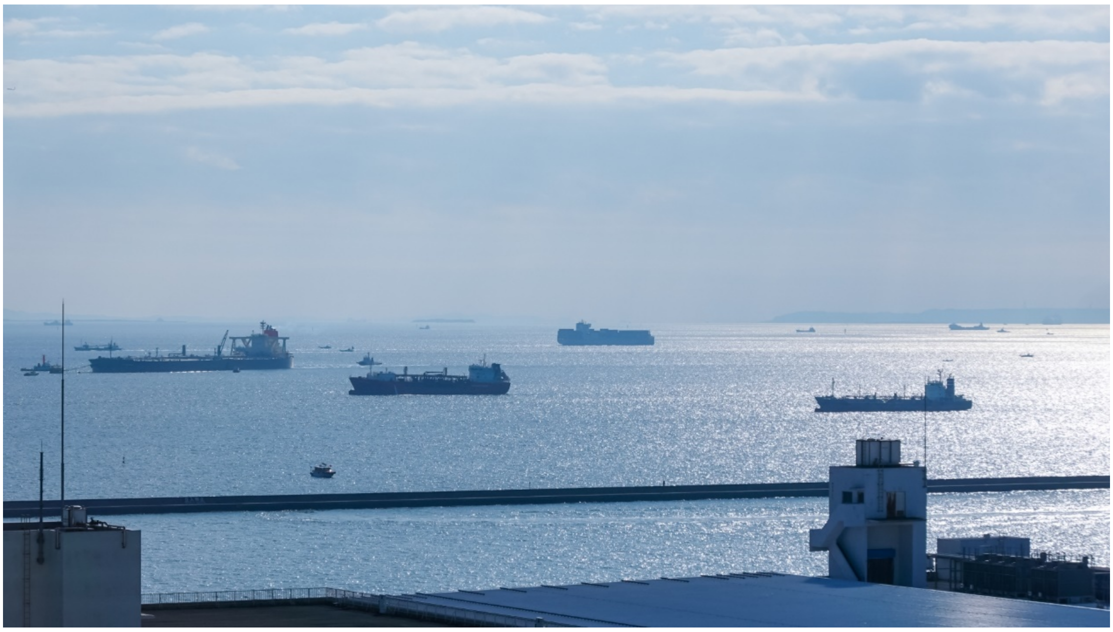
日本海事センター
JMC
補助事業

The Current Status of Carbon Neutrality in Shipping (2nd edition)

Basic Data (as of March 2024)



The Japan Association of Marine Safety

Contents

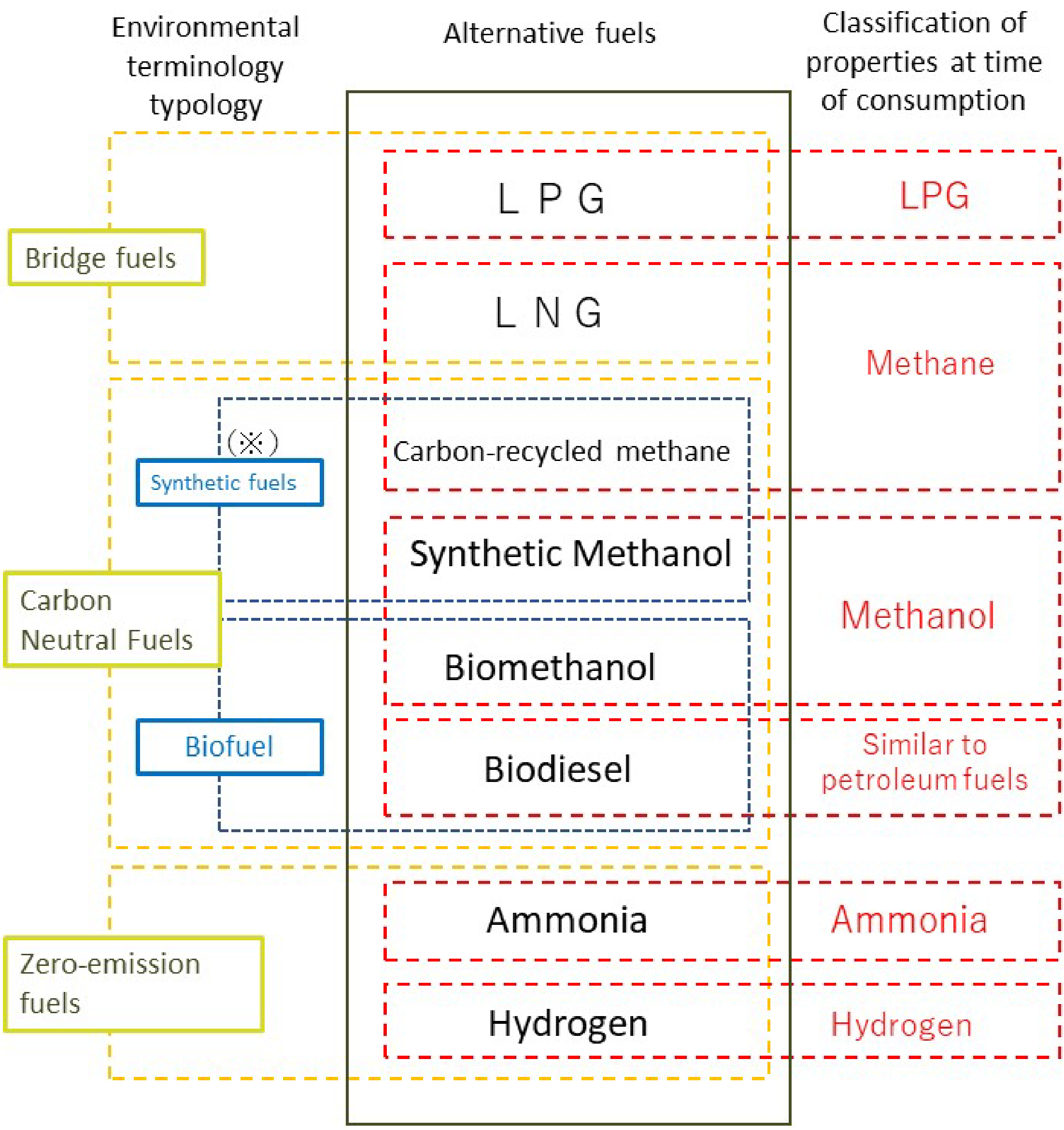
(Acronyms and common environment-related vocabulary used in this paper)

BOG	Abbreviation of Boil Off Gas: Gas that evaporates due to natural heat that enters from outside the storage tank when transporting or storing low-temperature fluids such as LNG.
CCC	Abbreviation of Carriage of Cargoes and Containers. Sub-Committee on Carriage of Cargoes and Containers (IMO)
CCS	Abbreviation of Carbon dioxide Capture and Storage.
CII	Abbreviation of Carbon Intensity Indicator: A rating system based on the results of the annual fuel consumption of existing vessels.
COP	Abbreviation of Conference of the Parties.
EEDI	Abbreviation of Energy Efficiency Design Index: An energy efficiency index to limit the carbon dioxide emissions volume per transport work (g of CO2 per ton-mile) in the design/construction stage of newly-built vessels.
EEXI	Abbreviation of Energy Efficiency Existing Ship Index: An energy efficiency index to limit the carbon dioxide emissions volume per transport work (g of CO2 per ton-mile) of existing vessels.
FAME	Abbreviation of Fatty Acid Methyl Ester: A biofuel (biodiesel) generated through a reaction of vegetable oil and methanol.
FC	Abbreviation of Fuel Cell.
GHG	Abbreviation of Greenhouse Gas: Gases in the atmosphere such as carbon dioxide, methane and nitrous oxide that produce the greenhouse effect by partly absorbing the infrared radiant energy from the earth's surface.
HVO	Abbreviation of Hydrotreated Vegetable Oil: A biofuel (biodiesel) produced from hydrotreated vegetable oil.
IMO	Abbreviation of International Maritime Organization
IPCC	Abbreviation of Intergovernmental Panel on Climate Change
MEPC	Abbreviation of Maritime Environment Protection Committee
MSC	Abbreviation of Maritime Safety Committee.
SVO	Abbreviation of Straight Vegetable Oil: A biofuel (biodiesel) extracted from pure plant oil.

UNFCCC	Abbreviation of United Nations Framework Convention on Climate Change.
Ammonia slip	The emission of ammonia remaining in exhaust gas into the open air. Ammonia is not a greenhouse gas but it does have a bad odor and is toxic.
Carbon neutrality	Zero greenhouse gas emissions from an overall perspective. For example, when biofuel burns, it does emit carbon dioxide but the vegetation that is used as the base material of the fuel absorbs carbon dioxide in the atmosphere by means of photosynthesis during its growth process. Therefore, it is referred to as a "carbon neutral" fuel because it essentially has zero emissions of carbon dioxide, a greenhouse gas. Net zero has the same meaning.
Carbon recycled methane (*)	Methane that is generated from a reaction between captured carbon dioxide and renewable energy-derived hydrogen. Also called synthetic methane (*).
Green/blue/gray fuel	Green fuel: Fuel that is generated using renewable energy-derived hydrogen. Blue fuel: Fuel that is generated using hydrogen formed by capturing carbon dioxide that is produced in the fossil fuel decomposition process. Gray fuel: Fuel that is generated using hydrogen formed without capturing the carbon dioxide that is produced in the fossil fuel decomposition process. Also called brown fuel.
Synthetic methanol (*)	Methanol that is generated from a reaction between captured carbon dioxide and renewable energy-derived hydrogen. Also called carbon recycled methanol and e-methanol.
Zero emissions	Zero GHG emission. For example, when hydrogen fuel and ammonia fuel burn, they do not generate carbon dioxide, a greenhouse gas, so they are "zero emissions fuels."
Biodiesel	A biofuel for diesel engines. It is produced from rapeseed oil, soy oil, sunflower oil and waste edible oil, etc., which undergo a chemical reaction to make them easier to use as fuels. Efforts are being made for use of SVO, FAME, and HVO.
Biomethanol	Methanol generated by gasifying and distilling raw materials derived from plants such as wood/vegetation.
Methane slip	The emission of unburnt methane in LNG fuel into the atmosphere. Methane has a greenhouse gas effect that is 28 times stronger than carbon dioxide.

*) In this paper, "synthetic fuel" refers to fuel that uses captured carbon dioxide and hydrogen derived from renewable energy and that is deemed to be carbon neutral.

Standard types of environmental vocabulary relating to the alternative fuels covered in this paper



*In this paper, "synthetic fuel" refers to fuel that uses captured carbon dioxide and hydrogen derived from renewable energy and that is deemed to be carbon neutral.

Introduction

Climate change is an issue confronting humanity as a whole. There are movements around the world to reduce greenhouse gases (GHG), and Japan has announced its goal of being carbon neutral by 2050. GHG reduction is an issue that is being tackled throughout all industries, including the shipping industry, where efforts to reduce GHGs are being promoted.

In order to reduce GHG emissions from ships, various technological developments are being promoted. Efforts are being made toward technological developments and system creation for the use of alternative fuels that do not generate any carbon dioxide, such as hydrogen and ammonia, which have never been used as ship fuels. However, it is undeniable that relevant information tends to be complex and specific to each field.

This paper gathers the basic data regarding efforts to reduce GHG emissions from ships, and a summary of related technologies and alternative fuels, with a primary focus on ship operators, ship owners and ship crews, etc. who work in shipping but who are unfamiliar with existing efforts to reduce ship GHG emissions. More than a year has passed since the first edition was published, and the content has been updated as of March 2024, in line with changes such as revisions to the IMO GHG reduction strategy during that time. The second edition can also be accessed via the website of the Japan Association of Marine Safety (https://www.nikkaibo.or.jp) as the first edition could be.

We hope that this paper will prove useful in helping readers to deepen their understanding of the current status of efforts to reduce GHG emissions from ships and that shipping industry can adapt to the process of reducing GHG emissions from ships without confusion.

Key points of this paper

- ○ GHG emissions reduction in international shipping has been discussed by IMO, and the reduction targets which had been set by IMO were revised in July 2023. GHG emission volumes in coastal shipping are calculated separately by each country. In Japan, the government has set its reduction targets in the “Plan for Global Warming Countermeasures.”
- ○ In Japan, based on the characteristics of international shipping and coastal shipping, various efforts are being promoted, both tangible and intangible, to develop technology and create systems to reduce GHG emissions.
- ○ Various technologies to promote GHG emission reductions continue to be researched and developed, although some of them, such as LNG-fueled ships in service, are in the stage of social implementation.
- ○ Various technologies undergoing research and development, including technologies for introducing ammonia fuel, which has never been used as shipping fuel before, will be implemented in society through pilot testing in the near future.

1 Global Frameworks for GHG Reduction Targets

International greenhouse gas (GHG) reduction discussions are taking place under the United Nations Framework Convention on Climate Change (UNFCCC). At the UNFCCC COP21 in 2015, the Paris Agreement was adopted as the international framework for countermeasures to global warming for 2020 onwards, which came into effect in November 2016. In addition to stating the global shared goals, including keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5 degrees Celsius, the Paris Agreement places the obligation on each country to renew and submit its GHG emissions reduction/control targets every 5 years. Each country examines its own targets for GHG emissions in coastal shipping by calculating the emissions volume within the framework of the UNFCCC Paris Agreement.

On the other hand, in international shipping, the relationships among ship registration countries, operators and the nationalities of cargo owners, etc. are complicated, and countries concerned are diverse, which does not fit within the framework of UNFCCC county-based reduction measures. Therefore, in the Kyoto Protocol adopted at the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) in Kyoto in 1997, the International Maritime Organization (IMO) was entrusted with investigating these issues under the Kyoto Protocol.

As of 2018, carbon dioxide (CO2) emissions from international shipping comprise approximately 2.1% of global total CO2 emissions. This amount corresponds to the CO_2 emissions volume of a single German country. If no countermeasures were taken, emissions would increase to about 7.0% by 2050. (see Fig. 1)[1)]

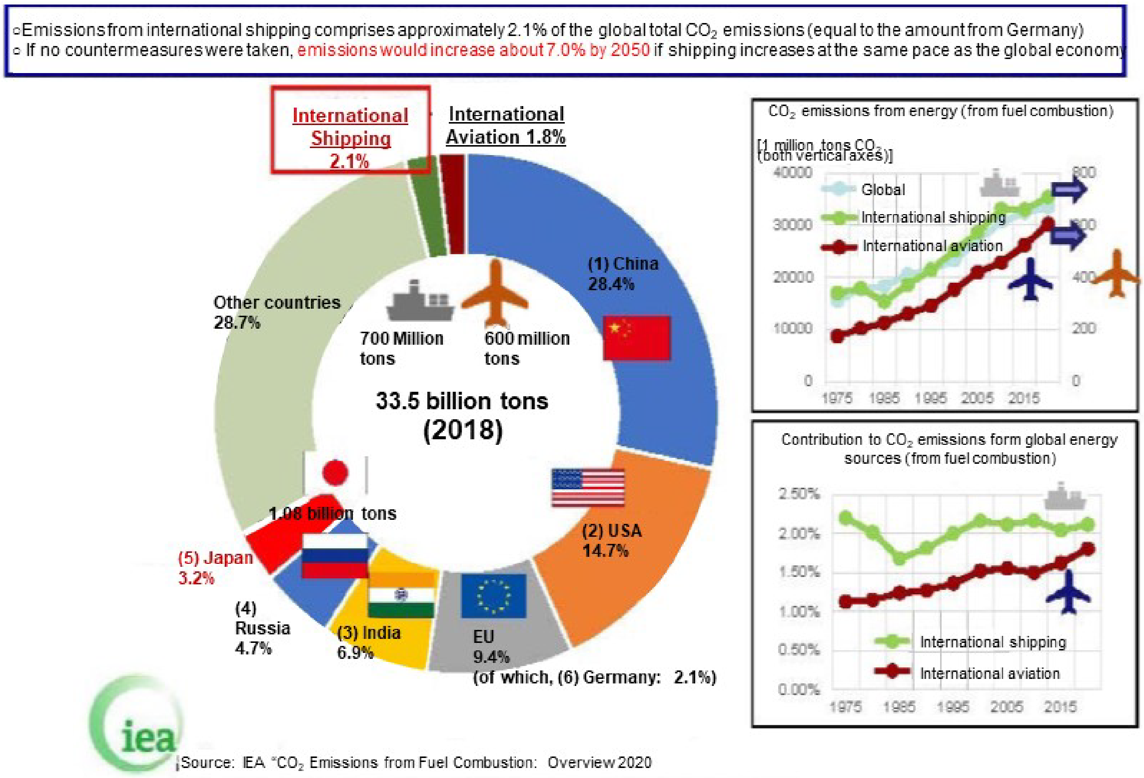
In view of this situation, in 2018, IMO formulated the GHG Reduction Strategy which aimed at:

i) reducing CO2 emissions by 40% or more per transport work by 2030 (compared to 2008),

ii) reducing GHG emissions by 50% or more by 2050 (compared to 2008), and

iii) realizing zero emissions as soon as possible in this century.

The GHG reduction strategy is reviewed every five years, and the revision shown in Table 1 was made in July 2023.



Source: MLIT: "Current status of coastal shipping CO2 emissions and related environments, etc."

Fig. 1 CO2 emissions from international shipping

Table 1 2023 IMO GHG Reduction Strategy (Main points)

Timeframe	"Levels of ambition" to be achieved	"Indicative checkpoints" to reach net-zero GHG emissions
2030	5-20% use of zero-emission fuel, etc. 40% or more reduction in CO2 emissions per transport work (compared to 2008)	20-30% reduction in GHG emissions (compared to 2008)
2040	―――	70-80% reduction in GHG emissions (compared to 2008)
By or around 2050	Zero GHG emissions (Net-zero)	―――

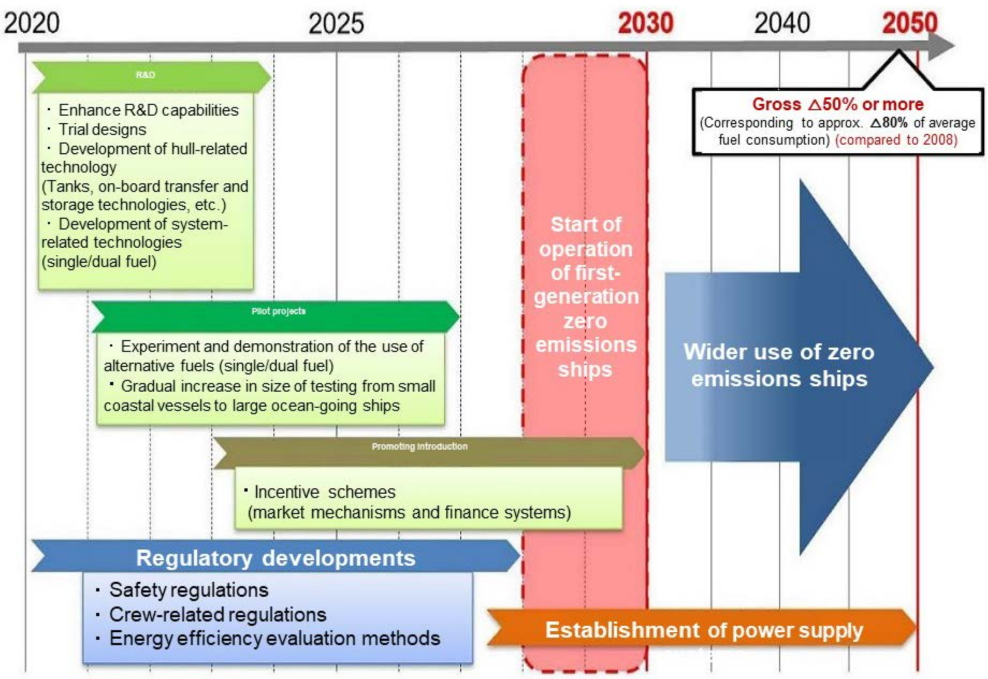
In terms of international shipping GHG reduction measures, the energy efficiency of newly-built vessels has been regulated (EEDI regulations) since 2013. As an energy efficiency improvement measure for existing vessels that were not covered by EEDI regulations, the IMO adopted a draft amendment to the International Convention for the Prevention of Pollution from Ships (MARPOL) in 2021 in order to introduce the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), which came into effect on January 1, 2023.

2 Japan's Actions with regard to Reduction Targets

(1) Challenging for net zero GHG in international shipping by 2050

Amid growing global momentum toward decarbonization, the aim of achieving "carbon neutrality by 2050" was declared in the Prime Minister's general policy speech in October 2020. Also, in October 2021, the Japanese Shipowners' Association announced that "the Japanese shipping industry will take on the challenge of net zero GHG by 2050[2]." In addition, MLIT announced that "Japan will propose to the IMO the target of becoming carbon neutral by 2050[3]." Furthermore, in 2021, Japan, together with the United States, the United Kingdom and other countries, jointly proposed a new target of reducing GHG emissions to zero by 2050 (carbon neutrality by 2050) with regard to the IMO GHG reduction strategy, and the IMO adopted a revised reduction strategy that aims to achieve zero GHG emissions (net zero) by or around 2050. Initiatives toward a reduction in GHG emissions are intensifying.

Japanese international shipping has already increased the number of LNG fuel operated ships, and is promoting other efforts toward net zero GHG, including the operation of bulk carriers equipped with hard sail wind power propulsion systems. In order to achieve carbon neutrality in international shipping, it is essential to switch from traditional heavy oils to zero emissions fuels such as hydrogen and ammonia. Therefore, in the International Shipping Zero GHG Emissions Project established in 2018 through industry-academia-government-public cooperation, in addition to presenting two scenarios toward emissions reductions in March 2020, namely, a transition from LNG→carbon-recycled methane and the increased use of hydrogen/ammonia fuels, a roadmap was presented toward realizing zero emissions ships (ships that achieve an improvement in energy efficiency of 90-100% compared to 2008). The timeframe of 2028-2030 was given for the introduction of zero emissions ships. R&D is now being promoted toward that goal, technical verifications are being conducted, and systems for the construction and operation of zero emissions ships are being developed. From 2030 onward, while it is expected that zero emissions ships will move toward wider use, it is important to provide onshore supply systems for alternative fuels. (see Fig. 2)[4]



Source: From MLIT's "Roadmap toward zero emissions in international shipping"

Fig. 2 Summary of the roadmap toward realizing zero emissions ships

(2) Promoting carbon neutrality in coastal shipping

Based on the Paris Agreement adopted at COP21 in 2015, the Plan for Global Warming Countermeasures was approved by cabinet decision in May 2016. The target for the transportation industry as a whole for FY 2030 was set as a reduction in carbon dioxide (CO_2) emissions of 27% compared to FY 2013. With this in mind, the target for coastal shipping for FY 2030 was a reduction in CO_2 emissions of 15% (approx. 1.57 million tons) compared to FY 2013 (approx. 10.83 million tons).

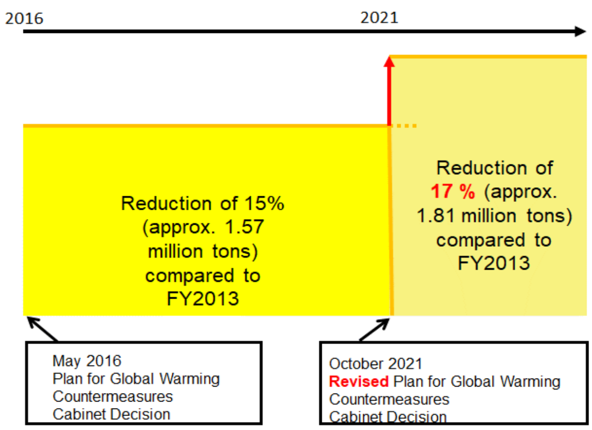


Fig. 3 Transition in targets for CO2 emissions reductions in coastal shipping by FY 2030

In view of the announcement of the aim of realizing "carbon neutrality by 2050" in the Prime Minister's general address in October 2020, and the increasing need to intensify and accelerate efforts toward CO_2 reduction in all areas, the "Committee for Carbon Neutrality Promotion in Coastal

Shipping” was held by MLIT in April 2021. Later, at the end of 2021, the findings of this committee were published[5)].

In October 2021, the Plan for Global Warning Countermeasures was revised, raising the transportation industry as a whole to a reduction in CO2 emissions of 46% by FY 2030 compared to FY 2013. Therefore, the coastal shipping CO2 reduction target was also raised to a reduction of 17% (approx. 1.81 million tons) by FY 2030 in comparison to FY 2013 (approx. 10.83 million tons). (see Fig. 3)

With regard to efforts to save energy and reduce CO2 emissions in coastal shipping, shipyards and ship manufacturers have so far been developing proprietary energy-saving/low CO2-emission equipment and vessels, including energy-saving ships and high-efficiency engines, which have been introduced by shipping businesses. In addition, ship operations that contribute to energy-saving and a reduction in CO2 are being carried out, while MLIT has also implemented various measures to promote the efforts of businesses in cooperation with other related Ministries. As a result, from FY 2013 to FY 2019, a reduction in CO2 emissions of approx. 450,000 tons was achieved, but further efforts toward emissions reduction are required. In the findings of the Committee for Carbon Neutrality Promotion in Coastal Shipping, in order to achieve the CO2 emissions reduction target for FY 2030 stated in the Plan for Global Warming Countermeasures and to achieve Japan’s contribution to carbon neutrality for 2050, it is important to engage in the two pillars of “the pursuit of greater energy-saving for ships” and “support for pioneering efforts toward the use of alternative fuels in coastal shipping, etc.” The orientation of policies for engagement was summarized in the findings, and, on that basis, efforts toward the reduction and elimination of carbon in coastal shipping are being promoted.

i) Pursuit of greater energy-saving for ships in order to achieve the FY 2030 target

In the findings of the "Committee for Carbon Neutrality Promotion in Coastal Shipping," the development/wider use of “Coordinated Energy-saving Ships” in new ship building, further improvements in the use of biofuels and greater navigation efficiency by existing ships, and the visualization of energy-saving and low carbon strategy were listed as immediate CO2 emission reduction measures to achieve the CO2 emission reduction target for FY2030.

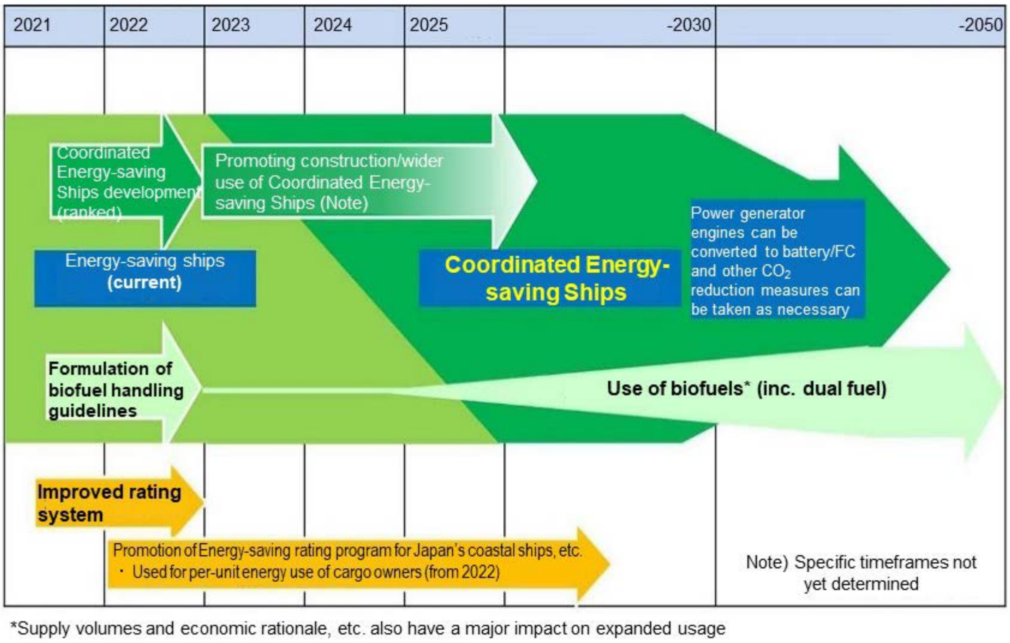
“Coordinated Energy-saving Ships” are coastal vessels that achieve greater energy-saving/ CO2 emission reduction through a combination of energy-saving ship hardware, corporation with cargo owners and other entities and new tangible and intangible energy-saving technologies and measures on land and in ports. Specifically, the aim is to achieve greater energy-saving/ CO2 emission reduction through a combination of new technologies and methods in cooperation with efforts of cargo owners and on-shore/port facilities, etc., including fuel consumption reduction by hybrid propulsion through a partial conversion to battery power for engines and power generators, navigational optimization by introducing navigation support equipment using automatic navigation/remote control technology and shared digital platforms, time and labor saving for cargo loading/unloading and pier docking/undocking by introducing remote centralized systems for cargo handling, automation/electrification of cargo loading/unloading and pier docking/undocking equipment, and shutting-off power generators when being berthed using shore power system and high-capacity storage cells, as well as further advancement of current energy-saving technologies by developing standard type of ship optimal for energy conservation and promoting further engine efficiency, etc.

With the objective of facilitating the introduction of coordinated energy-saving ships by businesses, MLIT is developing a model coordinated energy-saving ship, and, in order to investigate coordinated energy-saving ship concepts and to develop exemplary model ships, it established the "Committee for Development and Promotion of Coordinated Energy-saving Ship" in June 2022. In July 2023, the concept of coordinated energy-saving ship for general cargo ships, tankers, 749GT cement carriers, 5000GT cement carriers, Roll-on/Roll-off ships, long course service ferries, and small and medium-sized passenger ships was compiled and made public[6)]. With the idea of ship construction and introduction from FY2023 onwards in mind, efforts toward coordinated energy-saving ship development and promotion are continued.

On the other hand, because current diesel systems can be used as they are or with minor improvements, it is expected that biofuels will be used as an initiative toward reducing CO_2 emissions from existing vessels. MLIT established the "Committee for the Formulation of Guidelines for the Handling of Biofuels on Ships" in July 2022, which is examining the formulation of guidelines to enable the safe and efficient handling of biofuels. In March 2023, "Guidelines for Handling Biofuels on Ships" was published[7)].

An essential element of energy-saving and CO2 emission reduction measures for existing vessels is to aim for further improvement of navigation efficiency. To that end, efforts are being made to further improve navigation efficiency, including the introduction of shared digital platforms to optimize vessel assignment plans and sailing plans for entire fleets by feeding back voyage information, such as efficient vessel assignment according to transportation demand and delays caused by weather/sea conditions, to vessel assignment plans, and by saving time for cargo loading/unloading and pier docking/undocking through the introduction of automation/electrification.

To implement initiatives toward further energy-saving in order to achieve these targets for FY 2030, it is important that there is coordination between related parties, including cargo owners, operators, ship owners and shipyards. In order for these related parties to use their efforts toward energy-saving/ CO2 emission reduction as a means of highlighting their appeal to the outside world, an “Energy-saving rating program for Japan’s coastal ships” is being operated which visualizes and evaluates the energy-saving/ CO2 emission reduction effect of Japan’s coastal vessels. As of the end of December 2023, ratings had been applied to 170 ships. MLIT is promoting efforts to “visualize” the energy-saving/ CO2 emission reduction effect of coastal vessels, including efforts to further disseminate this program. (see Fig. 4)[5)]



Source: From MLIT “Carbon Neutral Port (CNP) Review Meeting” findings

Fig. 4 Roadmap for coordinated energy-saving ships, etc.

ii) Support for pioneering efforts toward the use of alternative fuels, etc. toward 2050

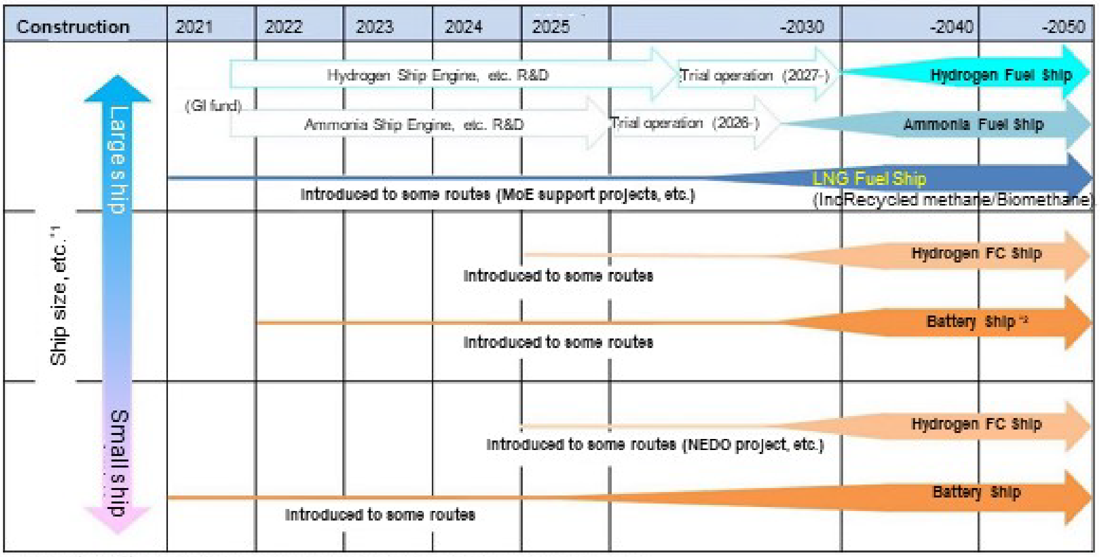
In order to achieve the CO_2 emissions reduction targets for FY 2030 stated in the Plan for Global Warming Countermeasures, while the pursuit of further energy-saving for ships through the development and promotion of coordinated energy-saving ships is an important action in the short-term, at the same time, it is also necessary to promote the utilization of alternative fuels and other innovative initiatives that will contribute to Japan becoming carbon neutral by 2050.

The Committee for Carbon Neutrality Promotion in Coastal Shipping has therefore identified a number of environmental improvements to support innovative initiatives toward 2050, including support for the demonstration and introduction of LNG-fueled ships, hydrogen FC (fuel cell) ships, and battery-powered ships; support for technological development in connection to hydrogen-fueled ships/ammonia-fueled ships; and the formulation of safety guidelines for gas-fueled ships.

With regard to the reduction and elimination of carbon emissions using LNG-fueled ships, hydrogen FC (fuel cell) ships and battery-powered ships, etc., businesses have eagerly commenced trial introductions, including coastal vessels. As introduced later in “5: Examples of initiatives to promote carbon neutrality in Japan,” some such ships are already in service and are operational. MLIT, in coordination with other relevant Ministries, is conducting projects to support the construction of such low- and de-carbonized ships. More of these ships will be introduced from FY 2030 onwards as the technology matures, costs reduce and fuel supply infrastructure is put in place.

Hydrogen-fueled ships and ammonia-fueled ships are gradually being introduced from the latter half of 2020 primarily as ocean-going ships, but they can also be used as larger coastal vessels in some cases. In order to steadily proceed with the development and demonstration trial of the engines, fuel tanks and fuel supply systems of such next-generation ships, support is being provided through the “Next-Generation Ship Development Project,” a Green Innovation Fund Project.

In terms of providing the environment needed for the wider use of gas-fueled ships, revisions are being made to the fuel cell ship safety guidelines that increase the freedom of design for hydrogen FC ships while also maintaining safety as well as promoting the provision of safety guidelines for gas-fueled ships. (see Fig. 5) [5)]



*1: Potential usage varies greatly depending on ship type and route, etc.
*2: Can be used for relatively short routes

Source: From MLIT “Carbon Neutral Port (CNP) Review Meeting” findings

Fig. 5 Use of alternative fuels and other potential applications of advanced technologies

3 GHG Emissions Reduction Technology

In order to achieve the 2030 and 2050 GHG reduction targets, various technologies are being developed, including the use of fuels (alternative fuels) to replace conventional petrol usage, battery-propulsion, and the use of wind power. There will be an increasing demand for knowledge and skills with regard to GHG reduction technology. For example, for LNG-fueled ships that are actually being used in society, ship crews who are responsible for handling fuel, including the ships' captain, chief engineer and engineers, need to obtain licenses as persons qualified to handle hazardous substances (low flash point fuel).

With regard to the GHG reduction effect from the main technological developments and the status of development and other characteristics, in Table 2-(1)-(3) and Table 3, the main findings are divided into technologies relating to power sources for ships, including the use of alternative fuels, and technologies other than alternative fuels.

Table 2-(1) Characteristics of GHG reduction technology relating to ship power sources (part 1)

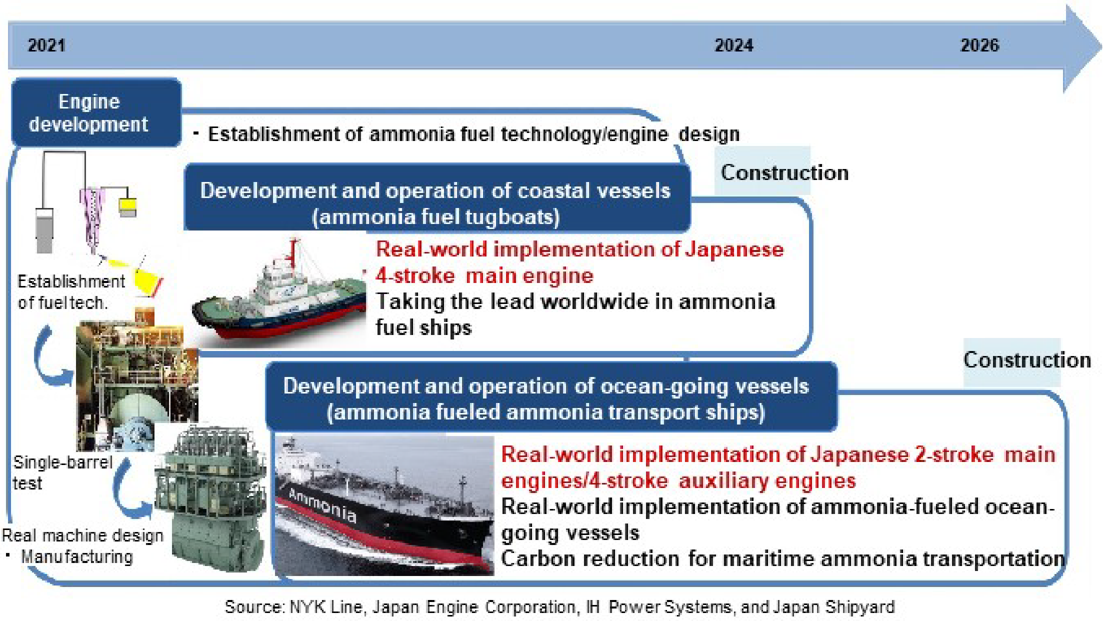
	LNG-fueled ships	LPG-fueled ships	Biofuel ships (biodiesel)
Reduction effect	o Carbon dioxide reduction effect of approx. 25% in comparison to conventional petroleum[8].	o Carbon dioxide reduction effect of approx. 16% in comparison to conventional petroleum[9].	o When navigating, carbon dioxide is generated, but it is viewed as being carbon neutral because of the absorption of carbon dioxide in the growth process of the vegetation that is used as raw materials for the fuel.
Development status, etc.	o Already introduced for tugboats and large ships. o Technology is being developed to reduce methane slip (The emission of unburnt methane in LNG fuel into the atmosphere. Methane has a greenhouse gas effect that is 28 times stronger than carbon dioxide). o In some regions, bunkering ships have been introduced and actual bunkering has commenced.	o In addition to being introduced for LPG transport ships, there is the potential for introduction in some commercial ships, including the acquisition of basic design approval for LPG-fueled large bulk carriers from the Nippon Kaiji Kyokai (ClassNK) by domestic shipyards[10].	o Sailing trials have commenced for small ships such as tugboats and tourist ships as well as larger ships. o Existing equipment can be used including diesel engines.

Issues and other notes	o Operator training is required for bunkering technology and fuel supply systems that differ from those of petrol-fired ships. o Wider use is expected as a gateway to zero GHG emissions. o In the future, there could be a shift to the use of carbon-recycled methane (methane synthesized by reacting captured carbon dioxide with hydrogen derived from renewable energy sources). o LNG fuel supply systems are being put in place.	o Operator training is required for bunkering technology and fuel supply systems that differ from those of petrol-fired ships. o Wider use is expected as a gateway to zero GHG emissions.	o Securing a stable supply (in terms of quality and quantity) as ship fuel is one of the issues.

Table 2-(2) Characteristics of GHG reduction technology relating to ship power sources (part 2)

	Methanol-fueled ships	Ammonia-fueled ships
Reduction effect	o Conventional methanol fuel has a carbon dioxide reduction effect of approx. 10% in comparison to petroleum[9]. o During navigation, biomethanol generates carbon dioxide, but it is viewed as being carbon neutral because of the absorption of carbon dioxide in the growth process of the vegetation that is used as raw materials for the fuel. o When synthetic methanol (methane synthesized by reacting captured carbon dioxide with hydrogen derived from renewable energy sources) is used in ships, the carbon dioxide emitted from combustion in the engine can be captured and reused as a carbon dioxide-derived fuel, so it does not emit any additional new carbon dioxide.	o Ammonia fuel does not generate carbon dioxide when burned.
Development status, etc.	o Conventional methanol is being used as a fuel for methanol transport ships. o Major overseas shipping companies have made bulk orders for the construction of large container ships that use biomethanol fuel/synthetic methanol fuel[11].	o Domestic and international manufacturers are developing ammonia-fired engines, and tugboats and ammonia-fueled ammonia transport ships are currently under design (see Fig. 6)[12].
Issues and other notes	o In order to make biomethanol fuel ships/synthetic methanol fuel ships more common, the large-scale	o Countermeasures are needed for the nitrous oxide (N2O: Has a greenhouse effect 265 times greater than carbon dioxide) generated

	reinforcement of biomethanol/synthetic methanol production and supply systems is required.	when ammonia is burned. o The development of bunkering technology is required. o Ammonia must be handled appropriately because of the bad odor and toxicity. o Operator training is required for bunkering technology and fuel supply systems that differ from those of petrol-fired ships.



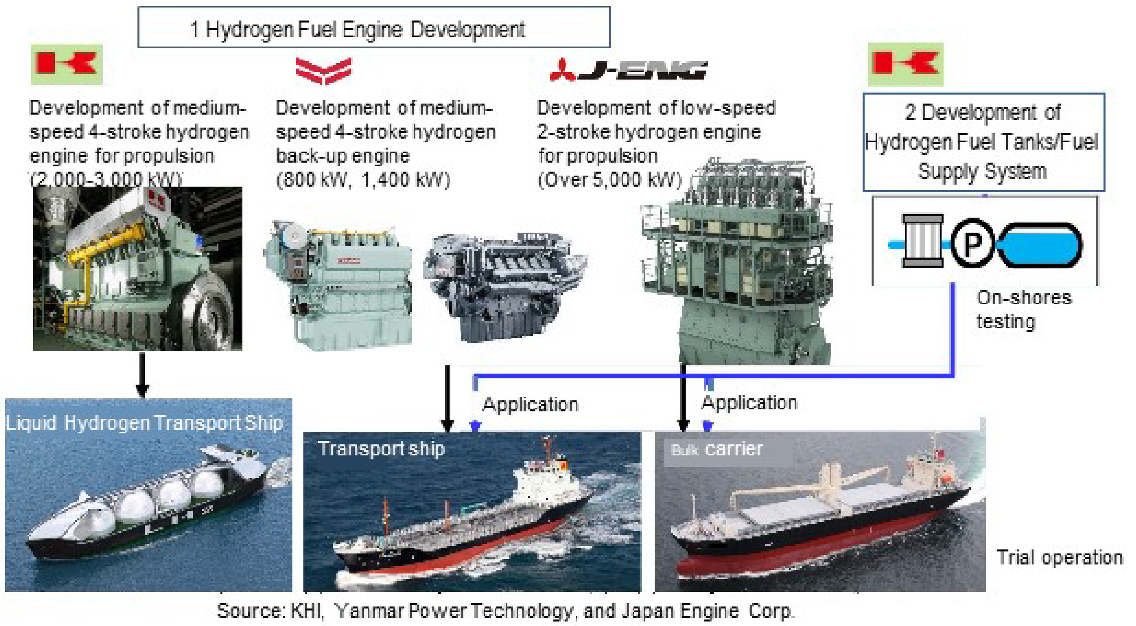
Source: MLIT Website: Toward the achievement of carbon neutrality in international shipping by 2050 (March 2022 International Shipping Zero GHG Emissions Project)

Fig. 6 Process of ammonia-fueled ship development and operation

Table 2-(3) Characteristics of GHG reduction technology relating to ship power sources (part 3)

	Hydrogen-fueled ships	Hydrogen fuel cell ships	Electric propulsion ships (EV ships: Battery ships)
Reduction effect	o Hydrogen fuel itself does not generate greenhouse gas.	o Does not generate greenhouse gas.	o Does not generate greenhouse gas.
Development status, etc.	o Manufacturers in Japan and overseas are working on developments including hydrogen fired-engines (See Fig. 7)[12]. o In Japan, pilot plants are being constructed for facilities for small ocean-going liquefied hydrogen	o Small tourist ships, pleasure boats and other small-to-medium ships are being developed and trialed. o (In other countries, ammonia fuel cell ships are being developed.)	o Already introduced in small-to-medium ships such as lithium-ion cell powered mid-size coastal tankers and small ferries.

	carriers and hydrogen cargo loading/unloading facilities, and verification tests are being conducted for the construction of supply chains.		
Issues and other notes	o The volume of hydrogen against the heat value is enormous (approx. 450% greater than petrol in liquefied condition), necessitating the development of tanks with superior capacity efficiency. BOG countermeasures are also required. o The development of bunkering technology is required. o Operator training is required for bunkering technology and fuel supply systems that differ from those of petrol-fired ships.	o Suited to use for short-distances and small-to-medium ships due to limitations on fuel tanks and output. o Low-vibration and low-noise.	o Suited to use for short-distances and small-to-medium ships due to limitations on battery capacity. o Low-vibration and low-noise.



Source: MLIT Website: Toward the achievement of carbon neutrality in international shipping by 2050 (March 2022 International Shipping Zero GHG Emissions Project) (partial amendment)

Fig. 7 Development of ship hydrogen engines and ship hydrogen fuel tanks and fuel supply systems

Table 3 Characteristics of GHG reduction technology other than alternative fuels

Wind propulsion	o Technology that contributes to propulsion for existing fuel ships using hard sails and kites is being developed. (See Fig. 8) o The degree of contribution depends on natural conditions.
On-board CO_2 capture equipment (See (Fig. 9))	o 80% of the carbon dioxide in exhaust gas can be captured. o On-board trials are being conducted. o Issues include the miniaturization of capture equipment and the need to construct systems to receive the captured carbon dioxide.
Energy-saving technology	o Energy-saving technologies are being introduced to further improve efficiency, including air lubrication (reduces hull resistance by using a ventilator to form small air pockets on the underside), changes in bow and stern shapes of the ship, propeller improvement (counter-rotating propellers, propeller boss cap fins, etc.), rudder appendage (attachment of fins to rudder, etc.), waste heat recovery systems, antifouling paints and the use of onshore power supply when being berthed.

Source: Provided by Mitsui OSK Lines/Tohoku Electric Power
Shofu Maru bulk carrier with hard sail propulsion system

Source: Provided by Kawasaki Kisen Kaisha Ltd.
Illustration of a ship with automated kite system

Fig. 8 Ships equipped with wind propulsion systems

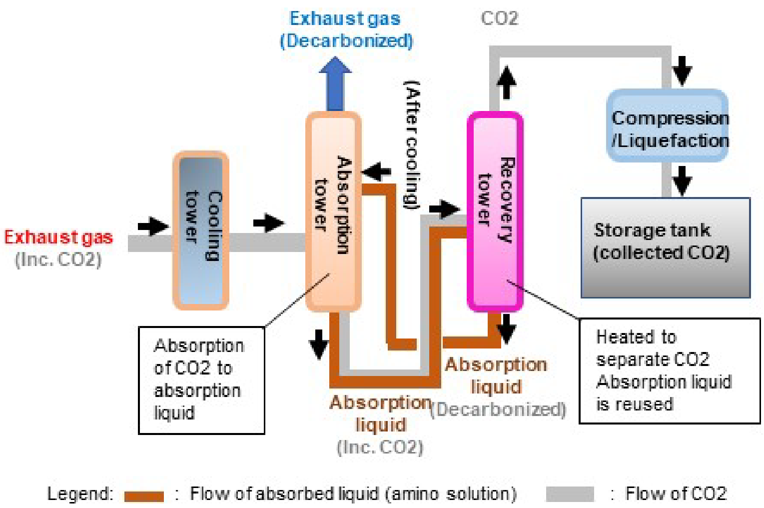


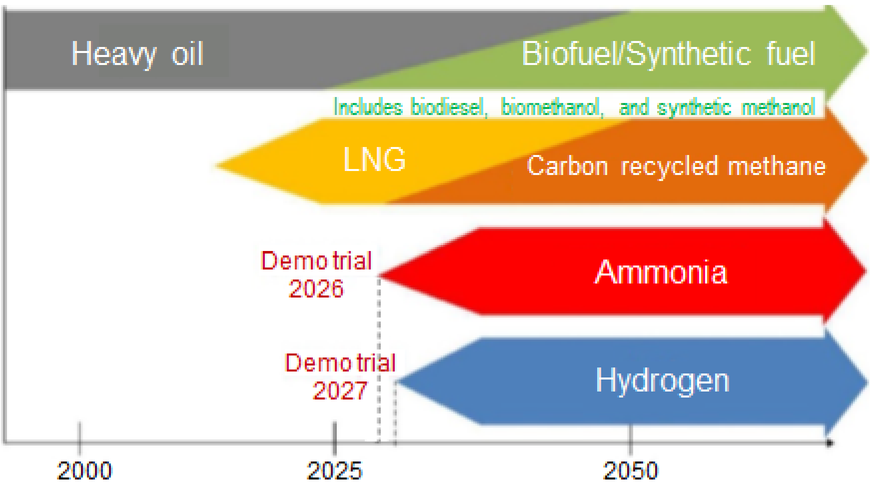
Fig. 9 CO2 capture system (amino absorption: conceptual diagram)

4 Alternative fuels

In order to realize carbon neutrality in international shipping, in addition to pursuing energy-saving technology, it is expected that there will be a conversion from petroleum, which is currently being used, to LNG (a low-carbon fuel), biofuels (carbon neutral fuels currently in the verification stage), carbon recycled methane and synthetic methanol, which have the potential to be carbon neutral fuels, and then to zero emission alternative fuels.

Efforts are being made to develop and examine the technology and systems for zero emissions ammonia-fueled ships, which will commence trial sailing from 2026, and hydrogen-fueled ships, which will commence trial sailing from 2027.

The illustration below shows the conversion of fuels in international shipping (see Fig. 10)[13].



Source: From MLIT "Efforts toward carbon neutrality in international shipping by 2050" (partially amended)

Fig. 10 Ship fuel conversion diagram

Of these alternative fuels, LNG is expected to transition to carbon-recycled methane and, in the future, to zero-emission fuels. LPG may also serve as a gateway to zero-emission fuels, which are sometimes referred to as bridge fuels. In contrast, biofuels such as biodiesel and biomethanol are considered carbon neutral fuels because the vegetation used as raw materials absorb carbon dioxide from the atmosphere during their growth, so even if carbon dioxide is emitted when they are burned, the total greenhouse gas emissions are considered zero. Carbon recycled methane and synthetic methanol, which are generated from captured carbon dioxide and renewable energy-derived hydrogen, have the potential to be carbon neutral fuels in the future.

Hydrogen fuel and ammonia fuel do not generate carbon dioxide and other GHG when burned, and are therefore called zero emissions fuels (see Fig. 11).

Table 4 shows the carbon neutral fuels and zero emissions fuels with the potential for use as fuel for ships.

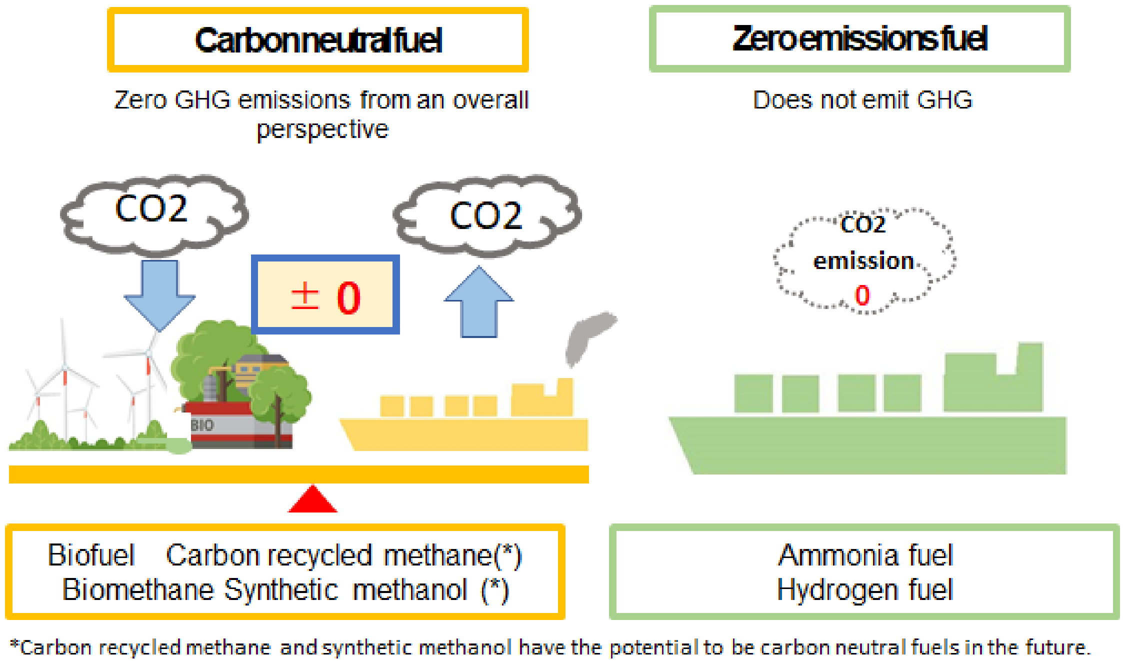


Fig. 11 Carbon neutral fuel and zero emissions fuel conceptual diagram.

Table 4 Carbon neutral fuels and zero emissions fuels with the potential for use as fuel for ships

	Biofuel (biodiesel)	Carbon recycled methane	Biomethanol/ synthetic methanol	Ammonia	Hydrogen
Classification	Carbon neutral fuel	Carbon neutral fuel	Carbon neutral fuel	Zero emissions fuel	Zero emissions fuel
Carbon dioxide emissions	Effectively zero	Effectively zero (*)	Effectively zero (*)	Zero	Zero
Greenhouse gas byproducts	None	Methane (28 times greater global warming potential than carbon dioxide)	None	Nitrous oxide (265 times greater global warming potential than carbon dioxide)	None
Stored condition (liquefied condition)	Normal temperature/normal pressure	Super-low-temperature or increasing pressure (boiling point approx. -162°C)	Normal temperature/normal pressure	low-temperature or increasing pressure (boiling point -33°C)	Super-low-temperature or increasing pressure (boiling point -253°C)

Compatible engines	Existing petrol fired-ship engines	Existing LNG ship engines	Existing methanol ship engines	Under development	Under development
On-board storage/supply system	Existing petrol fired-ships system	Existing LNG ship system	Existing methanol ship system	Under development	Under development
Bunkering technology	Existing petrol fired-ship technology can be used	Existing LNG ship technology can be used	Existing methanol ship technology can be used	Under development	Under development
Bunkering equipment	Enhancement required	Existing LNG ship technology can be used	To be installed	Under development	Under development

*Carbon recycled methane and synthetic methanol have the potential to be carbon neutral fuels in the future

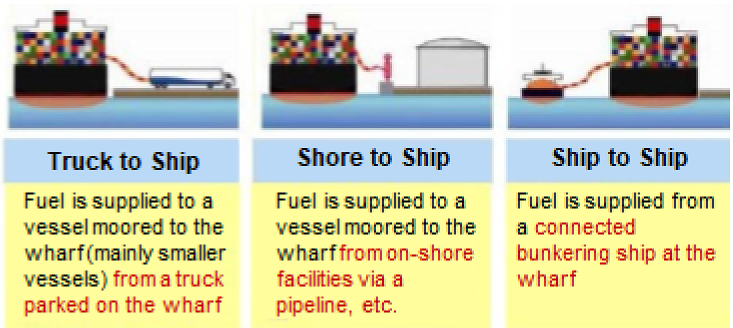
(1) Carbon neutral fuels/zero emissions fuels

Fuels that can be used by ships potentially include biofuel and biomethanol, which are carbon neutral, carbon recycled methane and synthetic methanol, which have the potential to be carbon neutral fuels in the future, and ammonia and hydrogen, which are zero emissions fuels. An outline of each fuel is given below.

i) Biofuels

Biofuels are produced using vegetation as the raw material, which absorbs carbon dioxide from the atmosphere during their growth. They are viewed as being carbon neutral fuels because, even though they emit carbon dioxide when burned, from an overall perspective, they have zero GHG emissions.

Biofuel for diesel engines is generally called "biodiesel." Efforts are being made for the use of three different biofuels for diesel engines, namely, straight vegetable oil (SVO), fatty acid methyl ester (FAME), which is produced through a reaction between vegetable oil and methanol, and hydrotreated vegetable oil (HVO). In addition to trial operations of large ships and small ships, such as tugboats and tourist ships, some supply on a commercial basis through ship-to-ship bunkering (see Fig.12)[13] also began in Japan in April 2023[14].

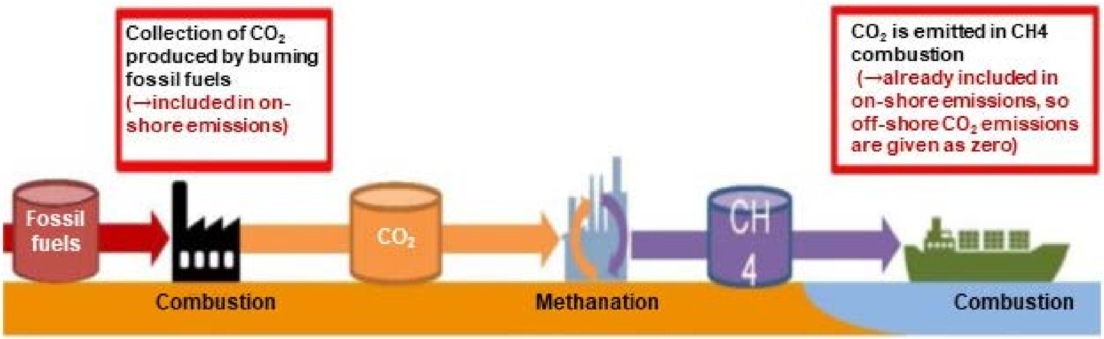


Source: From MLIT "Efforts toward carbon neutrality in international shipping by 2050" (partially amended)

Fig. 12 Supply of fuel to ships (bunkering)

ii) Carbon recycled methane

Carbon recycled methane is methane that is produced (methanation) from a reaction between captured carbon dioxide and renewable energy-derived hydrogen, which has the potential to be recognized as a carbon neutral fuel in the future. It can also be used in existing LNG-fueled ships. In addition to developing and testing carbon dioxide separation/capture and methanation technologies, investigations are being made into zero carbon dioxide emissions from ships (see Fig. 13)[13].



Source: From MLIT "Efforts toward carbon neutrality in international shipping by 2050" (partially amended)

Fig. 13 Reference image for investigation of zero Co2 emissions on ships

iii) Biomethanol/synthetic methanol

Although the carbon dioxide reduction effect when burning conventional methanol fuel is only around 10% in comparison to petroleum, biomethanol is produced using vegetation as the raw material, which absorbs carbon dioxide from the atmosphere, so it is viewed as being a zero emissions fuel from an overall perspective even though it emits carbon dioxide when burned. Synthetic methanol, which is produced from a reaction between captured carbon dioxide and renewable energy-derived hydrogen, also has the potential to be recognized as a carbon neutral fuel in the future. A major overseas shipping company has made bulk orders for the construction of large container ships that use biomethanol fuel/synthetic methanol fuel[11].

iv) Ammonia fuel

Ammonia includes green ammonia that is produced by synthesizing hydrogen generated by electrolyzing water using power from renewable energy sources (green hydrogen) and nitrogen separated from the atmosphere, blue ammonia that is produced by synthesizing hydrogen produced capturing carbon dioxide generated in the process of the decomposition of fossil fuels (blue hydrogen) and nitrogen separated from the atmosphere, and gray ammonia that is produced by synthesizing hydrogen produced without capturing carbon dioxide generated in the process of the decomposition of fossil fuels (gray hydrogen) and nitrogen separated from the atmosphere (see Fig. 14). Ammonia is currently widely used as manure and for industrial use, with gray ammonia that emits carbon dioxide in its production process being the most common. In the future, it will be necessary to transition to blue ammonia and green ammonia. In order to make use of ammonia fuel, which has a high greenhouse gas emissions reduction effect, R&D is being carried out with regard to compatible engine equipment and bunkering technology, and the necessary systems and infrastructure will also be developed.

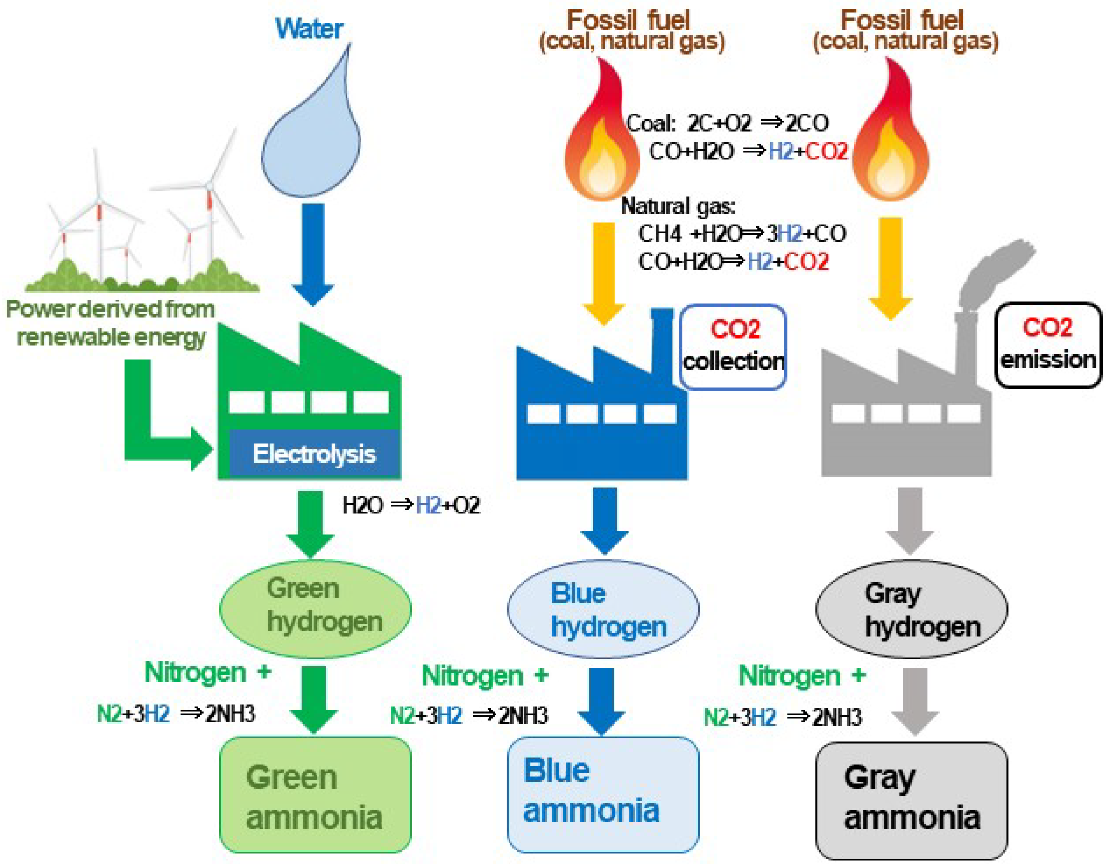


Fig. 14 Green ammonia (hydrogen), blue ammonia (hydrogen) and gray ammonia (hydrogen)

v) Hydrogen fuel

Hydrogen includes green hydrogen that is produced by electrolyzing water using power from renewable energy sources, blue hydrogen that is produced capturing carbon dioxide generated in the process of the decomposition of fossil fuels, and gray hydrogen that is produced without capturing carbon dioxide generated in the process of the decomposition of fossil fuels (see Fig. 14). In order to make use of hydrogen fuels, which are highly effective in reducing greenhouse gas emissions, in addition to conducting R&D regarding equipment such as compatible engines and bunkering technology, the necessary systems and infrastructure will be developed.

(2) Greenhouse gas reduction effect, etc.

Table 5, Table 6 and Table 7 show the effectiveness in reducing greenhouse gas emissions, supply chain conditions and physical properties for biofuels and biomethanol which are carbon neutral fuels, carbon recycled methane and synthetic methanol which have the potential to be carbon neutral fuels in the future, and ammonia and hydrogen which are zero emission fuels

Table 5 Characteristics of different fuels in terms of "effectiveness in reducing greenhouse gas emissions"

Biofuel (biodiesel)	o Biofuels are produced using vegetation as the raw material, which absorbs carbon dioxide from the atmosphere. They are viewed as being carbon neutral fuels because, even though they emit carbon dioxide when burned, from an overall perspective, they have zero GHG emissions. Therefore, they are classified as being carbon neutral in the IPCC Guidelines (Guidelines for National Greenhouse Gas Inventories). o IMO is developing a procedure for evaluating the CO2 reduction effect of biofuel in life cycle, so it will be necessary to pay close attention to future trends.
Carbon recycled methane	o The carbon dioxide emitted during engine combustion on board is derived from the captured carbon dioxide, so it does not emit any additional new carbon dioxide. o Carbon-recycled methane could be considered carbon neutral, although this is not currently explicitly stated in the IPCC guidelines that outline the methodology for calculating greenhouse gas emissions. o Monitoring and mitigation measures are required for methane slip (emission of unburnt methane in fuel into the atmosphere. Methane has 28 times greater global warming potential than carbon dioxide).
Biomethanol/synthetic methanol	o Biomethanol is produced using vegetation as the raw material, which absorbs carbon dioxide from the atmosphere. It is viewed as being carbon neutral fuel because, even though it emits carbon dioxide when burned, from an overall perspective, it has zero GHG emissions. Therefore, it is classified as being carbon neutral in the IPCC Guidelines. o In the case of synthetic methanol, carbon dioxide is emitted during engine combustion on board but it is derived captured carbon dioxide, so it does not emit any additional new carbon dioxide. o Synthetic methanol could be considered carbon neutral, although this is not currently explicitly stated in the IPCC guidelines that outline the methodology for calculating greenhouse gas emissions.
Ammonia	o Green ammonia does not generate carbon dioxide throughout its lifecycle from production to consumption. o Blue ammonia that undergoes carbon dioxide capture and storage (CCS) in the production process essentially has minuscule greenhouse gas emissions. o Monitoring and mitigation measures are required for nitrous oxide generated through combustion (N_2O: Has a greenhouse effect 265 times greater than carbon dioxide).
Hydrogen	o Green hydrogen does not generate carbon dioxide, etc. throughout its lifecycle from production to consumption. o Blue hydrogen that undergoes carbon dioxide capture and storage (CCS) in the production process essentially has minuscule greenhouse gas emissions. o Hydrogen can be used in the production of ammonia, carbon recycled methane and other zero emissions fuels and carbon neutral alternative fuels.

Table 6 Characteristics of different fuels in terms of "supply chain conditions"

Biofuel (biodiesel)	o The vegetation used as raw material include cereals and may also be used as food and fodder. There is also demand from various industries, including aviation, automobiles and business. A stable supply of biodiesel, known as the second generation, made from microalgae, waste cooking oil, etc., is needed. o The bunkering infrastructure and technology of existing petrol fired-ships can be used. In Japan, Ship-to-Ship bunkering (see Fig. 12)[13] has started in some areas[14]. o More expensive than petroleum.
Carbon recycled methane	o Can make use of the LNG supply chain. o Can make use of the bunkering infrastructure and technology of LNG-fueled ships. o Technology is being developed and tested for carbon dioxide separation and capture from factories as well as large-scale methanation. o More expensive than LNG.
Biomethanol/synthetic methanol	o In order to ensure a stable supply as fuel for ships, it will be necessary to greatly reinforce production and supply systems. o Major shipping companies in other countries are strengthening cooperative relationships with biomethanol/synthetic methanol supply companies.[15]
Ammonia	o Ammonia is already being produced in many countries as a raw material for fertilizers, and technologies for its transport and storage are already in place, but infrastructure needs to be developed for its use as ship fuel. o The equipment and technology for bunkering for use as fuel for ships is required. Currently, Japanese companies are getting involved in this, while research into the supply chain for use as fuel for ships in other countries is being promoted, including Ship-to-Ship bunkering (see Fig. 12)[13][16]. o Cheaper than liquefied hydrogen.
Hydrogen	o Hydrogen can be manufactured from various energy sources, and, in the future, there is the potential to construct a stable supply chain procured from various countries. o The equipment and technology for bunkering for use as fuel for ships is required. In Japan, small ocean-going liquefied hydrogen carriers and pilot facilities for hydrogen cargo loading/unloading are being constructed and tested[17]. o When liquefied, production costs are higher than for ammonia.

Table 7 Characteristics of different fuels in terms of "physical properties"

Biofuel (biodiesel)	o Can be used with existing petrol fired-engines. o Increase of 10-20% of nitrogen oxides (NOx) when using FAME compared to petroleum. However, at MEPC 78 in June 2022, in the case that there are no changes to NOx core products, and settings/operational values in the approved Technical File (handling of motors), unified interpretations were adopted, including the non-application of the requirement not to "exceed the regulated NOx values" stated in Annex VI of the International Convention for the Prevention of Pollution from Ships regardless of the blend ratio. o For FAME, in particular, it is necessary to use up all of the oil immediately after supply because it has a greater impact as more time passes. o It has the following characteristics, which makes it necessary to take certain handling precautions, such as temperature control, in-tank water removal, pipe, etc. inspection and cleaning, and to use antioxidants, etc. ※ Microbes in the vegetable oil used as raw material tend to multiply in the free water in the tank. ※ In comparison to light oil, it has the characteristic of a lower temperature fluidity, ※ Sediment tends to separate in the piping when replacing fuel because it has high solubility.

	※ Organic acids and sludge tend to be generated due to oxidative deterioration during longer periods of storage. o Corrodes rubber, and requires consideration for use of oil-resistance of materials.[18)]
Carbon recycled methane	o The basic nature is almost the same as LNG, and it can be used in existing LNG-fueled ships. Countermeasures for low-temperatures when in a liquefied condition (boiling point of approx. -162℃) are being put in place in LNG-fueled ships.
Biomethanol/synthetic methanol	o Although not to the same extent as hydrogen, it has a large volume for its heat value (approx. 240% that of heavy oil), which means that facility-based countermeasures may be necessary, including securing larger loading areas, or having tanks with superior capacity efficiency. o It has a normal temperature/normal pressure when in a liquid state, and is easier to store and manage than LNG, ammonia and hydrogen. o Must be kept away from flames because it ignites easily. o Must be handled appropriately because it is toxic.
Ammonia	o Although not to the same extent as hydrogen, it has a large volume for its heat value (approx. 270% that of heavy oil), which means that facility-based countermeasures may be necessary, including securing larger loading areas, or having tanks with superior capacity efficiency. o The liquefaction temperature is not particularly low (boiling point of -33℃), making it easier to liquefy, store and manage. o Due to the high ignition temperature, it is non-flammable, so there is a need for technology to improve combustion efficiency. o Countermeasures are required due to its metal corrosiveness. o Must be handled appropriately due to the bad odor and toxicity. o Monitoring and mitigation measures are required with regard to ammonia slip (emission of the ammonia remaining in exhaust gas into the open air).
Hydrogen	o It has a large volume for its heat value (approx. 450% that of heavy oil), which means that facility-based countermeasures may be necessary, including securing larger loading areas, or having tanks with superior capacity efficiency. o Advanced insulation for storage systems, etc. is required because of the massive difference from normal temperatures (boiling point of -253℃), and because it evaporates easily. o Air around liquefied hydrogen is liquefied and drops to the ground, making storage/supply system countermeasures necessary. Also, appropriate handling is required to prevent the formation of ice in the supply lines. o It has high permeability due to the low molecular weight, and low viscosity. It is necessary to take leak-prevention measures in storage/supply systems including pipe connections. o Advanced combustion control technology is required in system development due to the fast combustion speed. o Static electricity and other flame separation measures and sufficient ventilation are required due to the ease of ignition. o Flame detection measures are required because the flame is colorless and largely invisible to the human eye. o It is necessary to use metals with superior hydrogen embrittlement resistance.

5 Examples of Initiatives to Promote Carbon Neutrality in Japan

In Japan, greater efforts than ever are being made toward energy-saving/ CO2 emission reduction in all kinds of fields with a view to becoming carbon neutral by 2050. In the shipping industry, various efforts are already underway. Some examples of initiatives for carbon neutrality acceleration that are already being put to actual use or that are in the verification stage will now be introduced.

(1) LNG fuel ferries

In January 2023, the first LNG fuel ferry in Japan went into service. This ship is one of two ships which Mitsui O.S.K. Lines ordered the construction to Mitsubishi Shipbuilding Co., Ltd., in 2019, and began to be operated on the route between Osaka and Beppu by MOL Sunflower Ltd.

This ship is the first Japanese ferry to be equipped with a high-performance dual-fuel engine that can use both LNG and heavy oil A as fuel. It has excellent environmental performance, with carbon dioxide emissions reduced by about 25%, sulfur oxide (SOx) emissions reduced to zero, and nitrogen oxide (NOx) emissions reduced by about 80%. With a length of 199.9m and width of 28m, and a gross tonnage of 17,114, this ferry is able to carry up to 716 passengers, 137 13-meter trucks and 100 passenger cars at a speed of 22.5 knots. In comparison to existing vessels that have been operating on the Osaka-Beppu route since 1997, the number of trucks loaded in the vehicle compartment has been significantly increased (existing vessels can carry 92 13-meter trucks), and the drivers' room has been enhanced as part of a modal shift (transitioning from transporting cargo by truck to the use of ships and railways that have a smaller environmental burden).

LNG powered ferry Sunflower Kurenai harbored in Osaka shortly before commencing service (December 2022)

Source: Provided by MOL Sunflower Ltd.

This initiative demonstrating the energy saving effect of ferries operating in the Osaka-Beppu Route was adopted as being part of the FY 2019 MLIT and METI Joint Research Project "Demonstration Project for Comprehensive Efficiency Measures of Coastal Vessels".

The Mitsui O.S.K. Lines ferry business has placed an order with Naikai Zosen Corporation for the construction of two more state-of-the-art LNG powered ferries. In addition to LNG, the ship uses what is known as an ISHIN design for a streamlined shape with a rounded bow to facilitate the flow of wind by reducing wind pressure from the front and side. In addition, the ship can use the power of diagonal headwinds to propel the ship. It is also equipped with a small rectangular structure on both the left and right sides of the upper part of the bow called a Spray Tearing Plate (STEP). This energy-saving device limits any drop in ship speed and improves fuel consumption by suppressing resistance from waves on the surface of the water by separating the waves from the hull. In comparison to conventional ships, carbon dioxide emissions can be reduced by approx. 35%. Construction is scheduled to be completed in 2025, after which it will be operated on the Oarai-Tomakomai route by MOL Sunflower Ltd.[19)20)21)]

(2) EV Tanker Asahi

In March 2022, Asahi, the world's first battery-powered tanker, went into operation. Asahi is an electric propulsion tanker driven by a large-capacity lithium-ion battery developed by e5 Lab Inc. The construction of the tanker was commissioned by Asahi Tanker Co., Ltd. from KOA Industry Co., Ltd. With a length of 62.0m, a width of 10.3m, gross tonnage of 492 tons, a sailing speed of approx. 10 knots, and the capacity to load 1,277m^3 of heavy oil in the tank, Asahi is being used as a bunkering ship to supply fuel to ocean-going ships in Tokyo Bay from the fueling station in Kawasaki.

Utilizing a large-capacity battery propulsion system used in coastal vessels that was developed by Kawasaki Heavy Industries, Asahi is driven by an Azimuth thruster and a side thruster powered by a large-capacity lithium-ion battery on board the ship (capacity of 3,480kWh). In addition, this battery can supply all of the power needed for ship operation, including deck equipment and on-board power, thereby achieving zero carbon dioxide emissions during operation.

Asahi, an operational electric tanker (March 2022)
Source: Provided by Asahi Tanker Co., Ltd.

In addition to reducing the environmental burden in this way, Asahi improves the working environment for the crew by reducing the noise and vibrations that are common to conventional diesel ships. Asahi is also equipped with an integrated bridge system that integrates all bridge equipment into one system, thereby enabling steering operations to be carried out by just one person. It has an automatic cargo loading/unloading system that can be operated remotely using an explosion-proof tablet, while other excellent initiatives have also been implemented with regard to arranging the living room to encourage communication among crew members and providing a comfortable living environment through interior design. For these reasons, it won the special prize in the FY2022 MLIT Award for Safety and Smart Environment for Seafarers (Triple S) for "Operation of the next-generation electric tanker Asahi that gives special attention to the work environment of crew members."

In April 2023, the second vessel Akari built by Imura Shipbuilding Co, Ltd. entered service, and together with Asahi, serves as a bunkering vessel based at the Port of Kawasaki.[22)23)24)]

(3) Actual ship testing with use of biofuels

The Toyofuji Shipping car carrier "Toyofuji Maru" (length 165m, width 27.6m, gross tonnage 12,687, speed approx. 21.0 knots) underwent an actual operational trial using biofuel when travelling between Chubu, Shikoku, Kyushu, Tohoku and Kanto for a period of 3 days from August 7 to September 3, 2022. This trial was conducted in connection to an MLIT study regarding carbon neutrality promotion in coastal shipping. A mix of low-sulfur C heavy oil and biofuel (biodiesel) was used with the objective of understanding if there any technical issues when mixing biofuels, such as combustibility, mixture stability, and corrosion of parts.[25)]

Toyofuji Maru had undergone actual operational testing using biofuels

Source: Provided by Toyofuji Shipping Co. Ltd.

Biofuels can be used in current diesel systems without any modification or with minor modifications, which can achieve a reduction in carbon dioxide emissions. Therefore, in the findings of the Committee for Carbon Neutrality Promotion in Coastal Shipping published at the end of 2021, one of the measures for reducing carbon dioxide in existing vessels was given as "promoting the use of biofuels." MLIT established the Committee for the Formulation of Guidelines for the Handling of Biofuels in Ships in July 2022, which is conducting investigations toward the formulation of guidelines to enable the safe and efficient handling of biofuels. The results of the actual shipboard test on the "Toyofuji Maru" were utilized in the formulation of the "Guidelines for Handling Biofuels on Ships," which were published in May 2035.

6 Future Prospects

In order for international shipping to become carbon neutral in the future, in addition to making further improvements to efficiency through energy-saving technology, it will be necessary to transition toward the use of carbon recycled methane due to its carbon neutrality, and to shift to zero emissions fuels such as hydrogen and ammonia. Other than developing carbon dioxide separation/capture and methanation technologies in connection to carbon recycled methane, technological developments are being made with the aim of trial operations of ammonia-fueled ships in 2026 and hydrogen-fueled ships in 2027.

While safety measures are essential for the actual implementation of these technologies, there are no globally consistent standards for ammonia-fueled ships and hydrogen-fueled ships. For this reason, the International Maritime Organization (IMO) began work on the formulation of safety guidelines for ammonia-fueled and hydrogen-fueled vessels at its 8th Sub-Committee on Carriage of Cargos and Containers (CCC8) in September 2022, and consideration is underway for finalization by the end of 2024. In Japan, the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) launched a "Committee for Safe and Smooth Bunkering of Ammonia Fueled Ships" in January 2024 to examine the facilities and conditions necessary for safe and smooth bunkering of ammonia-fueled ships, and guidelines are expected to be compiled in FY2024[26)]. It is also important to ensure that ship crews who will navigate ammonia-fueled ships/hydrogen-fueled ships have the necessary skills. It is expected that investigations will be made into the requisite skills and the approach to suitable training for ship crews, including the establishment of international standards.

Even in coastal shipping, in addition to reducing the environmental burden by means of high-efficiency ships and energy-saving ships, etc., ever-greater energy-saving is being pursued toward achieving the FY 2030 target of improving navigation efficiency by developing and promoting coordinated energy-saving ships that combine new technologies and methods through the tandem approaches of cargo owners and on-shore/port initiatives, etc., including optimizing cargo loading/unloading and pier docking/undocking and using on-shore power, and using biofuels for existing vessels. In addition, with the aim of contributing to Japan becoming carbon neutral by 2050, from FY 2030 onwards, it is expected that the introduction of low-carbon and decarbonized ships such as LNG-fueled ships, battery-powered ships, and hydrogen

FC (fuel cell) ships will further be promoted on some routes where conditions are favorable, such as technology maturity, cost reduction, and provision of fuel supply infrastructure. There is also the future potential for ammonia-fueled ships and hydrogen-fueled ships, which will be gradually introduced from the mid-2020s primarily as ocean-going ships, to be used as coastal vessels.

Conclusion

R&D into various technologies is being conducted in connection to reducing ship GHG emissions, including the introduction of ammonia fuel and hydrogen fuel, which have never been used as fuel for ships before. These technologies will pass through to actual implementation after undergoing demonstration tests. An essential factor to that end is to deepen the understanding of new technologies of everyone involved in the shipping industry, including ship operators, ship owners and ship crews so that they can smoothly adapt to the process of reducing GHG emissions from ships. For the handling of fuels such as LNG, hydrogen and ammonia, which are stored at low- or super-low temperatures and at high pressure, there is an increasing need for expertise and skills with regard to GHG reduction technologies, including participating in the requisite training for the acquisition of new skills for the operation of equipment and plants that differ from those of existing petrol fired-ships. For this reason, the first edition of this paper was published in March 2023 with its basic content aimed primarily at those involved in the shipping industry who have been relatively unfamiliar with the movement to reduce GHG emissions from ships.

The technology for reducing ship GHG emissions is changing at a rapid pace. Further updates to this paper will be published on the Japan Association of Marine Safety website (https://www.nikkaibo.or.jp).

The first edition of this paper was produced with the guidance from academic experts, specialists, and relevant government ministries and with the assistance from the Japan Maritime Center. We would like to express our sincere gratitude once again to all those involved in its preparation. The second edition is based on the first edition and has been updated in light of developments related to GHG emission reductions from ships from

the compilation of the first edition to March 2024. As with the first edition, we hope that this report will be as useful as possible to those involved in the shipping industry.

The Japan Association of Marine Safety

https://www.nikkaibo.or.jp

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