emission fuels, the limit value of fuel efficiency for existing fossil fuel ships was assumed to be 0.45 (limited to LNG fueled ships), in terms of the dimensionless value shown in Figure 6.2.2-1, and we assume that the value of new fossil fueled ships is not less than this 0.45. On the other hand, since the A-rating threshold improves every year in the simulation, after a certain year, the performance distribution of new ships to be introduced will be below 0.45. For the ships in the region below 0.45 of the distribution, all the ships are assumed to be zero-emission ships, whose AER=0 (ships that annually operate with zero CO_2 emissions.) (See Fig 6.3.3-1).

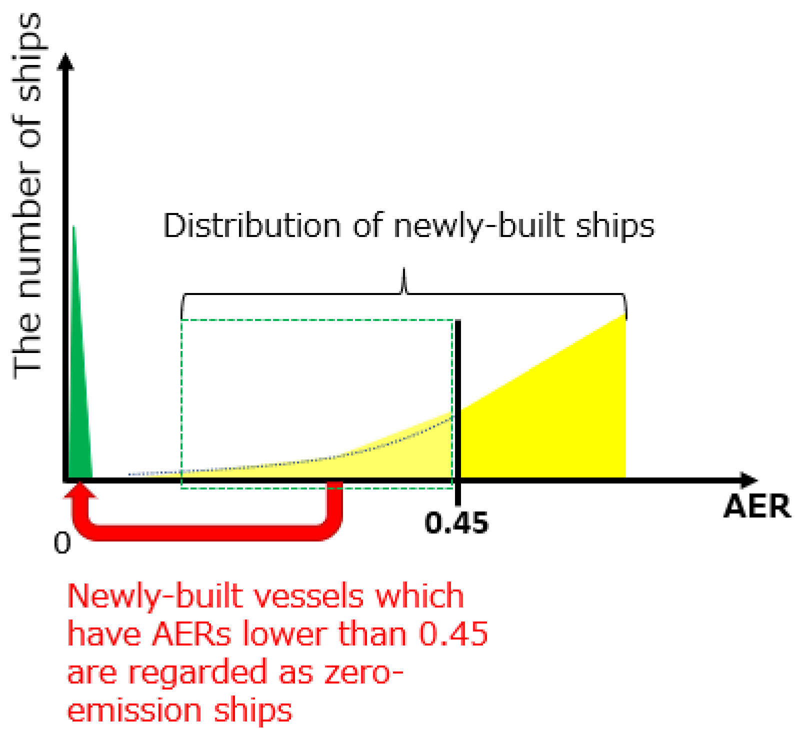


Figure 6.3.3-1 Introducing a zero-emission ship as a new ship

As zero-emission ships will not enter service until 2028, and that small portion of the performance distribution of new ships will be below 0.45 before 2027, then LNG fueled ships with performance of 0.45 are assumed to be built for all the ships with AER values below 0.45.

6.3.4 Assumptions about Future Technologies

There are various technical challenges in using alternative fuels as marine fuels, among which the factors that affect GHG emissions are pilot fuels, methane slips (for methane fueled ships), and N2O emissions (for ammonia fueled ships). To make the simulation more realistic, we decided to take into account these factors in this simulation and made the assumptions shown in Tables 6.3.4-1 through 6.3.4-3 for pilot fuels, methane slips, and N2O emissions in the years 2030, 2040, and 2050.

For the pilot fuels, the values were set for the case where the fuels are LNG and ammonia. For the intervening years in the table, values are set by performing linear interpolation. The units in Table 6.3.4-1 are calorific value based (%).

Table 6.3.4-1 Assumptions about pilot fuel

	LNG	Ammonia
2030	5%	5%
2040	3%	3%
2050	0%	0%

As for methane slips, the assumption was set for LNG fueled ships. For the intervening years in the table, values are set by performing linear interpolation. The unit is the amount [g] of unburned methane released into the atmosphere when 1 [g] of methane is burned.

Table 6.3.4-2 Assumptions about methane slips*

2030	0.004 g/g-fuel (2.3 g-CO2eq/MJ)
2040	0.002 g/g-fuel (1.2 g-CO2eq/MJ)
2050	0.0006 g/g-fuel (0.35 g-CO2eq/MJ)

*The IPCC AR5 values were used for GWP100 for CO2 conversion.

N2O emissions were set for ammonia fueled ships. For the intervening years in the table, values are set by performing linear interpolation. The unit is the amount [g] of N2O released into the atmosphere when 1 [g] of ammonia is burned. It should be noted that those assumption is not applied for the fuel used by boiler, the fuel consumption rates by main engine, auxiliary engine and boiler for each ship types are assumed from the data provided in the table 35 of the IMO 4th GHG Study.

Table 6.3.4-3 Assumptions about N2O emissions*

2030	0.0005 g/g-fuel (8.0 g-CO2eq/MJ)
2040	0.00025 g/g-fuel (4.0 g-CO2eq/MJ)
2050	0.0000025 g/g-fuel (0.04 g-CO2eq/MJ)

*The IPCC AR5 values were used for GWP100 for CO2 conversion.

Section 6.4: Differences by Scenario

6.4.1 Year in which All New Ships will be Zero-Emission Ships

The year when all new ships are to be zero-emission ships varies from scenario to scenario. For Scenarios 1 and 3, all new ships to be built as zero-emission after 2030, and for Scenarios 4 and 5, all new ships to be built as zero-emission after 2033, and the assumptions regarding the performance of new ships described in 6.3.3 are not applied. Note that for Scenarios 0 and 2, the lower performance limit for new ships described in 6.3.3 naturally falls below 0.45 in 2037, so all new ships to be built as zero-emission after 2037.

6.4.2 Improvement in AERs of Existing Ships or Not

Scenarios 2, 3, and 5 assume that existing fossil fueled ships after 2030 will improve their AERs as an additional setting. Specifically, it is assumed that ships that emitted CO2 above the CII reference line (Required CII) in the previous year will improve their AERs to the Required CII in the following year by using drop-in fuel, etc (See Figure 6.4.2-1). Possible ways to improve AERs include that: ships that has been operated as zero-emission fuels-ready expand the use of zero-emission fuels; ships that has been converted to use dual fuel by retrofit operate with zero-emission fuels; and ships operate with carbon-neutral fuels, etc. that have the same composition as fossil fuels (e.g. heavy fuel oil to biodiesel oil, LNG to synthetic methane) without retrofitting.

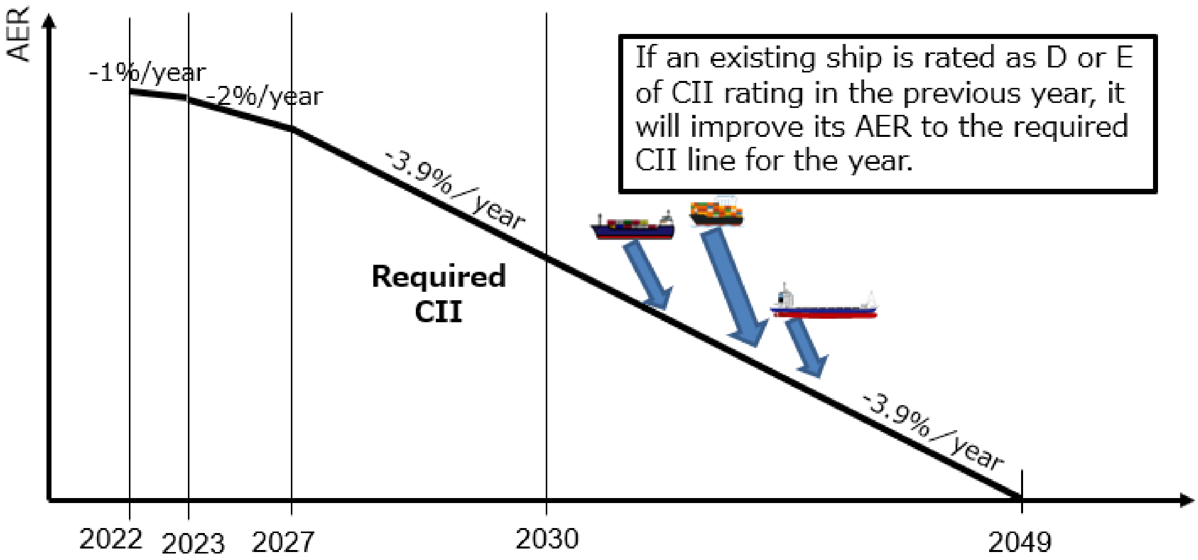


Figure 6.4.2-1 Improvement in AERs of existing ships

Section 6.5: Results and Discussion

6.5.1 Results of Bulk Carriers

For bulk carriers, the GHG emission trends, annual construction of zero-emission ships, and GHG emission reduction rates in 2040 and 2050, compared to 2018, are shown below (Figure 6.5.1-1, Figure 6.5.1-2 and Table 6.5.1-1) for each scenario.

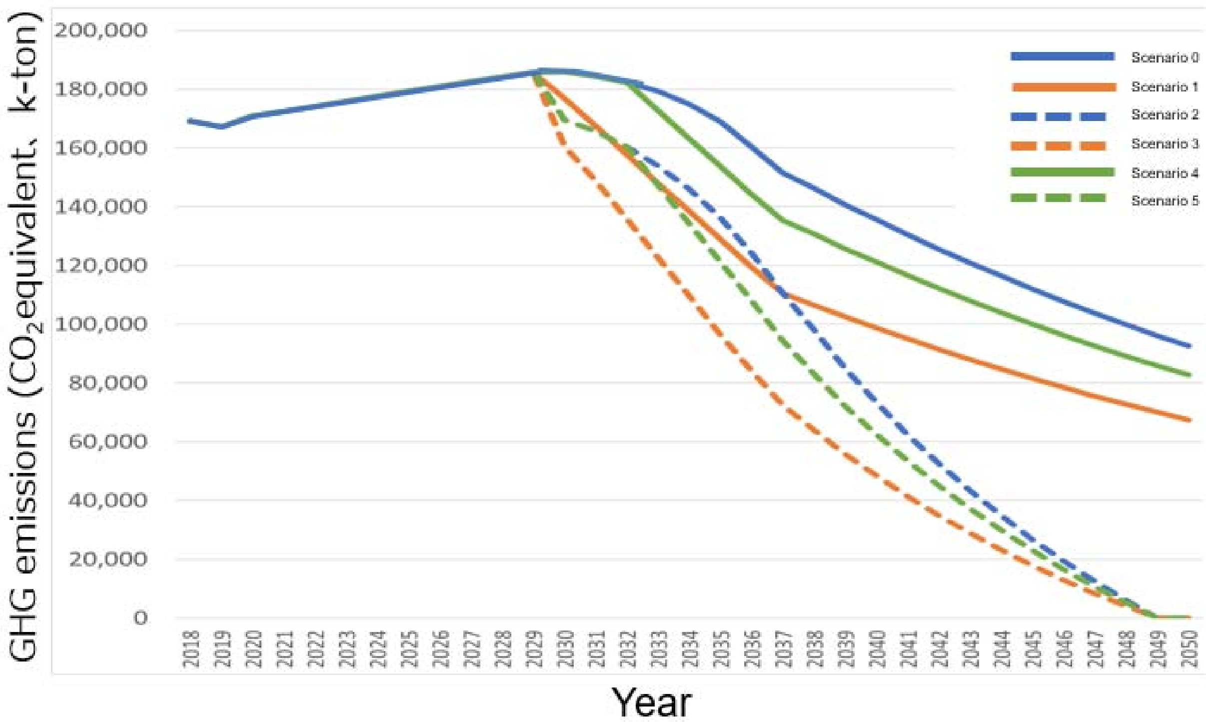


Figure 6.5.1-1 GHG emission trends for bulk carriers

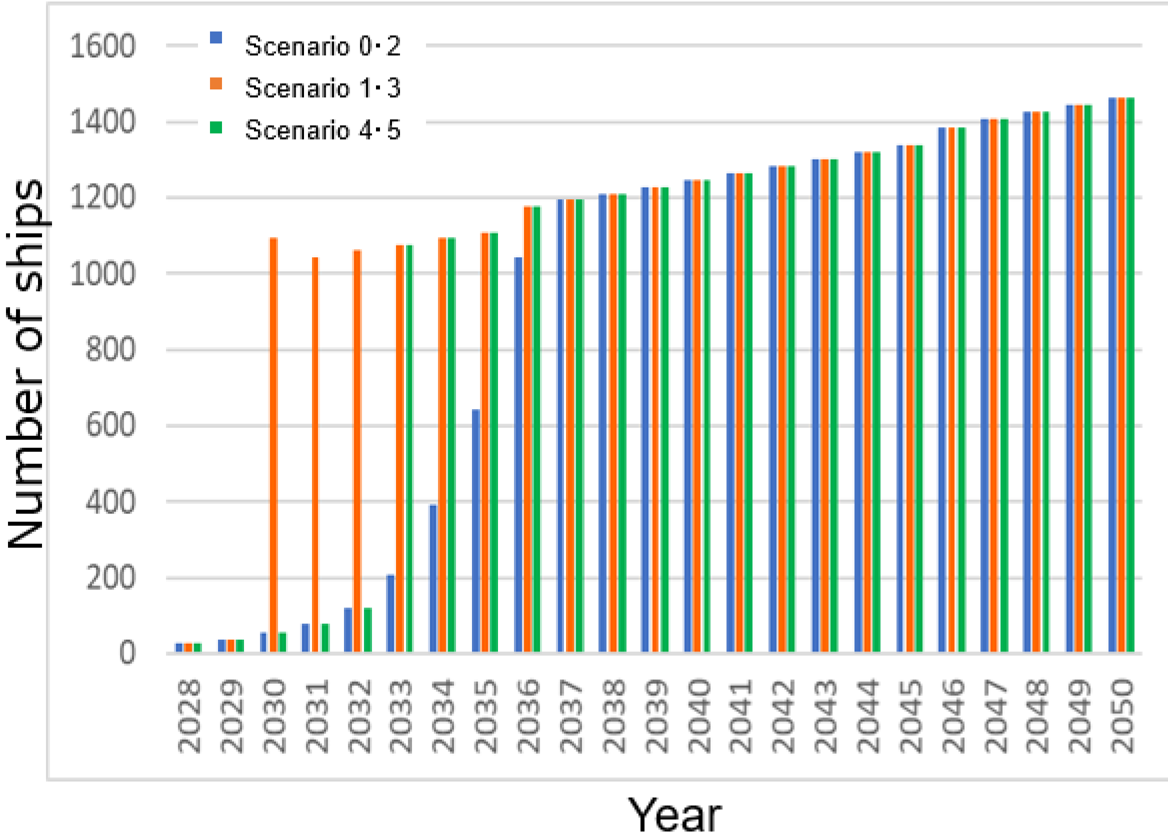


Figure 6.5.1-2 Annual construction number of zero-emission ships (bulk carriers)

Table 6.5.1-1 GHG emission reductions rates in 2040 and 2050 for bulk carriers (compared to 2018)

Scenario	Changes from Scenario 0	Reduction rate (2040)	Reduction rate (2050)
0		19.5%	44.7%
1	All new ships to be zero-emission from 2030	41.6%	60.2%
2	Improvement in AERs of existing ships from 2030	56.6%	99.9%
3	All new ships to be zero-emission from 2030 and Improvement in AERs of existing ships from 2030	71.3%	99.9%
4	All new ships to be zero-emission from 2033	28.4%	51.1%
5	All new ships to be zero-emission from 2033 and Improvement in AERs of existing ships from 2030	63.0%	99.9%

6.5.2 Results of Tankers

For tankers, the GHG emission trends, annual construction of zero-emission ships, and GHG emission reduction rates in 2040 and 2050, compared to 2018, are shown below (Figure 6.5.2-1, Figure 6.5.2-2 and Table 6.5.2-1) for each scenario.

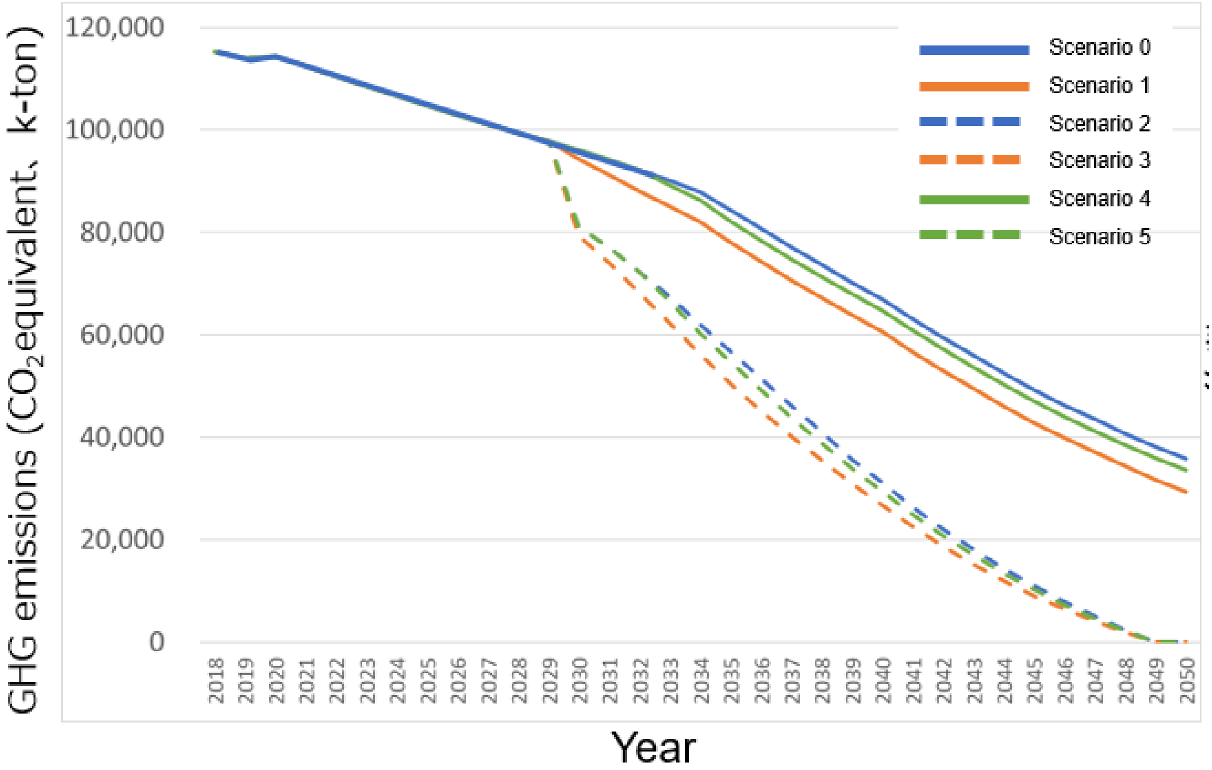


Figure 6.5.2-1 GHG emission trends for tankers

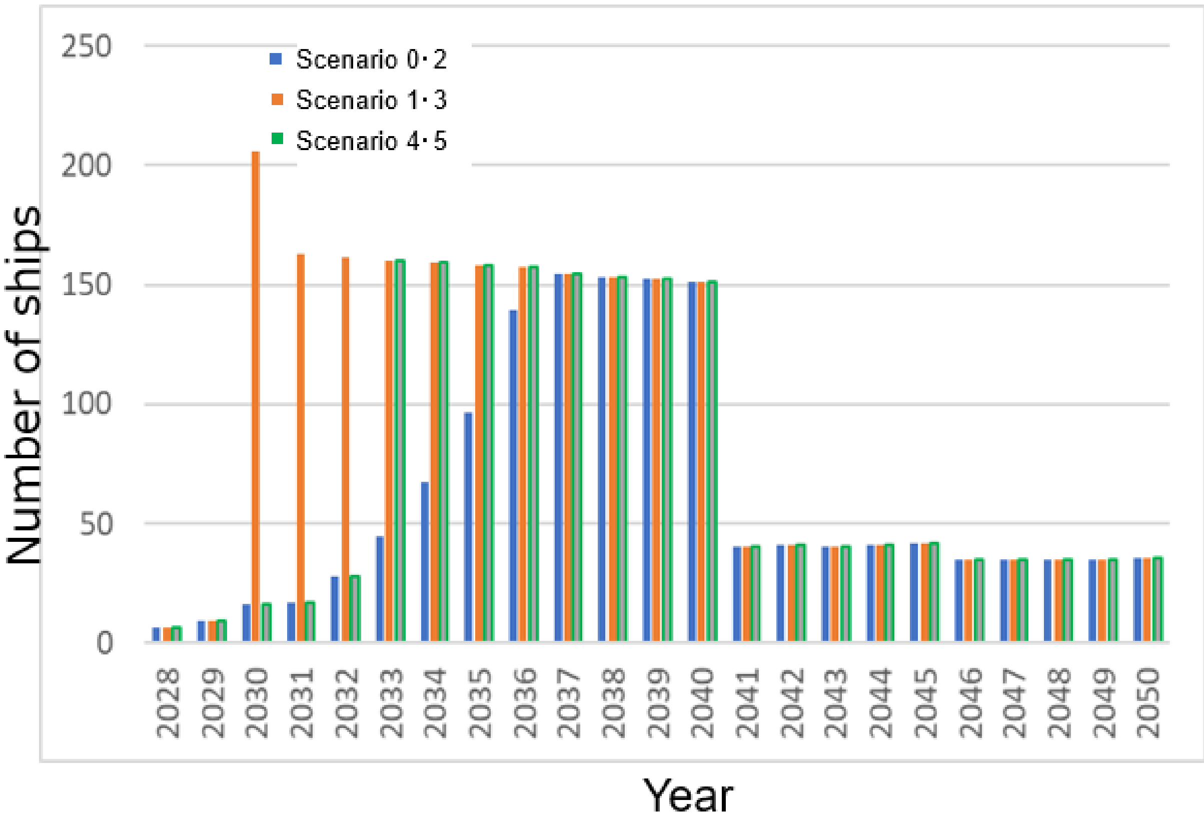


Figure 6.5.2-2 Annual construction number of zero-emission ships (tankers)

Table 6.5.2-1 GHG emission reduction rates in 2040 and 2050 for tankers (compared to 2018)

Scenario	Changes from Scenario 0	Reduction rate (2040)	Reduction rate (2050)
0		42.0%	69.0%
1	All new ships to be zero-emission from 2030	47.6%	74.5%
2	Improvement in AERs of existing ships from 2030	73.1%	99.9%
3	All new ships to be zero-emission from 2030 and Improvement in AERs of existing ships from 2030	76.9%	99.9%
4	All new ships to be zero-emission from 2033	44.0%	70.9%
5	All new ships to be zero-emission from 2033 and Improvement in AERs of existing ships from 2030	74.6%	99.9%

6.5.3 Result of Container Carriers

For container carriers, the GHG emission trends, annual construction of zero-emission ships, and GHG emission reduction rates in 2040 and 2050, compared to 2018, are shown below (Figure 6.5.3-1, Figure 6.5.3-2 and Table 6.5.3-1) for each scenario.

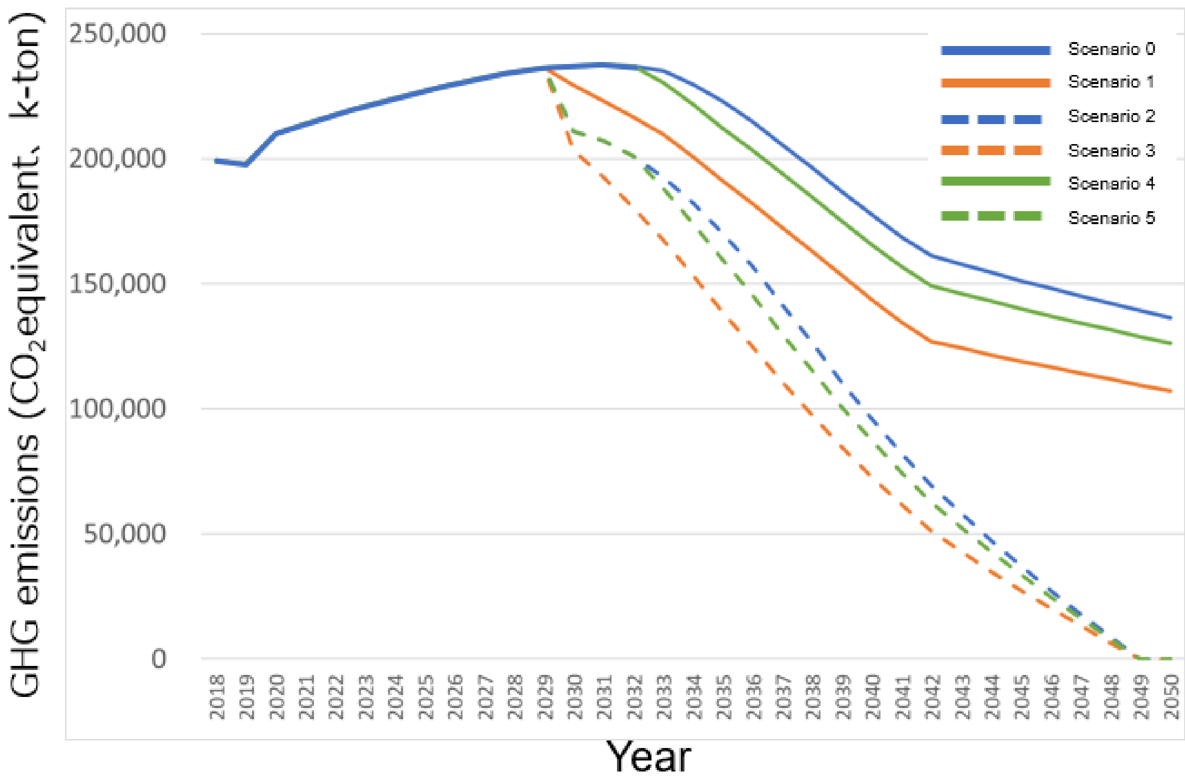


Figure 6.5.3-1 GHG emission trends for container carriers

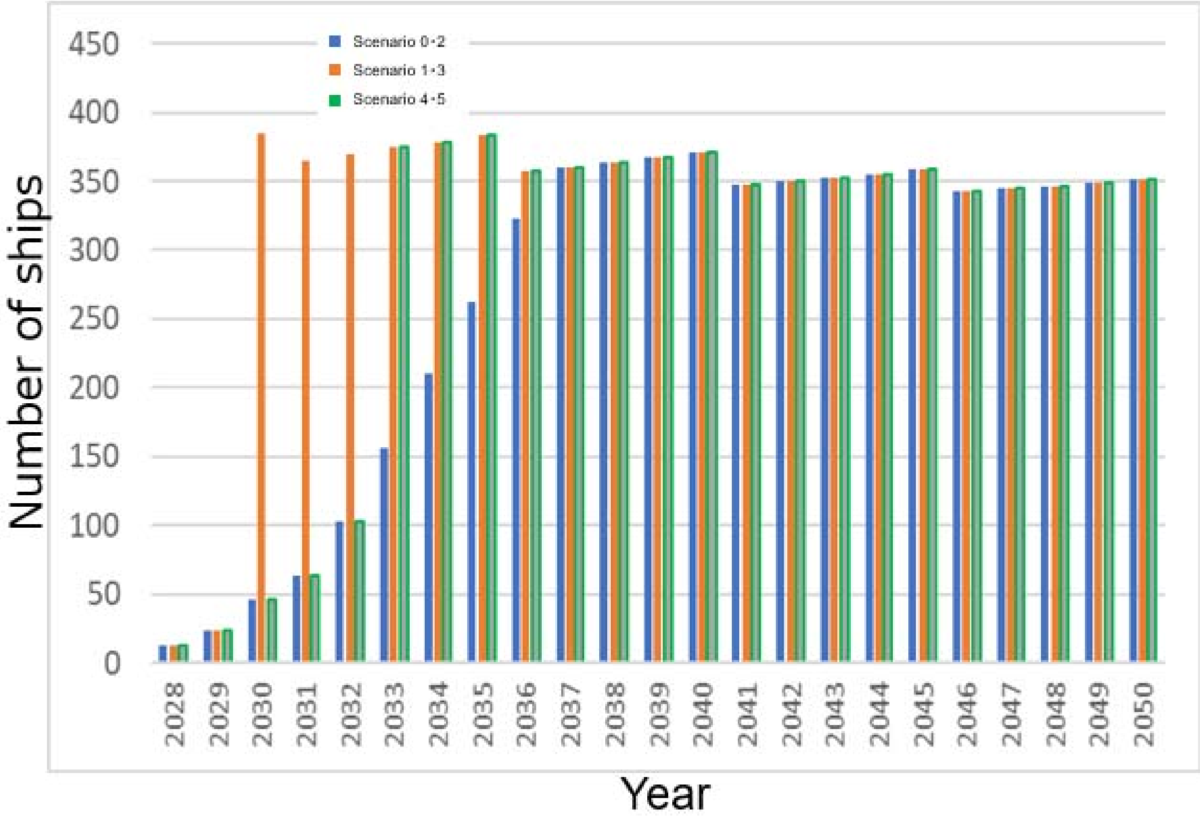


Figure 6.5.3-2 Annual construction number of zero-emission ships (container carriers)

Table 6.5.3-1 GHG emission reduction rates in 2040 and 2050 for containers carriers (compared to 2018)

Scenario	Changes from Scenario 0	Reduction rate (2040)	Reduction rate (2050)
0		10.9%	31.5%
1	All new ships to be zero-emission from 2030	27.9%	46.1%
2	Improvement in AERs of existing ships from 2030	52.0%	99.9%
3	All new ships to be zero-emission from 2030 and Improvement in AERs of existing ships from 2030	63.5%	99.9%
4	All new ships to be zero-emission from 2033	16.8%	36.6%
5	All new ships to be zero-emission from 2033 and Improvement in AERs of existing ships from 2030	56.3%	99.9%

6.5.4 Results of Car Carriers

For car carriers, the GHG emission trends, annual construction of zero-emission ships, and GHG emission reduction rates in 2040 and 2050, compared to 2018, are shown below (Figure 6.5.4-1, Figure 6.5.4-2 and Table 6.5.4-1) for each scenario.

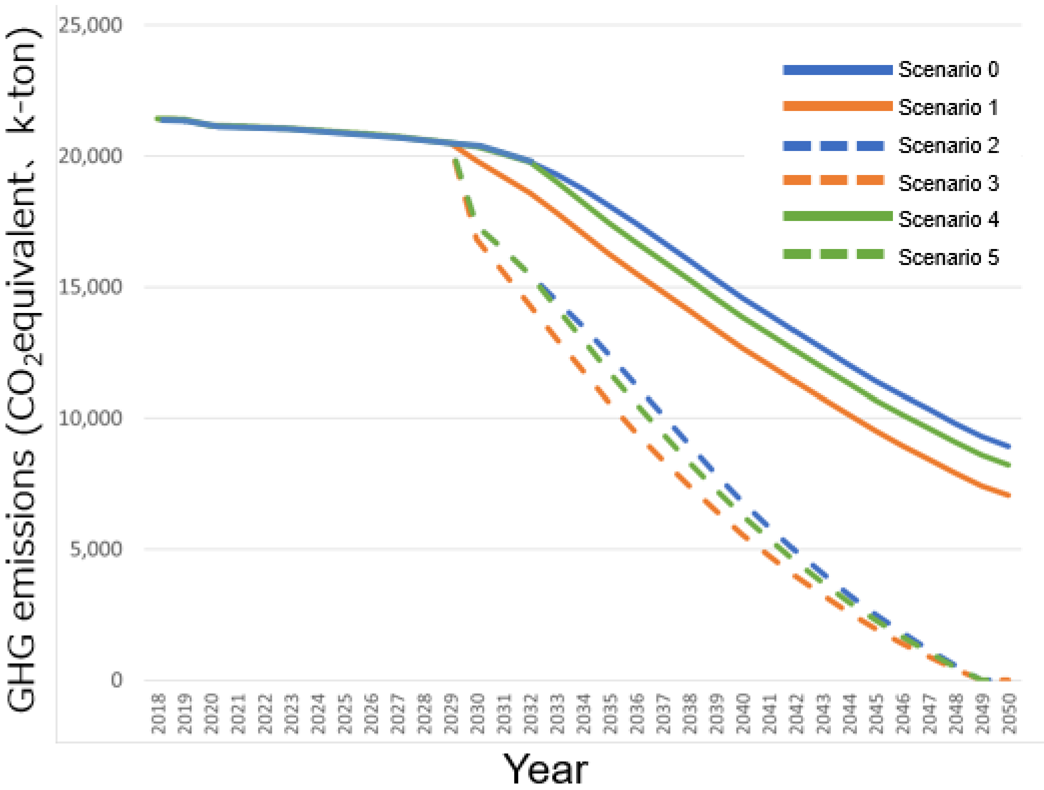


Figure 6.5.4-1 GHG emission trends from car carriers

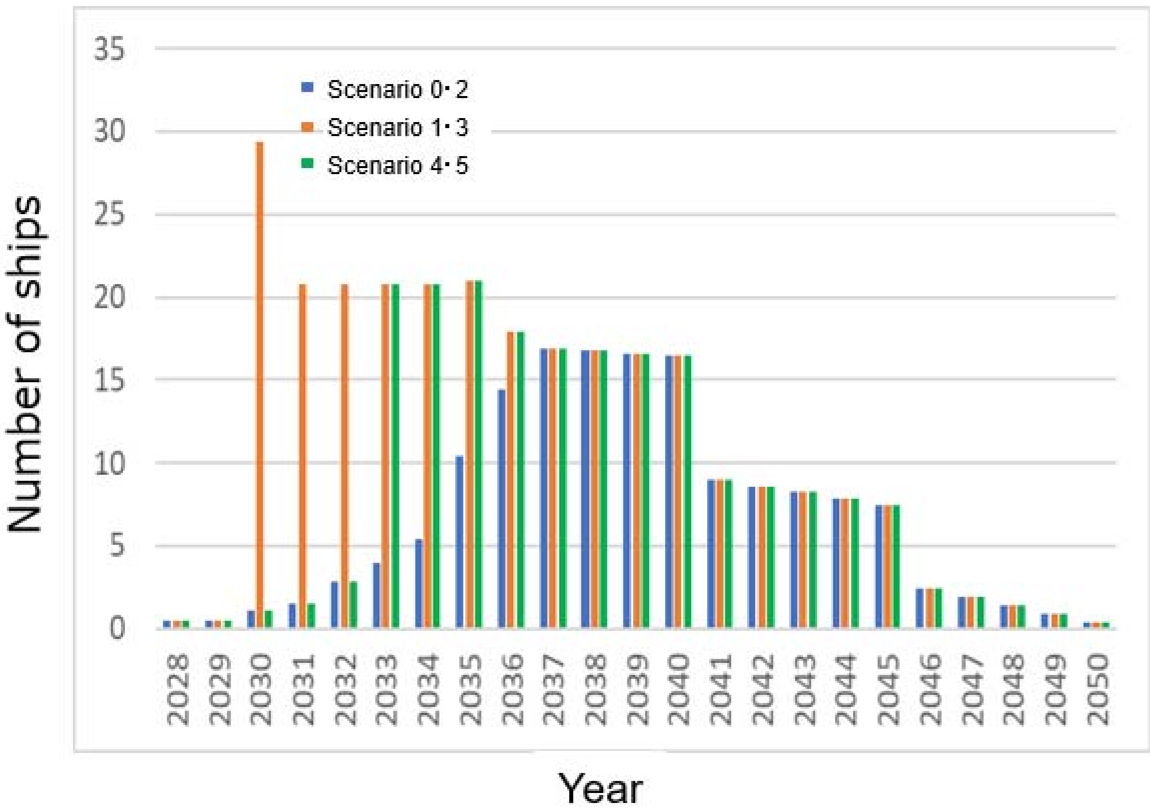


Figure 6.5.4-2 Annual construction number of zero-emission ships (car carriers)

Table 6.5.4-1 GHG emission reduction rates in 2040 and 2050 for car carriers (compared to 2018)

Scenario	Changes from Scenario 0	Reduction rate (2040)	Reduction rate (2050)
0		32.0%	58.3%
1	All new ships to be zero-emission from 2030	40.9%	67.0%
2	Improvement in AERs of existing ships from 2030	68.3%	99.9%
3	All new ships to be zero-emission from 2030 and Improvement in AERs of existing ships from 2030	74.1%	99.9%
4	All new ships to be zero-emission from 2033	35.4%	61.6%
5	All new ships to be zero-emission from 2033 and Improvement in AERs of existing ships from 2030	70.7%	99.9%

6.5.5 Discussion

Table 6.5.5-1 shows the GHG reduction rate and the number of remaining fossil fuel ships in 2050 under Scenario 1, in which zero emissions is mandatory required for new ships after 2030 and Scenario 4, in which zero emissions is mandatory required for new ships after 2033 for each ship type.

Table 6.5.5-1 GHG reduction rates for Scenarios 1 and 4 by ship type (2050)

Ship type	Scenario	GHG reduction rate in 2050 (%)	The number of existing fossil fueled ships in 2050 (% of ships in the fleet)
bulk carrier	1	60.2	5,957 (22%)
	4	51.1	7,697 (31%)
tanker	1	74.5	2,594 (54%)
	4	70.9	3,062 (64%)
container carrier	1	46.1	3,191 (34%)
	4	36.6	3,902 (41%)
car carrier	1	67.0	305 (54%)
	4	61.6	369 (65%)

This results indicate that forcing zero-emissions only to new ships will not result in zero GHG emissions in 2050, regardless of the advanced timing. This is because a certain amount of fossil fuel ships will remain according to the replacement effected both by the scrapping rate and growth of transportation, and the GHG reduction rate will only be 30-70% less compared to that in 2018.

On the other hand, the scenarios (2, 3, and 5), in which improvements in AERs of the existing ships is required, show that the GHG reduction rates could reach 99.9% in all the scenarios (see Table 6.5.5-2 below).

Table 6.5.5-2 GHG reduction rates for Scenarios 2, 3 and 5 by ship type (2050)

Ship type	Scenario	GHG reduction rate in 2040 (%)	GHG reduction rate in 2050 (%)
bulk carrier	2	56.6	99.9%
	3	71.3	99.9%
	5	63.0	99.9%
tanker	2	73.1	99.9%
	3	76.9	99.9%
	5	74.6	99.9%
container carrier	2	52.0	99.9%
	3	63.5	99.9%
	5	56.3	99.9%
car carrier	2	68.3	99.9%
	3	74.1	99.9%
	5	70.7	99.9%

As a method of improving the AERs of existing ships, all the scenarios assume that existing ships that emitted more CO_2 (with D or E score) than the CII reference line in the previous year will improve AERs to the reference line in the following year through drop-in of zero-emission fuel, etc. As the CII reference line will be reduced to zero in 2049, the total fleet AER for all existing ships will be zero in 2049. Note that the GHG reduction rate will not be 100% due to the effects of pilot fuels, methane slips and N_2O emission.

Based on the above results, it is concluded that a framework is necessary to ensure that measures to reduce emissions from existing ships will be implemented in order to achieve zero emissions in 2050.

Chapter 7: Regulatory Developments

Based on the technical development issues related to the realization of zero-emission ships and the simulation of GHG emission reductions up to 2050 under multiple scenarios, we have summarized the regulatory developments necessary to achieve "net zero GHG emissions in 2050," with a particular focus on mid- and long-term measures to be considered in earnest at IMO in the future.

Section 7.1: Mid- and Long-Term Measures at IMO

The IMO strategy adopted by IMO in 2018 lists the GHG reduction targets as well as candidate short-, mid-, and long-term measures to achieve the targets; the candidate mid- and long-term measures are listed below.

- Candidate mid-term measures (measures to be finalized and agreed upon between 2023 and 2030)

1. Implementation programs for the effective uptake of alternative low-carbon and zero-carbon fuels
2. Operational energy efficiency measures for both new and existing ships
3. New/innovative emission reduction mechanism(s), possibly including Market-based Measures (MBMs), to incentivize GHG emission reductions
4. Further continue and enhance technical cooperation and capacity-building activities such as under the Integrated Technical Co-operation Programme (ITCP)
5. Development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible information exchange on best practice

- Candidate long-term measures (measures to be finalized and agreed upon after 2030)

1. Pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century
2. Encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s)

At the 76th meeting of the Marine Environment Protection Committee held in June 2021, the Committee approved a work plan for considering mid- and long-term measures. In the work plan, the study will be carried out according to the following three phases.

Phase I (Spring 2021 to spring 2022)	Collation and initial consideration of proposals for measures
Phase II (Spring 2022 to spring 2023)	Assessment and selection of measure(s) to further develop
Phase III (Spring 2023 -)	Development of (a) measure(s) to be finalized within (an) agreed target date(s)

In considering mid- and long-term measures, it is considered effective to first organize them from the overall picture of mid- and long-term measures to ensure and effectively realize the transition from fossil fuel ships to zero-emission ships in order for international shipping to achieve net zero GHG emissions by 2050.

As mentioned earlier, the technology for zero-emission ships is still under development, and a supply chain for zero-emission fuel is not yet in place in sufficient quantities. In light of the various initiatives being launched at the governmental and private sector levels in Japan and around the world to promote zero-emission international shipping, it is expected that zero-emission ships will be in commercial operation in the late 2020s (around 2028), but at that time, the technology and fuel for zero-emission ships is expected to be more expensive than existing fossil fuel ships.

In order to reduce the cost related to technology and fuel for zero-emission ships, it is necessary to increase the demand and supply of such technology and fuel as well as to improve Technology Readiness Levels by accumulating operational experience, etc. To this end, in the initial stages of the transition to zero-emission ships, that is, in the initial stages of introducing zero-emission ships to the market, owners/operators who intend to introduce zero-emission ships ahead of others (hereinafter referred to as “first movers") should be encouraged to do so. It is considered most effective to introduce measures to support the emergence and expansion of first movers by appropriately supporting them and not creating competitive disadvantages between them and operators of fossil fueled ships. Such measures can be achieved by introducing the market-based measures (MBMs) described below.

As the transition to zero-emission ships progresses and the technology matures, as well as when the global fuel supply system is sufficiently large, it will be necessary to make a stronger (forceful) transition to zero-emission ships by introducing regulatory measures in order to achieve the goal of net zero GHG emissions by 2050.

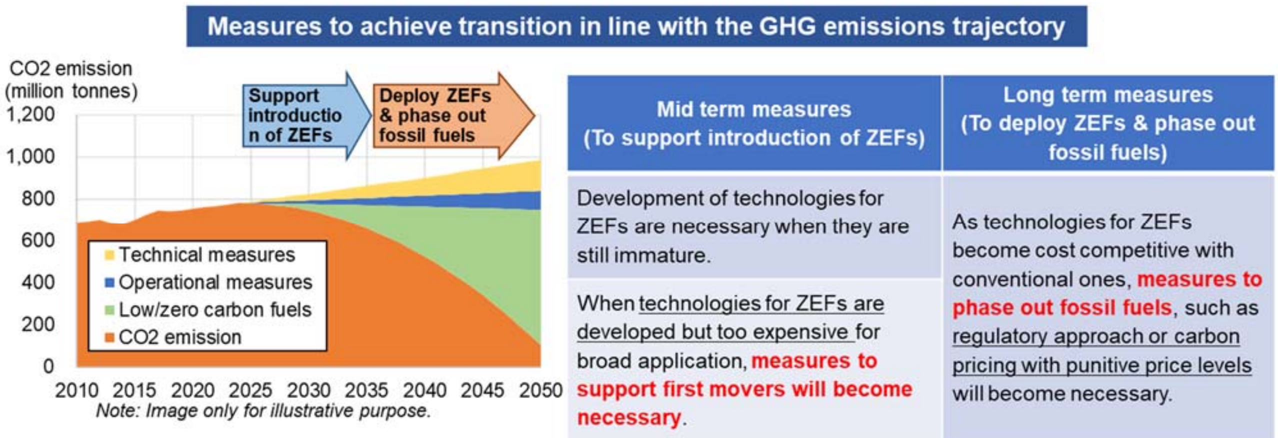


Figure 7.1-1 Image of GHG reduction scenario and mid- to long-term measures

Section 7.2: Concept of Market-Based Measures (MBMs) to be Introduced In IMO

In response to growing social demands to address global warming, efforts to realize effective GHG emission reductions by utilizing the market mechanism by introducing carbon pricing, etc. have already been seen all over the world. The following two concepts are representative of such efforts.

1. Carbon levy system: A system that charges a fixed amount per unit of fuel use (or per unit of GHG emissions). The carbon price (amount of levy) is determined in advance under the system, and the amount of emission reductions depends on the actions of the entity levied the charge under the system.

2. Emissions Trading Scheme (ETS): A scheme in which emission caps (emission allowances) are set, emission allowances are allocated, and surplus and deficit emission allowances are traded among businesses. The carbon price is determined by the market based on the supply and demand of emission allowances, and the amount

of emission reductions depends on the setting of emission allowances.

Both systems have their advantages and disadvantages. The carbon levy system has the advantage of predictability in the carbon price, while the emissions trading scheme is said to be superior in terms of certainty of meeting emission reduction targets (however, even with the carbon levy system, it is possible to increase certainty by adjusting the amount of levy.). Although there are arguments in economic theory, Nordhaus (2006)[34] suggests that price-based approach is more efficient than quantity-based approach when there are uncertainties and if curvature of the benefit function is smaller than the curvature of the cost function of emissions, as is clearly the case for climate change.

When considering the introduction of market-based measures (MBMs) in the international shipping sector, emissions trading schemes have the problem of making investment decisions for transitioning to zero-emission ships more difficult due to fluctuating carbon prices and less predictable costs for owners/operators. The International Chamber of Shipping (ICS) has also pointed this out[35]. Therefore, regarding the market-based measures (MBMs) to be introduced in IMO, it is considered that a method of determining the carbon price in advance under the system (price approach) should be adopted.

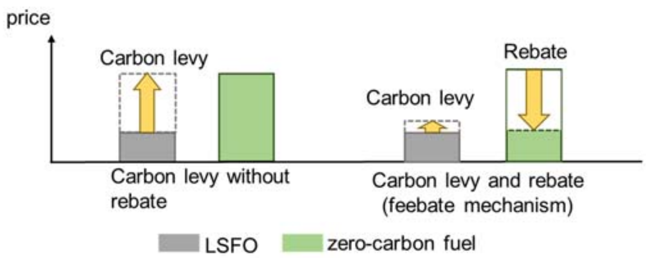
As for the revenue generated by the introduction of market-based measures, as mentioned earlier, it is considered to be effective to provide economic incentives to first movers through market-based measures (MBMs) in the initial phase of the transition to zero-emission ships. It is possible that a portion of the revenues could be used to implement fuel supply infrastructure development (including capacity buildings) to support zero-emission shipping in developing countries (especially Small Island Developing States (SIDS) and Least Developed Countries (LDCs)), but detailed discussions are required regarding the necessary funds, their use, and how they would be managed.

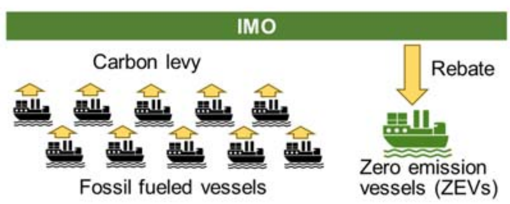
Based on the above, and in accordance with the work plan for development of mid- and long-term measures, the following two concepts are proposed by Japan in Phase I.

1. Feebate system
   A system that combines a fee for fossil fuel ships and a rebate for zero-emission ships.

   The system is to refund zero-emission ships at a level that ensures sufficient economic incentives based on cost differences (differences in fuel prices, ship prices, etc.) with fossil fuel ships, and to impose a levy on fossil fuel ships to secure the necessary revenue.

   The levy rate and the rebate rate will be determined based on future projections regarding fuel prices and penetration rates, etc., and will be reviewed periodically by IMO.





34 Nordhaus, W. D. (2006) *After Kyoto: Alternative Mechanisms to Control Global Warming*. The American Economic Review, Vol. 96, No. 2, pp.31-34.

35 Comments on proposal for a cap-and-trade system, as opposed to a carbon levy (MEPC77/7/23)

Figure 7.2-1 Image of feebate mechanism

2. Fixed price allocation of CO2 allowances by benchmarking
   Compared to emissions trading schemes, the feebate system does not have a direct link between the system and emission reduction targets, and there is an aspect of uncertainty in the reduction effects of the introduction of the system.

   Therefore, as an alternative to 1, the concept of fixed price allocation of CO2 allowances by benchmarking can be considered as a system that is linked to reduction targets while adhering to the approach where a carbon price is set in advance under the system.

   Under this system, IMO allocates allowances for a fixed price calculated as the product of a benchmark (CO2 emissions per ton-mile) and the amount of transportation activity (ton-miles) to individual ships. The surplus or deficit of allowances may be traded among ships.

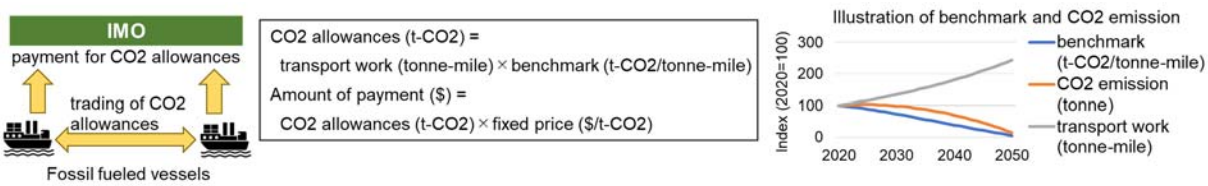


Figure 7.2-2 Image of fixed price allocation of CO2 allowances by benchmarking

Under this system, in order to increase predictability of carbon price, the price of emission allowances allocated by the IMO can be fixed (set in advance) without allocating allowances through an auction. Furthermore, since the benchmark is used as the basis, international shipping activities will not be restricted by this system even if the demand for shipping activities increases due to the increase in the volume of maritime cargo transportation. As with the feebate system, the fixed price of emission allowances will be set based on future projections of fuel prices, penetration rates, etc., and on estimates of the amount required to secure a refund amount that provides sufficient economic incentives for zero-emission ships.

Benchmarks will be set for each appropriate ship type and size, and will be strengthened sequentially to induce a steady reduction in emissions from international shipping.

It should be noted, however, that the design of this system is more complicated than that of a feebate system, including the establishment of benchmarks and rules for trading emission allowances.

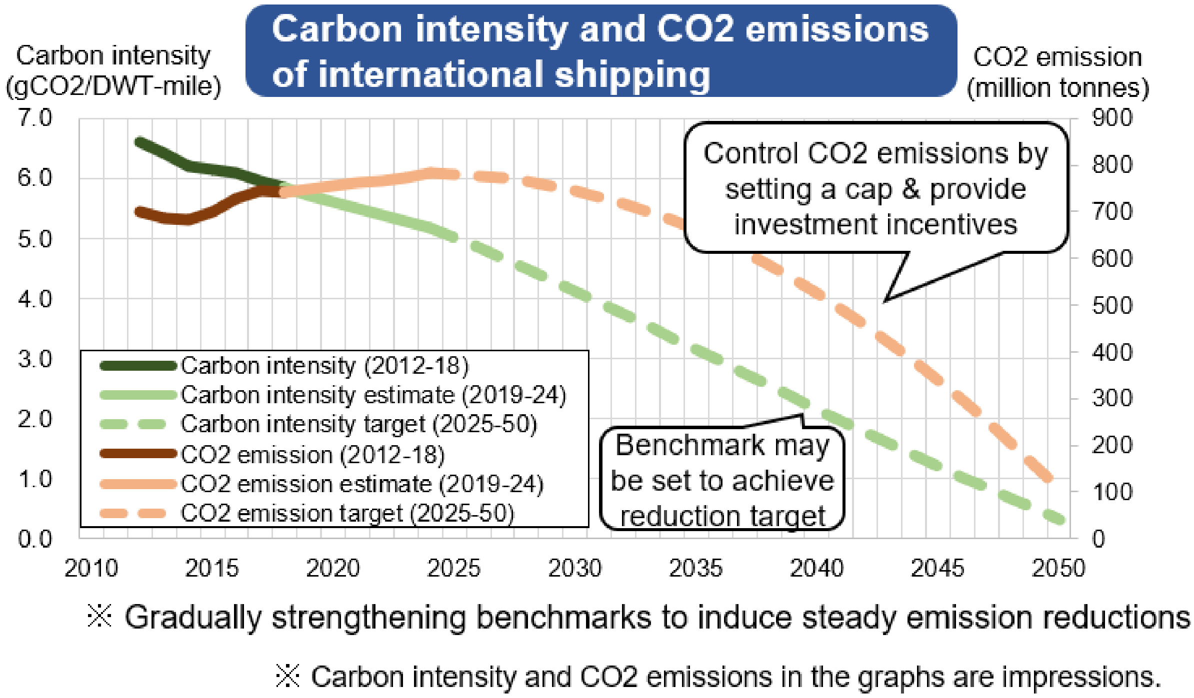


Figure 7.2-3 Image of emission reduction inducement by benchmark

Section 7.3: Regulatory Approach

As outlined in 7.1, once zero-emission ship technologies and fuels have become widespread enough and a certain level of cost reduction has been achieved by supporting the emergence and expansion of first movers through the market-based measures (MBMs), the key to achieving net zero GHG emissions by 2050 will be how to ensure a transition from fossil fuel ships to zero-emission ships. In such a phase, it will be necessary to strongly (forcibly) shift to zero-emission ships through regulatory measures.

Specifically, the first step would be to introduce regulations mandating new ships built after a certain year to operate with zero emissions. However, as the simulation results in Chapter 6 show, it will be difficult to achieve net zero emissions simply by mandating zero-emission operation for new ships, since it is expected that a certain number of fossil fuel ships will remain in operation in 2050. Therefore, in addition to regulations for new ships, it will be necessary to further introduce regulations mandating existing ships to operate with zero emissions through the use of drop-in fuel, etc in later years. Based on the above discussion, the overview of mid- and long-term measures is shown in Figure 7.3-1.

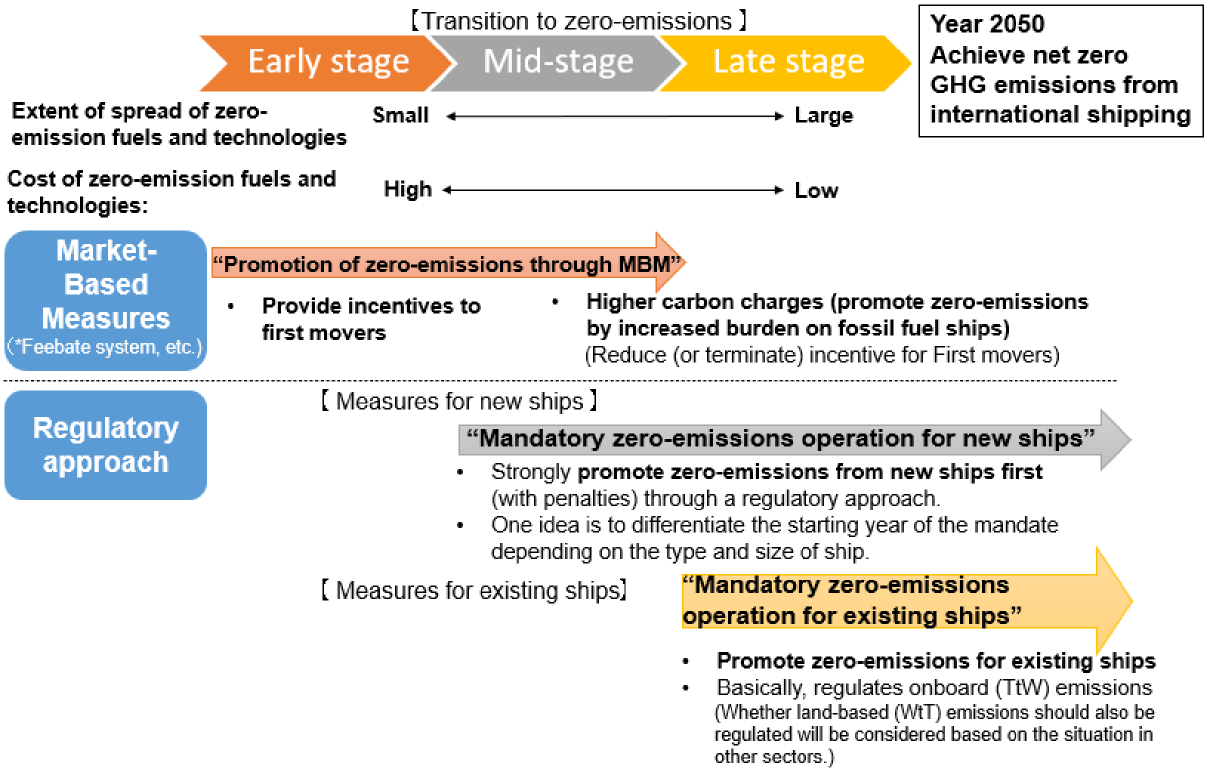


Figure 7.3-1 Overview of mid- and long-term measures

Section 7.4: LCA (Life Cycle Assessment) of GHG Emissions

Global warming is a common issue worldwide, and it is important to be aware that GHG emissions from fuels used in the shipping sector are not only generated during onboard combustion, but also during production and other processes. IMO is currently developing guidelines for assessing life cycle GHG emissions from marine fuels (LCA Guidelines). The main concepts of the LCA guidelines are as follows:

1. Evaluate land-based (Well-to-Tank) and onboard (Tank-to-Wake) emissions respectively.

2. The assessment of GHG emissions should be consistent with IPCC guidelines[36]. For example, for carbon-recycled fuels, which are produced by capturing CO2 emitted from the use of fossil fuels as raw materials, the emission of captured CO2 shall be accounted as land-based emissions and the CO2 emissions on board shall be treated as zero.

3. In addition to the method of calculating GHG emissions according to the production process of the fuel used, etc., default values that can be used simply for each type of fuel shall also be set.

In the LCA guidelines, the evaluation method for land-based emissions, including the setting of default values, will require further discussion by experts in the future, and it will take a certain period of time to complete. On the other hand, if an evaluation method for onboard emissions is established, GHG emissions when alternative fuels are used will be clarified, and the use of alternative fuels is expected to be promoted through the adoption of this method for CII ratings, etc. Furthermore, if an evaluation method for land-based emissions can be established and made available, it is expected to raise awareness of GHG emission reductions throughout the

[36] 2006 IPCC Guidelines for National Greenhouse Gas Inventories

life cycle and promote GHG emission reduction efforts on the fuel supply side.

Section 7.5: Rules on Ship Safety and Seafarers

When considering the utilization of alternative fuels, rules on safety of the ships and seafarers are needed to be reviewed and revised, or newly developed, according to the progress of R&D on the use of those fuels.

Currently, IMO has already developed safety standards for LNG-fueled ships under the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code). However, there is no safety standards for ships using hydrogen or ammonia.

In addition to that, the use of ammonia cargo as a fuel is prohibited under the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).

Therefore, in order to facilitate hydrogen/ammonia fueled ships, it is urgent to understand the application of existing in-force regulations and develop safety standards, taking into account the ongoing R&D. In addition, it will be necessary to develop safety standards for the installation of wind propulsion systems and onboard CO2 capture and storage systems.

In introducing alternative fuels such as hydrogen fuel and ammonia fuel as well as new systems such as onboard CO2 capture to ships, the requirements of competence for seafarers to operate such ships should be considered, and the international standardization of such requirements should be promoted.

Chapter 8: Concluding Remarks

It is difficult to make definitive future predictions on future trends toward zero emissions in international shipping due to uncertainties such as the fuel supply side, technology development issues, and costs. We will continue to monitor trends.

This report is based on currently available information and presents the contents and timing of the necessary zero-emission ship technology development and regulatory developments, based on analysis and study of GHG reduction measures that should be introduced to achieve net zero GHG emissions from international shipping by 2050.

In order to achieve net zero GHG emissions by 2050, it is necessary to continue to grasp and organize information on the outlook for the supply of zero-emission fuels and trends in the development of zero-emission ships, as well as to further study the following.

- Supply and price outlook of zero-emission fuels to the maritime sector

- Organize technical development issues and technology readiness levels for early introduction of zero-emission ships

- The state of mid- and long-term measures based on the progress of discussions at IMO