ClassNK

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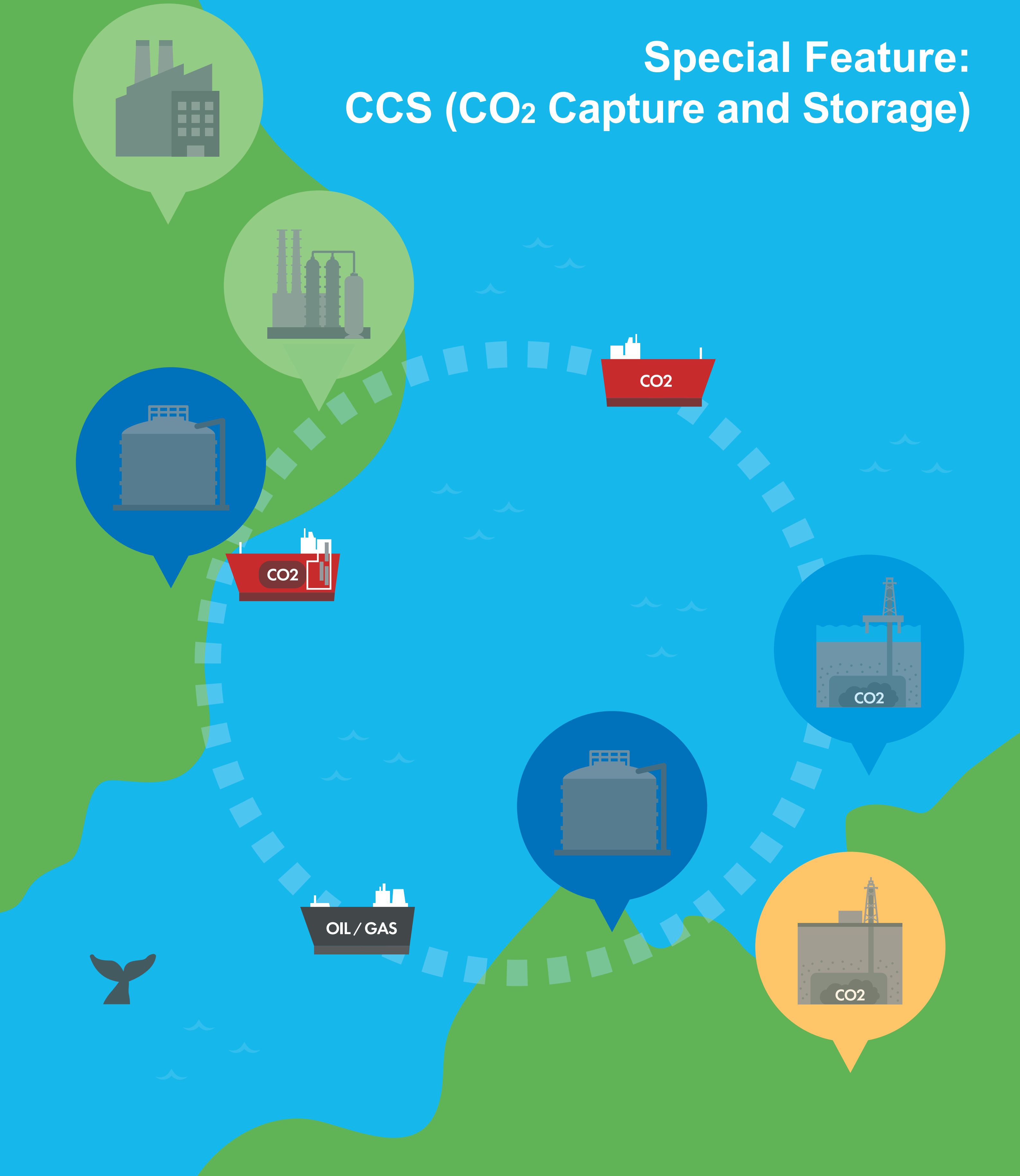
Special Feature:
CCS (CO_2 Capture and Storage)



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Interest in onboard CCS/CCU (Carbon dioxide Capture and Storage/Carbon dioxide Capture and Utilization) as a means of reducing GHG emissions from ships in order to achieve net-zero GHG emissions by 2050 is increasing rapidly. However, how the reduction effects of onboard CCS/CCU are treated in GHG emission reduction regulations will have a significant influence on penetration of this technology. This paper explains the treatment of onboard CCS/CCU under EU and IMO GHG regulations and related issues, incorporating the latest information.

Onboard CO_2 capture and storage (OCCS) technologies have attracted attention as an effective means of reducing GHG emissions. In 2023, ClassNK issued the first edition of Guidelines for Onboard CO_2 Capture and Storage Systems based on chemical absorption. In recent years, consideration of alternative capture methods has progressed, and in October 2025 the Society published a revised Edition 2.0 with additional requirements for membrane separation. This paper outlines the revised guidelines and provides an overview of the newly-added membrane separation technology.

In October 2020, the Japanese government set a target of achieving carbon neutrality by reducing emissions of greenhouse effect gases (GHG) to net zero by the year 2050, and declared in April 2021 that Japan would reduce GHG gases by 46% from the FY 2013 level by FY 2030. This paper focuses on CCS as one method for reducing carbon dioxide (CO_2), and presents an overview of low temperature/low pressure ship transportation of liquefied carbon dioxide (LCO_2) and "Guideline for Setting Common Specifications in the LCO_2 Ship Transportation Value Chain."

Japan's New Energy and Industrial Technology Development Organization (NEDO) is involved in the development of technologies for liquefication and transportation of CO_2 by ship as a safe, low-cost means of transporting CO_2 recovered from CO_2 emission sources to storage/use locations. NEDO is promoting the development of cargo tank systems that enable transportation of liquefied CO_2 under temperature and pressure conditions suitable for large-volume transport, as well as study of the technologies necessary in an integrated ship transportation system including liquefaction, storage, cargo handling and land transportation of CO_2. This article presents an overview of the demonstration test ship "EXCOOL," which is equipped with a tank system capable of carrying liquefied CO_2 under various temperature and pressure conditions, and a series of demonstration tests of long-distance ship transportation linking land-based facilities (Maizuru, Kyoto Prefecture) and Tomakomai (Hokkaido).

The "GHG Strategy" of the International Maritime Organization (IMO) was extensively revised, and the application of CO_2 capture technology in the shipping sector is being examined. Mitsubishi Heavy Industries, Ltd. (MHI) has been developing CO_2 capture technology for about 30 years, and has operated 18 CO_2 capture systems on land, including the world's largest CO_2 capture system. For marine use, we MHI were participating in the demonstration project "CC-Ocean" of onboard CO_2 capture systems with Kawasaki Kisen Kaisha, Ltd. and Nippon Kaiji Kyokai. These examples are introduced in this paper.

Technical Topics

In the Seventh Basic Energy Plan formulated this February, Japan set a target of increasing the share of renewable energy power generation to 40-50 % by 2040. Consequently, construction of offshore wind power plants is expected to expand into broader maritime areas. Focusing on enhancing the safety of work vessels engaged in such construction projects, ClassNK launched a third-party evaluation service last year to assess safety management practices of such vessels. Based on the results obtained so far, this paper presents an overview of the challenges related to the safety management and operational aspects of these work vessels.

MASS (Maritime Autonomous Surface Ships) are attracting attention as a solution that reduces human error and addresses the issues of an aging population of seafarers and labour shortages. Various countries are advancing social implementation through cumulative demonstrations. Concurrently, regulatory frameworks are being developed, including the MASS Code as an international framework. To further accelerate social implementation, establishment of detailed technical requirements is also essential. This paper provides an overview of the development of MASS and the trends in regulatory frameworks in various countries. It then introduces the initiatives of the Society, which has responded to these trends from an early stage, and the outcomes achieved.

At MSC107 in June 2023, an amendment to the SOLAS Convention on Lifting Appliances and Anchor Handling Winches was adopted as IMO Resolution MSC. 532 (107). In addition, relevant guidelines describing specific safety requirements were approved as MSC. 1/Circ. 1662 and MSC. 1/Circ. 1663.
In order to incorporate the SOLAS amendment and relevant guidelines in ClassNK Rules, the Society amended "Rules for Cargo Handling Appliances" to "Rules for Lifting Appliances and Anchor Handling Winches." The amended rules are applicable from January 2026. This paper introduces the background of the deliberations in the IMO, C152 Convention of the International Labour Organization (ILO) and the amendment of "Rules for Cargo Handling Appliances."

This paper provides an overview of cost assessment methodologies required under the mid-term GHG reduction measures currently under consideration in the International Maritime Organization (IMO). An outline of future decarbonization strategies, including fuel switching and improvements in operational efficiency, is also presented.

Most small and medium-sized bulk carriers operate on non-fixed routes, making them unsuitable for the relatively "predictable" new energy (i.e. alternative fuel) retrofits that are being utilized by fixed-route vessels. To meet IMO's new emission requirements throughout their operational lifecycle, this paper systematically categorizes carbon reduction technologies applicable to small and medium-sized bulk carriers, that are currently in service, and proposes a "phased" emission reduction pathway. Using a 10-year-old KAMSARMAX bulk carrier as a case study and based on established assumptions, we demonstrate that a staged "phased" retrofit approach currently represents the most cost-effective option. The corresponding research has also been validated on an 11-year-old ULTRAMAX bulker. This research provides sustainable, affordable compliance solutions for small and medium-sized bulk carriers, offering retrofit references for vessels currently in operation.

This article introduces recent topics discussed at International Maritime Organization (IMO). At this issue, a summary of the decisions taken at 83rd Marine Environment Protection Committee (MEPC 83) and 110th Maritime Safety Committee (MSC 110) is provided.

Prefatory Note

Introduction to the Special Feature on "CCS (CO_2 Capture and Storage)"

General Manager of Research Institute, Research and Development Division, ClassNK
Kinya ISHIBASHI

On the occasion of the publication of ClassNK Technical Journal No. 12, I would like to extend a warm welcome to all our readers.

ClassNK Technical Journal is a technical publicity journal which is published with the aim of contributing to the progress of technology in the maritime industry by providing information on the technological activities and research achievements of ClassNK to a wider audience. The previous issue (ClassNK Technical Journal No. 11) reported on technological trends and the latest results of research and development related to the theme of lectures at the ClassNK R&D Forum held in January 2025, "Towards Safer and Environmentally Friendly Ships."

In recent years, there has been a rapid increase in interest in onboard CCS/CCU (Carbon dioxide Capture and Storage/Carbon dioxide Capture and Utilization) technology as a means of reducing CO_2 emissions from ships, towards achievement of the goal of "aiming for net-zero emissions of GHG by around 2050 at the latest" set by the International Maritime Organization (IMO). However, how the reductions achieved by using those technologies are treated in the GHG emissions reduction regulations of the EU and IMO will have a substantial impact on the adoption of the technologies. Therefore, this Special Feature presents an overview of latest related regulatory trends and status of issues regarding the development of storage infrastructure, which will be essential for achieving this goal. In addition, related to onboard CO_2 capture and storage technology that can be implemented on the ships, a technical commentary is provided on revisions to the ClassNK Guidelines issued in October 2025, adds new requirements related to the membrane separation method for CO_2 capture.

Meanwhile, the Japanese government as a whole set a target of realizing carbon neutrality by 2050, and is implementing initiatives to reduce CO_2 emissions. As part of the CCS technology necessary to achieve that target, this Special Feature includes papers by outside experts on the formulation of common guidelines for low temperature/low pressure ship transportation of liquefied CO_2 (LCO_2) and the related value chain, and the development of an LCO_2 ship transportation technology as a safe, low cost means of transporting CO_2 based on the guidelines, and a long-distance transportation demonstration test between Maizuru (Kyoto Prefecture) and Tomakomai (Hokkaido) using the demonstration ship "EXCOOL".

Finally, this Special Feature on "CCS (CO_2 Capture and Storage)" also presents a commentary on technologies related to large-scale CCS facilities and onboard CO_2 capture equipment from a private-sector company which has record of about 30 years in the development of CO_2 capture technologies and actual operational results of 18 land-based CO_2 capture plants, including the world's largest.

Other topics in this issue include recent trends in international conventions, etc. such as the IMO's interim GHG reduction measures, as well as recent technological trends in the safety of work vessels used in offshore wind turbine construction and MASS (Maritime Autonomous Surface Ships), which were the subjects of lectures at the ClassNK Technical Seminars held in October and November 2025.

Until now, ClassNK has devoted its efforts to the creation of “good ships” as its highest-priority issue. However, in addition to that goal, in the future we will also endeavor to contribute to the future progress of the maritime industry through diligent efforts in research and development that contribute to securing the safety of life and property at sea, preservation of the marine environment, and the creation of innovations that will lead society based on the needs of society and the industry, also including the viewpoints of “good management” and “good operation.”

In closing, we sincerely request the continuing understanding and support of all those concerned in future, as in the past.

Treatment and Issues of Onboard CO_2 Capture and Storage/Utilization under GHG Regulations

Ryuji MIYAKE*

1. INTRODUCTION

The European Union (EU) has set a target of reducing GHG emissions by at least 55 % from the 1990 level by 2030, with the aim of achieving net-zero GHG emissions by 2050. In July 2021, the comprehensive climate policy package "Fit for 55" was announced to achieve the 2030 target. This package included regional regulations such as extending the carbon pricing mechanism "EU Emissions Trading System (EU-ETS)" to the maritime sector, and drafting of the "FuelEU Maritime" regulation to promote GHG reductions across the entire lifecycle of fuels used in ships. "EU-ETS" was subsequently introduced for the maritime sector from January 2024, and "FuelEU Maritime" commenced in January 2025.

Meanwhile, the International Maritime Organization (IMO) has focused its efforts on reducing GHG emissions by improving the energy efficiency of individual ships, aiming to balance GHG reduction with economic development. The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) were implemented in 2013 as design- and operational-based fuel efficiency regulations, respectively. The IMO also agreed on an "initial IMO strategy on reduction of GHG emissions from ships (initial IMO GHG Strategy)" in 2018. As short-term measures, the Energy Efficiency Existing Ship Index (EEXI) for in-service ships and the Carbon Intensity Indicator (CII) rating system for operational fuel efficiency performance commenced in 2023. The "initial IMO GHG Strategy" was revised at MEPC 80 in July 2023, setting a new ambitious goal of achieving net-zero GHG emissions by around 2050 at the latest. To achieve this goal, amendments to MARPOL Annex VI were approved at MEPC 83 in April 2025. These amendments include GHG intensity regulations for fuels (GFI regulations) and promotion of decarbonization through the IMO Net Zero Fund. The amendments are scheduled to commence in 2028.

Measures to reduce GHG emissions from ships include improving fuel efficiency and operational efficiency, as well as transitioning to low-carbon and decarbonized fuels. However, achieving net-zero GHG emissions will require transitioning to decarbonized fuels because there are limits to improvement of ship fuel efficiency and operational efficiency. Therefore, establishing a robust value chain for decarbonized fuels is essential. However, a significant number of fossil fuel-powered ships are expected to remain in operation even in 2050. Addressing this issue will be crucial going forward. Although measures such as slow steaming and installation of energy-saving equipment have been implemented to reduce GHG emissions from ships, transitioning to low-carbon and decarbonized fuels will require time. As a "bridge solutions" until then, "Onboard Carbon Capture and Storage/Utilization (OCCS/OCCU)," which involves capturing emitted CO_2 onboard ships for storage or utilization, is attracting significant attention, and interest in this technology is increasing rapidly. Onboard CCS/CCU is applicable not only to heavy fuel oil-powered vessels, but also to fuels like LNG, which have relatively lower GHG emissions. Since heavy fuel oil is often used as a pilot fuel, use in combination with zero-emission fuels such as hydrogen or ammonia is also possible. Although trials of onboard CO_2 capture have already been conducted for some time, practical implementation has been considered difficult, particularly due to cost concerns. However, the aforementioned GHG emission reduction regulations now impose penalties or require contributions toward remedial measures, meaning CO_2 emissions are now included in a ship's operational costs. Technological advances have also improved the efficiency of CO_2 capture and reduced the associated costs, making onboard CO_2 capture potentially economically viable.

Interest in onboard CCS/CCU is increasing rapidly as a means of reducing GHG emissions from ships to achieve net-zero GHG emissions by 2050. On the other hand, how the reduction effects of OCCS/CCU are treated in GHG emission reduction regulations will have a significant influence on the penetration of this technology. Therefore, this paper explains the treatment and issues of onboard CCS/CCU under EU and IMO GHG regulations, incorporating the latest information.

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2. TREATMENT OF ONBOARD CO_2 CAPTURE AND STORAGE/UTILIZATION (ONBOARD CCS/CCU) IN EU GHG REGULATIONS

2.1 EU-ETS

2.1.1 Treatment of Onboard CO_2 Capture and Storage (Onboard CCS)

Under the EU-ETS for the maritime sector, allowances equivalent to CO_2 emissions from covered vessels must be verified and surrendered. However, as shown in Fig. 1, under “Article 12(3a) of the EU ETS Directive” [1], CO_2 captured onboard and transported for permanent storage in EU/EEA storage facilities authorized by the competent authorities of EU/EEA Member States under the “EU CCS Directive” [2] is exempt from the obligation to surrender allowances.

CO_2 leaked during transport or storage of CO_2 captured onboard for permanent storage is subject to the obligation to surrender emission allowances equivalent to the leaked CO_2 by the operator of the transport or storage facility, and not the vessel that emitted the CO_2. This is because Annex I of the EU ETS Directive designates facilities involved in transporting and storing CO_2 to storage sites authorized under the EU CCS Directive [2] as installations covered by the EU-ETS. Therefore, according to “EU ETS and MRV Maritime General guidance 5.2.3-2” [3], the CO_2 exempt from the obligation to surrender allowances through onboard CCS is not the amount of CO_2 captured onboard, but rather the amount transferred to the operator transporting the CO_2, or the amount transferred directly to the storage facility.

Voyages	Voyages between an EU/EEA port and a non-EU/EEA port(①)	Voyages between the EU/EEA ports(②) and berth in EU/EEA ports
CO_2 emissions subject to EU-ETS	50% of CO_2 emissions	100% of CO_2 emissions
CO_2 emissions excluded from EU allowances	**50% of captured/stored CO_2**	**100% of captured/stored CO_2**

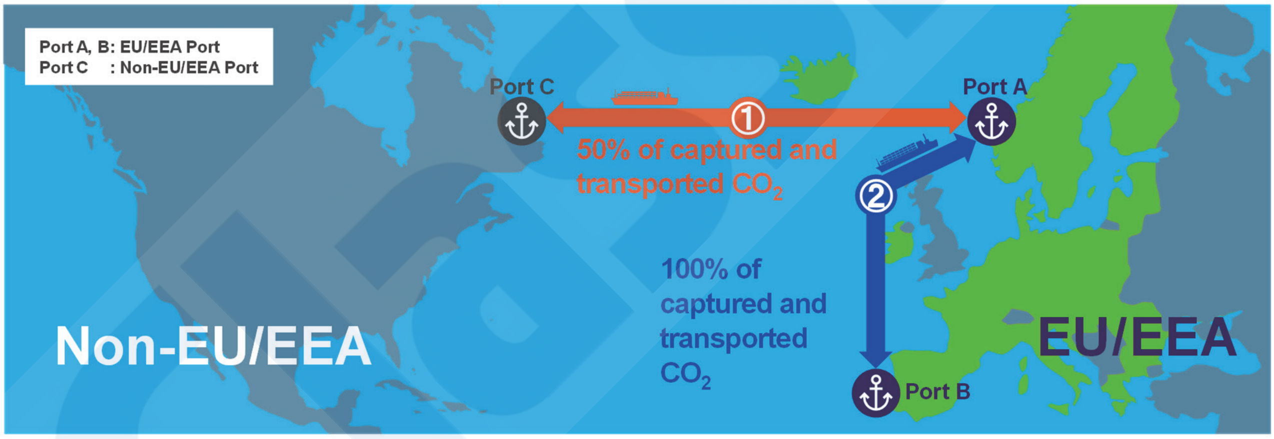

Fig. 1 CO_2 emissions excluded from EU allowances by onboard CCS

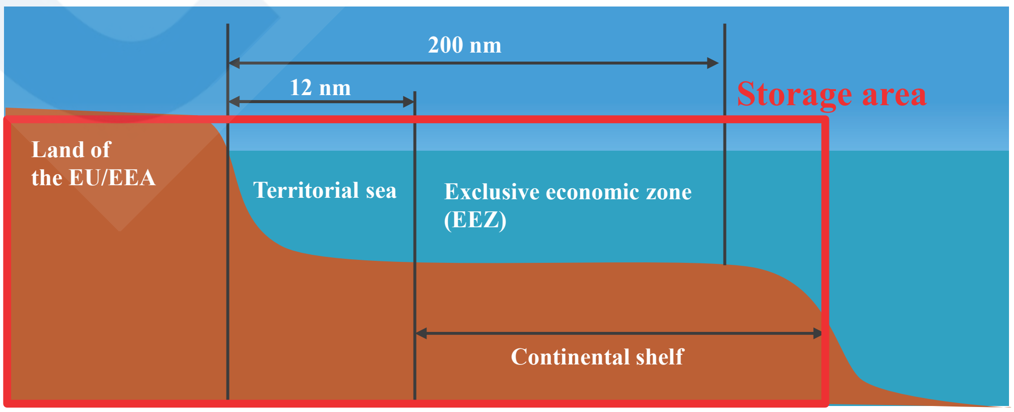

Fig. 2 Recognized CO_2 storage area in EU/EEA

On the other hand, according to "EU ETS and MRV Maritime General guidance 5.2.3-4" [3], additional CO_2 emissions generated on board for the purpose of CO_2 capture are subject to the obligation to surrender allowances. Therefore, onboard CCS equipment must be added to the monitoring plan, and the additional CO_2 emissions must be reported in the emissions report. However, CO_2 leaked during the transport or storage of captured CO_2 is not subject to monitoring. As shown in Fig. 2, "CCS Directive Article 2" [2] stipulates that captured CO_2 must be stored within the territory, territorial waters, exclusive economic zones, or continental shelves of EU/EEA Member States. CO_2 stored outside these areas is not recognized as eligible for emission allowance cancellation.

According to research by the Global CCS Institute, Global Status of CCS 2024, IOGP, and CO_2 storage projects in Europe etc., as of January 2025, 191 commercial CCS projects were either operational or planned in Europe. However, among these projects, only 10 CO_2 storage facilities, including pilot operations, are currently operational in the EU/EEA region, as shown in Table 1. The total CO_2 storage capacity of these storage facilities is approximately 7.5 million tons per year.

The CCS Directive includes provisions for third-party access to storage facilities in Article 21 [2], allowing third parties other than the storage facility operator to use existing storage facilities and transport infrastructure. This means that CO_2 captured and transported elsewhere can also be stored in those facilities. However, in CCS projects, the source of CO_2 capture is typically contractually predetermined for specific emission sources or operators. Since storage for specific operators takes priority, third parties are required to enter into a separate contract with the storage facility operator in order to store CO_2. As shown in Table 2, as of January 2025, only three ports in Europe are capable of handling CO_2 cargoes. Ports under development are being constructed as part of CO_2 capture and storage projects. While none of these projects is specifically designed to receive CO_2 captured onboard ships, they may potentially accept CO_2 captured onboard ships.

Table 1 Storage facilities in operation in the EU/EEA, and examples of storage facilities with permission from the authorities (as of January 2025)

	Country	**Site name**	**Overview**	**CO_2 storage capacity of facility(ton/year)**	**Operational year**	**Permission status**
EU	Croatia	Zutica and Ivanic grad strage	Capture/Transport/Storage of CO_2 from gas processing plants	Unknown	Operational (2014)	Unknown
	Hungary	MOL Szank Field	Capture/Transport/Storage of CO_2 from gas processing plants	Unknown	Operational (1992)	Unknown
	Netherlands	Porthos	Transport/Storage of CO_2 captured from multiple emission sources	2,500,000	2026	Permitted
	Denmark	Greensand	Ship transport/Storage of CO_2	1,500,000 to 8,000,000	2025 to 2026	Under application (will be first permitted site in Denmark)
EEA	Iceland	Climeworks Orca	Storage of CO_2 captured by DAC	4,000	Operational (2021)	Unknown
	Iceland	Climeworks Mammoth	Storage of CO_2 captured by DAC	36,000	Operational (2024)	Unknown
	Iceland	Silverstone	Capture/Storage of CO_2 from geothermal power plant	37,000	2025	Permitted
	Norway	Equinor Sleipner	Separate/Storage of CO_2 from natural gas fields during gas production	1,000,000	Operational (1996)	Permitted
	Norway	Equinor Snøhvit	Separate/Storage of CO_2 from natural gas fields during gas production	700,000	Operational (2008)	Permitted
	Norway	Longship (Northern Lights)	Ship transport of captured CO_2 to intermediate storage facility and storage via submarine pipeline	1,500,000 to 3,500,000	2025	Permitted

Source: Global CCS Institute, Global Status of CCS 2024, IOGP, CO_2 storage projects in Europe, European Commission, and Reports on the implementation of the CCS Directive, etc.

Table 2 European ports capable of handling CO_2 and examples of ports under development (as of January 2025)

	Country	Name of port/project	Overview	CO_2 handling capacity (ton/year)	Operational year
Operational	UK	Nippon Gases, Tilbury, Warrenpoint&Teesside Ports	Loading/Unloading liquid CO_2 (used for food/drink)	Unknown	2019
	Finland	Loviisa Port	Loading/Unloading liquid CO_2 (used for food/drink)	Unknown	Unknown
	Germany	Port of Hamburg	Unloading liquid CO_2 (used for food/drink)	Unknown	Unknown
Planned	Poland	Port of Gdansk	Open access multi-modal liquid CO_2 import-export terminal	2,700,000 to 8,700,000	2025
	Norway	Northern Lights	Unloading liquid CO_2 terminal in Øygarden	1,500,000 to 3,500,000	2025
	Sweden	Port of Gothenburg	Development of logistics chain of CO_2	4,000,000	2025
	Netherlands	CO_2 Next Terminal, Port of Rotterdam	Open access liquid CO_2 terminal for reception and delivery of liquid CO_2	5,400,000	2028
	Netherlands	Project Aramis, Maasvlakte, Port of Rotterdam	Unloading liquid CO_2	22,000,000	2030

Source: Global Centre for Maritime Decarbonization (GCMD) and Concept Study to Offload Onboard Captured CO_2, etc.

2.1.2 Treatment of Onboard CO_2 Capture and Utilization (Onboard CCU)

Under "Article 12(3)(b) of the EU ETS Directive" [1], if onboard captured CO_2 is permanently incorporated into products, thereby preventing its release into the atmosphere, the CO_2 is exempt from the obligation to surrender allowances.

According to the supplementary rules of the ETS Directive concerning CCU, "Commission Delegated Regulation (EU) 2024/2620 Annex" [4], CO_2 must be fixed to prevent its release into the atmosphere. Uses that presuppose combustion, such as fuel, are not permitted. Instead, CO_2 must be permanently chemically bound as mineral carbonates in the following construction products:

(a) carbonated aggregates used unbound or bound in mineral based construction products;

(b) carbonated constituents of cement, lime, or other hydraulic binders used in construction products;

(c) carbonated concrete, including precast blocks, pavers or aerated concrete;

(d) carbonated bricks, tiles, or other masonry units.

The CCU regulation [5] does not specify the location of CO_2 capture or utilization. However, given the intention of the EU-ETS and the provisions for CCS in the EU ETS Directive, it can be inferred that CO_2 captured and utilized within the EU/EEA territory would be covered.

2.2 FuelEU Maritime

Because FuelEU Maritime currently does not contain provisions for storage or utilization of CO_2 captured onboard ships, deduction of captured CO_2 from GHG intensity is not permitted. However, according to "FuelEU Maritime Regulation Article 30(2)(i)" [5], the European Commission (EC) is scheduled to prepare a report and consider the possibility of including new GHG reduction technologies, including onboard CCS/CCU, in GHG intensity calculations by the end of 2027.

3. TREATMENT OF ONBOARD CO_2 CAPTURE AND STORAGE/UTILIZATION (ONBOARD CCS/CCU) IN IMO GHG REGULATIONS

The International Maritime Organization (IMO) is currently implementing measures to reduce CO_2 emissions from international shipping. These include the Energy Efficiency Design Index (EEDI) regulation for new ships, the Energy Efficiency Existing Ship Index (EEXI) regulation for ships in service, and the Carbon Intensity Indicator (CII) scheme. However, since these schemes do not contain provisions for onboard CCS/CCU, captured CO_2 cannot currently be deducted from a ship's CO_2 emissions under any of these schemes. Furthermore, under the GHG intensity (GFI) regulations for used fuel set to begin in 2028, the current GFI calculation formula does not include a term for deducting CO_2 captured onboard. However, since the "EIj (GHG emissions per unit of energy)" factor is included in the GFI calculation formula, a key point for future discussion will be how to incorporate onboard captured CO_2 into this factor. On the other hand, the "2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines)" [6)] adopted at MEPC 81 in March 2024 includes a term for deduction of onboard captured CO_2 in the GHG intensity calculation formula, but since the details of the calculation method and other aspects are not specified, it is currently not possible to apply this deduction. Therefore, the "correspondence group on measurement and verification of non-CO_2 GHG emissions and onboard carbon capture" submitted a report on this issue at MEPC 83 in April 2025. As a result, a "work plan for development of a regulatory Framework for the use of Onboard Carbon Capture and Storage (OCCS)" [7)] was established. The work plan incorporates the development of guidelines on testing, survey and certification of onboard CCS. Crucially, it also includes consideration of legal barriers under relevant international conventions, as it is necessary to ensure consistency with these conventions in order to avoid potential impediments to the permanent storage or utilization of CO_2 captured onboard. A correspondence group was also re-established to develop a "regulatory framework for the use of onboard CCS" based on the work plan. The report is scheduled to be submitted to MEPC 84, planned for April 2026.

On the other hand, issues such as how to deduct captured CO_2 from a ship's CO_2 emissions when that CO_2 is permanently stored underground or under the seabed, reused as a feedstock for electric fuels such as electric methanol or electric methane , or permanently fixed in materials like cement, and how to allocate such credits, are scheduled to be addressed in the further development of the LCA regulatory framework.

4. INTERNATIONAL CONVENTION ON THE TRANSBOUNDARY MOVEMENT OF CAPTURED CO_2

International conventions that could potentially impede the permanent storage or utilization of CO_2 captured onboard include the London Protocol, which regulates sub-seabed storage of CO_2 and the export of CO_2 for sub-seabed storage purposes, and the Basel Convention, which regulates the export of hazardous waste.

4.1 The London Convention and The London Protocol

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly known as the London Convention) was adopted in London in December 1972 and entered into force in August 1975.

This Convention specifically listed hazardous wastes such as mercury, cadmium, and radioactive waste, prohibiting only their marine dumping. In response to the subsequent global recognition of the need to protect the marine environment, the "1996 Protocol to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter" (commonly known as the London Protocol) was adopted in London in November 1996 and entered into force in March 2006 to further strengthen marine pollution prevention measures under the Convention. This Protocol prohibits, in principle, ocean dumping and incineration at sea of wastes and other matter. It includes CO_2 within the scope of "wastes and other matter," and the concept of "dumping" encompasses not only disposal in the sea but also disposal in sub-seabed strata. Furthermore, it completely prohibits the export of wastes and other matter for the purpose of ocean dumping, including sub-seabed storage.

The London Protocol has been amended four times, in 2006, 2009, 2013, and 2022. The 2006 amendment (permitting the disposal (storage) of CO_2 in sub-seabed strata) and the 2022 amendment (removing sewage sludge from the list of wastes that could be considered for marine disposal) have entered into force. The 2009 amendment (permitting the export of CO_2 for disposal (storage) in sub-seabed formations) and the 2013 amendment (regulating marine geoengineering activities) have not yet entered into force. As of January 2024, there are 87 Contracting Parties to the London Convention and 54 Contracting Parties to the London Protocol (the United States has not signed the Protocol). The Secretariat is located at the headquarters of the

International Maritime Organization (IMO).

4.1.1 Subsea Storage of CO_2 (2006 Amendments) and Export of CO_2 for Subsea Storage Purposes (2009 Amendments)

The 2006 amendment to the London Protocol added CO_2 captured for CCS purposes to Annex I, permitting sub-seabed storage of CO_2 subject to authorization. While the London Protocol previously prohibited all exports of waste for ocean dumping purposes (including sub-seabed storage), the growing necessity of CCS utilization led to the 2009 amendment permitting CO_2 exports for sub-seabed storage purposes as an exception. This is conditional upon the exporting and receiving countries having concluded an agreement or arrangement. However, for the 2009 amendments to enter into force, acceptance by two-thirds of the contracting parties (36 out of 54 countries) is required, but as of January 2024, only 11 countries have accepted. Although the 2009 amendments have not yet entered into force, a 2019 resolution of the Conference of the Parties enabled countries that have deposited a declaration with the IMO concerning the provisional application of these amendments to apply them provisionally. Eight countries, Norway, the United Kingdom, the Netherlands, Sweden, Denmark, Belgium, Switzerland, and South Korea, have declared provisional application, and the 2009 amendments are being applied provisionally.

4.2 The Basel Convention

Transboundary movement of hazardous waste has frequently occurred since the 1970s, primarily involving Western nations. By the 1980s, problems emerged, such as dumpling of waste from developed European countries in developing African nations, causing environmental pollution. Although it became apparent that transboundary movements of hazardous waste were occurring without prior notification or consultation, the ultimate responsibility for such movements remained unclear. In response, discussions were held in the OECD and the United Nations Environment Programme (UNEP), and in March 1989, in Basel, Switzerland, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was drawn up. This convention established an international framework and procedures regulating the transboundary movement of certain hazardous wastes. (It entered into force on 5 May 1992. As of November 2023, the number of Contracting Parties stood at 189 countries, the EU and Palestine).

Since the Basel Convention requires written consent from the importing country for the export of hazardous wastes specified under the Convention and other wastes, even if the importing country is a Party, exports cannot proceed without such consent. While the import and export of waste with non-Contracting Parties is generally prohibited, it is permitted on the condition that bilateral or multilateral agreements concerning the transboundary movement of waste are concluded with such non-Contracting Parties, provided that this does not contravene the spirit of the Convention.

4.2.1 Regulated Hazardous Wastes

The Basel Convention specifies regulated hazardous wastes in Annexes I, III, VIII, and IX. It further stipulates that wastes defined or recognized as hazardous under the domestic legislation of a Party that is the exporter, importer, or transit country are also subject to the Convention’s regulations. Although CO_2 is not listed in the Annexes, if an importing or transit country designates CO_2 as a “hazardous waste” under its domestic legislation, it falls under the regulations of the Basel Convention, and exports require the consent of the importing or transit country.

5. ISSUES CONCERNING ONBOARD CCS/CCU UNDER GHG REGULATIONS

Penetration of onboard CCS/CCU faces numerous challenges, but establishing a value chain for the storage and utilization of captured CO_2 is particularly essential. As shown in Fig. 3, expectations are placed on permanent storage of captured CO_2 in the seabed or underground, Enhanced Oil Recovery (EOR), which improves crude oil recovery rates by injecting captured CO_2 into oil fields, and carbon recycling, which reuses captured CO_2 as a feedstock for electric fuels such electric methane or electric methanol or feedstock for chemicals. While projects are underway in these areas, they have not yet reached a commercially viable stage. To promote onboard CCS/CCU, port facilities for offloading CO_2 captured onboard ships must first be established. However, as mentioned above, even in Europe, ports capable of handling such cargoes are limited, and equipping ports worldwide with reception facilities is likely to take considerable time. Furthermore, as also mentioned above, the London Protocol regulates sub-seabed storage of CO_2 and exports of CO_2 for sub-seabed storage purposes, while the Basel Convention regulates exports of hazardous waste. Since both require the consent of both the exporting and receiving countries, landing CO_2 captured onboard ships may necessitate explicit agreements between the flag state of the vessel and the receiving country.

Under the EU-ETS, while permanent fixation of CO_2 captured onboard in cement and similar materials is permitted as exempt from the obligation to offset emissions, carbon recycling into electric fuels such as electric methanol or electric methane, is not permitted. The treatment of these carbon-recycled fuels is currently under consideration by the IMO, but the allocation of responsibility for CO_2 emissions, that is, whether it should be assigned to the entity that captured the CO_2 or to the entity that ultimately emitted it by using the carbon-recycled fuel, remains an extremely difficult issue.

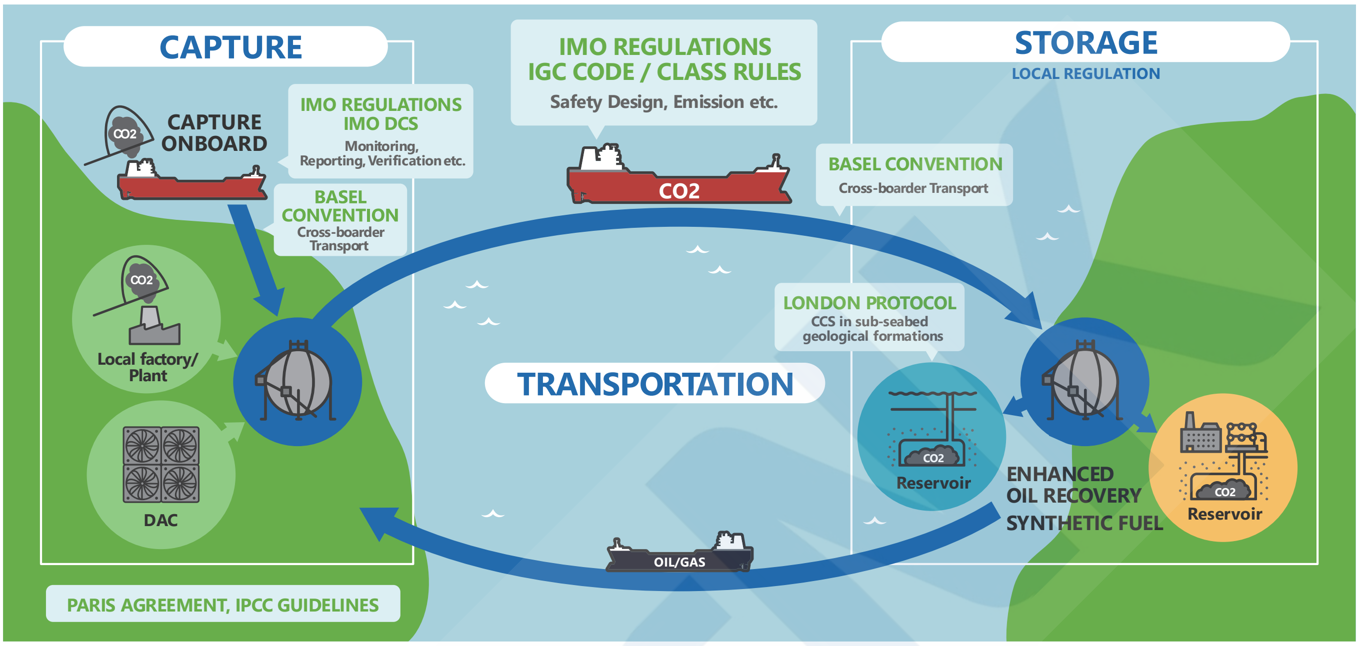

Fig. 3 Regulatory framework of value chain for captured CO_2 storage and utilization

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3) EU: The EU ETS and MRV Maritime General guidance for shipping companies, Guidance document No. 1, Updated Version, 5 November 2024

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5) EU: Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance)

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Overview of Guidelines for Onboard CO_2 Capture and Storage Systems and Their Latest Revision

Takuya WAKO*, Yuzhong SONG*, Shunsuke HATTORI**, Yohei FUKUSHI***

1. INTRODUCTION

Amid growing global awareness of the climate crisis, in 2023, the International Maritime Organization (IMO) adopted a greenhouse gas (GHG) reduction strategy which clearly sets a goal of achieving net-zero GHG emissions from international shipping by around 2050. In response, a wide range of technological developments and policy measures are being pursued, centred on the introduction of carbon-free fuels such as ammonia and hydrogen, as well as carbon-neutral fuels including synthetic fuels (e-fuels) and biofuels. However, it has been pointed out that relying solely on the adoption of these new fuels will make it extremely difficult to achieve net-zero emissions by around 2050 due to time constraints. The International Energy Agency (IEA) has also stated that achieving international climate goals will be virtually impossible without implementing carbon capture, utilization, and storage (CCUS) [1)]. Consequently, there is growing momentum in the maritime sector to reduce CO_2 emissions by implementing onboard CO_2 capture and storage (OCCS) systems, while continuing to use existing fuels with stable supplies, such as heavy fuel oil and LNG.

In 2021, the joint project "CC-OCEAN" conducted by Nippon Kaiji Kyokai (ClassNK), Kawasaki Kisen Kaisha, Ltd., and Mitsubishi Shipbuilding Co., Ltd. (hereinafter, Mitsubishi Shipbuilding) successfully conducted a world-first demonstration of onboard CO_2 capture from exhaust gas at sea using an amine-based chemical absorption process [2)]. This milestone has significantly accelerated interest in deploying onboard carbon capture systems across the shipping industry, leading to the emergence of vessels equipped with various OCCS configurations. Based on Clarksons Research data as of August 2025, Fig. 1 and Fig. 2 show the global number of OCCS-equipped vessels and the trend in retrofit installations, respectively. Although retrofits currently account for the majority of OCCS adoptions, an increasing number of projects now evaluate installation in the newbuilding contract stage, and deployments on newbuilds are expected to increase in the future.

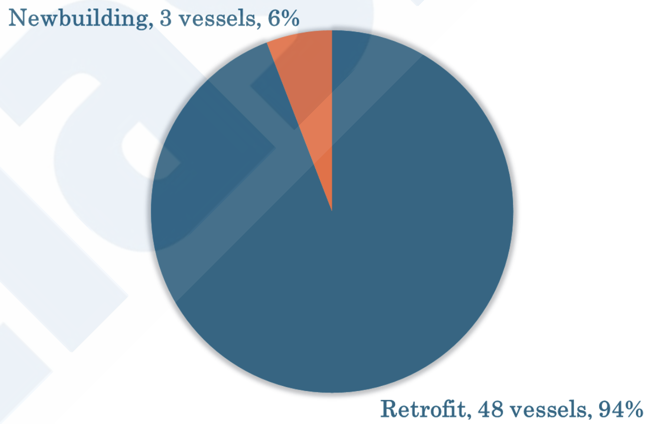


Fig. 1 Global fleet count of OCCS-equipped vessels (Clarksons Research)

* Research Institute, Research and Development Division, ClassNK
** Machinery Department, Plant Approval and Technical Solution Division, ClassNK
*** Technical Solution Department, Pant Approval and Technical Solution Division, ClassNK

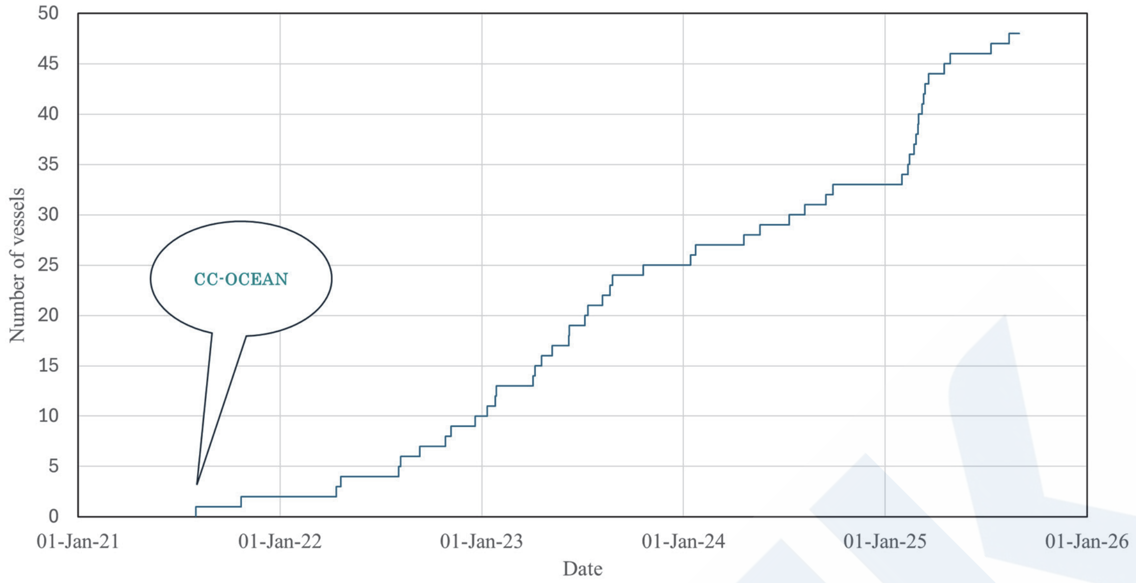


Fig. 2　Trend in retrofit installations of onboard CO_2 capture and storage systems (based on Clarksons Research data)

Fig. 3 shows the distribution of OCCS-equipped vessels by vessel type, propulsion system, and deadweight tonnage (DWT). While there are some differences in numbers for different ship types, propulsion systems, and deadweights, OCCS systems have been installed out across a wide range of vessel specifications.

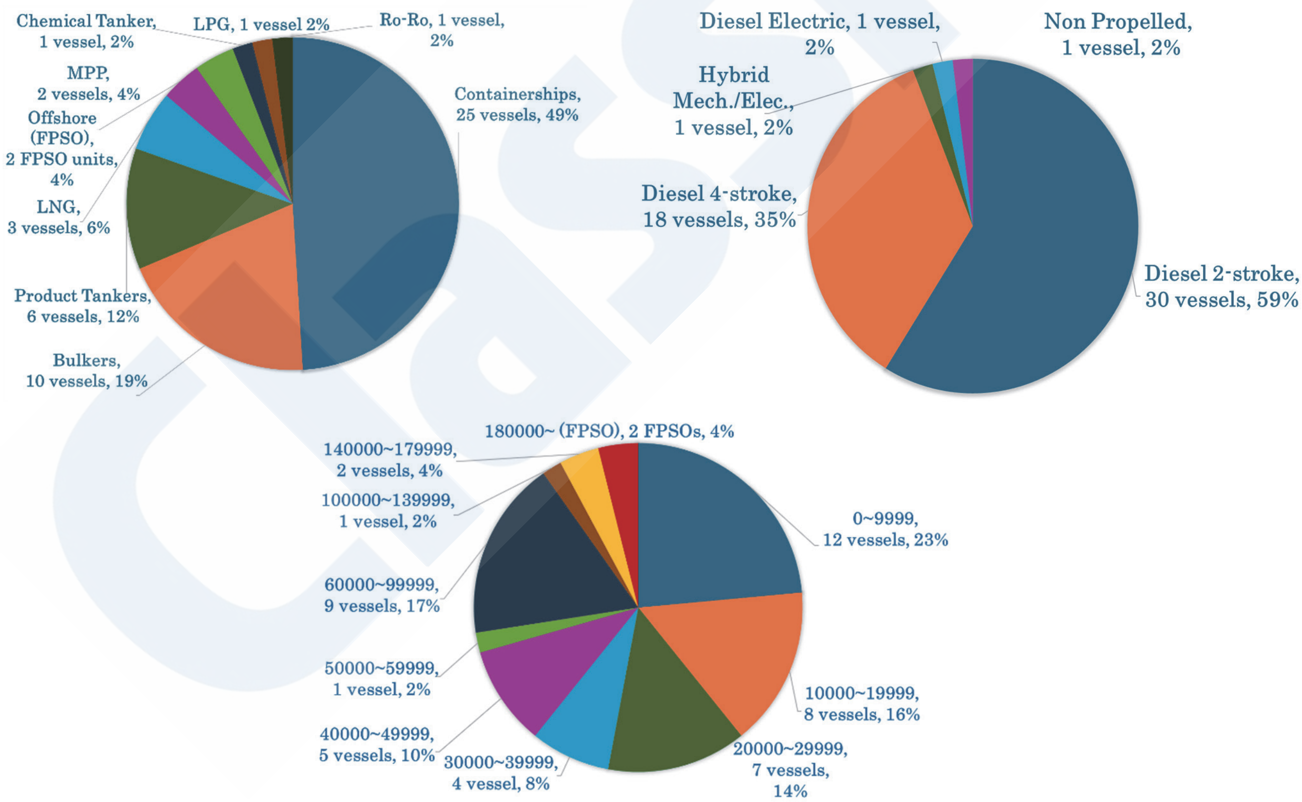


Fig. 3　Composition of OCCS-equipped vessels by type, propulsion configuration, and DWT (Clarksons Research)

Accordingly, the Society (ClassNK) issued a set of Guidelines in April 2023, specifying the relevant requirements for OCCS systems based on chemical absorption using amine solutions. Since then, the Society has also supported social implementation by providing certification services under the Guidelines. In April 2024, the OCCS system installed on Evergreen's Neopanamax containership (Flag: Panama, RO: ClassNK) successfully captured CO_2 from its exhaust gas emissions and offloaded the captured CO_2 to a shore facility for recycling. ClassNK verified the amount of offloaded CO_2, and deducted the amount from the ship's annual CO_2 emissions in a CII assessment under the direction of the Flag Administration of the Panama Maritime Authority [3]. This series of initiatives is the first case of its type in the world, and anticipates practical operations that may be adopted widely in the future to reduce GHG emissions. Thus, this is a significant step for the maritime industry towards achieving net-zero GHG emissions.

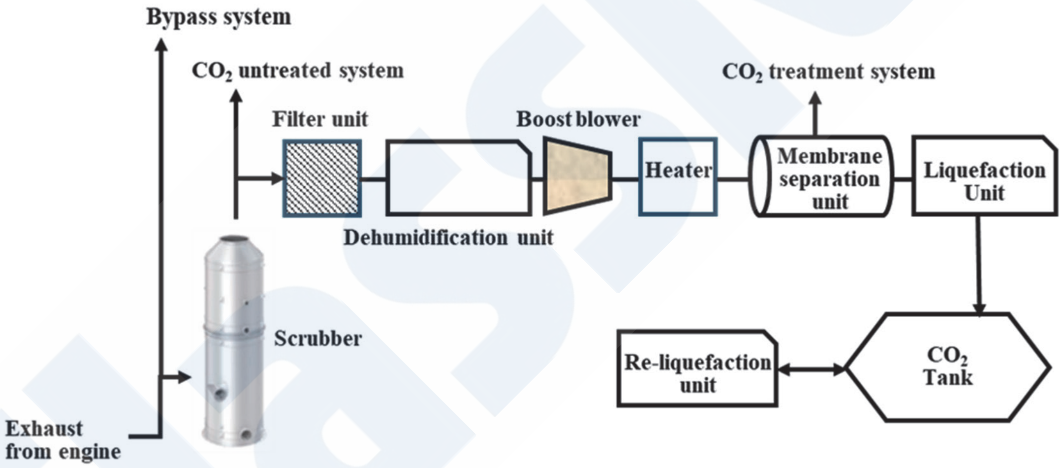
At the IMO, ongoing discussions are underway on appropriate accounting procedures for emissions avoided through capture and storage by vessels equipped with OCCS [4]. At the same time, however, OCCS technologies are expanding beyond chemical absorption methods to various other approaches such as membrane separation, depending on the type of vessel and the capture target, thereby increasing the range of available technical options. To address this technological diversification, the Society issued revised ClassNK Guidelines incorporating requirements for membrane separation methods in October 2025 [5].

This paper explains the basic principles of CO_2 capture and storage by membrane separation, and presents an overview of ClassNK's *Guidelines for Onboard CO_2 Capture and Storage Systems* and the scope of the October 2025 revision.

2. FUNDAMENTAL PRINCIPLES OF CO_2 SEPARATION AND CAPTURE BY MEMBRANE SEPARATION

2.1 Basic Configuration of OCCS Using Membrane Separation

The basic configuration of an OCCS system using membrane separation is shown in Fig. 4. As shown in the figure, the exhaust gas is pretreated in each unit and fed to the separation membranes, where CO_2 is separated, and is then liquefied and stored.



Desulfurization Heat removal Dust removal	Dust removal Desalination	Dehumidification	Boosting	Anti-condensation	Capture	Liquefaction	Storage	Re-liquefaction
Scrubber	Filter unit	Dehumidification unit	Boost blower	Heater	Membrane separation unit	Liquefaction unit	CO_2 tank	Re-liquefaction Unit

Fig. 4 Overall schematic of OCCS system based on membrane separation

2.2 Membrane Performance

The performance of a separation membrane is characterized by CO_2 permeance and CO_2 selectivity. Although permeance reflects interrelated mass-transfer phenomena such as dissolution and diffusion, it can be broadly understood in terms of molecular sieving governed by kinetic diameter, as illustrated schematically in Fig. 5. Kinetic diameter is a convenient representative dimension that indicates how readily a molecular species can pass through membrane pores. Table 1 shows the gas species relevant to engine exhaust and their kinetic diameters. Because H_2O has a smaller kinetic diameter than CO_2, dehumidification (drying) is required before membrane separation.

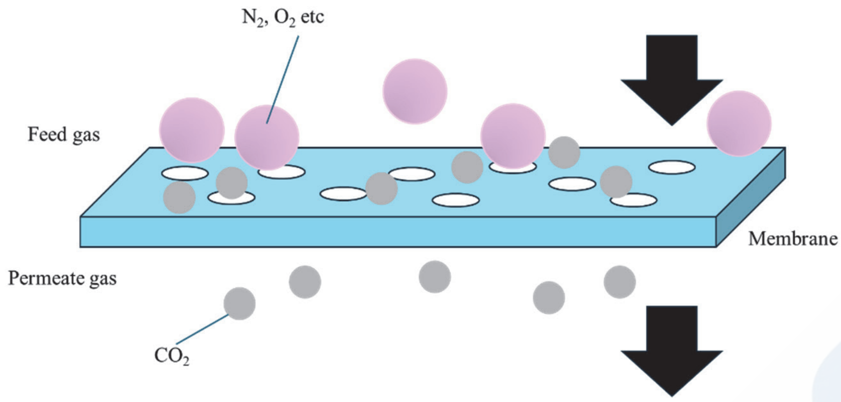


Fig. 5　Conceptual illustration of molecular sieving

Table 1　Representative kinetic diameters of selected gases

Molecule name	Molucular weight	Kinetic diameter (pm)
CO_2	44	330
O_2	32	346
N_2	28	364
H_2O	18	265
CH_4	16	380
NH_3	17	260
N_2O	44	330

Table 2 shows the permeance and selectivity of CO_2, O_2, and N_2 at various temperatures. As the temperature increases, the permeance of CO_2, O_2, and N_2 also increases because, as suggested by Fig. 5, membrane pores are not ideal straight cylinders but rather tortuous, maze-like pathways. In other words, gas molecules must have sufficient kinetic energy to pass through the membrane. For this reason, permeance is a key parameter when considering how to maximize CO_2 recovery through a membrane.

Selectivity is defined as the ratio of the permeances of two gases. For example, CO_2/N_2 in Table 2 is the permeance of CO_2 divided by permeance of N_2 ($CO_2/N_2 = P_{CO2}/P_{N2}$). Although the permeance of CO_2 increases with temperature, the permeance of N_2 also increases, causing selectivity to decrease as temperature rises. Thus, selectivity and permeance have a trade-off relationship with respect to temperature. It may also be noted that selectivity is the critical parameter when targeting high purity of the recovered CO_2.

Table 2　Examples of permeance and selectivity

Temperature (°C)	Permeance (GPU)※			Selectivity	
	CO_2	O_2	N_2	CO_2/N_2	CO_2/O_2
21	530	28	12	44	19
35	908	50	22	41	18
50	1,160	93	43	27	12

※GPU (Gas Permeation Unit): Indicator of permeance.

$$X = 10^{-6} \times V / (A \times T \times \Delta P) \qquad (1GPU = 10^{-6} \frac{cm^3(STP)}{cm^2 \cdot s \cdot cmHg})$$

V: Gas volume converted to standard conditions, (cm^3 (STP))
A: Membrane area (cm^2)
T: Time required for permeation, (s)
ΔP: Pressure difference across the membrane (as head of mercury, cmHg)

Maintaining the CO_2 capture performance of membrane separation devices depends critically on the pressure (partial pressure of CO_2) difference before and after the membrane. This pressure difference can be created by two methods, as shown in Fig. 4. One involves increasing the gas pressure upstream of the membrane by using a boost blower, and the other uses a vacuum pump downstream of the membrane to reduce the pressure.

The first method requires a relatively large amount of energy, since a large volume of gas must be compressed simultaneously. In the second method, the vacuum pump mainly reduces the pressure of the CO_2 that permeates through the membrane, so the energy requirement is comparatively low. However, the vacuum pump may not generate a sufficient pressure difference, and in this case, it may be necessary to increase the membrane surface area in order to recover a larger amount of CO_2.

2.3 Structure of Separation Membranes

There are two main forms of CO_2 separation membranes, flat-sheet membranes and hollow fibers. These two types are described below.

2.3.1 Structure of Flat-Sheet Membranes and Modules

A flat-sheet membrane is a thin, planar separation film. Exhaust gas at a higher pressure is passed along one side of the membrane, and the CO_2 in the gas permeates through the membrane and is collected on the opposite, lower-pressure side. Because the selective layer itself is extremely thin, a three-layer construction is typically used to ensure mechanical strength, as shown in Fig. 6. The bottom support layer has a porous structure that combines high strength with high gas permeability and ensures the mechanical integrity of the membrane package. An intermediate “gutter layer” is usually provided between the selective layer and the support to prevent the selective film from being pushed into the pores of the support under the applied pressure differential.

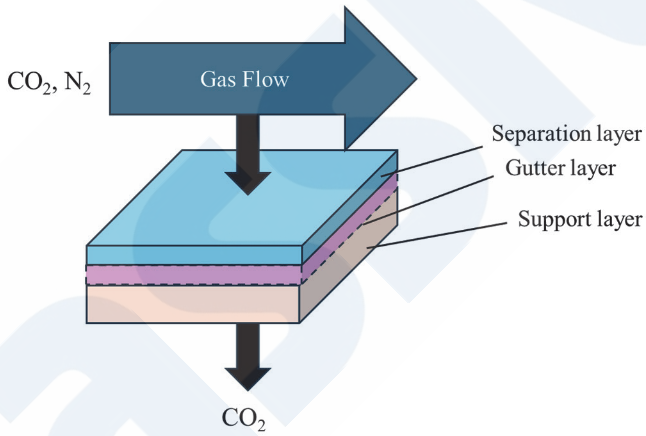


Fig. 6 Structure of flat-sheet membrane

As shown in Fig. 7, the membrane area density of flat-sheet modules is typically increased by stacking a feed (upstream) spacer, selective membrane, and permeate (downstream) spacer, in that order. The higher-pressure exhaust stream flows across the membrane on the feed side, and CO_2 permeates to the lower-pressure side, where it is separated and collected.

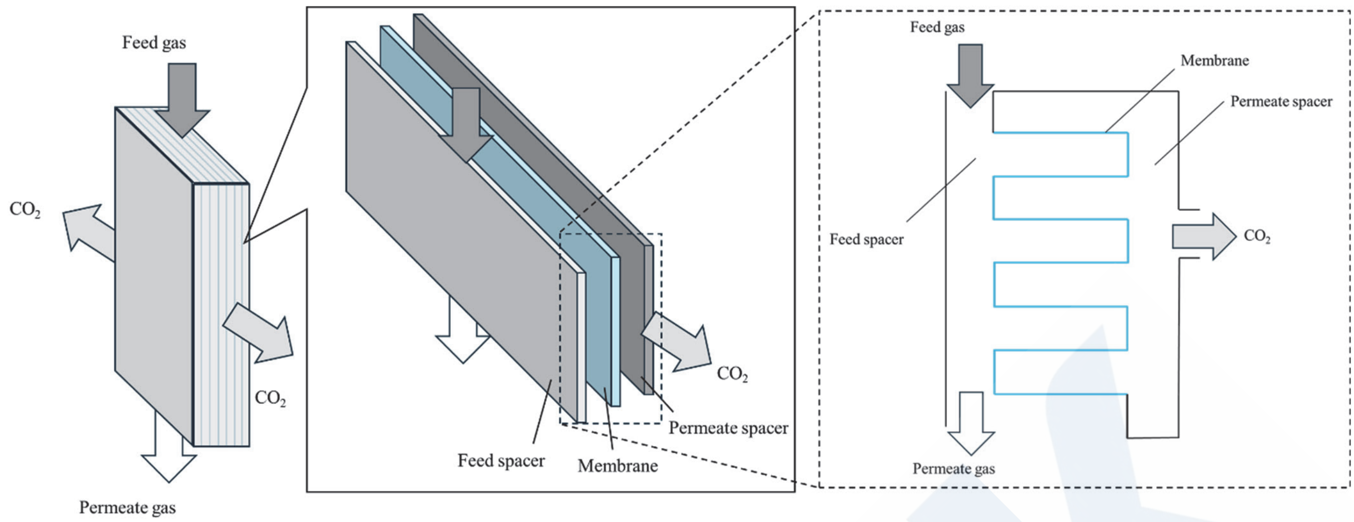
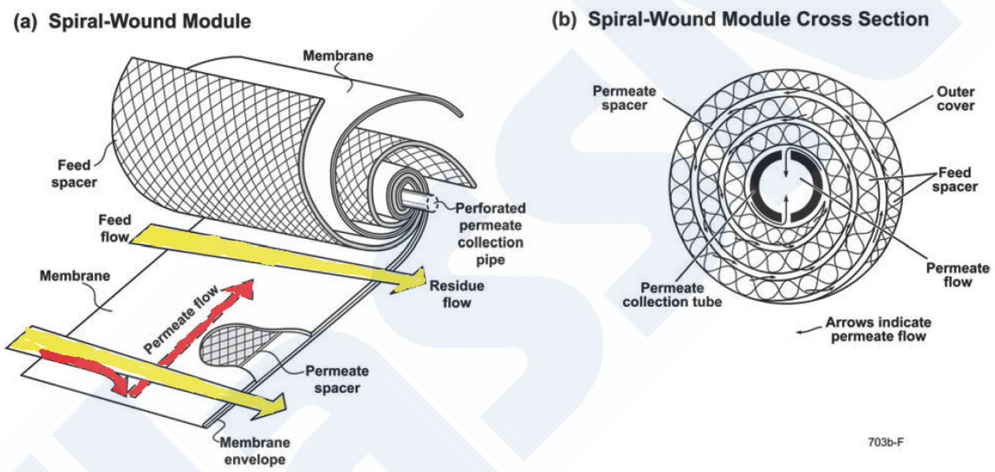
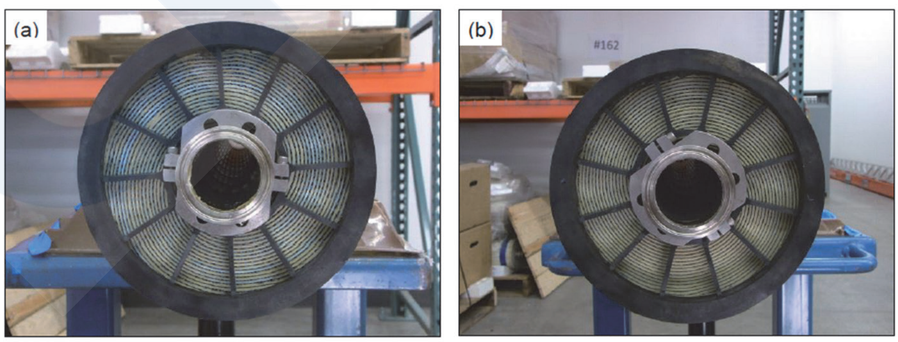


Fig. 7　Module architecture of flat-sheet membrane

A design in which the membrane area density is improved by forming a flat-sheet into a spiral-wound element is also used. For reference, Fig. 8 shows a module devised by Membrane Technology and Research, Inc. (MTR) [6, 7)*1]. In this design, the gas flows through the spiral channel, and the separated CO_2 is collected at the central core.



(a) Exploded view of a conventional spiral-wound gas separation module and (b) a cross-section of this module.



Pictures of feed gas inlet (a) and residue gas outlet (b) of module 6419. The module was tested on the 1 TPD system at NCCC from April to August of 2012.

Fig. 8　Spiral-wound flat-sheet membrane module

[*1] The colored portions in Fig. 8 were added by the authors.

2.3.2 Structure of Hollow-Fiber Membranes and Modules

In a hollow-fiber membrane, the exhaust gas flows through the lumen (bore) of each fiber. As the gas travels along the fiber, CO_2 permeates through the fiber wall and is collected on the shell side (Fig. 9). In practice, multiple fibers are bundled and arranged in parallel flow lines to form a module that enables effective CO_2 recovery.

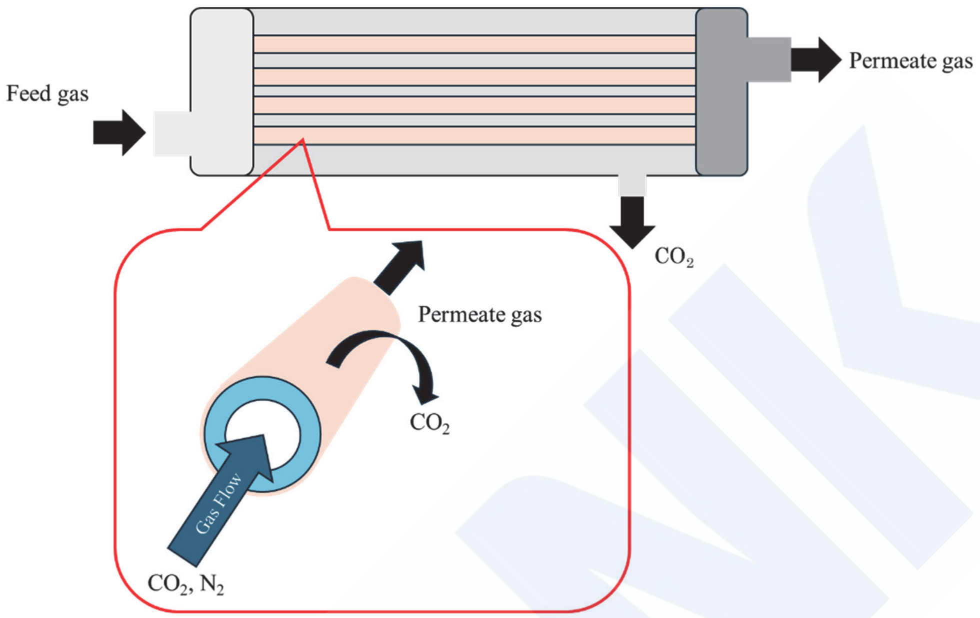


Fig. 9 Structure of hollow-fiber membrane and its module

3. OVERVIEW OF CLASSNK GUIDELINES FOR ONBOARD CO_2 CAPTURE AND STORAGE SYSTEMS (EDITION 2.0)

3.1 Background of Development and Revision

The first edition of the Guidelines was prepared based on chemical absorption. This technology has an extensive land-based track record and a high level of maturity, and even today, systems based on chemical absorption remain the mainstream.

At the same time, recent years have seen a growing number of trials of alternative capture methods tailored to specific application needs, considering the vessel type and size, fuel choice, and trading area. In particular, membrane separation has attracted increasing attention. Large-scale land-based trials of this technology are underway, and commercialization efforts are accelerating [8]. Because multiple companies are already studying OCCS using membranes and wider deployment is also foreseen, ClassNK issued a revised edition of the Guidelines. Fig. 10 shows the cover of the revised Guidelines.

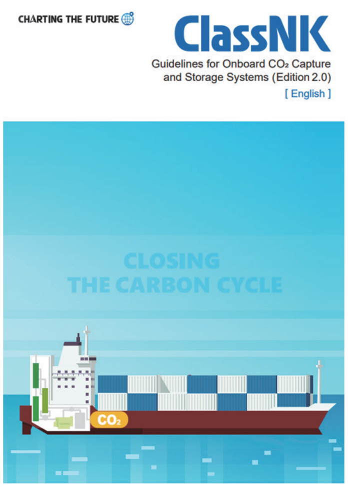


Fig. 10 Cover of revised ClassNK Guidelines

3.2 Structure of ClassNK Guidelines for Onboard CO_2 Capture and Storage Systems (Edition 2.0)

The Guidelines consist of six chapters and an appendix. Table 3 shows the titles and a brief summary of each chapter.

Table 3 Titles of the Guidelines and their summaries

Chapter	Title	Summary
Chapter 1	General	Describes scope of application, terminology, an overview of basic post-combustion CO_2 separation and capture technologies, and properties of CO_2.
Chapter 2	Functional Requirements	Specifies requirements to ensure the safety, maintainability, and reliability of OCCS (CO_2 capture and storage) equipment.
Chapter 3	CO_2 Capture Systems and Associated Equipment	Sets requirements for CO_2 capture systems using chemical absorption and membrane separation, including functions, materials, risk assessment, construction and arrangement, controls and alarms, stability, electrical installations, and safety/protective equipment.
Chapter 4	CO_2 Storage Systems and Associated Equipment	Specifies requirements for CO_2 storage systems: functions, materials, risk assessment, storage tanks, pumps, compressors, heat exchangers, stability, construction and arrangement, ventilation, controls, safety and alarm systems, gas detection/monitoring, and protective equipment.
Chapter 5	Class Notation	Defines the handling of class notation assignments for ships that comply with part or all of the Guidelines (including OCCS Ready and ships with installed OCCS).
Chapter 6	Surveys	Specifies inspection requirements during and after manufacture for the capture and storage equipment defined in Chapters 3 and 4 (Initial, Periodical, and Occasional surveys).
—	Appendix	Provides approximate calculations of additional energy for OCCS with amine solution and principal dimensions of related equipment (capture unit and liquefied CO_2 storage tank).

3.3 Update Details of the Revised Guideline

The requirements for membrane-based systems added in this revision appear in Section 1.4 ("CO_2 Capture and Storage Systems Using Membrane Separation") and Section 3.3 of the Guidelines. Section 1.4 outlines the basic system configuration of a membrane-based OCCS system, the functions of each unit, and the fundamental membrane performance parameters. Section 3.3 primarily specifies the risk mitigation requirements for membrane-based CO_2 capture systems.

3.3.1 Newly-Added Functional Requirements

To ensure that the design, construction, and operation of equipment related to OCCS systems give due consideration to safety, the following four functional requirements have been newly added:

1. Filter unit: Shall provide dust removal and de-salting functions necessary to protect downstream equipment.
2. Dehumidification unit: Shall ensure the humidity required by the separation membranes.
3. Boost blower: Shall be capable of supplying the pressure and flow rate required by the separation membranes.
4. Heater: Shall ensure the temperature required by the separation membranes.

3.3.2 Newly-Added Risk Mitigation Requirements

The revised Guidelines stipulate that risks to personnel, the environment, and the structural strength or integrity of the ship arising from the installation and use of OCCS are to be assessed using an approved risk analysis methodology. Requirements for membrane separation have been added, stipulating consideration of the following risks 1 to 3.

1. Gas leakage
2. Failures of membrane-based capture equipment downstream of the scrubber
3. Membrane integrity

It is also desirable to conduct appropriate design- and operation-related risk assessments suited to the specifications of the equipment.

4. CONCLUSION

ClassNK published *Guidelines for Onboard CO_2 Capture and Storage Systems, Edition 2.0* in October 2025, which includes new provisions for membrane separation. In the future, when capture and storage systems employing new technologies not yet covered by the Guidelines reach the stage of practical use, they can be reviewed as appropriate based on the fundamental principles of the Guidelines. Successive updates of the Guidelines are also expected, accompanying the accumulation of new knowledge and operational experience with OCCS systems.

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Ship Transportation in the CCS Business

— An Overview of Low Temperature/Low Pressure LCO_2 Transportation Methods —

Tomoyuki MURATA*

1. INTRODUCTION

In October 2020, the Japanese government set a target of achieving carbon neutrality by reducing emissions of greenhouse effect gases (GHG) to net zero by the year 2050, and declared in April 2021 that Japan would reduce GHG gases by 46% from the FY 2013 level by FY 2030. This paper focuses on CCS [*1] as one method for reducing carbon dioxide (CO_2), and presents an overview of low temperature/low pressure ship transportation of liquefied carbon dioxide (LCO_2) and JOGMEC's "Guidelines for Setting Common Specifications in the LCO_2 Ship Transportation Value Chain" (hereinafter, Common Guidelines).

2. LOW CARBON TECHNOLOGIES

Technologies for realizing carbon neutrality, that is, low carbon technologies, include the following:

a) Energy saving in existing equipment
b) Renewable energy (solar, wind power, hydropower, geothermal power, etc.)
c) Alternative fuels (hydrogen, ammonia, biomass fuels, SAF (sustainability aviation fuel), biodiesel fuel, e-fuels (synthetic fuels), RPF (refuse-derived paper and plastics densified fuels), etc.
d) CCS/CCUS
e) Nuclear power generation

Intensive research and development are underway in each of these fields. All of these technologies have advantages and disadvantages. However, in terms of both the development period/feasibility and total value-chain cost, d) CCS/CCUS is considered to be the most realistic method for addressing the issue of CO_2 reduction at this time, particularly in industries where discharges of CO_2 are unavoidable and large amounts of CO_2 must be processed.

3. CCS BUSINESS AND LEGAL AND REGULATORY SYSTEMS

3.1 Conventions, Laws and Regulations Related to CCS

◆ Basel Convention (Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal): An international convention that regulates the movement of hazardous substances and other wastes across national boundaries and their disposal. The purpose of the Basel Convention is to prevent environmental pollution and damage to human health. It was ratified 1989, and currently does not include carbon dioxide among its target substances.

◆ London Convention (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter): Prohibits the disposal of waste (specified items) at sea. Commonly called the London Convention, this convention was ratified in 1972 and took effect in 1975, and was ratified by Japan in 1980. The 1996 Protocol to the Convention strengthened prevention of marine pollution.

The 1996 Protocol to the Convention was revised in 2009 to allow the export of gases containing carbon dioxide ("CO_2 streams") for sequestration in sub-seabed geological formations under certain conditions. On the condition that the

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*1 CCS and CCUS are abbreviations for Carbon dioxide Capture and Storage and Carbon dioxide Capture Utilization and Storage, respectively, and are methods for recovering and either storing (CCS) or effectively utilizing (CCUS) CO_2 that otherwise would be discharged into the atmosphere, thereby reducing CO_2 emissions, which are considered to be the cause of global warming. These processes can be broadly divided into three parts: ①Separation and recovery, ②Transportation and ③Effective utilization or storage.

exporting nation and receiving nation have concluded a bilateral agreement, this revision made it possible to export gases containing CO_2.

- ◆ Act on the Prevention of Marine Pollution and Maritime Disasters: A Japanese law concerning dumping in the Sea of Japan, which limits sub-seabed sequestration to CO_2 streams with a CO_2 concentration ≥ 99 vol% and as the recovery method, only permits chemical absorption by amines.
- ◆ Act on Carbon Dioxide Storage Business (so-called CCS Business Act): A Japanese law enacted in May 2024.
- ◆ 2025 Revision of the GX Promotion Act, GX-ETS Green Transformation Emissions Trading System: A Japanese law that legally requires companies with annual CO_2 emissions of 100000 t/y-CO_2 or more to participate in the GX-ETS emissions trading system. The anticipated objects of this system are approximately 300 to 400 companies with large CO_2 emissions, beginning with electric power companies, steel makers, chemical companies and the shipping industry.
- ◆ EU Emission Trading System (EU-ETS): Application to the shipping sector began in January of 2024.

3.2 Legal and Regulatory System Related to Ship Transportation of LCO_2

- ◆ IGC Code: "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk" adopted in the International Maritime Organization.
- ◆ ClassNK Rules for the Survey and Construction of Steel Ships: Specifies rules for ships carrying liquefied gases in bulk, Type-C cargo tanks, post-weld heat treatment (PWHT), tank materials, etc.
- ◆ Regulations for the Carriage and Storage of Dangerous Goods in Ship: High pressure gas. [*2, *3]
- ◆ Port Regulations Act: When handling dangerous goods
- ◆ Seaman's Act: Persons responsible for handling hazardous cargoes
- ◆ SIGTTO [*4]: Guidelines for Carbon Dioxide Cargo on Gas Carriers

4. ADVANCED EFFORTS FOR COMMERCIALIZATION OF CCS BY JOGMEC

4.1 JOGMEC's Advanced CCS Projects

To prepare the business environment for the start of CCS businesses by the beginning of the 2030s based on Japan's GX Promotion Strategy, JOGMEC is supporting advanced role-model projects, targeting total CO_2 sequestration of approximately 20 million t/y-CO_2 in 9 projects, including 5 in Japan and 4 overseas. Including domestic and international transport, 6 of the 9 projects involve ship transportation.

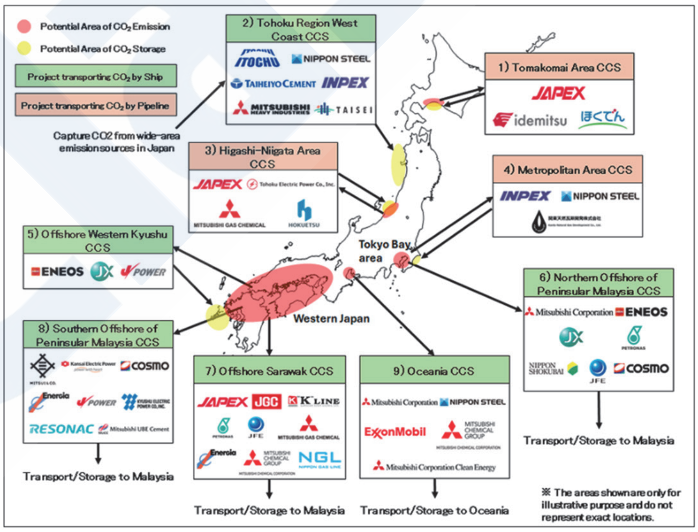

Fig. 1 JOGMEC's advanced CCS projects (Source: https://www.jogmec.go.jp/ccs/advancedsupport_002.html)

[*2] LCO_2 transport ships are not classified as "ships carrying dangerous goods" under Japan's Maritime Traffic Safety Act. The Piloting Law is also interpreted similarly.
[*3] The Act on Preventing Collisions at Sea does not directly describe navigation methods for ships carrying dangerous goods.
[*4] SIGTTO: Society of International Gas Tanker and Terminal Operators, a non-profit non-governmental organization (NGO) https://www.sigtto.org/

As the result of a feasibility study examining the possibility of building a CCS value chain conducted in 2023, the following points were recognized as common issues for realizing CCS.

① Reduction of the cost of utilities such as steam, electric power, etc. necessary for recovery of CO_2

② Strengthening of domestic construction capacity for storage tanks and ships required for CO_2 transportation by ship

③ Acquisition of data for evaluating the possible CO_2 sequestration capacity and injectability, containment capacity and long-term integrity of geological formations for sequestration.

The following sections of this paper focus in particular on ② Ship transportation.

4.2 Means of Mass Transportation of CO_2

The means of mass transportation of CO_2 in CCS can be broadly classified into two types, pipeline transportation and ship transportation.

(1) Pipeline transportation: Pipeline transportation is a fully-established, mature transportation technology for liquids in the modern era, and is also used to transport LPG and LNG, as well as CO_2 for enhanced oil recovery (EOR). After the equipment has been completed, it has the advantage of enabling continuous mass transportation, irrespective of day or night. As disadvantages, location of the production plants, storage facilities and routes connecting them are fixed at the time of construction, and thus are difficult to change after installation. It is also necessary to note the capital expenditure (CAPEX) required for long-distance pipeline construction, the operating expenses (OPEX) associated with maintenance, land use fees and the like, the risk of accidents that may occur in normal temperature/high pressure transportation (for example, leakage from a pipeline passing through a densely populated region) and transportation stoppages.

(2) Ship transportation: On land, transportation of medium temperature/medium pressure LCO_2 is usually performed by tank trucks or gas pressure cylinders. Japan has a record of domestic ship transportation by the ship “Amagi Maru” (medium temperature/medium pressure LCO_2, tank capacity: 365m^3, constructed in 1986), but a low temperature/low pressure ship transportation technology still has not been established.

In ship transportation, the CO_2 shipping point (port) and receiving point (port) can be set and changed easily, and there is also a high degree of freedom in changing transportation routes. In the event of a leakage accident at sea, the danger of asphyxiation is slight because the gas is immediately dispersed in the atmosphere by wind. In terms of the transportation system, redundancy is excellent, as it is possible to continue transportation by a substitute ship even if an accident occurs. It is necessary to note the CAPEX of ship construction (particularly the cost of materials for low-temperature cargo tanks and arranging manufacturing equipment suitable for scaling up the tanks), the OPEX of ship operation and management and fuel costs, requirements for reduced CO_2 emissions from ship engines during transportation, and the difficulty of securing seamen with the qualifications necessary for transportation of liquefied gas.

There are known research results showing that ship transportation is more cost-effective than pipeline transportation when the LCO_2 transportation distance exceeds 200km. In marine transportation, increasing the transportation capacity per voyage by increasing the ship size is preferrable, but there are limitations on the specifications of the tanks for medium temperature/medium pressure transportation (steel material, plate thickness and diameter for high-pressure application), which make it difficult to increase the ship size beyond a certain point. In this regard, low temperature/low pressure transportation is superior, in that the design pressure of the pressure tanks is low, making it possible to increase the tank size. However, the conditions used in low temperature/low pressure transportation (–50°C/0.58MPaG) of LCO_2 are near the triple point (–56.6°C/0.42MPaG) of CO_2, where dry-icing of LCO_2 occurs. To avoid this risk, it is necessary to determine the best balance of transportation safety, the transportation temperature and pressure range, and economic rationality.

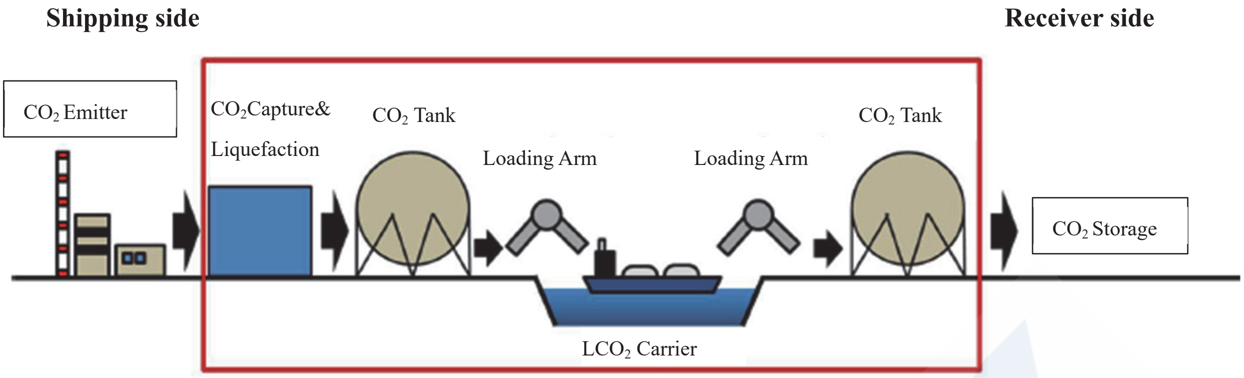

Fig. 2 General flow of CCS by LCO_2 carrier transportation (Source: Common Guidelines, p.3)

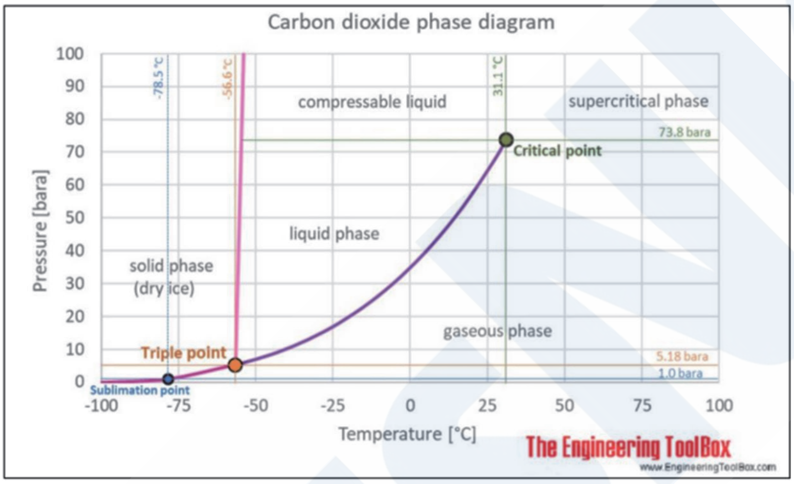

Fig. 3 Phase diagram of LCO_2 (Source: https://www.engineeringtoolbox.com/CO2-carbon-dioxide-properties-d_2017.html)

4.3 Comparison of Two Types of LCO_2 Transportation by Ship

(1) Medium temperature/medium pressure type

In research on CCS technologies, medium temperature/medium pressure type ship transportation was adopted in almost all the pioneering CCS projects in Europe, and the LCO_2 carrier used in Norway's Northern Lights project, which was the world's first full-scale LCO_2 transportation project, was also a medium temperature/medium pressure type.

The reasons for adopting the medium temperature/medium pressure type in European projects are as follows.

① Because the Technology Readiness Level (TRL) of the medium temperature/medium pressure type was high (already an established technology with a track record of long-term use).

Since Michael Faraday and Humphry Davy succeeded in liquefying gases for the first time in the world in 1823, CO_2 has been used in various fields. For example, it is used in carbonated beverages, beer and sparkling wine, as a shield gas in arc welding, as a feedstock in the chemical industry and as a fire-extinguishing agent. In recent years, it has also been used in agriculture (as an environment for greenhouse cultivation), as a repair agent for punctured tires and in CO_2 lasers. In Japan, CO_2 is contained in green-colored cylinders (Fig. 4) under the provisions of the High Pressure Gas Safety Act. Fire-extinguishing equipment using CO_2 (or halogens or other suffocating gases) is sometimes installed where water fire-extinguishing is not suitable, such as in multistory parking buildings and electrical rooms. In some cases, large-scale LCO_2 tank equipment (Fig. 5) is provided for use in fire-fighting on ships where car fires are a risk, such as large ferries and dedicated car carriers. Work to replenish these stationary-type tanks is normally performed by transportation from the CO_2 production plant by tank truck (medium temperature/medium pressure) and filling using a flexible hose.

② Because the transportation distances of projects in the EU region are short.

When the transportation distance is short, the boil off gas (BOG) generated as a result of heat transfer into the tank during transportation of a liquefied gas is slight. This means that heat transfer can be suppressed simply by providing heat insulation, without costly reliquefying equipment or chilling equipment that require installation space, and pressure-keeping transportation is possible without exceeding the working pressure of the tank. Of course, the tank design pressure must be set taking into account the pressure rise during transportation. Therefore, as points to note, it may be necessary to either use a high grade steel material, such as high Ni steel or increase the tank wall thickness if carbon steel is to be used, or there may be limitations on the maximum diameter of the tank.

③ Because the risk of dry-icing is low.

Since the phenomenon of a phase transition of liquid LCO_2 to solid dry ice occurs when the liquid temperature/pressure decreases to the triple point or below, a transportation temperature/pressure condition far from the triple point has the merit of a relatively low risk of dry-icing.

Fig. 4 Liquefied CO_2 gas cylinders (the small cylinder is a normal temperature/high pressure type)

(Source: Website of Shinko AirTech, Ltd., https://shinko-airtech.com/gasliquid_CO2.html)

Fig. 5 Marine CO2 fire-extinguishing system (–17°C/2.1MPa)

(Sources: Website of Air Water Safety Service Inc., https://awb.co.jp/service/vessel/)

(2) Low temperature/low pressure type

When considering large-volume transportation and large-volume sequestration of CO_2 in the CCS business in Japan in the future, sequestration in overseas countries is a promising option. While this will require large-scale LCO_2 carriers capable of long-distance, large-volume transportation, it can perhaps be said that low temperature/low pressure transportation is the most rational choice under those conditions. The relevant Common Guidelines set the lowest working temperature of LCO_2 tanks at –50°C and the lowest design temperature at –55°C. As the temperature of the LCO_2 decreases, its density increases and the transported mass also increases. However, as specified in the IGC Code, “6.4 Requirements for metallic materials,” a response to higher-level design conditions is required if the design temperature of marine cargo tanks is set lower than –55°C. Therefore, the above-mentioned set value was adopted in order to avoid cost increases due to the increased difficulty of design and manufacture, and to secure a margin of safety from the triple point (–56.6°C), where there is a risk of dry-icing.

In comparison with the aforementioned medium temperature/medium pressure type, the low temperature/low pressure type has the following weaknesses: ①The Technology Readiness Level (TRL) is “6-7: Demonstration stage,” which is inferior to the medium temperature/medium pressure type, ②A reliquefying or chilling device for treating BOG is essential due to long distances of transportation to overseas sequestration sites, ③The risk of dry-icing is high because the liquid temperature and pressure are near the triple point, and ④The land-side CAPEX is high because the capacity of the shipping/receiving facilities must be larger than the amount of LCO_2 transported in per voyage.

On the other hand, the advantages of the low temperature/low pressure type are as follows:

a) Transportation efficiency is good because the density of LCO_2 at –50°C (1.15kg/L) is more than 10% larger than the density at –20°C (1.03kg/L).

b) It is possible to use low-temperature carbon steel, which is relatively inexpensive in comparison with high Ni steel, because the design pressure of the cargo tanks is lower than that of the medium temperature/medium pressure type; in addition, light weight, a larger loading capacity and lower costs can also be expected because a thinner plate thickness or larger tank diameter can be used. (Explanations of steel plate thickness limits and post-weld heat treatment are omitted here.)

c) If the ship is as large as possible, this means that the number of ships or number voyages required for the amount of LCO_2 necessary in the project can be reduced and rationalized, and a reduction of the total transportation cost of CAPEX and OPEX can be expected.

d) Reducing the number of ships is advantageous for easing the shortage of shipbuilding capacity in Japan's domestic shipbuilding industry, and is also an advantage for easing the shortage of seamen because fewer seamen are needed to crew the reduced number of ships.

Japan's New Energy and Industrial Technology Development Organization (NEDO) carried out a study on long-distance, large-volume ship transportation of LCO_2 and discovered that the low temperature/low pressure type is superior. Using the demonstration test ship "EXCOOL" (996G/T, commissioned in 2023), which was constructed for large-volume, long-distance transportation tests of LCO_2 under the low temperature/low pressure condition (–50°C, 0.58MPaG) as a CCUS R&D and Demonstration Project from 2021, NEDO has been conducting demonstration tests of various cargo-handling and ship transportation conditions.

Demonstration test ship "EXCOOL"
Length overall: 72.0 m
Breadth overall: 12.50 m
Full load draught: 4.55 m
Gross tonnage: 996 G/T
Cargo tanks: 725 m^3 x 2
Design enables transportation of LCO_2 under conditions from medium temperature/medium pressure to low temperature/low pressure.
Cruising speed: 12.0 kts
Engine output: 1,471 kW
Navigation area: Short sea(non-international)
LPG combination carrier specification

Fig. 6 "EXCOOL [*5]" demonstration test ship

(Source: Website of Nippon Gas Line Co. Ltd., NEWS 2023.12, https://ngl.co.jp/news/)

[*5] The origin of the ship name "EXCOOL" is an idea premised on the themes of "CCS is a countermeasure for prevention of global warming" and "a ship that transports LCO_2 at a cryogenic temperature of –50°C." Analyzing "LCO_2," which means liquefied CO_2 (carbon dioxide) into its component letters, we discover LCOO, which can be converted to COOL as an anagram. Affixing EX to COOL, we have the portmanteau word "EXCOOL," with the double meanings of "CCS to cool the Earth" and "LCO_2 at –50°C is extremely cool." To express global environment-friendliness and its Japanese nature, "EXCOOL" is written in Japanese in soft hiragana characters as "えくすくぅる." (The ship's name was devised by the author of this paper.)

4.4 Features of European CCS Projects

The form of CCS frequently seen in CCS projects in Europe is transmission of CO_2 collected from the factories of multiple emitters by pipeline to a facility at the loading port, where the CO_2 is stored in payout tanks after aggregation and liquefaction, loading on LCO_2 carriers at medium temperature/medium pressure, transportation to destinations within the EU region, and offloading to receiving tanks at the sequestration facility, where it is pressurized/heated to a supercritical state and finally injected into a geological formation deep below the sea bottom. This process assumes that transnational transportation between two countries in the EU or an EU country and non-EU country is performed based on application of the London Protocol (i.e., a bilateral agreement).

In Europe, small-scale marine transportation of CO_2 was commercialized from several years ago. Ships and barges are used to transport food-quality CO_2 from producing plants to distribution terminals on the coast. The size of the ships currently in use is between 1,000 and 1,500m^3, and the transport pressure is in the range of 14 to 20barA, which is classified as medium temperature/medium pressure.

The following presents several examples of research on LCO_2 ships in Europe and projects that are currently underway.

(1) ZEP [*6] Report: Achieving a European market for CO_2 transport by ship

This report positions ship transportation in Europe as follows: "The European Commission aims to store at least 50 million tonnes of CO_2 by 2030. Shipping will play a crucial role in Europe for the development of carbon capture and storage. 1 million tonnes of CO_2 can be transported per year by a 20,000 tonne cargo liquefied ship with a one-week round trip. 26 storage projects identified could use shipping to transport CO_2. European policymakers should support the development of CO_2 transport by ship for industrial decarbonisation. (Report, p.7)."

(2) ZEP Report: Guidance for CO_2 transport by ship 2022

According to the Executive Summary of the Report, it was determined that "For CCS projects aiming at transporting CO_2 by ship, interoperability could be important in order to optimise the development of CO_2 infrastructure . . . .There is a need for some degree of standardisation on CO_2 specifications (composition, pressures, temperatures, etc.), ship design and specifications (e.g. referring to loading and off-loading). (Report, p.7)"

(3) SINTEF [*7] Report

In 2021, SINTEF conducted a detailed comparative study on medium temperature/medium pressure type and low temperature/low pressure type transportation of LCO_2, and finally concluded that large-volume shipping of CO_2 at a pressure of 7barG and liquid temperature of –46°C achieves the largest cost reduction (approx. 30%). (Also confirmed from the original SINTEF paper.)

A July 2021 SINTEF paper entitled "At what pressure shall CO_2 be transported by ship? An in-depth cost comparison of 7 and 15 Barg Shipping" concludes that 7barg /-46C is the optimal condition for large volume shipping due to the lower vessel cost(~30%)
Source: https://www.mdpi.com/1996-1073/14/18/5635/pdf

Fig. 7 ZEP Guidance for CO_2 transport by ship 2022 (p.14)

(4) Northern Lights projections

In a report by the Northern Lights Project on a full-chain economic assessment using market-based ship CAPEX costs, the project concluded that low temperature/low pressure transportation gives the lowest cost in transportation by large-volume LCO_2 ships with capacities of more than 20000m^3.

[*6] ZEP: Abbreviation of Zero Emissions Platform, a European Technology and Innovation Platform (ETIP) under the European Strategic Energy Technology Plan (SET-Plan) of the European Commission; ZEP was established as the technical advisor to the European Commission on the development of CCS and CCU.

[*7] SINTEF: Abbreviation for The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, an independent research organization which was established in 1950 and is headquartered in Trondheim, Norway. It carries out research and development projects on a contract basis.

5.1.1.2 Recent Northern Lights projections

The Northern Lights project has provided information advising that their full chain economic evaluation using market-based ship CAPEX costs indicates that

Vessel cargo size	Lowest end-to-end costs
Up to 15,000m^3	Medium pressure ((~15 barg) and at -30°C) gives lowest cost
15,000-20,000 m^3	Evaluation inconclusive. Either medium or low pressure may be lower cost depending on finer details of the project
Above 20,000 m^3	Low pressure ((~7 barg) and at -50°C). gives lowest cost

Figure 6: Cryogenic ship cargo size at different pressure and temperature

The reason for the two cryogenic operating conditions relates to the mass of steel required. In the smaller vessels the steel required to contain a pressure of 15 barg is acceptable. In a larger vessel the mass of steel required to contain 15barg becomes uneconomic despite the greater energy requirement to cool the liquified gas to -50°C.

Fig. 8 ZEP Guidance for CO_2 transport by ships 2022, p.15

(5) Examples of European LCO_2 Ships

Northern Lights / The Longship CCS project

Project outline: Transportation of CO_2 recovered from customers in Norway, Denmark and the Netherlands to a receiving terminal located in Oygarden in western Norway. Will transport at least 400,000tonnes/year from each location for injection in a reservoir 2,600 meters below the sea bottom via a pipeline.

Northern Pioneer
Length overall: 130 m
Breadth overall: 21.2 m
Draught: 7.5 m
Gross tonnage: 8,035 G/T
LCO_2 capacity: 7.500 m^3/2 tanks
Transported LCO_2: Medium temperature/medium pressure, 18 barG
LNG-fueled ship with ship bottom air lubrication system
Equipped with rotor sail
Constructed by Dalian Shipbuilding Industry Co., Ltd., China
Classified by DNV
Phase I will include 4 sister ships

Fig. 9 From the website of Kawasaki Kisen Kaisha, Ltd. ("K" Line), news release, Nov. 26, 2024
(https://www.kline.co.jp/ja/news/liquefied_gas/liquefied_gas-20241126.html)

Greensand Future Project

Project outline: Planned to transport 400,000t/y from the Port of Esbjerg, Denmark to Nini West Platform (depleted oil field in the Danish North Sea).

Carbon Destroyer 1: Launched 14 May 2025 as the first large LCO_2 ship built in the EU.

Carbon Destroyer 1
Length overall: 149.95 m
Breadth overall: 15.9 m
Draught: 8.6 m
The design incorporates a total of 8 LCO_2 tanks in 2 rows x 4 tanks, based on the hull of a multi-purpose bulker (hold capacity: 14,000 m^3)
LCO_2 capacity: Approx. 5,000 m^3
Transport LCO_2: Medium temperature/medium pressure

Fig. 10 From an article in the Maritime Observer dated 14 May 2025
(https://maritime-executive.com/article/video-carbon-destroyer-1-eu-s-first-co2-carrier-for-ccs-is-launched)

5. GUIDELINES FOR SETTING COMMON SPECIFICATIONS IN THE LCO_2 SHIP TRANSPORTATION VALUE CHAIN (COMMON GUIDELINES)

5.1 Formulation of the Common Guidelines

In order to achieve optimum efficiency not only in the ship transportation portion of the Advanced CCS Project, but in the value chain as a whole, repeated discussions and studies were carried out in JGOMEC's Council for Discussion on Common Specifications in LCO_2 Ship Transportation Value Chain (hereinafter, Common Guidelines Council) in cooperation with the Ministry of Economy, Trade and Industry (METI), and on 30 May 2025, JOGMEC issued "Guidelines for Setting Common Specifications in the LCO_2 Ship Transportation Value Chain [*8]" (Common Guidelines) for use in the Advanced CCS Support Project and as reference when studying CCS projects where ship transportation of CO_2 is to be performed in the future.

In conducting its study on setting common specifications for the LCO_2 ship transportation value chain, the Common Guidelines Council carried out the study and compiled the results on the premise that low temperature/low pressure LCO_2 transportation is the optimum method for realizing long-distance, large-volume ship transportation.

5.2 Large Low Temperature/Low Pressure LCO_2 Carriers [*9]

5.2.1 Common Specifications

The conditions in CCS ship transportation in Japan are decisively different from those in European projects. Japanese CCS projects assume quite long transportation distances to overseas sequestration sites, with a one-way transportation distance of approximately 2,300 to 5,000 nautical miles and the number of voyage days of 6 to 16. For this reason, there are areas where large ships and cost reduction by large-volume transportation are necessary.

(1) Basic ship type

① Length overall: Less than 235m

This is the result of a survey of the participants in the Common Guidelines Council regarding the maximum ship length that can be received, based on the limitations of quays, etc.

[*8] The Common Guidelines state to the effect that "Although ①Securing the possibility of interoperability and shared used of shipping and receiving facilities, ②Securing an efficient supply chain and ③Reducing transportation costs are expected in ship transportation of LCO_2 preconditioned on ensuring safety, these Guidelines do not specify standards/criteria that include regulatory provisions or have binding force on the CCS business concepts of individual operators." (From Common Guidelines, p.2)

[*9] In the Common Guidelines, in addition to specification for large ships, specifications were also formulated for medium-sized (23,000 m^3 type) and small coastal ships (5,000 m^3 type) for use in hubs and clusters or domestic transportation. However, due to space limitations, the explanations of those types will be omitted in this paper.

② Draught: Not more than 11.5m

This is the result of “a survey of the draught limits of quays where new construction of cargo-handling piers is assumed at existing berth which are expected to be used in shipping/receiving of LCO_2, and the water depth, navigation rules, tides, etc. of the planned navigation routes,” planned by the Council participants.

③ Cargo capacity: 50,000m^3

The result of a trial calculation of the maximum cargo was 50,000 m^3 with a total of 6 tanks, assuming construction of tanks using low-temperature carbon steel, which can be loaded under the above-mentioned hull conditions and navigation conditions.

④ Tank design temperature/pressure and working temperature/pressure range

Design temperature: –55°C, design pressure: 0.8MPaG

Working temperature: –50°C to –44°C, working pressure: 0.58MPaG to 0.76MPaG (values assuming pure LCO_2)

(2) Cargo-handling equipment

① Cargo-handling time: 16 to 20 hours

In many cases, the harbour master places restrictions on nighttime port entry/departure and the cargo-handling time of ships carrying dangerous goods specified in the Act on Port Regulation. Therefore, it is necessary to carry out a study with the aim of optimizing the cargo-handling cycle, considering port entry/departure time and the allowable cargo-handling time in each case.

② Flow velocity: 2m/s to 5m/s

If the flow velocity of the LCO_2 in the piping is increased, it is thought that the risk of dry-icing will also increase. Although this issue has been researched by many experts, particularly in Europe, the maximum flow velocity for safe cargo-handling of low temperature/low pressure LCO_2 still has not been determined. As an actual result, in cargo-handling of LCO_2 on NEDO’s demonstration test ship “EXCOOL,” a transfer test between the ship and land-based facilities was carried out based on a piping flow velocity of 2m/s [*10]. Accordingly, in these Guidelines, the flow velocity is examined with 2m/s as a starting point from the viewpoint of securing safety. While it goes without saying, when the flow velocity is low, a larger number of piping will be needed to cover the scheduled cargo-handling volume and time. Furthermore, since the designs of shipyards in other countries show maximum piping flow velocities in the range of 4 to 8m/s, if Japanese shipyards cannot offer designs with a flow velocity at least on a similar level, their competitiveness will fall behind in the future.

③ Number and arrangement of manifold piping on ship

The piping diameter is assumed to be DN200 to DN400. Since the flow rate (flow volume) decreases when the pipe diameter is reduced, it is necessary to allow a longer cargo-handling time or increase the number of pipes. Moreover, use of general-purpose products and cost reduction can be expected by standardizing the pipe diameters of LPG ships and LNG ships, which are current liquefied gas carriers.

The cargo volumes and cargo-handling times for one voyage required in CCS projects vary widely, and pipe diameter, flow velocity and number of piping which satisfy those requirements also differ. In case the LCO_2 carrier to be used is substituted due to a change in ship allocation, etc., it is possible to respond by using a reducer, even when the manifold diameter is different by one step, but adoption of common specifications for piping arrangements as far as possible may be more efficient. A basic example of the layout of the manifold liquid piping and vapor piping is presented, in which the vapor piping is located in the center so that it is possible to respond even if the number and arrangement of liquid piping is different at the terminals of the shipping port and the receiving port, or the port and starboard docking side of the ship are reversed.

④ Loading arm

The equipment weight of loading arms for LCO_2 is greater than that of loading arms for LPG and LNG because the thickness must be increased to withstand pressure. When the number of loading arms increases due to the relationship of the cargo-handling time and flow rate, the total equipment weight of the loading arms will also increase. Therefore, it is necessary to note that the weight-bearing capacity of the berth and space for installation must be secured.

In installation of the loading arm piping, common specifications should be adopted as much as possible to enable trouble-free connection to the ship’s manifold. For loading arms as well, in order to allow connection even if the type and number of piping

[*10] In a report on recent demonstration tests by Nippon Gas Line, a demonstration of shipboard CO_2 handling of LCO_2 between tanks was carried out using the two cargo tanks installed on the ship (“EXCOOL”), and transfer tests were conducted at flow velocities of 4 m/s and higher.
https://ngl.co.jp/wordpress/wp-content/uploads/2025/06/20250630 船上高流速 PR-和文.pdf

are different from those of the ship, the Guidelines present an example in which the vapor piping is arranged in the center of the manifold line, as in the manifold of the ship, and the liquid piping is arranged symmetrically before and after it, thereby achieving high compatibility in connection of the piping with the ship.

5.2.2 Types of Impurities and Their Effects

The types and concentrations of impurities contained in transported LCO_2 cargoes differ depending on the CO_2 discharge source, separation/recovery method, pretreatment for liquefaction, etc. As in the case of dry-icing risk due to the flow velocity, in ship transportation of LCO_2, the items to be noted are the existence and concentration of impurities. The conceivable problems that may occur when impurities are contained in LCO_2 can be broadly divided into ①Vapour pressure rise due to non-condensable components, ②Formation of corrosive substances and ③Components with adverse effects on human health and the environment.

At present, the list of types of impurities and allowable concentrations in LCO_2 cargoes published by Northern Lights (medium temperature/medium pressure LCO_2) shown in Table 1 is generally used as reference.

Table 1　Northern Lights table of allowable concentrations of impurities

Component	Unit	Limit for CO_2 Cargo within Reference Conditions[1]
Carbon dioxide (CO_2)	mol-%	Balance (Minimum 99.81%)
Water (H_2O)	ppm-mol	≤ 30
Oxygen (O_2)	ppm-mol	≤ 10
Sulfur oxides (SO_x)	ppm-mol	≤ 10
Nitrogen oxides (NO_x)	ppm-mol	≤ 1.5
Hydrogen sulfide (H_2S)	ppm-mol	≤ 9
Amine	ppm-mol	≤ 10
Ammonia (NH_3)	ppm-mol	≤ 10
Formaldehyde (CH_2O)	ppm-mol	≤ 20
Acetaldehyde (CH_3CHO)	ppm-mol	≤ 20
Mercury (Hg)	ppm-mol	≤ 0.0003
Carbon monoxide (CO)	ppm-mol	≤ 100
Hydrogen (H_2)	ppm-mol	≤ 50
Cadmium (Cd), Thallium (TI)	ppm-mol	Sum ≤ 0.03
Methane (CH_4)	ppm-mol	≤ 100
Nitrogen (N_2)	ppm-mol	≤ 50
Argon (Ar)	ppm-mol	≤ 100
Methanol (CH_3OH)	ppm-mol	≤ 30
Ethanol (C_2H_5OH)	ppm-mol	≤ 1
Total volatile organic compounds (VOC)[2]	ppm-mol	≤ 10
Mono-ethylene glycol (MEG)	ppm-mol	≤ 0.005
Tri-ethylene glycol (TEG)	ppm-mol	Not allowed
BTEX[2]	ppm-mol	≤ 0.5
Ethylene (C_2H_4)	ppm-mol	≤ 0.5
Hydrogen cyanide (HCN)	ppm-mol	≤ 100
Aliphatic hydrocarbons (C_2+)[4]	ppm-mol	≤ 1,100
Ethane (C_2H_6)	ppm-mol	≤ 75
Solids, particles, dust	ppm-mol	≤ 1

Table: 14: LCO_2 Quality Specifications [24].

https://ww2.eagle.org/content/dam/eagle/publications/knowledgecenter/CO2 Impurities and LCO2 Carrier Design-Practical Considerations.pdf（Page20）

Research on impurities by experts and research groups in countries around the world has a long history, and diligent efforts are underway even now. Nevertheless, additional time and costs will be required in order to investigate the effects of the many individual impurities that exist by concentration, and to investigate and reach conclusions regarding the phenomena in a state where multiple impurities are combined.

As noted above, the types of impurities and the content of their effects can be classified in the following three types.

(1) Non-condensable components

These are components that exist in a gaseous state, even in LCO_2, because their molecular weights and boiling temperatures are lower than those of CO_2, and include hydrogen (H_2), nitrogen (N_2), argon (Ar), carbon monoxide (CO) and methane (CH_4).

When LCO_2 contains a trace amount of these non-condensable components, its vapour pressure tends to be higher than that of pure LCO_2, and the pressure may exceed the design pressure of the tank. Therefore, individual study of the allowable pressures of these non-condensable components is necessary to ensure that, at minimum, the vapour pressure does not exceed the range of the working pressure (0.58MPaG to 0.76MPaG) of the ship's cargo tanks. In addition, these non-condensable components are an obstacle when reliquefying BOG, and reliquefaction may become impossible.

(2) Formation of Corrosive Substances

Water (H_2O) reacts with CO_2 to form carbonic acid, which causes corrosion of carbon steel.

Similarly, water (H_2O) also reacts with oxygen (O_2), sulfur oxides (SOx), nitrogen oxides (NOx), hydrogen sulfide (H_2S) and carbon monoxide (CO), forming corrosive compounds. Mercury (Hg) reacts with aluminum, forming amalgam. From a different viewpoint, there is a possibility that corrosion-related problems can be significantly reduced by reducing the moisture content as far as possible.

Although it has also been reported that moisture (H_2O) does not exist in liquid form in liquid LNG at cryogenic temperatures, and corrosion does not occur because acids are not formed. Additional research and verification of whether similar behavior also occurs in LCO_2 at –50°C or not will be necessary in the future.

(3) Components with Adverse Effects on Human Health and the Environment

As emission standards for exhaust gas containing CO_2 that has been discharged into the atmosphere, until now, emissions were controlled based on Japan's Air Pollution Control Act. The laws and regulations regulating impurities contained in CO_2 are as follows.

- Air Pollution Control Act
- Japanese Industrial Standard JIS K 1106, Liquid carbon dioxide
- Food Sanitation Act, Standards for Food Additives

It may be necessary to note the allowable concentrations so as not to exceed the regulatory values under these standards when a leak occurs.

5.3 Issues for Future Research

Although the First Edition of "Guidelines for Setting Common Specifications in the LCO_2 Ship Transportation Value Chain" was issued recently, there are two subjects that still have not been adequately confirmed, as follows. These will be issues for future research by the Common Guidelines Council.

(1) Determination of types of impurities to be limited and maximum allowable concentrations

Processes that remove impurities from LCO_2 impact the CAPEX of separation/recovery facilities, but it is difficult to judge the required level of cleanliness of LCO_2, which is primarily a waste to be sequestered underground, and not a product. As mentioned previously, the only published table of the types of impurity contained in LCO_2 transported by ship and their allowable concentrations is the list published by Northern Lights (medium temperature/medium pressure), and in many other projects, there is a tendency to study this issue based on that document. Moreover, the corrosion tests were performed by a certain European research group, and were experiments under a gas environment, and not in liquid LCO_2. Based on the reaction equation, it is thought that the corrosion tests of the steel materials were carried after corrosive substances were first formed by reactions involving water (H_2O) in impurity gases, making it difficult to refer directly to those results.

Therefore, in order to determine the type of impurities and allowable concentrations that should be listed, assuming the low temperature/low pressure conditions of the Japanese standard, it is necessary to prepare phase diagrams for CO_2 containing impurities based on convincing scientific grounds and computer simulations, carry out experiments actually using LCO_2 at –50°C, and provide evidence supporting economic rationality.

Even assuming the type of impurities and maximum allowable concentrations are determined and a list is prepared, in the first place, it will be necessary to investigate whether methods for continuous measurement of individual substances with precision at the ppm order are actually available, and whether it is necessary to measure and verify all of those substances, and at what points in the value chain and with what frequency, and also to determine the range of responsibility and implementation procedure. Here, it may be noted that in the Northern Lights project, the three types of impurities (O_2, H_2O and H_2S) were measured in-line, immediately before the LCO_2 was transferred into the receiving-side storage tanks.

(2) Determination of the safe maximum flow velocity in cargo-handling

Increasing the LCO_2 flow velocity has the advantages of increasing cargo-handling efficiency and making it possible to reduce the number of piping, but is also considered to increase the risk of abnormal vibration and dry-icing. There are already several examples of CFD (Computational Fluid Dynamics) simulations of the behavior in piping during ship cargo-handling, premised on pure LCO_2, and no technically significant problems have been reported. In the NEDO demonstration project described previously, construction of a high-flow velocity liquid transfer technology verification facility of liquefied CO_2 began at the Tomakomai terminal in July 2025, and high-flow velocity tests are also planned. However, since the behavior of LCO_2 (changes in pressure, etc.) containing impurities studied in (1) above still has not been adequately clarified, further research is needed, particularly to determine what kind of behavior occurs at higher flow velocities when non-condensable impurities exist in the LCO_2.

6. CONCLUSION

This paper has presented an overview and explanation of low temperature/low pressure ship transportation of LCO_2 based on "Guidelines for Setting Common Specifications in the LCO_2 Ship Transportation Value Chain," which was issued by JOGMEC in conjunction with its Advanced CCS Project. Long-distance, large-volume transportation by ships is an essential technology for social implementation of CCS businesses in Japan, and research on this technology is progressing steadily. Navigation and cargo-handling demonstrations tests of the low temperature/low pressure method are being carried out on a continuing basis, actually using pure LCO_2 at –50°C and a demonstration test ship for low temperature/low pressure transportation. As a result, considerable knowledge has been obtained, and the technical advantages of the low temperature/low pressure method have been verified. However, since it can be inferred that overseas competitors are rapidly catching up, it is considered that further research (particularly on the two issues discussed in Chapter 5.3 above) should also be promoted in the future, and a low temperature/low pressure transportation for LCO_2 should be established in Japan at the earliest possible timing.

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NEDO's Technology Development for Liquefied CO_2 Ship Transportation

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1. INTRODUCTION

To realize carbon neutrality by reducing emissions of greenhouse effect gases (GHG) to net zero, development of technologies for carbon recycling by capturing and reusing carbon dioxide (CO_2) as a resource and CCS (Carbon dioxide Capture and Storage) by capturing and storing CO_2 underground is currently in progress, as CO_2 represent the largest part of GHG. The "Strategy for the Promotion of Transition to the Decarbonized Growth-Oriented Economic Structure (GX Promotion Strategy)," approved by a Cabinet decision in July 2023, presented a policy of promoting social implementation of green transformation (GX) through decarbonization, premised on securing a stable energy supply, and development of the technologies necessary to achieve this goal [1]. For CCS, which enables direct sequestration of large quantities of CO_2, Japan intends to develop a business environment for private sector to start CCS businesses by 2030. In line with this, the Act on Carbon Dioxide Storage Business (CCS Business Act), which establishes the permitting system for storage projects, was enacted and promulgated in May 2024. Also, "Advanced CCS projects" are being promoted based on the CCS long-term roadmap [2), 3)].

In social implementation of CCS, it is important to construct a "CCS value chain" in which the CO_2 discharged as a result of industrial activities flows through a series of processes consisting of capture, transportation and storage. In Japan, CO_2 emitting areas and storage areas are frequently different, requiring technologies for concentrating CO_2 separated and recovered at multiple emission sources of different scales, and collectively transporting it to distant locations efficiently and economically. Therefore, in 2021, Japan's New Energy and Industrial Technology Development Organization (NEDO) launched the NEDO project "R&D and Demonstration Test of CO_2 Ship Transportation" as one means of transporting CO_2 recovered from CO_2 emission sources to storage or use sites safely and at low cost. In this project, a cargo tank system enabling transportation under liquefied CO_2 temperature and pressure conditions suitable for mass transportation is being developed, and technical study of an integrated marine transportation system for liquefaction, storage, loading/unloading and land transport of the liquefied CO_2 is being carried out. This paper presents an outline of the demonstration test ship "EXCOOL," which is equipped with a tank system capable of loading liquefied CO_2 with various temperature and pressure conditions, and a ship transportation demonstration test conducted in cooperation with land-based facilities located in Maizuru (Kyoto Prefecture) and Tomakomai (Hokkaido).

2. OVERVIEW OF THE PROJECT

2.1 Aims of Technology Development

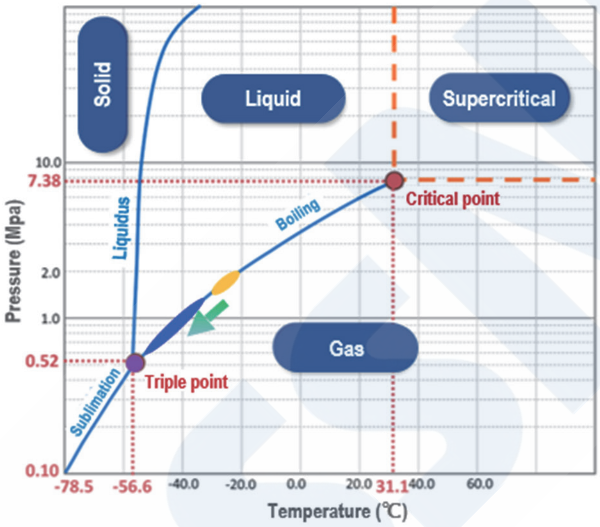
Liquefied CO_2 is used in a wide range of applications, including welding, beverages, cooling, steelmaking and chemicals, and others. Domestic demand in Japan is around 700 000 tons/year. Liquefied CO_2, which is produced by refining carbonic acid gas generated by petrochemical plants and steel works as the feedstock, is filled into tank lorries or high-pressure gas vessels in a condition of approximately –20 °C/2.0 MPa(abs), which is referred to as medium temperature/medium pressure, and then shipped to users by land transportation. However, since social implementation of CCS will require low-cost transportation of large quantities of liquefied CO_2 to storage locations in Japan and other countries, ship transportation is expected to play a key role in transportation of liquefied CO_2.

One effective means of large-scale ship transportation is transportation under a liquefied CO_2 condition of about –50 °C/0.7 MPa(abs), which is termed low temperature/low pressure. Since this pressure condition makes it possible to reduce the design pressure of the liquefied CO_2 tanks, large-volume and lightweight CO_2 tanks can be used. This means the cargo capacity per ship increases, and as a result, the required number of ships or voyages can be reduced, leading to a reduction in

* Circular Economy Department, New Energy and Industrial Technology Development Organization (NEDO)
** Hydrogen and Ammonia Department, New Energy and Industrial Technology Development Organization (NEDO)

the transportation cost per unit weight of CO_2.

On the other hand, formation of dry ice, that is, “dry-icing” from liquefied CO_2 is a risk. Fig. 1 shows the phase diagram of CO_2. In a liquefied CO_2 tank, the CO_2 exists in the two phases as liquid and gas, and the interface between these two phases is the temperature-pressure condition shown by the “boiling line,” which represents the boundary between the liquid and gas phase. If the temperature-pressure is decreased, the CO_2 will reach the “triple point,” where the solid, gas and liquid phases coexist in equilibrium, at –56.6 °C/0.52 MPa(abs). Below that point, existence as liquid CO_2 becomes impossible, and a phase transition to solid dry ice will occur. If dry-icing occurs in the tanks or piping, it becomes impossible to transport the CO_2, and depending on the case, equipment damage is also a concern. To avoid this problem, in achieving low temperature/low pressure ship transportation of liquefied CO_2, the development of liquefied CO_2 carriers equipped with tanks for loading liquefied CO_2 and an understanding of the behavior of the CO_2 when using land-based facilities for storage and loading under controlled temperature and pressure conditions are essential. Thus, in this project, it is also important to establish a liquefied CO_2 handling technology that ensures safe and efficient marine transportation through demonstration tests of liquefied CO_2 ship transportation through the series of processes consisting of liquefaction, storage, loading/unloading and transportation.



State	Temperature/pressure	Special notes
● Medium temperature /medium pressure	Approx −20 °C/2.0 Mpa	Current transportation and storage condition for liquefied CO_2.
● Low temperature /low pressure	−30 °C/1.5 Mpa to −50 °C/0.7 Mpa	Expected condition in large-volume transportation of CO_2. This condition is near the triple point of CO_2.
● CO_2 triple point	−56.6 °C/0.52 MPa	State where the 3 phases (gas, liquid and solid phases) coexist in equilibrium.

Fig. 1 Phase diagram of CO_2 and transportation conditions

2.2 Project Implementation Method

The key points for establishing a technology for marine transportation of liquefied CO_2 are “Development of cargo tanks for use in ship transportation of liquefied CO_2,” “Securing a stable condition of liquefied CO_2” and “Safety of ship operation and equipment operation.” As efforts to address these challenges, in June 2021, NEDO launched a project called “R&D and Demonstration Test of CO_2 Ship Transportation” with the aim of developing an integrated marine transportation system for shipping, transportation and receiving of CO_2 liquefied under the optimum temperature and pressure conditions. The organizations commissioned with this project and the implementation items are shown in Table 1. Together with study of the physical properties of liquefied CO_2 and stability in handling liquefied CO_2 in ship transportation, construction of a liquefied

CO_2 transportation demonstration test ship called "EXCOOL," which is equipped with a marine cargo tank system for loading liquefied CO_2 under various temperature/pressure conditions, was completed in November 2023 [4], and efforts related to crew training and liquefied CO_2 handling were begun. In November 2024, land-based equipment for adjusting the temperature/pressure conditions of liquefied CO_2 and unloading it onto the "EXCOOL" was also completed in Maizuru and Tomakomai.

An overview of the liquefied CO_2 ship transportation demonstration test integrating this series of facilities is shown in Fig. 2. The marine transportation tests will be conducted with liquefied CO_2 loaded on both the outbound and return routes to enable efficient study of various liquefaction conditions, ship transportation of liquefied CO_2 under actual environments, and cargo-handling technology in order to steadily accumulate know-how related to ship operation. The land bases at Maizuru and Tomakomai were equipped with loading arms, liquid pumping equipment and CO_2 storage tanks to allow both loading and unloading of the liquefied CO_2. In addition, to allow adjustment of the liquefied CO_2 conditions as required by the test items, liquefaction equipment was constructed to produce liquefied CO_2 under various temperature and pressure conditions at Maizuru base. The main navigation route in the liquefied CO_2 transportation test was a round-trip of approximately 1 100 miles (2 000 km) from the land station at Maizuru on the Sea of Japan through the Tsugaru Strait to Tomakomai in Hokkaido. However, ship transportation demonstration tests are also planned in all coastal regions of Japan, not limited to this route, but also including the offshore areas in the Pacific Ocean, Seto Inland Sea, East China Sea, etc.

Table 1 Project consignees and implementation items

Consignees	Items
Japan CCS Co., Ltd. (JCCS) Mitsui O.S.K. Lines, Ltd. Kanden Power-Tech Corporation Mitsubishi Heavy Industries, Ltd.	Technology development of CO_2 liquefaction system Technology development of large-volume liquefied CO_2 storage system Conceptual design of large-scale liquefied CO_2 carrier Construction of shipping terminals Planning/implementation of demonstration tests
Engineering Advancement Association of Japan (ENNA) Ochanomizu University Nippon Ekitan Corporation Nippon Gas Line Co., Ltd. (NGL) *1 Kawasaki Kisen Kaisha, Ltd.	Study of safety in marine transportation of CO_2 Study of specifications of liquefied gas dual purpose carrier Development of marine tank system Planning/implementation of demonstration test of ship transportation Safety management methods for ship operation and cargo-handling
Itochu Corporation	Survey of CO_2 emission sources and CO_2 transportation businesses Study of business model for CO_2 transportation
Nippon Steel Corporation *2	Study of business model for CO_2 transportation (Japanese steel industry)

*1: Reconsignment to ENAA until Nov. 2023, consignment from Nov. 2023
*2 Until Mar. 2024

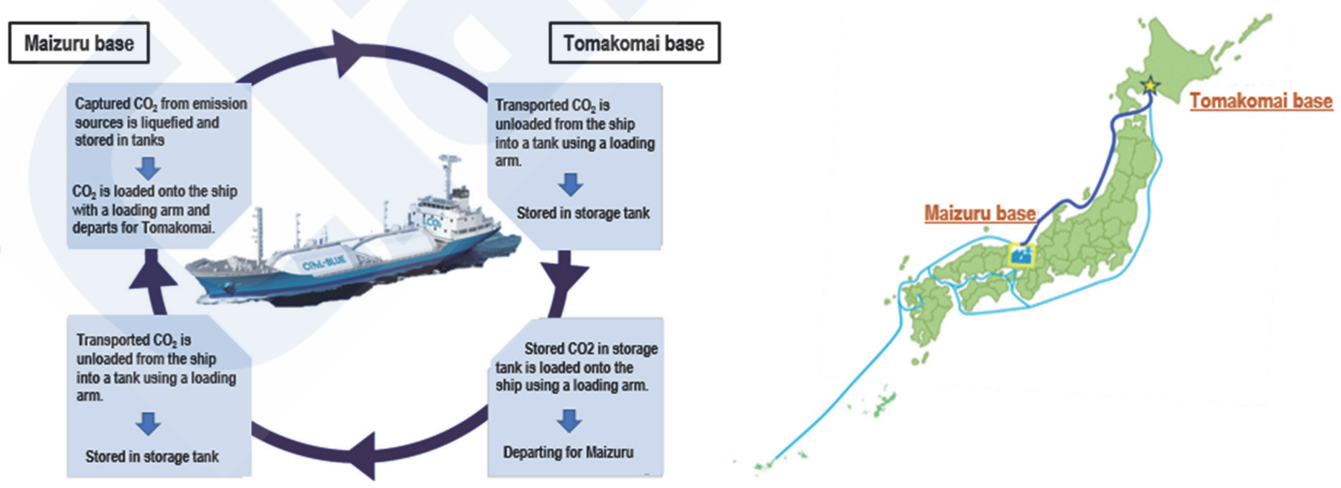


Fig. 2 Overview of liquefied CO_2 ship transportation test and main route

2.3 Liquefied CO_2 Transportation Demonstration Test Ship "EXCOOL"

The liquefied CO_2 transportation demonstration test ship "EXCOOL," which was constructed for this project, is a pressurized liquefied gas bulk carrier with a forecastle and poop. The external appearance and a schematic layout diagram of the ship are shown in Fig. 3, and its principal particulars are given in Table 2. The main hull is of single hull construction and has two cargo holds; one horizontal cylindrical cargo tank (volume: 725 m^3) is installed in each hold. As the propulsion system, a one engine/one shaft type with a variable pitch propeller was adopted, and the vessel has a side thruster at the bow for docking and undocking. The navigation area is coastal waters, and the specifications place few restrictions on changes in the demonstration test area in home waters (non-international) when necessary. As a distinctive feature, the vessel can carry not only liquefied CO_2 (maximum load: 850 tons) at temperature of –20 °C to –50 °C with different specific weights and temperature-pressure, but also propane, butane and other types of liquefied petroleum gas (LPG). It is particularly noteworthy that the “EXCOOL” is the first ship in the world that can carry low temperature/low pressure liquefied CO_2, which is the purpose of technology development in this project [5)].

The ship owners of this ship are NEDO and Sanyu Kisen, and the ship is operated under a bareboat charter by Nippon Gas Line Co., Ltd. (NGL), which provides the crew and performs ship management. In parallel with the operation of the ship, NGL is also responsible for reliable operational management in this project, which includes studying the demonstration test plan and formulating and executing operation plans from the perspective of a shipping line in order to establish safe and efficient cargo-handling plans and solve various problems in ship transportation of liquefied CO_2, such as management of the cargo during transportation.

Fig. 3　External appearance and schematic layout of EXCOOL

Table 2　Ship’s principal particulars

Length overall, breadth overall and draught	72 m, 12.5 m, 4.5 m
Gross tonnage, deadweight tonnage	997 tons, 1,261 tons
Classification society	Class NK
Cargo tank type and capacity	Independent Type-C, 1,450 m^3
Design temperature and pressure	-50℃～+45℃・1.9MPaG
Main loading equipment	Deep well pump, compressor
Other	Gas detectors Sensors and data acquisition equipment

3.　STATUS OF SHIP TRANSPORTATION TEST IMPLEMENTATION

3.1　Loading Tests under Different Liquefied CO_2 Conditions

Liquefied CO_2 transportation tests are being carried out with the “EXCOOL” while changing various ship transportation conditions in steps, including the liquefied CO_2 loading method, amount loaded, temperature, pressure, etc. Table 3 shows the main liquefied CO_2 loading conditions in the ship transportation tests conducted since the ship was completed.

The first loading of liquefied CO_2 on the “EXCOOL” was carried out from lorries used in transportation on land. In this

Truck-to-Ship test, the functional integrity of the cargo tanks and the operability of loading when used with liquefied CO_2 were confirmed, and the technical possibility of loading liquefied CO_2 on the ship, even without a large-scale liquefied CO_2 shipping/receiving terminal, was verified. Thus, provided the port facilities and functions required for liquefied CO_2 loading are arranged, it is considered possible to collect liquefied CO_2 recovered from multiple CO_2 emission sources by ships, and the port can be expected to play the role of a hub & cluster in the CO_2 network necessary for expansion of CCUS (carbon capture, utilization and storage).

In handling of liquefied CO_2, as in handling of other liquefied gases, the ship and land sides are connected not only by the liquid piping, but also by return piping that returns the gas phase to the liquefaction plant, in order to balance the pressure between the ship and land sides. Since dry-icing of the liquefied CO_2 was a concern, the loading quantity and temperature-pressure conditions in the loading tests using the loading arm from the land base were adjusted in steps. Low temperature/low pressure conditions were progressively applied to the liquefied CO_2 while confirming the integrity of the ship and land base, and in January 2025, liquefied CO_2 with the target conditions of –50 °C/–0.7 MPa(abs) (0.6 MPaG) was successfully transported from the Maizuru base to the Tomakomai base.

Temperature-pressure adjustment of the liquefied CO_2, large-volume loading in the cargo tanks, (upper limit of 750 tons due to port restrictions), additional loading (completive loading) and other operations were carried out. Coordinated tests involving the ship and land side facilities that realize the low temperature/low pressure condition in the liquefied CO_2 are also being conducted, in which the CO_2 gas (BOG: Boil Off Gas) which evaporates in the ship's cargo tanks is reliquefied by the land base.

During the liquefied CO_2 transportation voyages with liquefied CO_2 loaded under these various conditions, changes in the temperature, pressure, liquid level, etc. of the cargo were constantly monitored by measuring equipment installed on the ships. Ship motion values were also measured during the voyages transporting liquefied CO_2, considering the comparatively high specific weight of the cargo, and the results of those tests were then reflected in an operation manual for liquefied CO_2 ship transportation.

Table 3 Main conditions of liquefied CO_2 loading tests

	Test item	Loading method	Loading quantity (ton)	Temperature (°C)	Pressure (MPaG)
July 2024	First loading / Truck-to-Ship	Truck-to-Ship	85.3	-35.3	1.11
November 2024	Loading from land base	Maizuru base L/A	424.4	-46.4	0.68
January 2025	Loading in –50 °C region	Maizuru base L/A	422.9	-49.3	0.60
April 2025	Loading in –35 °C region	Tomakomai base L/A	446.7	-36.0	1.04
June 2025	Large-volume loading	Tomakomai base L/A	750.0	-41.1	0.88
June 2025	Completive loading to cargo tank	Maizuru base L/A	743.2	-45.6	0.73
July 2025	Coordinated operation with land-side liquefaction facility	Maizuru base L/A	496.8	-47.8	0.64

L/A: Loading arm Quantity, temperature and pressure values are after loading

3.2 Liquefied CO_2 / LPG Dual Purpose Carrier

Since the structure, specifications and composition of the auxiliary equipment of the liquefied CO_2 cargo tank is similar to those of tank used in LPG transportation, the tanks incorporated in the "EXCOOL" were designed and constructed to "dual purpose carrier" specifications, making it possible to transport both liquefied CO_2 and LPG. In this project, liquefied CO_2 and LPG transshipment tests were conducted to clarify the operability of the ship as a liquefied CO_2/LPG combined carrier. Fig. 4 shows the condition of the connection of the loading arm during LPG loading.

In the transshipment test, after first completely offloading the liquefied CO_2 and performing gas replacement with air and N_2, LPG gas replacement, loading, sailing in the loaded condition and offloading were performed. The operation necessary to return again to liquefied CO_2 loading was then carried out through N_2 gas replacement. The quantity of LPG loaded on the ship was approximately 660 tons, which was the full load of the cargo tanks, and a transportation voyage test was made, although only for a short time and distance. No change was observed in the concentration of LPG offloaded from the cargo tanks after docking, and there were no problems with the subsequent gas replacement to CO_2. This test verified the operability of the "EXCOOL" as a liquefied CO_2/LPG dual purpose carrier. Based on these results, ship operation with liquefied CO_2 loaded on the outbound route and LPG loaded on the return route becomes clear, and an overall reduction in ship transportation costs can be expected.

As technical issues related to operation as a liquefied CO_2/LPG dual purpose carrier, time and costs are required for adjustment and monitoring of the flowrate, temperature, pressure and concentration in the gas replacement operation, and operation by workers who possess expertise at the work site is also necessary. Other issues include loss of CO_2 and LPG as a result of gas replacement. Therefore, one aim of this project is to improve the efficiency of the liquefied CO_2/LPG transshipment method. Study of the integrity of the cargo tanks and auxiliary equipment in operation as a liquefied CO_2/LPG dual purpose carrier and the balance of the hull during transportation of LPG are also planned.

Fig. 4　Loading arm connection during LPG loading (sign indicates loading of flammable hazardous material)

3.3　Changes in State of Liquefied CO_2 during Voyage

Although the cargo tanks used in the liquefied CO_2 carrier have a heat-insulated structure, some of the CO_2 evaporates due to the effects of thermal conduction from the outside air and seawater and hull oscillation. Since the “EXCOOL” is a small-scale demonstration test ship, it is not equipped with reliquefying system, but so long as the tank pressure does not exceed the design pressure (1.9 MPaG) of the cargo tanks, transportation of CO_2 in the gas phase is possible by pressure accumulation, without releasing BOG.

Fig. 5 shows an example of the results of measurements of the pressure rise in the cargo tanks and the temperature rise of the liquefied CO_2 during transportation. In this transportation test, the ship sailed a round-trip route of approximately 1 900 miles (3 500 km) from Maizuru Port in Kyoto Prefecture to Hirara Port on Miyakojima Island in Okinawa Prefecture in July 2025, assuming long-distance transportation under severe weather conditions. Although the ship docked at Hirara Port for about 50 hours, cargo-handling of the liquefied CO_2 was not performed, and BOG was not vented including the voyage. Therefore, there was no change in the cargo weight (496 tons), and the transportation test was carried out with no change in the full amount of CO_2 stored in the cargo tanks.

At the start of the outbound route from Maizuru Port, the temperature and pressure of the liquefied CO_2 were –47.8 °C and 0.64 MPaG, respectively, and the temperature and pressure upon docking at Hirara Port after approximately 90 hours, including offshore anchorage, were –44.9 °C and 0.74 MPaG. Thus, the rates of increase of the temperature and pressure were 0.032 °C/h and 0.0011 MPaG/h. On the other hand, the temperature and pressure on departure from Hirara Port on the return route were –43.5 °C and 0.79 MPaG, and the temperature and pressure on arrival at Maizuru Port after a voyage of approximately 73 hours were –41.1 °C and 0.86 MPaG, showing rates of increase of 0.033 °C/h and 0.0010 MPaG/h, respectively. Since these changes were within the assumed ranges of the insulation design of the cargo tanks, and were also similar to the rates of increase of the temperature and pressure (0.028 °C/h and 0.0010 MPaG/h) while moored for approximately 50 hours at Hirara Port, it can be inferred that the influence of ship motion while sailing on the evaporation of the liquefied CO_2 (i.e., increase in BOG) is minimal.

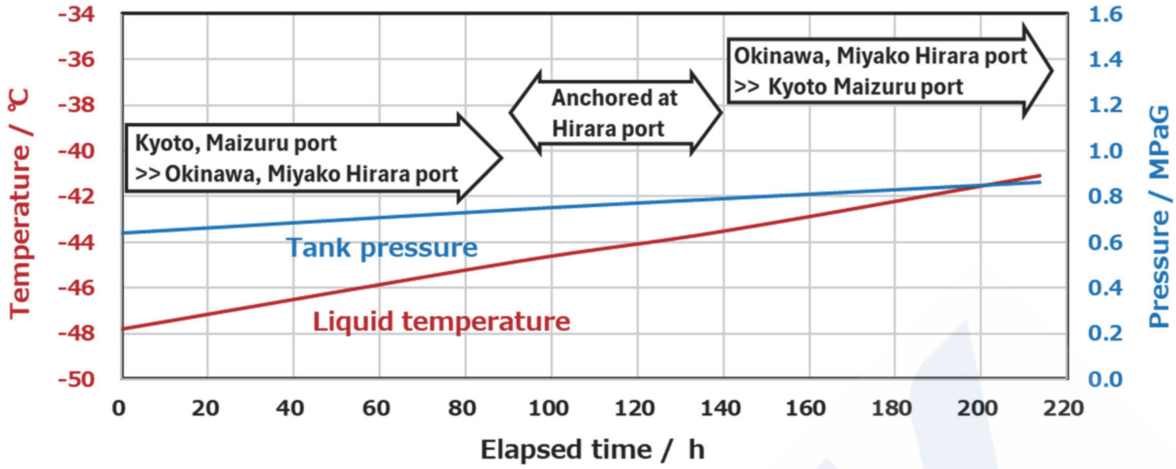


Fig. 5 Change over time in temperature and pressure of cargo tanks during transportation of liquefied CO_2

4. FUTURE PLANS FOR DEMONSTRATION TESTS

In this project, there are plans to obtain knowledge concerning the handling of liquefied CO_2 and acquire data leading to the development of ship transportation technology for liquefied CO_2 by conducting demonstration tests with linkage between ship and land-based facilities. In the cargo tanks of the "EXCOOL," multiple thermometers have been installed at different heights, considering the temperature gradient due to the liquid level, and surface thermometers are provided to measure the temperature of the tank surface and saddle parts. Many thermometers and pressure gauges have also been installed in the cargo-handling piping before/after points where pressure loss is assumed to occur, allowing measurements of the flow rate, load condition of the cargo pumps, and vibration and distortion of the piping during cargo-handling. Instruments for measurement of acceleration and angular velocity are also arranged near the center of the ship's center of gravity. Collecting, analyzing and evaluating ship data assuming various types of ship motion by using these instruments will contribute to the development and demonstration of technologies for safe, efficient, low-cost ship transportation of liquefied CO_2.

In social implementation of CCS, large amounts of liquefied CO_2 will be transported in one shipment by large ship sizes. For efficient, economical cargo-handling work in the loading and unloading processes, the liquefied CO_2 must be handled at a high flow rate, by adopting large-diameter cargo-handling piping and a high liquefied CO_2 flow velocity. In particular, increasing the liquefied CO_2 flow velocity has the potential not only to shorten the cargo-handling time, but also to reduce equipment requirements, for example, by reducing the number of manifolds and loading arms, which is expected to reduce the total cost of ship transportation of liquefied CO_2. Therefore, as part of the study of operability in liquefied CO_2 transportation, plans call for demonstrations of high-speed pumping of liquefied CO_2, in the targeted low temperature/low pressure condition, both onboard the ship and at land bases. High flow velocity (4 m/s) liquid transfer tests using the two cargo tanks installed on the "EXCOOL" and the piping and cargo pumps connecting them has already begun [6]. In conjunction with this, equipment for evaluating high flow velocity liquid transfer of liquefied CO_2 is being installed at the Tomakomai base [7], and safe, sure enhancement of technologies for cargo-handling between ships and land is planned.

5. CONCLUSION

Since CCS can realize decarbonization, even in fields where CO_2 discharges are unavoidable, by electrification and conversion to non-fossil energy such as hydrogen, etc., it has become an essential technology for simultaneously achieving a stable supply of energy, economic growth and decarbonization. In social implementation of CCS, when efficient, low-cost collection of CO_2 from multiple sources is demanded, ship transportation of liquefied CO_2 is a technology that can play a significant role. Global warming and the reduction of GHG emissions have received international attention, but when they are perceived not as "problems," but as "opportunities for achieving future technological innovation," it will be important to promote effective efforts for realizing carbon neutrality as innovation based on a broad technological and social perspective.

The NEDO project "R&D and Demonstration Test of CO_2 Ship Transportation" is being carried out safely and steadily, taking full advantage of the high technological capabilities of the project participants based on their extensive knowledge and experience, with the understanding and cooperation of the related government agencies, local governments, ships and ports, and all local stakeholders. We look forward to future efforts in the field of CCS utilizing the technological results of this project and the liquefied CO_2 carrier.

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CO_2 Capture Technology of Mitsubishi Heavy Industries

— Results to Date and Application to Onboard Systems for Ships —

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1. INTRODUCTION

In July 2023, the International Maritime Organisation (IMO) extensively revised its GHG Strategy and set the target for 2050 at net zero, strengthened from the previous target of 50% [1]. Shipping is a so-called “hard to abate” sector, i.e., decarbonization is more difficult in the shipping sector than in other sectors. However, GHG emissions from shipping account for about 3% of total GHG emissions and are therefore not negligible. Mitsubishi Heavy Industries, Ltd. (MHI) began the development of technology for CO_2 capture from combustion flue gas with Kansai Electric Power Co., Inc. in 1990, and delivered the first commercial plant to a Malaysian fertilizer company in 1999. As of August 2025, a total of 18 commercial CO_2 capture plants are currently in service around the world. MHI’s CO_2 capture plant is applicable to various types of combustion flue gases, including heavy oil, coal, and natural gas, and the recovered CO_2 is used in a variety of applications, such as enhancement of fertilizer and methanol production, general uses such as dry ice, and EOR (Enhanced Oil Recovery) to increase oil production. Most notably, MHI delivered the world’s largest CO_2 capture plant (4776 metric tonnes per day) for a coal-fired power plant to Petra Nova Parish Holdings LLC, U.S. at the end of December 2016. MHI continues to promote research and development of CO_2 capture technologies with the aims of improving reliability, reducing the cost of future CO_2 capture plants, and increasing the application of its technology.

2. MHI’S R&D AND COMMERCIAL EXPERIENCE

MHI’s CO_2 capture technology was commercialized as the KM CDR Process and uses a proprietary solvent, KS-1™ [2]. This process can capture more than 90% of the CO_2 from a flue gas stream and produce CO_2 with a purity of more than 99.9%. Steam consumption is also lower than that of other conventional technologies. Fig. 1 shows the schematic flow of the KM CDR Process and the process description.

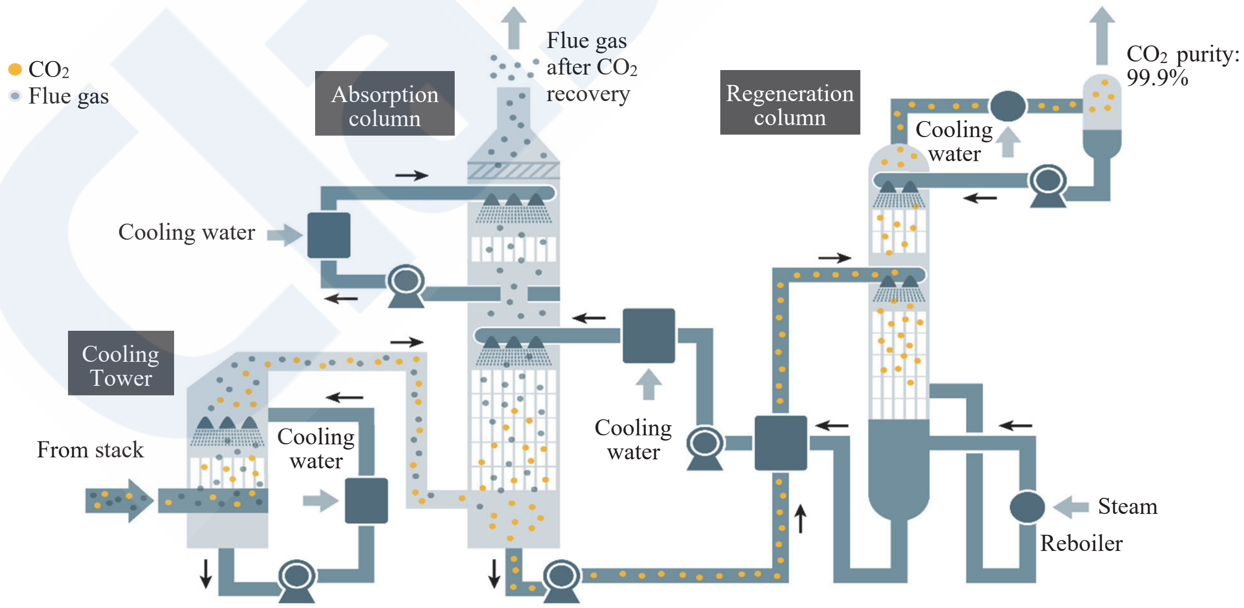

Fig. 1 MHI’s CO_2 capture process (KM CDR Process™)

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Flue gas containing CO_2 is introduced into the flue gas quencher, where it is cooled, and is then pressurized by a blower installed downstream of the quencher, and delivered to the CO_2 absorber filled with packing. The flue gas enters the bottom section of the absorber and reacts with the alkaline absorption solvent on the packing surface. The solvent absorbs the CO_2 from the flue gas, and the remaining flue gas is discharged into the atmosphere. The solvent, now rich in CO_2, is transferred to the regenerator, where the CO_2 is separated from it by steam stripping, resulting in regeneration of the solvent (ready for re-use). Use of MHI's latest energy-saving regeneration process can considerably reduce the amount of steam required in this process, reducing operational expenditure (OPEX).

In 2016, MHI successfully delivered a highly-reliable CO_2 capture plant (capacity: 4776 tpd) for the Petra Nova Project. The Petra Nova Project is jointly owned by NRG Energy Inc., a U.S. Independent Power Producer, and JX Nippon Oil & Gas Exploration Corporation. The plant started commercial operation at the end of December 2016. Table 1 details the plant specifications, and Fig. 2 is a photo of the completed plant. The CO_2 captured from a 240MW equivalent slipstream of flue gas is compressed by the CO_2 compressor, transferred through a 130km pipeline, and injected into an oil field. As a result of these efforts, oil production at the oil field was expected to increase significantly from about 300 barrels per day when CO_2 injection began. As of October 2017, oil field production had increased to roughly 4000 barrels per day [3].

Table 1　Overview of plant for EOR project in Texas (USA)

Item	Content
Plant location	Thompsons (Texas, USA)
Gas source	NRG WA Parish power plant 610 MW coal-fired thermal power plant
Process	KM CDR Process™
Solvent (absorbent solution)	Amine-based solvent KS-1™
Plant scale	240 MW equivalent
CO_2 capture rate	90%
CO_2 capture amount	4776 t/d

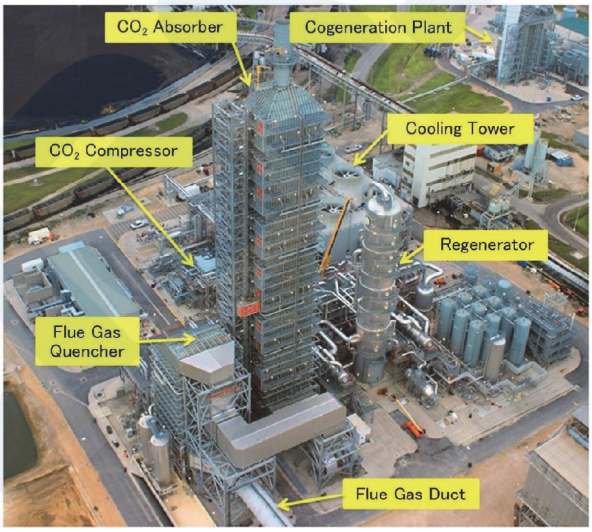

Fig. 2　Appearance of CO_2 capture plant for EOR project in Texas (USA)

Fig. 3 shows the facility configuration of this CO_2 capture plant and other related facilities. The CO_2 capture plant is located downstream of existing air quality control systems (AQCS) to limit impurities in the flue gas. The electricity and steam required for the CO_2 capture plant are supplied from a cogeneration unit consisting of a gas combustion turbine connected to an electrical generator and a heat recovery steam generator. As a result, CO_2 can be recovered without decreasing the existing power generation output from the host unit or affecting how its power is dispatched to the power market. The compression process employs the world's largest eight-stage integrally-geared CO_2 compressor, which was supplied by Mitsubishi Heavy Industries Compressor Corporation. A dehydrator is installed in the CO_2 compression process to meet the moisture specifications of the

CO_2 pipeline.

At a coal-fired power plant, the operational load is adjusted according to daily electric power demand. Boiler operation changes constantly, and with it, flue gas conditions such as the flow rate and CO_2 concentration also change. MHI developed an automatic load adjustment control system for the CO_2 capture plant to maintain optimized operation following the dynamic flue gas condition of the host coal-fired plant. Use of this control system allows operation of the CO_2 plant without constant attention by the CO_2 capture plant operator [4].

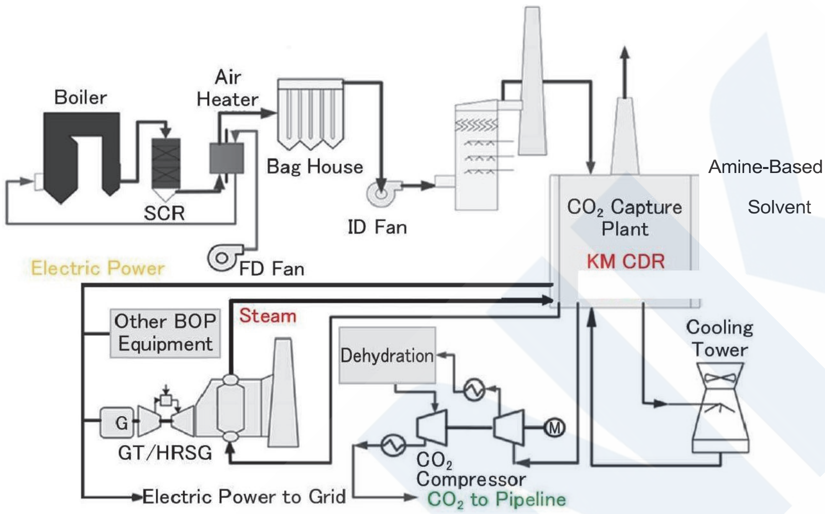

Fig. 3 System configuration of CO_2 capture plant for EOR project in Texas (USA)

3. FEATURES OF SMALL-SCALE CO_2 CAPTURE SYSTEMS

MHI has delivered a proprietary CO_2 capture process, the KM CDR Process™, to coal-fired power plants and chemical plants. The scale of the plants delivered so far is approximately 500t-CO_2/day or larger. Based on this technology, MHI is now developing small-scale CO_2 capture systems to realize concurrent CO_2 reductions while also responding to the reduction needs of small-scale CO_2 emission sources.

Although the basic process of the small-scale CO_2 capture system under development is the same as that of large-scale plants, the following features are required in a small-scale system:

(1) Applicable to many emission sources
(2) Installable in a limited area
(3) Operable without full-time operators

In order to respond to various inquiries, we adopted a standard design for small-scale systems, and not a design tailored to each customer's specifications, like the designs used in conventional large-scale plants. A system with a compact design was realized by modularization to enable installation in a smaller area. Modularization has the advantages of reducing field works and allowing an early start of system operation, and also eliminates the need for storage sites for construction materials, etc. The small-scale system is equipped with an automatic operating and remote monitoring system, allowing operation without a full-time operator.

In addition to MHI's conventional customers, such as thermal power plants and chemical plants, these systems are expected to be applied in various industrial sectors such as biomass power plants, cement factories, steel mills, gas engines, waste incineration facilities, etc. (Fig. 4), where efforts to reduce CO_2 are expected to accelerate in the future [5].

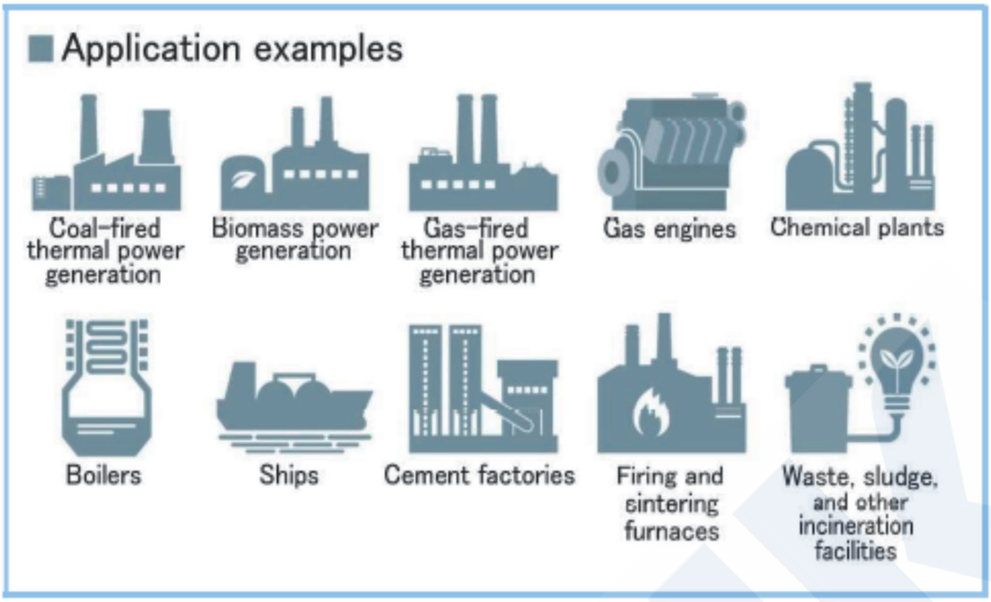

Fig. 4　Examples of applications of small-scale CO_2 capture plants

4.　DEVELOPMENT OF ONBOARD CO_2 CAPTURE SYSTEMS FOR SHIPS

MHI is also developing onboard CO_2 capture systems to reduce CO_2 emissions from ships. This chapter introduces our latest initiative in this area, the onboard CO_2 capture system demonstration project CC-Ocean (Carbon Capture on the Ocean)[*1], which was carried out jointly with Kawasaki Kisen Kaisha, Ltd. and Nippon Kaiji Kyokai [6)].

To verify the CO_2 capture technology under offshore conditions and formulate the requirements for onboard use, in this project, a demonstration test of a small-scale CO_2 capture demonstration plant (hereinafter, demo-plant) was conducted under commercial operating conditions by installing the demo-plant on the coal carrier “CORONA UTILITY” operated by Kawasaki Kisen, Ltd. This demonstration under actual commercial conditions was a “world’s first.” The project was conducted over a two-year period. A HAZID evaluation of the demo-plant and a safety evaluation of the equipment and system were conducted by Nippon Kaiji Kyokai (ClassNK), after which the demonstration plant was fabricated, installed on the coal carrier, and operated in an offshore environment for approximately six months to measure and check its performance. The CO_2 capture system of the demo-plant installed on the coal carrier was originally a unit for exhaust gas treatment employing the chemical absorption method at an onshore plant, and was converted for onboard installation (Fig. 5).

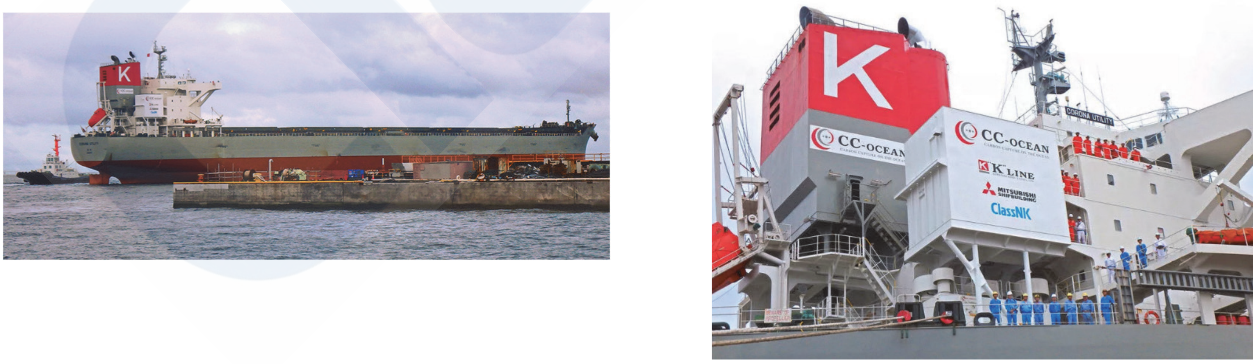

Fig. 5　Test ship “CORONA UTILITY” and demo-plant (white container)

In this project, the performance of the demo-plant exceeded the planned values for the CO_2 capture amount, CO_2 capture rate, and captured CO_2 purity, and the equipment could be operated and maintained by the crew of the coal carrier without any problems. The effects of engine load fluctuations and ship motion on CO_2 capture performance and the effects of the ship’s exhaust gas on the CO_2 absorbent were also verified. In addition, guidelines for safety measures associated with ship operation, including measures against leakage of the CO_2 absorbent, ventilation concepts for equipment installation areas, etc., were established as requirements for operating CO_2 capture systems in an offshore environment.

Based on the knowledge obtained and the technical issues discovered as a result of this demonstration, in the future, we will promote efforts toward commercialization of the onboard CO_2 capture system by establishing the concept of a total system, including onboard CO_2 liquefaction and storage, and optimizing the system as an offshore system, considering unloading the onboard CO_2 to land.

5. CONCLUSION

The IMO has extensively revised its GHG Strategy and set the target for 2050 at net-zero carbon emissions, which was strengthened from the previous target of 50%. Mitsubishi Heavy Industries, Ltd. (MHI) recognizes that reduction of GHG emissions is a major issue, and promotes the development of technologies for this purpose not only by the company itself, but also in cooperation with others companies in the Mitsubishi Heavy Industry Group and external organizations. We will continue developing MHI technologies to contribute to the transition to net-zero emissions in international shipping.

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Prospects for Offshore Wind Power and ClassNK's Initiatives for the Safety of Related Work Vessels

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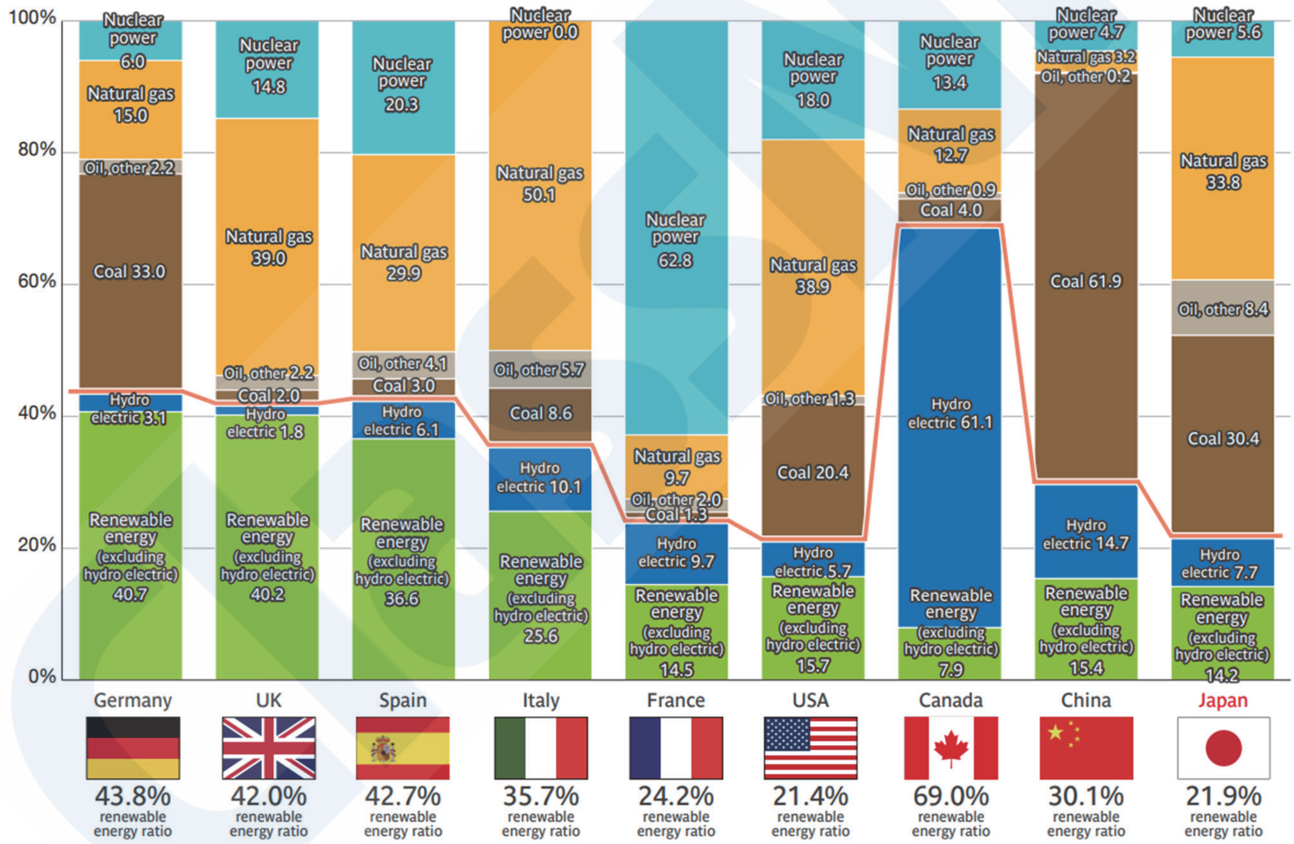
1. PROSPECTS FOR OFFSHORE WIND POWER GENERATION IN JAPAN

At present, the world depends on fossil fuels for more than 80 % of its energy supply, but considering the increasing frequency of abnormal torrential rains and other severe weather events, which appear to be traceable to global warming in recent years, a transition to renewable energy in order to reduce emissions of greenhouse effect gases (GHG) has become an urgent issue in both the advanced nations and other countries.

In the several European nations, the share of power generation by renewable energy (except hydropower) in the electric power generation mix has already reached around 40 % (see Fig. 1). Wind power generation is the most widely disseminated form of renewable energy in the European nations and the United States. The share of wind power in total generated output now exceeds 20 % in the United Kingdom, Germany and elsewhere.



Source: Created by the Agency for Natural Resources and Energy based on the IEA "Market Report Series—Renewables 2023" (Power Generation in Each Country as of 2022), IEA database, and the Comprehensive Energy Statistics of Japan (FY2022 confirmed figures).

Fig. 1 Comparison of power generation mix by country (2022)

In contrast to those European countries, in Japan, the share of power generation (preliminary figures) using renewables (except conventional hydropower) in 2023 fiscal year was 15.3 % of total generated output. The shares for solar power, wind power, biomass, etc., which are generally called "new energy," were limited to 9.8 % for photovoltaic (PV) power, 4.1 % for biomass and 1.1 % for wind power.

In view of this situation, in February 2025, the Seventh Basic Energy Plan formulated by the Cabinet announced a policy of increasing the share of renewables, including conventional hydropower, to approximately 40 % to 50 % in FY 2040, and also proposed raising the share of wind power to 4 % ~ 8 % (see Table 1). For solar power, which had been in the vanguard in the diffusion of renewable energy in Japan until now, the introduction of new generating methods such as perovskite solar cell is expected to result in increased generating capacity, but together with this, high expectations are also placed on offshore wind power.

Table 1 Outlook for introduction of renewable energy based on Japan's Seventh Basic Energy Plan

		FY 2023 (preliminary report)	FY 2040 (outlook)
Energy self-sufficiency		**15.2 %**	**Approx. 30-40 %**
Generated output		**985.4 billion kWh**	**1.1 to 1.2 trillion kWh**
Power generation mix	**Renewables**	**22.9 %**	**Approx. 40-50 %**
	Solar (PV) power	9.8 %	Approx. 23-29 %
	Wind power	1.1 %	Approx. 4-8 %
	Hydropower	7.6 %	Approx. 8-10 %
	Geothermal power	0.3 %	Approx. 1-2 %
	Biomass	4.1 %	Approx. 5-6 %
	Nuclear power	**8.5 %**	**Approx. 2 %**
	Thermal power	**68.6 %**	**Approx. 30-40 %**
Final energy consumption		**300 million kL**	**Approx. 260 to 270 million kL**
GHG reduction rate (compared to FY 2013)		**22.9 %** ***Actual results in FY 2022**	**73 %**

Source: Outline of the Seventh Strategic Energy Plan (SEP), p. 9
https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/7th_outline.pdf

Full-scale wind power development in Japan started from port and harbour areas where the relationship with fishing rights was already well-organized, but at present, the center of development activities is continuing to shift to general public waters. By type of foundation, offshore wind turbines are classified as the fixed type or floating type. Most existing offshore wind turbines in Japan are the bottom fixed type, in which the structure supporting the wind turbine is fixed directly to the sea bed. However, in comparison with the waters of northern Europe, where the wind power field is particularly advanced, the water depth of Japan's coastal waters quickly becomes deeper in offshore areas. Since the waters where the fixed type can be installed are limited, 2030s and beyond, high expectations are placed on development of the floating type, in which the wind turbine is mounted on a floating structure and moored to the sea bed with anchor chains, etc (see Fig. 2).

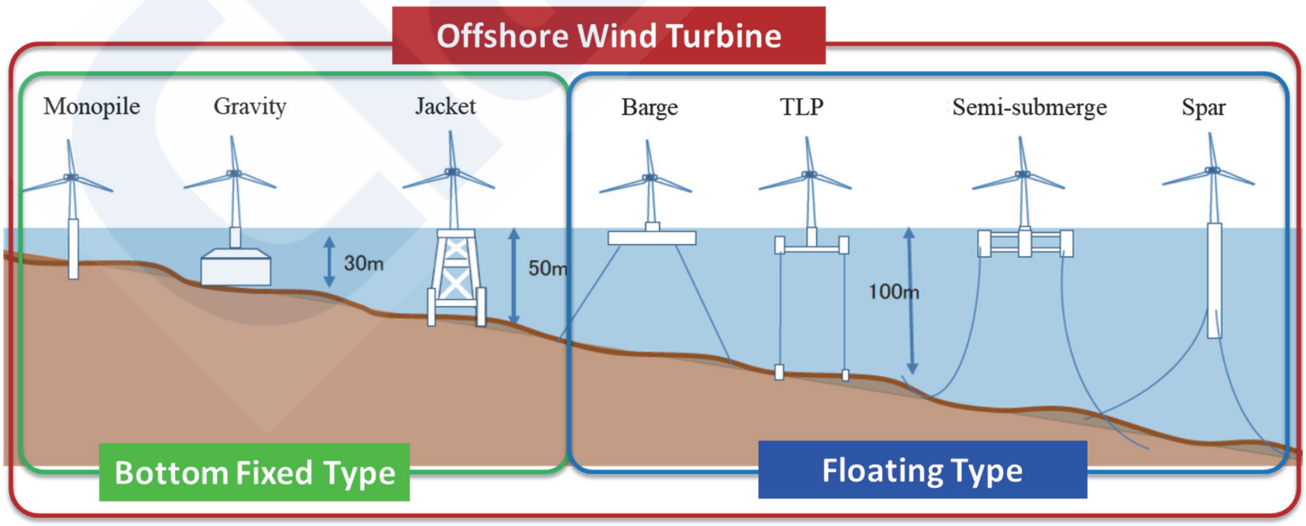


Fig. 2 Offshore wind turbine installation methods

It may be noted that Japan's Exclusive Economic Zone (EEZ), within which Japan has the right to develop wind power, etc., is the world's 6th largest, covering approximately 4.5 million km^2, which is equivalent to more than 11 times Japan's land area, and contains vast potential wind power energy (see Fig. 3). Since the development of this kind of domestically-produced energy is also critical from the viewpoint of Japan's national energy security, a revision of the Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities to make it possible to install offshore wind power generation facilities in Japan's Exclusive Economic Zone was approved by the Japanese Diet on June 3, 2025.

In August of 2025, the "Vision for Offshore Wind Power Industry (2nd) (Public-Private Council on Enhancement of Industrial Competitiveness for Offshore Wind Power Generation)," which was formulated under the leadership of the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), set various targets, including the drafting of proposals for offshore wind power projects with a capacity of 30 to 45 GW by 2040, with at least 15 GW to be the floating type, and the drafting of proposals for large-scale floating-type offshore wind power aiming by FY 2029 to meet this goal.

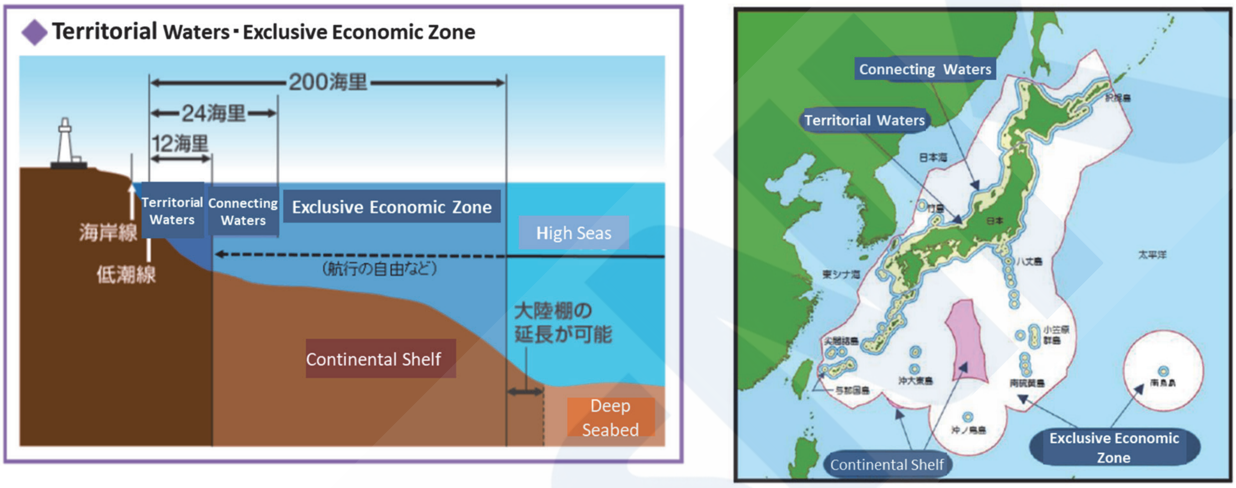


Fig. 3 Japan's Exclusive Economic Zone (EEW)

On the other hand, installation work for offshore wind farms consists of various stages, including transportation of the wind turbine components and supporting structure, trial assembly at the base port, foundation installation work, cable-laying work, installation of the wind turbine, etc. Various types of work vessels are also required in this work, according to the type of work. Figs 4 and 5 show the main construction processes for an offshore wind farm and the types and applications of the vessels.

Fig. 4 Offshore wind farm construction processes

Ship Category	Purpose of Use
SEP (Self Elevating Platform)	Self-Elevating work Platforms used for offshore installation of foundation components and wind turbine parts for offshore wind turbines. 
CTV (Crew Transfer Vessel)	Boats transporting workers and materials to offshore wind turbines  
SOV (Service Operation Vessel)	Offshore support vessels with multiple accommodation facilities that can operate offshore for a certain period of time, allowing maintenance technicians to be dispatched to multiple offshore wind turbines 
CLV (Cable Laying Vessel)	Work vessels that lay and bury power cables between wind turbines in offshore wind farms, connecting them to offshore substations and land 
AHTSV (Anchor Handling Tug Supply Vessel)	Multipurpose vessels used for towing and installing floating offshore wind turbines, laying mooring facilities, and transporting materials 

(Source of photos) Following companies' Web site
SEP : SHIMIZU Corporation, CTV : NYK、Tokyo Kisen, SOV : MOL, CLV : TOYO Construction, AHTSV : KLINE Offshore

Fig. 5　Types and applications of work vessels

2.　HEIGHTENED NECESSITY OF SAFETY MEASURES FOR WORK SHIPS

As described in the previous chapter, construction of offshore wind power facilities based on Japan's energy policy is becoming in full swing, and in the actual construction, it is necessary to use a large number of work vessels and handle heavy and long objects at sea over long periods of time. Moreover, expansion of construction work to the waters of Japan's Exclusive Economic Zone and an increase in work in deeper waters are also foreseen in the future. Considering the fact that serious accidents and incidents have already been seen occasionally in work related to offshore wind power development up until now, it is thought that safety measures for work vessels will become even more important than in the past.

Non-Japanese developers and constructor with track records in Europe are also involved in offshore wind power development in Japan. There have been calls in those companies for the introduction of international safety management methods based on the experience of the oil and gas industry, requests for clarification of international safety standards and the safety standards of the companies themselves, and assessment of the safety levels of the work vessels to be used in Japan. In response, there is a view among owners and operators of work vessels in Japan that safety management is basically the responsibility of the contractor side, and some have expressed confusion about assessments by unfamiliar international safety management methods (see Fig. 6).

Japanese Companies	Foreign Companies
■ There have been no major accidents so far, and safety management is a matter for the construction team. We want to avoid any unnecessary hassle if possible.	■ The client is also responsible for safety management. ■ I'm unfamiliar with Japanese ship-related laws and regulations. (Non-self-propelled vessels are not subject to inspections and are not required to have crew on board, for example.)
■ We are not familiar with the items required by international management methods. ■ We have never undergone an overseas inspection before, so we are worried. There is also the language barrier. ■ Overseas companies have high demands, and we are struggling to keep up.	■ It's difficult to evaluate the safety and soundness of Japanese work vessels (including barges). ■ I'd like to confirm differences between international standards and my own company's standards.

Fig. 6　Comparison of the thinking of Japanese and overseas companies on safety management Japanese companies

Since the first mission of the Society is to contribute to improving the safety of ships, we understand the intentions of the overseas companies. However, on the other hand, we also think it is necessary not only to contribute to improving the safety management of Japanese work vessels but also to enable smooth chartering of vessels in domestic offshore wind power construction by bridging the gap between the thinking of the two sides, while also taking into consideration the views of the owners and operators of work vessels on the Japanese side.

In the case of ships registered by a ship classification society ("classified ships"), the integrity of the hull, engine and shipboard equipment are verified by classification surveys. For ship subject to the ISM Code, the Society also examines the ship's operational management system. Nevertheless, among work vessels engaged in coastal operation, the actual situation is that some have not acquired ISM certification, even though they are registered with the Society, and furthermore there are many vessels, such as non-self-propelled crane vessels and other towed vessels, those not covered by the scope of regulatory ship survey requirements.

In light of this reality, the Society has been providing a new business service called "Marine Assurance Service" since 2024. Unlike conventional ship surveys, which mainly concern the overall construction of the hull, etc. and the ship's equipment, this service is intended to verify the experience and qualifications of ship crews and assess the usage of safety management and operation of the onboard equipment, focusing on work procedures and work judgment criteria, from the viewpoint of the charterers of the vessel, before the chartering agreement for each project. The next chapter presents an overview of this new service.

3. ClassNK MARINE ASSURANCE SERVICE

3.1 Overview

The Society's Marine Assurance Service consists of two types of services, General Ship Inspection and DP Operation Assessment, as described below.

① General Ship Inspection

[Purpose]

To support the judgments of charterers by performing third-party assessments of the safety management/operational condition of work vessels to ensure compliance with predetermined standards.

[Content of work]

Premised on the condition that the vessel will be engaged in the specified work, the Society assesses the experience and history of the ship crews and the management/operation of work manuals and onboard equipment from the viewpoint of the charterer (reliable implementation of work, existence of potential accident risks). This work is classified in three types, based on differences in the standards used.

1) International Marine Contractors Association(IMCA) eCMID inspection

2) Assessment of conformity with the clients' internal standards

3) Independent assessment by the Society based on international standards, etc.

The IMCA eCMID (electronic Common Marine Inspection Document) inspection system is an inspection system for ship safety management systems which is operated by the IMCA, an international body with approximately 700 member companies including constructors in the petroleum/gas and renewable energy sectors, business development companies, educational institutions, ship classification societies and others. eCMID inspections are conducted in accordance with the flow in Fig. 7.

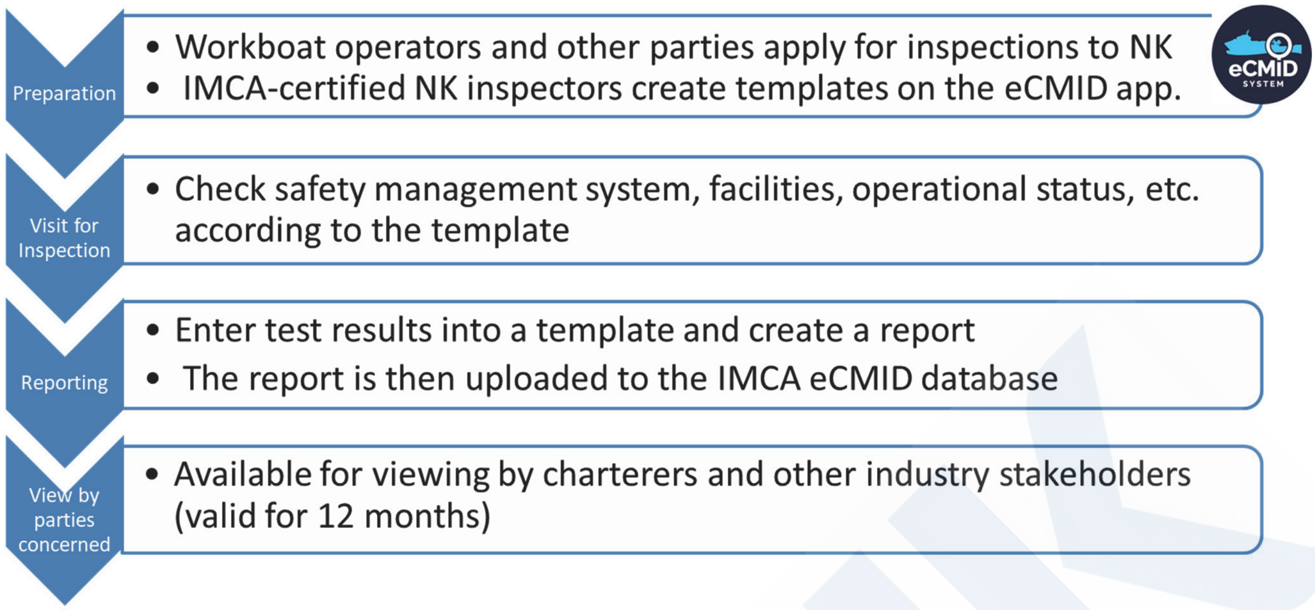


Fig. 7 Flow of IMCA eCMID inspections

IMCA eCMID inspections can only be performed by certified inspectors whose work experience, etc. have been examined by the IMCA. At present, the Society has two inspectors who have receiving certification by the IMCA, and can respond to inspection requests with using both Japanese and English.

Upon receiving an application for inspection from a work vessel operator, etc., a certified inspector inputs the information on the ship type, etc. of the work vessel concerned and creates a template. Based on this template, the inspector then arranges the schedule with the applicant, visits the site and checks the safety management system and equipment of the ship, and prepares a report. The report is uploaded to the IMCA eCMID database and can be viewed by related parties. The period of validity is 12 months. The items examined in the IMCA eCMID inspection are as shown in Fig. 8.

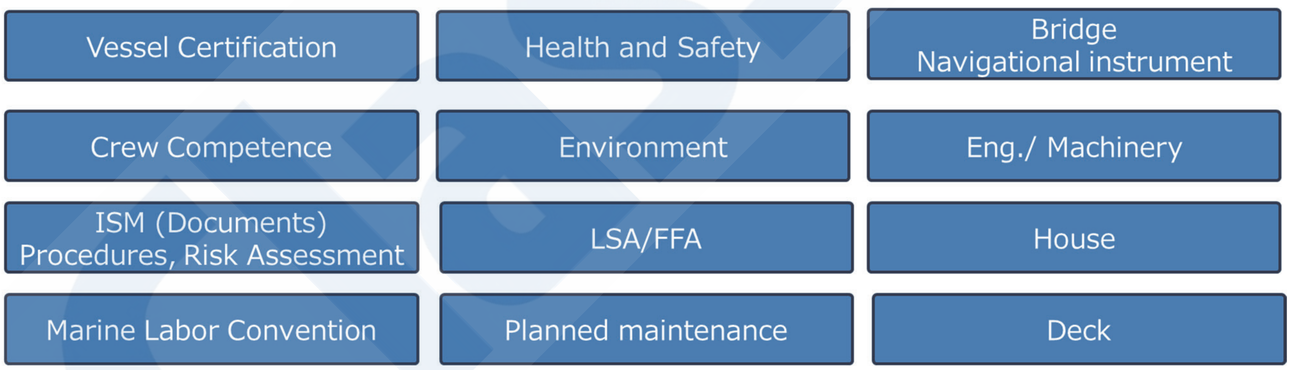


Fig. 8 Examination items in IMCA eCMID inspections

② DP Operation Assessment

[Purpose]

The dynamic positioning system (DPS) has an extremely important function in offshore construction, for example, for carrying out construction while maintaining the proper separation distance from the structure under construction, and in cable-laying work, laying the cable on the specified route without applying excessive tension. In the unlikely event of an abnormality in the DPS, it will become impossible to maintain the ship's position accurately, possibly resulting in a collision between the vessel and the wind turbine foundation during construction. If a malfunction occurs while personnel are moving to another vessel, there is a danger of accidents, such as drowning and also being crushed between the two vessels in the worst case.

Although the DPS of classified ships is examined in classification survey, these surveys are conducted periodically at set intervals, so changes in the condition of a device may occur after a survey. The DP Operation Assessment is carried out as a third-party assessment of the DPS operation and management system to support judgments by charterers.

[Content of work]

The inspector examines whether adequate study and countermeasures have been implemented for the DPS operation management system and the work concerned. For example, the inspector checks whether operation and management are being carried out with an awareness of the response in the unlikely event of a malfunction.

3.2 Status of Implementation of Marine Assurance Service and Feedback Based on Results

Since 2024, the Society has provided its Marine Assurance Service for candidate chartered ships in construction work related to offshore wind power. Based on the results of this service to date, this section of the article provides feedback on items that are considered to be useful as reference for safety improvement to those concerned in Japan.

3.2.1 Overall Trends in the Results of General Ship Inspections

At the time of this writing, the Society had conducted General Ship Inspections for 10 ships. Based on the results, the points that should be noted as feedback are as follows.

◆ In the case of non-self-propelled ships, a safe operation management plan should be prepared, considering the actual condition and content of work of the ship concerned.

◆ Work implementation records should be prepared properly and stored carefully.

◆ Equipment maintenance and servicing should be performed in a planned manner, and records of that work should be retained properly.

The following describes typical examples of each of the examination items.

① Implementation of Risk Assessments

In order to secure work safety in each individual job accompanied by danger, it is important to consider what kinds of risks can occur in a chain reaction if some kind of unexpected trouble, etc. occurs during work. In such cases, it is essential to take countermeasures to ensure that the chain reaction of risk is effectively cut.

Therefore, the General Ship Inspection checks whether "study of the effects of accidents that occur as a result of trouble during work in individual jobs and their countermeasures (= risk assessment) is being carried out." Specifically, the following items are checked:

✓ Definition of works that require a risk assessment and records of the risk assessments

✓ Whether the personnel who perform the jobs actually participate in the risk assessments (signature)

✓ Whether identification of risk factors, assessments of the degree of danger, and reevaluation of the degree of danger after countermeasures are implemented are being carried out or not.

As a result of this process, the feedback items based on approximately 80 % of cases, that is, items requiring improvement, discovered in about 8 out of 10 in the inspections to date, are as follows:

◆ The Form to be used in risk assessments of the ship concerned should be decided.

◆ Not only the written procedures for risk assessments, but also materials to be used in training personnel and records of that training should be established.

◆ When evaluations of the degree of danger and planning of risk reduction measures for each job have been carried out, the risk after implementation of countermeasures should be reevaluated.

In Japan, there is a tendency to consider safety countermeasures simply in terms of having and maintaining qualifications and observing the safety rules formulated based on past cases. However, it is important to reduce potential risks by studying preventive measures flexibly, in line with the actual working environment, procedures, etc.

② Emergency Response Procedure Manual

In the unlikely event that a major accident, fire, explosion, grounding, marine pollution accident, etc. actually occurs, it is necessary to develop an emergency response procedure manual in order to promptly prevent the spread of the disaster by calmly responding to the situation which has occurred on the ship using the ship's equipment. Therefore, when conducting inspections, the Society checks the following items:

✓ Has an Emergency Procedure specific to the ship in question been prepared?

✓ Do the crew members acknowledge and understand the content of the Procedure?

Based on the same 80 % cases as in ①, the feedback items are as follows:

◆ An Emergency Response Procedure should be established, and emergency response training drills should be carried out to confirm the effectiveness of the Procedure.

◆ When crew members confirm the Emergency Procedure, the records (signature) of confirmation should be retained.

◆ Firefighter's outfits and other lifesaving equipment should be stored in a condition where they can be used immediately.

◆ Handbooks concerning firefighter's outfits and lifesaving equipment should be carried on the ship at all times.

As also described as a general tendency, it is important to incorporate this in the Emergency Procedure, while having a concrete image in line with the actual situation of the ship in question. It is also important not to be satisfied simply with completing the preparation of the Procedure manual, but also to consider how emergency procedures can be carried out quickly and surely under emergency conditions.

③ Work Permit System

When performing work, it is necessary to ensure that the organization has implemented adequate countermeasures in preparation for rare events. It is also essential to share information about the situation, especially in case the works which are performed simultaneously in parallel may increase potential risks, persons in a position with a comprehensive view of the work as a whole should make efforts to avoid such situations. From this perspective, it was considered necessary to introduce the Work Permit system. For this system, the following items are checked when carrying out an inspection:

✓ Is the Work Permit system applied in the ship?

✓ Is work that requires the Work Permit system clearly defined?

✓ Are the items listed in each Work Permit system appropriate?

✓ Are the records of operation of the Work Permit system managed properly?

Based on the above-mentioned 80 % cases, the feedback items are as follows:

◆ The Work Permit system should be established in line with the actual situation of the ship.

◆ In the Work Permit application form, in addition to the work items, the countermeasures for securing safety should also be described (e.g., when performing work using fire, a watch person should also be assigned, etc.).

◆ A record showing that the items described in the Work Permit application form were carried out properly should be retained.

In Japan, the person in charge of construction is sometimes responsible for securing work safety, and the decision to start work is based on the judgment of the work site. If construction operations have been carried out in this manner without significant problems until now, those concerned may feel that requiring separate work permit system from a safety section is needlessly complicated. However, with the increasingly large scale of projects like the construction of offshore wind power facilities, management to ensure construction safety, including the response at the work site by an expert line, will be important.

④ Lockout/Tagout System

The Lockout/Tagout system means taking physical preventive action so that certain operations cannot be performed during work (Lockout), and taking visual actions that can be understood by anyone (Tagout). This system is generally applied in conjunction with the above-mentioned work permit system.

For example, when performing an "intermediate valve exchange," the shut-off valve is locked (Lockout) so it cannot be operated, and when performing "electrical construction work," the breaker is cut off and a "Do not operate" tag is placed on it (Tagout).

The following items concerning this system are checked in inspections.

✓ Has the Lockout/Tagout System been introduced?

✓ Are lockout/tagout records being retained?

✓ Is implementation of the Lockout/Tagout System linked to work permits?

In this case, the feedback items are based on 90 % of inspections, and are as follows.

◆ The Lockout/Tagout system should be used effectively to reduce the possibility of human error.

◆ A person in charge of control of the objects subject to Lockout should be assigned, and records of Lockout control should be retained.

The Lockout/Tagout system is premised on the fact that humans tend to make mistakes. With the progressively larger scale of construction projects such as offshore wind power, and the increasing number of persons engaged in construction, this system will also become increasingly important.

3.2.2 General Trend of DP Operation Assessment Service

Up to the time when this paper was written, the Society had provided the DP Operation Assessment Service for four ships. As checks of the qualifications/experience of crew members and examination of the documents, the Society verified that a DP operation manual, DP checklist, Activity Specific Operating Guidelines (ASOG) and written Emergency Response Procedures, etc. had been prepared and are being used. Upon request, we also witnessed DP trials, and evaluated the redundancy of DP system was ensured , also the performance of its crew based on the trial, and reported the results in a written report. The results of these activities and the feedback items based on them are as follows.

- ◆ When it was not possible to check records of a DP trial of a ship within the past 12 months in the examination of documents, the Society witnessed an offshore DP trial and verified the redundancy of all related devices and the proficiency of the crew.
- ◆ In many cases, the qualifications of the DP operator did not satisfy the requirements of the IMCA Guidelines, which require a DP Certificate from the Nautical Institute or DNV certification. However, since the track record of offshore construction in Japan is still small, there are many cases where it would be difficult for operators to comply with the requirement of the Nautical Institute for actual operating time. To address this need, the Society established standards separate from the IMCA Guidelines, and recognizes a certificate of completion of a ClassNK-certified training course or a DP operator's certificate issued by the DP manufacturer as a qualification.
- ◆ Multiple persons should be assigned as DP operators for one shift in case of unforeseen situations, etc.

4. CONCLUSION

This paper has presented an overview of the Marine Assurance Service of ClassNK, together with concrete examples, and has introduced some of the results of implementation. Those who received this service expressed the following impressions:

- ・The service clarified the points that should be improved on the ship, when compared with the thinking of international safety management standards and regulations.
- ・Although we had not used "Work permits," "Lockout/Tagout System," "Risk Assessment," etc. until now, we understood the usefulness of these tools in contributing to safe operation.

It is especially noteworthy that these inspections by the Society also resulted in chartering of Japanese work vessels by overseas companies in some cases.

Continuously, the Society will try to bridge the gap between Japanese coastal work vessels and the international standards for work vessels considered by European companies, and to improve safety and foster mutual understanding between the charterers of work vessels and work vessel owners and operators, through this Marine Assurance Service.

Current Status of MASS and Initiatives of ClassNK

Makoto ITO*

1. INTRODUCTION

Nearly a decade has passed since the International Maritime Organisation (IMO) formally began its examination of Maritime Autonomous Surface Ships (MASS). During this period, international discussions have progressed, and various countries initiated demonstration trials and commercial operation of MASS, resulting in gradual progress towards social implementation. For example, the Nippon Foundation's MEGURI2040 project successfully completed its Phase 1 demonstration trials in 2022, and is currently proceeding with Phase 2 trials.

The background of interest in MASS is the need to reduce human error, which accounts for about 70 % of accidents involving ships [1], and to cope with an aging population of seafarers and shortages of human resources [2]. Automation and remote control of seafarers' tasks are expected to reduce their workload and improve the working environment, thereby improving safety and maintaining sustainable logistics. In light of this situation, various scenarios for the use of MASS are being considered in a number of countries.

Use cases for MASS are organized along two axes, the Mode of Operation (MoO) and the environments under which automation and remote control are used [3]. For MoO, there are cases in which the operation of the vessel is entrusted to an Autonomous Navigation System (ANS), and seafarers are in charge of monitoring and emergency response on board the vessel. There are also cases that involve remote human control of the vessel from a Remote Operation Centre (ROC). Since uniformity of the MoO across all phases of ship navigation is not necessary, there are examples where an ANS controls the vessel in the open sea and remote control is used in coastal areas where communication between the vessel and an ROC is stable.

Since these use cases will only be acceptable to all stakeholders if they are consistent with laws and regulations, each country is improving its legal and regulatory framework based on the progress of technological development and the results of demonstration experiments. For example, the MASS Code, which is an international regulation being developed by the IMO, is being finalised first as a non-mandatory code, and this work is now in its final stage. However, since the MASS Code only specifies functional requirements, it is essential to establish more detailed technical requirements to ensure social implementation.

The Society has responded to these trends from an early stage. In addition to conducting safety assessments in demonstration projects from the standpoint of a third-party organization, the Society is also actively working to establish technical requirements by compiling and publishing the knowledge obtained through those projects in ClassNK Guidelines. From the standpoint of a classification society, we believe that these efforts will contribute to ensuring the safety of technological development and the establishment of laws and regulations for MASS.

This paper first reviews the trends in the development of MASS and the establishment of laws and regulations in each country, and then introduces the initiatives of the Society and their results.

2. DEVELOPMENTS OF MASS

Development and actual operation of MASS are progressing rapidly in various countries. Although the efforts of each country differ according to the circumstances and objectives of their respective regions, they all aim to establish MoOs and system configurations for practical use while gradually verifying the technology.

In Norway, development is progressing on the assumption that MASS will navigate the country's coastal fjord areas and operate from berth to berth with unmanned operation on board (automation of navigation) and remote human participation (monitoring and emergency response). One example is the electric propulsion RO-RO ship ASKO Marit (Fig. 1), which is

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operating on a route of approximately 10.5 km between Moss and Horten ports. Verification is being carried out in a step-by-step manner. At present, ASKO Marit is operating with remote monitoring and crew members on board in case an emergency occurs while the system is operating. Another feature of ASKO Marit is automation of port side operations. The infrastructure necessary for unmanned operation on board is being developed, including a hull fixing device for automatic berthing and an automatic power supply system.

Fig. 1 Automatic berthing of ASKO Marit (going astern)

In Belgium, remote navigation in inland waters by Seafar is a distinctive feature. The company operates and manages MASS from its own ROC, and commercial operation is already underway at the ROC in Antwerp (Belgium) shown in Fig. 2. With the aim of commercial operation outside Belgium, demonstration tests in Amsterdam Port (Netherlands) and Duisburg (Germany) are also underway with operation from the ROCs. In the future, Seafar aims to operate vessels that are unmanned on board, but the current commercial operation uses manned vessels with a reduced crew to cope with situations such as communication interruptions. At the ROC, one Remote Operator is in charge of each vessel, and the Supervisor, who has higher authority, monitors the entire fleet and responds to emergencies.


Fig. 2 ROC of Seafar

In Korea, seafarer support systems utilizing automation of navigation have been developed. For example, Samsung Heavy Industries (SHI) has developed an ANS called SAS (Samsung Autonomous Ship) and received AiP (Approval in Principles) and a Technology Qualification statement from the Society. Avikus, a subsidiary of Hyundai Heavy Industries (HHI), has also developed an ANS, HiNAS Control, and is already deploying it as a commercial product. As remote operation technologies, the smart ship demonstration vessel Ulsan Taehwa was constructed, and a new ROC called the Ship Integrated Data Centre was established at UIPA (Ulsan ICT Promotion Agency), as shown in Fig. 3, enabling remote monitoring of the operational status of the vessel.

Fig. 3 Ship Integrated Data Centre at UIPA

In Japan, the second phase of the MEGURI2040 project by The Nippon Foundation is underway. As shown in Fig. 4, demonstration tests are being conducted with a total of four vessels: one remote island passenger ferry, one container ship, one RO-RO ship and one newly-built container ship. For example, the MoO of the new container ship is assumed to be automation of navigation from berth to berth and remote monitoring of the engine. Various elemental technologies are being developed to realize these functions. The Society is also conducting safety assessments from a classification society perspective, advancing the survey of NK-classed ships and the evaluation of elemental technologies.

Fig. 4 Second phase of MEGURI2040 project [4)]

In this manner, each country is carrying out step-by-step verifications tailored to regional conditions and objectives with the aim of social implementation of MASS, and the transition from demonstration to commercial operation is now entering a realistic phase.

3. DEVELOPMENT OF LAWS AND REGULATIONS

In line with advances in technological development, each country is also progressing with the establishment of supporting laws and regulations. Since MASS involve operations not contemplated in the framework for conventional vessels, mechanisms are required to underpin safety and operational systems from an institutional perspective, based on the insights gained from technological demonstrations. With this background, each country is advancing the development of its regulatory framework by various approaches, such as utilising existing legal systems or enacting new legislation.

Norway issued guidance RSV12-2020 (Guidance in connection with the construction or installation of automated functionality aimed at performing unmanned or partially unmanned operations) concerning MASS in 2020. This document stipulates that assessments should be conducted based on existing regulations, whilst requiring that MASS demonstrate equivalent safety to conventional vessels using the risk-based assessment methodology outlined in IMO MSC.1/Circ.1455

(Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments).

A notable feature in Belgium is that legislative amendments were enacted in June 2021 based on the outcomes of demonstration experiments. This legislation (Royal Decree on unmanned navigation in Belgian maritime zones) includes the definition that “An unmanned ship is a seagoing ship that can sail partially without human intervention for all or part of its voyage or that can sail with remote control.” It also states that “remote control centres are considered an integral part of the unmanned ship,” thereby legally permitting use scenarios involving remote operation from land without human intervention on board.

In Korea, the Enactment of the Enforcement Decree of the Act on the Promotion of Development and Commercialization of Autonomous Ships came into force in January 2025. Its section on “Test Operation and Special Provisions for Autonomous Ships” stipulates that authorisation is required for test operations and demonstration trials. It further specifies that upon receiving such authorisation, the vessel is exempt from certain legal regulations within designated navigation zones. This is positioned as part of the country’s efforts to foster an enabling environment to encourage the demonstration of development technologies and accumulation of operational track records.

In Japan, the relevant ministerial ordinances were amended and came into force in June 2025. MASS (vessels equipped with ANS) were positioned within the framework of the Ship Safety Act as subject to inspection as special vessels. The main amendments are outlined below.

- The Ship Safety Act Enforcement Regulations classify vessels equipped with ANS as special vessels.
- The Special Regulations for Automated Equipment on Ships prescribe the functional requirements for ANS.
- Instructions and procedures for ship inspection prescribe the flow of specific inspections of vessels with ANS and the timing of issuance of ship inspection certificates.

Discussions are expected to be held regarding manning and responsibilities, based on the results of demonstration tests.

The IMO agreed that, rather than amending individual conventions to address the issues identified in the Regulatory Scoping Exercise (RSE) for the use of MASS, a new Goal-Based Standard (GBS) code, the MASS Code, should be developed. The MASS Code is divided into the three Parts outlined below. PART 2 contains requirements applicable to all MASS, irrespective of whether tasks are autonomous or remotely controlled. PART 3 contains task-specific requirements, the applicability of which is determined by the flag States.

- PART 1 (Introduction)
  The scope of application is defined. The non-mandatory Code is intended to apply to cargo ships.
- PART 2 (Main Principles)
  Common requirements for all MASS are prescribed. An approval process based on the ConOps is described.
- PART 3 (Goal, Functional Requirements and Expected Performance)
  Functional requirements for each task to be autonomous or remotely controlled are specified. The applicability of these requirements should be determined by the flag States in accordance with the ConOps.

It was deemed appropriate for the MASS Code to establish a non-mandatory Code as provisional guidance in order to indicate the direction at an early stage. Consequently, the roadmap is to first adopt the non-mandatory Code in 2026, gather feedback through an Experience Building Phase (EBP), and then aim for the mandatory Code to enter into force in 2032.

While legislative and regulatory frameworks aligned with use case implementation are being advanced by individual nations and the IMO as described above, it is also essential to concurrently establish specific technical requirements to ensure the safe implementation of MASS technologies. For example, the MASS Code comprises Tier I (goal(s)) and Tier II (functional requirements) in the GBS framework shown in Fig. 5, and ensuring its effectiveness will require the development of more detailed technical requirements, namely Tier IV (class rules, etc.) and Tier V (industry practices and standards). Tier IV, in particular, is expected to be developed primarily by classification societies, including the Society.

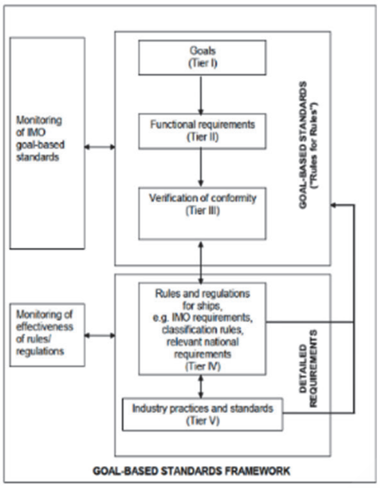

Fig. 5 Goal-Based Standards framework (MSC. 1/Circ. 1394)

4. INITIATIVES OF THE SOCIETY

4.1 Overview

The Society has proactively advanced safety assessments and regulatory development by establishing a cross-functional project team, MASS PT, in response to trends concerning MASS. For safety assessments, the Society reviews and evaluates demonstration projects from a third-party perspective to confirm compliance with guidelines and requirements prescribed by the Society. Based on these findings, the Society revises its guidelines, contributing to the establishment of technical requirements. To support these efforts, the Society also conducts research on improving evaluation methodologies and utilising simulation technology with domestic and international leaders in the field. The following sections describe these initiatives in more detail.

4.2 Safety Assessment

Since issuing "Guidelines for Automated/Autonomous Operation on Ships (hereinafter, the Guidelines) [5)]" in 2020, the Society has conducted safety assessments of MASS and their onboard systems both domestically and internationally.

For ANS, the Society has issued AiPs for APExS-auto by NYK, MTI, and Japan Marine Science; Advanced Maneuvering Assistant System by Kawasaki Kisen Kaisha, Kawasaki Kinkai Kisen Kaisha, Japan Radio, and YDK Technologies; and overseas, for SHI's SAS. The Society also assesses elemental technologies based on the Guidelines and issues Technology Qualification statements. For instance, statements for collision avoidance functions have been issued for Japan Marine Science's ARS and SHI's SAS-IBS following assessments of results of simulations of multiple collision avoidance scenarios.

For remote operation technology, an AiP has been issued for SHI's ROC, SROC (Samsung Remote Operation Centre). Through these safety assessments, the Society is confirming the safety of key functions of MASS and accumulating knowledge for establishing future technical requirements.

4.3 Rule Development

This section details the key changes introduced in the Guidelines ver. 2.0 published in March 2025, specifically the establishment of new notations and a new annex.

4.3.1 Notations

For vessels equipped with ANS, the notation "Autonomous-XY(Z)" (abbreviated as "AUTO-XY (Z)") is affixed to the classification characters of the vessels in accordance with the Guidelines. The notations "X," "Y" and "Z" indicate the automated function, the level of autonomy and the phase of navigation, respectively.

The automated function "X" explicitly specifies which tasks are to be automated. Its content is chosen from Navigation (Nav), Engineering (Eng), Safety (Saf), or Operation (Ops). The level of autonomy "Y" uses the following numbers to express the degree of human intervention in the functions being automated.

1: (Support) Partially automated with decision-making by humans.

2: (Conditional autonomous) System use monitored by humans.

3: (Advanced autonomous) Human intervention is basically not necessary; however, the system can always be overridden based on decision-making by humans.

The phase of navigation “Z” represents sea areas where the ANS is to be used. The content of “Z” is either Limited or All, corresponding to the functions to be automated. In the case of “Nav,” Limited is then chosen from Berth/unberth (Be), Harbor (Ha), Coastal (Co) or Open Sea (Os).

For example, vessels equipped with an ANS that can control the vessel under human supervision only in the open sea would be assigned the notation AUTO-Nav2(Os).

4.3.2 New Annex

As regulations corresponding to Tier IV, the Society decided to concretize the knowledge so far in the form of an annex. The annex can be roughly divided into two parts, requirements for ANS that automate navigation (Annex I) and requirements for remote monitoring and operation of machinery (Annex II).

Annex I specifies common requirements, definitions, approval processes, etc. in “General,” and provides detailed requirements for each of the essential ANS functions, namely situational awareness, collision and grounding avoidance, and route execution and monitoring. In particular, evaluations using simulation techniques involve simulation scenarios and mathematical manoeuvring models, reflecting the results of the research activities described in the following section.

Annex II specifies the scope of application and specific functional requirements as safety requirements for engine monitoring and operation from remote control facilities. For example, this annex describes requirements for monitoring multiple vessels and information requiring warnings and display in remote engine monitoring.

4.4 Research Activities

The Society conducts research that contributes to safety assessment and rule development in cooperation with domestic and international research institutions and companies. This section outlines the research activities that form the basis of the development of the Guidelines.

4.4.1 Research on Manoeuvring Models

In the route execution function of MASS, automation of in-port manoeuvring including automatic berthing and unberthing is regarded as a highly novel technology. For safety assessments, the validity of the manoeuvring model used in simulation evaluations is important. Ideally, it is desirable to standardize the manoeuvring motion model used in simulations, but because port manoeuvring involves complicated motions in the low-speed range, efforts to standardise the model are still in progress.

Given this situation, from the perspective of safety assessment, it is more practical not to prescribe a single standard model, but rather to define the requirements to be satisfied by manoeuvring models, and to require simulations using models that meet those requirements in assessments. In other words, it is necessary to establish the requirements demanded from the motion calculation component of simulators reproducing in-port manoeuvring.

Therefore, in 2023, the Society established a study group to examine the requirements for manoeuvring models, and invited experts in ship manoeuvring and ship control from domestic universities, research institutions, shipyards, and manufacturers to participate. Discussions were held with the aim of examining the requirements for manoeuvring models and their verification methods, and the outcomes were published on the Society’s website [6]. For example, Fig. 6 shows the verification scenarios for thruster manoeuvring. The findings have also been presented at both domestic and international academic conferences [7), 8)].

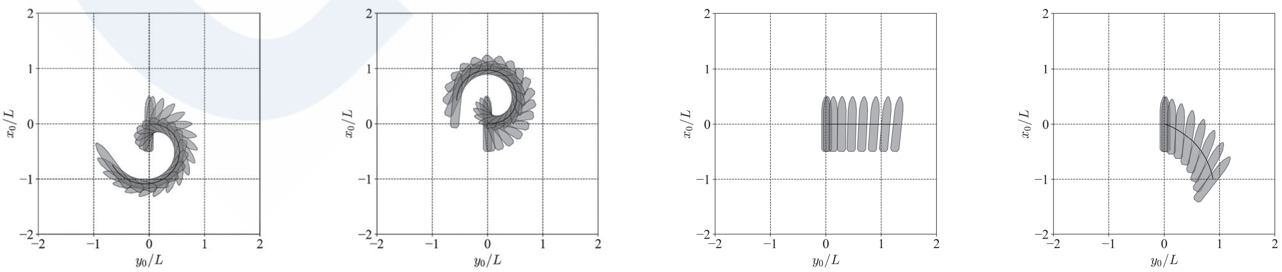

Fig. 6 Scenarios for confirmation of thruster manoeuvring (excerpt)

In automating navigation, the collision and grounding avoidance functions are crucial. Particularly, as the COLREG Convention prescribes manoeuvring according to the encounter situation with other vessels, compliance with that regulation is also required for MASS. Therefore, it is necessary to verify that MASS can appropriately avoid collisions with other vessels and grounding while adhering to COLREG.

In response, the Society has conducted research into simulation-based verification methods through collaborative studies with domestic research institutions. For instance, when simulating collision avoidance manoeuvring, basic scenarios based on the clustering of encounter situation [9] shown in Fig. 7 involving one-to-one or two-vessel encounters were examined, as shown in Fig. 8. As one method for evaluating collision avoidance routes, the Society carried out studies and experiments on the evaluation area diagram shown in Fig. 9 [10), 11)]. Since "good seamanship" as described in COLREG includes elements that are difficult to express numerically, the Society has also examined methods for subjective evaluation by experts such as experienced seafarers, termed expert judgement, and conducted experiments targeting specific collision avoidance algorithms [12)].

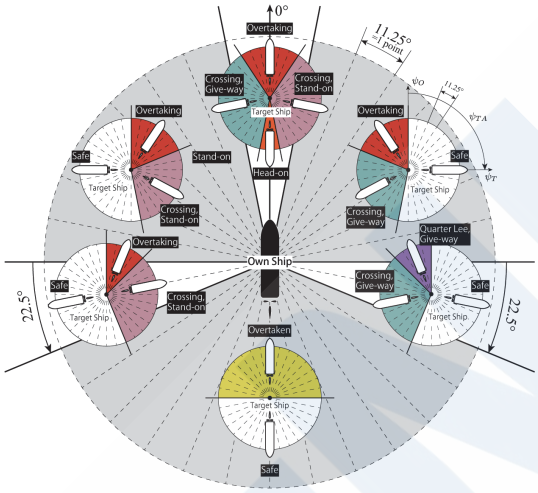

Fig. 7　Clustering of encounter situation

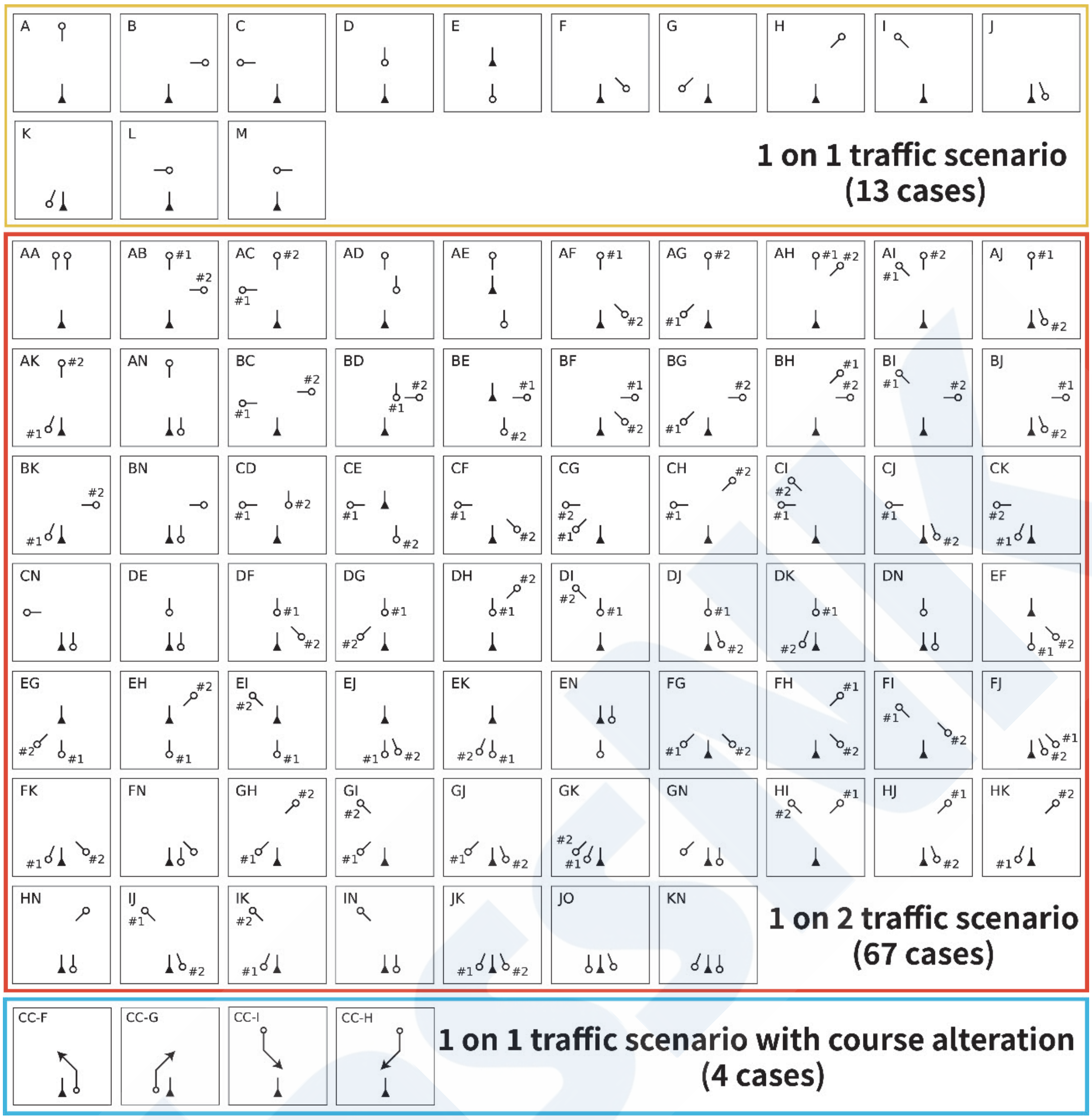

Fig. 8　Basic scenarios

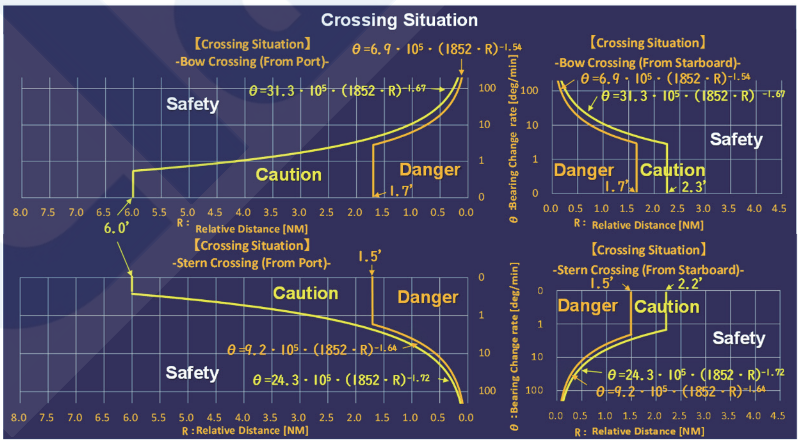

Fig. 9　Evaluation area diagram

4.4.2　Technology Related to Remote Operation

In remote monitoring and control, operations where humans on shore view real-time video are envisioned. In such cases, video transmission is one of the key technologies essential for situational awareness in the ROC [13]. Therefore, the Society is verifying the video transmission requirements necessary for situational awareness in ROCs and the technical feasibility of long-distance, wide-field-of-view video. As part of this effort, a demonstration experiment was conducted to receive and play back live video transmissions from an experimental vessel using Starlink and cellular (LTE) communications. This experiment quantitatively demonstrated the trade-off relationship between latency, image quality, and playback stability, highlighting the necessity for dynamically balancing these factors according to the phase of navigation and the level of remote operation [14).

The Society is also investigating the latest trends in communications technology, which is crucial for achieving remote operations, and publishes the results on its website as they become available. For example, one research report [15) examines the current status of optical wireless communication and its potential applications in the maritime sector, as this technology is attracting attention as a means of supplementing limited radio wave resources. By compiling these recent trends and assessing their technological maturity, the Society is contributing to the formulation of fair and objective requirements.

5. CONCLUSION

This paper summarises the current status of MASS development and regulatory frameworks, and introduces the Society's initiatives in the areas of safety assessment, rule development, and research activities. Regarding MASS development and regulatory frameworks, the paper highlights how each country is advancing development incrementally within their respective regulatory frameworks and the IMO is progressing with the formulation of the MASS Code. As the MASS Code is expected to organise functional requirements based on the GBS framework, the development of more specific Tier IV requirements is anticipated, primarily by classification societies including the Society. In response to the current status, the Society has addressed relevant issues through research activities, guideline development, and safety assessments from an early stage. In the future, the Society intends to continue to provide support for the social implementation of MASS from the perspective of a classification society, drawing upon the expertise accumulated over time.

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Lifting Appliances and Anchor Handling Winches

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1. INTRODUCTION

The International Maritime Organization (IMO) has conducted studies with the aim of formulating international safety standards to reduce accidents involving onboard lifting appliances.

Among international standards for onboard lifting appliances, ILO C152 (International Labour Organization Convention No. 152) is a safety standard for port workers engaged in "dock work," ILO C152 is widely recognized by related parties in the industry and is already applied in the ports of countries that ratified ILO C152 as well as in some non-ratifying countries, and the requirements of the technical rules of ship classification societies also take this Convention into account.

However, since ILO C152 does not apply to onboard lifting appliances not used by dock workers, such as engine-room overhead cranes, provision cranes, etc., its deficiencies as an international standard uniformly applicable to onboard lifting appliances were as concern, and the necessity of developing a new international standard separate from ILO C152 was recognized.

At the 89th session of the Maritime Safety Committee (MSC89) of the IMO held in May 2011, related national governments, beginning with Japan, submitted proposal MSC 89/22/12 (proposal for incorporating safety standards for onboard lifting appliances in the SOLAS Convention), and discussions on the establishment of internationally-unified safety standards for onboard lifting appliances were begun. Discussions on anchor handling winches were also carried out in parallel with the discussions on lifting appliances based on proposal DE56/22/4 (proposal for requirements for towing, anchor handling and stern lifting winches) submitted by Norway at the 56th session of the Sub-committee on Ship Design and Equipment (DE56) held in February 2012.

At MSC107 held in June 2023, an amendment to the SOLAS Convention concerning lifting appliances and anchor handling winches was adopted as IMO Resolution MSC.532(107) [1]. Specific safety requirements were also approved as MSC.1/Circ.1662 [2] and MSC.1/Circ.1663 [3] at MSC107 as requirements to be specified in guidelines.

The ClassNK (the Society) incorporated the provisions of the amendment to the SOLAS Convention and the related guidelines in its Rules, and "Rules for Cargo Handling Appliances" was formally amended to "Rules for Lifting Appliances and Anchor Handling Winches," and is to be applied beginning in January 2026. Furthermore, the implementation of the Rules has commenced, with our Material and Equipment Department responsible for matters related to lifting appliances, Machinery Department for the matters related to anchor handling winches, and Survey Department for the matters related to surveys.

This paper introduces the history of discussions at the IMO, ILO C152, and amendments to the Rules for Cargo Handling Appliances.

2. HISTORY OF DISCUSSIONS IN IMO

In the IMO, discussions on the establishment of international safety standards for onboard lifting appliances and anchor handling winches were carried out over a lengthy period of 12 years, substantially from 2011 to 2023. Including proposals from related governments, industry groups and others, and reports from committees and sub-committees, related working groups and correspondence groups, and the IMO Secretariat, almost 100 related documents were prepared (Table 1). This suggests how difficult it was to formulate unified international standards for lifting appliances and anchor handling winches, and also shows the high interest of the stakeholder.

Although these related documents are all important for understanding the content of the discussions in the IMO, in particular, the following presents an overview of the documents that led to the preparation of the amendment to the SOLAS Convention and related guidelines. Since it is not our intention to present a comprehensive description of the entire content of these documents, the reader should understand that they are presented here only for reference.

2.1 MSC 89/22/12

Against the backdrop of a serious accident that occurred during cargo handing between the cargo ship “M.V. RICKMERS JAKARTA” and the barge “18 Shin Ei-Maru” in Keihin Port (Japan) in September 2008, at least 18 accidents involving lifting appliances for cargo handling that occurred in Japan (including the aforementioned serious accident), and 64 accidents that raised safety concerns due to failure of onboard lifting appliances reported by New Zealand, this proposal was made to point out the necessity of incorporating requirements for the manufacture and installation of onboard lifting appliances in the SOLAS Convention.

2.2 DSC 16/5/5 and DE 56/2/3 (ICHCA: International Cargo Handling Coordination Association)

These are reports of results of preliminary investigations of accidents involving lifting appliances by the IMO’s Sub-committee on Dangerous Goods, Solid cargoes and Containers (DSC) and Sub-committee on Ship Design and Equipment (DE). Since 2001, 29 accidents involving lifting appliances for non-cargo handling had occurred in ships of a certain flag state, and in all cases, the cause was poor maintenance. Since ILO C152 is applicable only to lifting appliances for cargo-handling, this result suggested that countermeasures for lifting appliances for non-cargo handling were also necessary. In addition, the necessity of involvement of the flag state under the SOLAS Convention was also suggested. As examples of lifting appliances for non-cargo handling, DE56/INF.2 (Japan) mentioned hose handling cranes installed on tankers, small cranes for retrieval of provisions, engine-room overhead cranes, and davit cranes for deploying lifesaving equipment.

2.3 DE 56/22/4 (Norway)

In response to the capsizing of the anchor handling vessel “M.V. BOURBON DOLPHIN,” the need to draw up technical requirements for emergency release, tension control of towing, anchor handling and stern lifting winches was proposed.

2.4 DE 57/18/1 (Korea) and DE 57/18/2 (ICHCA)

The necessity of drawing up internationally-unified mandatory requirements under the SOLAS Convention was pointed out, and addition of Regulation 3-13, Chapter II-1 of the SOLAS Convention was proposed as the concrete content of an amendment. As the content of guidelines referenced from the SOLAS Convention after amendment under these proposals, DE 57/18/3 (Japan) proposed a guidelines including the construction, strength, installation, maintenance, inspection, certification and operation manuals.

2.5 DE 57/18/4 (New Zealand)

Application to the lifting appliances of existing ships and application to cranes for stores and engine-room overhead cranes were proposed.

2.6 SSE 1/WP.5 (Chair, SSE1 WG) and SSE 1/21 (IMO Secretariat)

The Sub-committee on Ship Systems and Equipment (SSE; a sub-committee created by reorganizing former DE and others) concluded that application should not be limited to lifting appliances for cargo-handling, and requirements should not be applied to elevators and escalators for human use, equipment related to the International Life-Saving Appliance Code (LSA Code), mobile offshore drilling units (which are subject to the MODU Code) or fishing boats. As the content of the requirements, these documents indicated that items relate to operation, maintenance, training, inspections, testing and certification should be applicable to all newly-constructed ships and existing ships, and items related to ship design and construction should be applied when lifting appliances are newly installed on newly-constructed ships and existing ships.

2.7 SSE 2/8/3 (Japan)

As clarification of the meaning of lifting appliances, this document proposed that the objects of application be defined as power-operated lifting appliances. It also proposed excluding from application to personnel/passenger/provisions elevators (lifts), escalators, removable hoists, items designated for special purposes such as accommodation ladders, pilot ladders, sludge winches and the like, and equipment regulated under the LSA Code. However, SSE 2/WP.2 (Chair, SSE2 WG) and SSE 2/20 (IMO Secretariat) took the view that personnel/passenger elevators (lifts), non-power-operated lifting appliances, removable hoists and sludge winches can be excluded from the scope of application.

2.8 MSC 95/22 (IMO Secretariat)

This is an agreement that the development of a proposal for a goal- and functional -based SOLAS amendment, supplementation of the SOLAS Convention after amendment with guidelines, and the contents of the guidelines should be specified based on items related to the design and manufacture of newly-installed lifting appliances and winches, items related to the inspection, maintenance and operation of all lifting appliances and winches, and items related to the familization of ship’s crew and shore-based personnel. It also requested the establishment of a correspondence group, with Japan as the coordinator.

2.9 SSE 3/8 (Japan)

Draft amendments to Chapter II-1 of the SOLAS Convention and the related guidelines were submitted. The draft amendment to the SOLAS Convention provided the definition of lifting appliances and thresholds for the safe working loads (SWL) of lifting appliances outside the scope of application, etc. The draft amendment to the related guidelines specified treatment refer to rules of classification societies in requirements for design, fabrication and construction, and concrete safety requirements also for anchor handling winches.

2.10 SSE 3/8/1 (Norway)

A supplementary explanation of the safety requirements for anchor handling winches in the proposed guidelines in SSE 3/8 was provided.

2.11 SSE 4/8/2 (Antigua and Barbuda, New Zealand, ICHA, IHMA (International Harbour Masters' Association) and SSE 4/8/3 (China, Hong Kong)

This item proposed treating out of service or out of order lifting appliances as maintaining the validity of the SOLAS Convention certificate when the equipment does not pose a danger to the ship or crew.

2.12 SSE 4/WP.4 (Chair, SSE4 WG)

A study was carried out on an amendment to the SOLAS Convention comprising definitions (lifting appliances, anchor handling winches, and loose gear), application (also including a description of items outside the scope of application), and goals and functional requirements. Based on the opinion that manually-operated lifting appliances are not outside the scope of application, manually-operated lifting appliances were not explicitly excluded from the scope of application. However, the possibility that they may inevitably be excluded from application by the SWL thresholds was noted.

2.13 MSC 98/23 (IMO Secretariat)

Accompanying the inclusion of requirements related to anchor handling winches in the amendment to the SOLAS Convention, a change in the name of the agenda item from "Onboard lifting appliances and winches" to "Onboard lifting appliances and anchor handling winches" was approved, and instructions were given that work related to the proposed SOLAS Convention amendment and related guidelines should be carried out in line with the general guidelines for IMO Goal-Based Standards (GBS) specified in MSC/1/Circ.1394/Rev. 1.

2.14 SSE 5/10 (Japan)

Revision of the proposed amendment to the SOLAS Convention in the correspondence group based on the request of MSC98/23 was studied. To clarify the scope of application, this item presents a policy of also providing specific examples of lifting appliances that are within the scope of application, in addition to items that are outside the scope.

2.15 SSE 5/10/5 (Japan)

Based on the fact that manually-operated lifting appliances are not excluded from the scope of application, it was proposed that an SWL threshold of 1 000 kg or more should be set for application in order to avoid including such small-scale lifting appliances in the scope of application. Assuming that manufacturers of small-scale lifting appliances no longer exist, inclusion of a procedure for also recognizing the SWLs specified by shipowners or operators was proposed as a response to the inability to obtain design information.

2.16 MSC 100/9/5 (IMCA: International Marine Contractors Association)

A proposal was made that lifting appliances installed on offshore construction ships should be excluded from application of the amended SOLAS Convention because those lifting appliances are fundamental to the purpose of the ship, and are already designed and maintained based on rigorous international standards.

2.17 SSE 6/9/1 (Japan and ICS: International Chamber of Shipping) and SSE 6/9/2 (Japan and ICS)

Since development of the amendment to the SOLAS Convention has taken a significant period of time , and the content of ILO C152 is based on the prescriptive requirements of standard types and is already widely used among the variety of stakeholders, a proposal was made to the effect that the content based on the prescriptive equirements of standard types developed up to the time should be adopted, rather than an amendment to the SOLAS Convention based on Goal-Based Standards (GBS) as specified in MSC/1/Circ.1394/Rev.1. It was also proposed that threshold SWL values for application of the amendment should be set for design, construction and installation, but should not be set for items related to maintenance, inspection and testing/examination.

2.18 SSE 6/9/4 (Germany)

Assuming the use of lifting appliances with small SWLs, increased risks due to careless operation, operation by unauthorized personnel, inadequate inspection and maintenance, etc. were a concern. Therefore, a proposal was made opposing the introduction of thresholds for application of the amendment so that the requirements are applicable to all lifting appliances and loose gear.

2.19 SSE 6/WP.5 (Chair, SSE6 WG) and SSE 6/18 (IMO Secretariat)

It was agreed that content based on the prescriptive requirements of standard type developed up to the time, and not the SOLAS Convention amendment based on Goal-Based Standards (GBS) should be adopted. The SWL threshold for applicability of the amendment was set at 1 000 kg, and a policy excluding items with SWLs of less than 1 000 kg from application was adopted for the design, constructoin, installation and load testing of newly-installed lifting appliances and load testing of existing lifting appliances.

It was also agreed that definitions (lifting appliances, anchor handling winch, loose gear, etc.) should be revised; SWL thresholds should not be applied to anchor handling winches; provisions referencing the MODU Code should be deleted and offshore construction ships should be outside the scope of application; additional requirements for application of the SOLAS Convention should not be applied to standards conforming to ILO C152; the handling of out of service or inoperative lifting appliances should be incorporated in the amendment to the SOLAS Convention; and the guidelines for lifting appliances and anchor handling winches, which had been developed in a single document, should be prepared separately as two guidelines.

2.20 SSE 7/9 (Japan)

In addition to the proposed guidelines for lifting appliances, the proposed draft of the newly-established guidelines for anchor handling winches were also reported. For requirements related to the basic design of the winch itself, including the winch holding capacity, brake holding capacity, safety factor, etc., the proposed guidelines for anchor handling winches proposed a policy of not taking any action related to these items, based on the fact that there were no specific proposal.

2.21 SSE 7/9/3 (China)

It was pointed out that various problems will occur if the SOLAS Convention and ILO C152 coexist without harmonizing the two different examination intervals and certification systems, including increases in maintenance and testing, difficulty in ship management, and confusion and uncertainty in the implementation of examinations by the industry and the administration, and request further instructions from the MSC were requested.

2.22 SSE7 WP.5 (Chair, SSE7 WG) and SSE 7/21 (IMO Secretariat)

After making certain cosmetic corrections, the amendment to the SOLAS Convention was finalized. Development of the guidelines for lifting appliances was continued, and a overall revision was carried out, including definitions, test loads in load testing, examples of certificates for load testing and thorough examination, the response* to the inconsistencies in the survey intervals of thorough examinations between the SOLAS Convention and ILO C152, and provisions for marking, maintenance, inspections, operational testing, operation, etc. In the guidelines for anchor handling winches, it was agreed that “automatic spooling devices” would be changed to “remotely operated spooling devices” in SSE 7/9/4 (Norway).

(*This response allows either confirmation of proper implementation of a thorough examination based on ILO C152 in annual survey and renewal survey based on the SOLAS Convention, or granting of a 3-month postponement of the due date for the thorough examination, at the discretion of the flag administration.)

2.23 MSC 102/24 (IMO Secretariat)

The amendment to the SOLAS Convention finalized at SSE 7 was approved in principle, and a policy of adopting the amendment to the SOLAS Convention when the guidelines for anchor handling winches are finalized was adopted. However, due to the spread of the novel coronavirus (COVID-19), adoption taking effect on 1 January 2024 was difficult (because SSE would not be held in 2021). Therefore, as an exceptional measure, a policy of adopting the amendment effective at the earliest possible timing outside the 4-year cycle was announced (the actual effective date of 1 January 2026).

2.24 SSE 8/9 (Japan)

Revisions of the guidelines for anchor handling winches related to application, definitions, design, construction, installation, testing and thorough examinations (commissioning tests, periodical testing, thorough examinations and their records), demonstration of compliance, name plates, maintenance, inspections, operational testing, operation, loose gear, and inoperative anchor handling winches, etc. were reported.

2.25 SSE 8/9/2 (Japan)

Regarding the different survey intervals of thorough examinations of lifting appliances under the amendment to the SOLAS Convention and ILO C152, a proposal was submitted touching on the possibility that this difference may cause confusion among the stakeholders, including port authorities and others, and requesting that the IMO Secretariat inform the ILO on the SOLAS Convention amendment and take appropriate action.

2.26 SSE 8/9/3 (Japan)

Regarding the guidelines on anchor handling winches, as issues related to the load testing required once every 5 years, since huge test weights are used, the safety risk of testing is high, and the availability of testing locations is limited, and without an appropriate testing standard, it is difficult to carry out the testing safely and in a uniform manner. To address these issues, a proposal was made to eliminate the requirement that load testing be performed once every 5 years.

2.27 SSE 8/WP.5 (Chair, SSE8 WG) and SSE 8/20 (IMO Secretariat)

In the guidelines for anchor handling winches, periodical load testing was eliminated due to the difficulty of carrying out the tests safely. In its place, a provision that witnessing of periodical testing (operational tests) conducted once every 5 years by the administration or the recognized organization is required, and the guidelines were finalized. In the guidelines for lifting appliances, the provision recognizing a 3-month postponement of the due date for thorough examinations was deleted, as there is already a provision addressing the Administration's discretion on the flexibility for the due date, and this additional description may cause unnecessary concern.

2.28 MSC 106/19 (IMO Secretariat)

Reflecting the revised proposal for clarification in MSC 106/11/4 (Germany, IACS: International Association of Classification Societies) and MSC 106/11/7 (Japan), the respective guidelines for lifting appliances and anchor handling winches were approved in principle, anticipating final approval at MSC107. In addition, a request was made to the IMO Secretariat to inform the ILO on the amendment to the SOLAS Convention, and request that the ILO take appropriate action to avoid duplicative surveys under ILO C152.

2.29 MSC 107/20 (IMO Secretariat)

The SOLAS Convention amendment concerning onboard lifting appliances and anchor handling winches was adopted and final approval was also given to the related guidelines, and it was agreed that all of these documents will take effect on 1 January 2026.

2.30 SSE 10/12/6 (Germany, IACS)

Issuance of a Factual Statement was proposed in order to distinguish existing lifting appliances without a valid certificate based on international instruments such as ILO C152 from lifting appliances that conform to Paragraphs 1 and 3 of Regulation 3-13, Chapter II-1 of the SOLAS Convention, under which safety-related examinations are to be carried out in the design stage. Instructions were given in SSE 10 to perform a partial revision and submit it at the next session (SSE 11). The revision was then resubmitted as SSE 11/10/5 and approved as MSC.1/Circ.1696 in MSC 110/21 in the same year.

Table 1 Documents proposed by related governments, industry groups, etc. and IMO minutes

Document	Committee	Sub-committee	Year held
MSC 83/20/2（New Zealand）	MSC 83	-	2005
MSC 89/22/12（Chile , Japan, New Zealand, Norway, Korea）	MSC 89	-	2011
DSC 16/5/5（ICHCA）	-	DSC 16	2011
DE 56/2（IMO Secretariat）	-	DE 56	2012
DE 56/22/2（IMO Secretariat）	-	〃	〃
DE 56/22/3（ICHCA）	-	〃	〃
DE 56/22/4（Norway）	-	〃	〃
DE 56/22/6（ISO）	-	〃	〃
DE 56/INF.12（Japan）	-	〃	〃
DE 56/INF.13（Japan）	-	〃	〃
DE 57/18（Liberia, Vanuatu, IADC: International Association of Drilling Contractors）	-	DE 57	2013
DE 57/18/1（Korea）	-	〃	〃

Document	Committee	Sub-committee	Year held
DE 57/18/2（ICHCA）	-	〃	〃
DE 57/18/3（Japan）	-	〃	〃
DE 57/18/4（New Zealand）	-	〃	〃
DE 57/INF.5（New Zealand）	-	〃	〃
DE 57/18/5（IMCA）	-	〃	〃
SSE 1/13（New Zealand）	-	SSE 1	2014
SSE 1/INF.3（New Zealand）	-	〃	〃
SSE 1/13/1（Germany）	-	〃	〃
SSE 1/INF.4（Germany）	-	〃	〃
SSE 1/13/2（New Zealand）	-	〃	〃
SSE 1/13/3（New Zealand）	-	〃	〃
SSE 1/WP.5（Chair, SSE1 WG）	-	〃	〃
SSE 1/21（IMO Secretariat）	-	〃	〃
SSE 2/8（New Zealand）	-	SSE 2	2015
SSE 2/INF.2（New Zealand）	-	〃	〃
SSE 2/8/1（Vanuatu, IMCA）	-	〃	〃
SSE 2/8/1/Corr.1（Vanuatu, IMCA）	-	〃	〃
SSE 2/INF.5（Vanuatu ,IMCA）	-	〃	〃
SSE 2/8/2（Antigua and Barbuda, New Zealand, ICHCA）	-	〃	〃
SSE 2/8/3（Japan）	-	〃	〃
SSE 2/8/4（ICHCA）	-	〃	〃
SSE 2/WP.5（Chair, SSE2 WG）	-	〃	〃
SSE 2/20（IMO Secretariat）	-	〃	〃
MSC 95/12/1（Antigua and Barbuda, Australia, Netherlands, New Zealand, Norway, ICHCA, IHMA, ITF: International Transport Workers' Federation, Nautical Institute）	MSC 95	-	〃
MSC 95/12/2（ICS）	〃	-	〃
MSC 95/12/3（Vanuatu）	〃	-	〃
MSC 95/22（IMO Secretariat）	〃	-	〃
SSE 3/8（Japan）	-	SSE 3	2016
SSE 3/8/1（Norway）	-	〃	〃
SSE 3/8/2（China）	-	〃	〃
SSE 3/INF.5（OCIMF: Oil Companies International Marine Forum）	-	〃	〃
SSE 3/16 （IMO Secretariat）	-	〃	〃
SSE 4/8（Chair, SSE3 WG）	-	SSE 4	2017
SSE 4/8/1（Japan）	-	〃	〃
SSE 4/8/2（Antigua and Barbuda, New Zealand, ICHCA, IHMA）	-	〃	〃
SSE 4/8/3（China, Hong Kong）	-	〃	〃
SSE 4/8/4（China）	-	〃	〃
SSE 4/8/5（Japan）	-	〃	〃
SSE 4/WP.4（Chair, SSE4 WG）	-	〃	〃
SSE 4/19（IMO Secretariat）	-	〃	〃
MSC 98/12/5（Germany）	MSC 98	-	〃
MSC 98/23（IMO Secretariat）	〃	-	〃
SSE 5/2（IMO Secretariat）	-	SSE 5	2018
SSE 5/10（Japan）	-	〃	〃
SSE 5/10/1（Germany）	-	〃	〃

Document	Committee	Sub-committee	Year held
SSE 5/10/2 (China)	-	〃	〃
SSE 5/10/3 (IACS)	-	〃	〃
SSE 5/10/4 (ICS)	-	〃	〃
SSE 5/10/5 (Japan)	-	〃	〃
SSE 5/WP.5 (Chair, SSE5 WG)	-	〃	〃
SSE 5/17 (IMO Secretariat)	-	〃	〃
MSC 100/9/1 (Japan, New Zealand, ICHCA)	MSC 100	-	〃
MSC 100/9/5 (IMCA)	〃	-	〃
MSC 100/20 (IMO Secretariat)	〃	-	〃
SSE 6/9 (Japan)	-	SSE 6	2019
SSE 6/9/1 (Japan, ICS)	-	〃	〃
SSE 6/9/2 (Japan, ICS)	-	〃	〃
SSE 6/9/3 (Canada)	-	〃	〃
SSE 6/9/4 (Germany)	-	〃	〃
SSE 6/9/5 (Germany)	-	〃	〃
SSE 6/WP.5 (Chair, SSE6 WG)	-	〃	〃
SSE 6/18 (IMO Secretariat)	-	〃	〃
SSE 7/2 (IMO Secretariat)	-	SSE 7	2020
SSE 7/9 (Japan)	-	〃	〃
SSE 7/9/1 (China)	-	〃	〃
SSE 7/9/2 (IACS)	-	〃	〃
SSE 7/9/3 (China)	-	〃	〃
SSE 7/9/4 (Norway)	-	〃	〃
SSE 7/WP.5 (Chair, SSE7 WG)	-	〃	〃
SSE 7/21 (IMO Secretariat)	-	〃	〃
MSC 102/24 (IMO Secretariat)	MSC 102	-	〃
SSE 8/9 (Japan)	-	SSE 8	2022
SSE 8/9/1 (IACS)	-	〃	〃
SSE 8/9/2 (Japan)	-	〃	〃
SSE 8/9/3 (Japan)	-	〃	〃
SSE 8/WP.5 (Chair, SSE8 WG)	-	〃	〃
SSE 8/20 (IMO Secretariat)	-	〃	〃
MSC 106/11/4 (Germany, IACS)	MSC 106	-	〃
MSC 106/11/7 (Japan)	〃	-	〃
MSC 106/19 (IMO Secretariat)	〃	-	〃
MSC 107/3/6 (China)	MSC 107	-	2023
MSC 107/20 (IMO Secretariat)	〃	-	〃
SSE 10/12/6 (Germany, IACS)	-	SSE 10	2024
SSE 11/10/5 (Germany, New Zealand, Norway, IACS)	-	SSE 11	2025
MSC 110/21 (IMO Secretariat)	MSC 110	-	〃

3. INTERNATIONAL LABOUR ORGANIZATION CONVENTION NO. 152 (ILO C152)

As outlined above, requirements for onboard lifting appliances were specified in the SOLAS Convention. However, due to concerns about the compatibility of those requirements with the requirements of the International Labour Organization Convention No. 152 (ILO C152), which is widely recognized among the stakeholders, the author would like to review ILO C152 once again and organize the relevant points.

ILO C152 is a convention that specifies safety and health standards for dock workers (workers performing “all and any part of the work of loading or unloading any ship as well as any work incidental thereto”). It is widely recognized as an international safety standard applied to onboard lifting appliances (excluding engine-room overhead cranes, provision cranes, and others which are not used by dock workers). The concrete implementation procedure for this convention is supplemented by ILO Recommendation No. 160 (R160), which further specifies that each Member should take into consideration the technical suggestions in the latest edition of the “Code of Practice on safety and health in dock work” published by the International Labour Office. This Code was revised as the “Code of Practice on safety and health in ports” and, as of 2005, it is also posted on the IMO website [4].

As this suggests, although the “Code of Practice on safety and health in ports” is cited in the technical requirements of ILO C152, it is ultimately only guidance and lacks legal binding force. Consequently, its implementation is left to the discretion of the ratified countries of the ILO Convention.

The composition of the above-mentioned documents is as shown in Table 2. In particular, the main technical requirements for onboard lifting appliances are specified in Chapter 4 Lifting appliances and loose gear of the “Code of Practice on safety and health in ports” as 4.1 Basic Requirements, 4.2 Testing, thorough examination, marking and inspection of lifting appliances and loose gear, 4.3.1 Ships’ lifting appliances (in 4.3), 4.4 Loose gear, and 4.5 Lifting devices forming an integral part of a load. Parts of these requirements have also been incorporated in the Rules of the Society.

The obligation to implement ILO C152 is, in principle, borne by the ratified countries of the Convention. However, on the condition that safe labour conditions are maintained, Article 2.1 of the Convention recognizes exemptions or exceptions to the requirements for dock work at any place where the traffic is irregular and confined to small ships, as well as in respect of dock work in relation to fishing vessels or specified categories thereof. Article 2.2 of the same Convention permits variation of particular requirements specified in Part III of the Convention provided that, after consultation with organizations of employers and workers, the competent authority is satisfied that overall protection will not be inferior to that if the provisions of the Conventions were fully applied. Based on these points, there are, strictly speaking, cases where the handling will differ in each port, even when the ports are under the jurisdiction of the ratified countries. Moreover, some nations have also established independent systems similar to ILO C152 under domestic law, even though the country has not ratified ILO C152. (For example, the examination requirements of ILO C152 are applied mutatis mutandis in Australia and the United States.)

Thus, whether ILO C152 is applied or not differs at each port, not limited to ratified countries, and as a result, those engaged in ship operation work must pay careful attention to whether dock work is being carried out, and under what type of safety and health management, at each port of call.

It may be noted that the only 27 countries listed in Table 3 had ratified ILO C152 as of November, 2025 [5]. From the beginning of the proposed amendment to the SOLAS Convention, this small number of ratifying countries is pointed out as the reason for international standards that can be applied uniformly to onboard lifting appliances are inadequate in conjunction with the application of ILO C152 is limited to lifting appliances for cargo applications used by dock workers (DSC 16/5/5 (ICHCA).

Safety requirements related to onboard lifting appliances and anchor handling winches are specified as Regulation 3-13 in Chapter II-1 of the SOLAS Convention. After they become effective, the thorough examinations and load tests required for onboard lifting appliances move to the survey schedules under Chapter II-1 of the SOLAS Convention. Specifically, the requirements of ILO C152 stipulate that thorough examinations are to be carried out at intervals not to exceed 12 months, and load testing is to be performed once in every 5 years. In contrast to the ILO C152, the survey schedules move to at Safety Construction surveys under Chapter II-1 of the SOLAS. In particular, for thorough examinations, the SOLAS provides a grace period of 3 months before and after the anniversary dates for annual surveys and interim surveys.

Concerns regarding the coexistence of two different survey schedules, as provided in ILO C152 and Regulation 3-13, Chapter II-1 of the SOLAS Convention, were also expressed in the discussion of the amendment to the SOLAS Convention (SSE 7/9/3 (China)). As the response by the IMO, in periodical survey of Safety Construction surveys, handling that ensures appropriate implementation of thorough examinations based on examination of records was introduced (SSE 7/21 (IMO Secretariat)), and informing the ILO of the proposed SOLAS Convention amendment and requesting appropriate action (MSC 106/19 (IMO Secretariat)) is also agreed, while continuing to accept the survey schedule in accordance with ILO C152.

As of November, 2025, no additional information on the results of requests to the ILO has been obtained. Therefore, the possible responses for ships subject to application of the survey schedule based on ILO C152 are either to check the records of implementation of thorough examinations when Safety Construction surveys are conducted, or to specifically conduct a thorough examination when deemed necessary.

Table 2 Composition of ILO C152, ILO R160 and the Code of Practice on safety and health in ports

ILO C152	
Preamble	
Part I.	Scope and Definitions (Articles 1 to 3)
Part II.	General Provisions (Articles 4 to 7)
Part III.	Technical Measures (Articles 8 to 40)
Part IV.	Implementation (Articles 41 and 42)
Part V.	Final Provisions (Articles 43 to 51)

ILO R160	
Preamble	
I.	Scope and Definitions (Paragraphs 1 and 2)
II.	General Provisions (Paragraphs 3 to 6)
III.	Technical Measures (Paragraphs 7 to 27)

Code of Practice on safety and health in ports	
Preface	
List of abbreviations and acronyms	
1.	Introduction, scope, implementation and definitions (Paragraphs 1.1 to 1.5)
2.	General provisions (Paragraphs 2.1 to 2.8)
3.	Port infrastructure, plant and equipment (Paragraphs 3.1 to 3.15)
4.	Lifting appliances and loose gear (Paragraphs 4.1 to 4.5)
5.	Safe use of lifting appliances and loose gear (Paragraphs 5.1 to 5.4)
6.	Operations on shore (Paragraphs 6.1 to 6.25)
7.	Operations afloat (Paragraphs 7.1 to 7.11)
8.	Dangerous goods (Paragraphs 8.1 to 8.4)
9.	Health (Paragraphs 9.1 and 9.2)
10.	Personnel welfare facilities (Paragraphs 10.1 to 10.7)
11.	Emergency arrangements (Paragraphs 11.1 to 11.3)
12.	Other relevant safety matters (Paragraphs 12.1 and 12.2)
References	
Appendices (Appendix A to H)	
List of figures	

Table 3 Ratified countries of ILO C152 (27 countries as of November, 2025)

Country	Ratification date
Brazil	18 May 1990
Congo	24 Jun 1986
Cuba	15 Oct 1982
Cyprus	13 Nov 1987
Denmark	22 Dec 1989
Ecuador	20 May 1988
Egypt	03 Aug 1988
Finland	03 Jul 1981
France	30 Jul 1985
Germany	17 Dec 1982
Guinea	08 Jun 1982
Iraq	17 Apr 1985
Italy	07 Jun 2000
Jamaica	04 Nov 2005
Lebanon	06 Sep 2004

Country	Ratification date
Mexico	10 Feb 1982
Montenegro	27 Apr 2017
Netherlands(Kingdom of the)	13 May 1998
Norway	05 Dec 1980
Peru	19 Apr 1988
Republic of Moldova	22 Jan 2007
Russian Federation	14 Jul 2004
Seychelles	28 Oct 2005
Spain	03 Mar 1982
Sweden	13 Jun 1980
Türkiye	17 Mar 2005
United Republic of Tanzania	30 May 1983

4. AMENDMENT OF RULES FOR CARGO HANDLING APPLIANCES

Accompanying the establishment of Regulation 3-13, Chapter II-1 of the SOLAS Convention and its related guidelines, the Society's Rules for Cargo Handling Appliances were amended to incorporate the content of SOLAS Regulation 3-13. Although this amendment also includes some provisional content, the content of the amended Rules is introduced in this chapter.

Conventionally, the Society's Rules for the Survey and Construction of Steel Ships have specified requirements generally related to the structural safety and seaworthiness of ships, such as requirements for the hull construction, machinery, materials and welding. In contrast, the Society's Rules for Installations provide technical requirements for various types of equipment that are not handled in the Rules for the Survey and Construction of Steel Ships but are necessary for ship operation, including life-saving equipment, radio equipment, accommodation and sanitation equipment, equipment for prevention of marine pollutions, and cargo handling appliances, in which safety is particularly required. Based on this, the requirements for anchor handling winches were specified in the Rules for Installations, and the title "Rules of Cargo Handling Appliances" was amended to "Rules for Lifting Appliances and Anchor Handling Winches."

The composition of "Rules for Lifting Appliances and Anchor Handling Winches" is as shown in Table 4. The Technical Requirements for lifting appliances and anchor handling winches are specified in Part 1 and Part 2, respectively. The contents of the two parts are introduced in the following.

Table 4 Composition of Rules for Lifting Appliances and Anchor Handling Winches and its Guidance

After amendment: Rules for Lifting Appliances and Anchor Handling Winches		Before amendment: Rules for Cargo Handling Appliances
Part 1 LIFTING APPLIANCES	Chapter 1 GENERAL **(partial revision)**	Chapter 1 GENERAL
	Chapter 2 SURVEYS **(partial revision)**	Chapter 2 SURVEYS
	Chapter 3 DERRICK SYSTEMS (no important revisions)	Chapter 3 DERRICK SYSTEMS
	Chapter 4 CRANES (no important revisions)	Chapter 4 CRANES
	Chapter 5 CARGO FITTINGS (no important revisions)	Chapter 5 CARGO FITTINGS
	Chapter 6 LOOSE GEAR (no important revisions)	Chapter 6 LOOSE GEAR
	Chapter 7 MACHINERY, ELECTRICAL INSTALLATIONS AND CONTROL ENGINEERING SYSTEMS (no important revisions)	Chapter 7 MACHINERY, ELECTRICAL INSTALLATIONS AND CONTROL ENGINEERING SYSTEMS
	Chapter 8 CARGO LIFTS AND CARGO RAMPS (no important revisions)	Chapter 8 CARGO LIFTS AND CARGO RAMPS

After amendment

Rules for Lifting Appliances and Anchor Handling Winches	
Part 1 LIFTING APPLIANCES	Chapter 9 CERTIFICATION, MARKING AND DOCUMENTATION **(partial revision)**
	Chapter 10 OPERATION, MAINTENANCE, INSPECTION AND OPERATIONAL TESTING **(new)**
Part 2 ANCHOR HANDLING WINCHES **(new)**	Chapter 1 GENERAL
	Chapter 2 SURVEYS
	Chapter 3 DESIGN, CONSTRUCTION AND INSTALLATION
	Chapter 4 OPERATION, MAINTENANCE, INSPECTION AND OPERATIONAL TESTING

Before amendment

Rules for Cargo Handling Appliances
Chapter 9 CERTIFICATION, MARKING AND DOCUMENTATION

After amendment

Guidance for Lifting Appliances and Anchor Handling Winches	
Part 1 LIFTING APPLIANCES	Chapter 1 GENERAL (no important revisions)
	Chapter 2 SURVEYS (no important revisions)
	Chapter 3 DERRICK SYSTEMS (no important revisions)
	Chapter 4 CRANES (no important revisions)
	Chapter 6 LOOSE GEAR (no important revisions)
	Chapter 7 MACHINERY, ELECTRICAL INSTALLATIONS AND CONTROL ENGINEERING SYSTEMS (no important revisions)
	Chapter 8 CARGO LIFTS AND CARGO RAMPS (no important revisions)
	(For foreign flag ships) Annex 1.1.1-9 ADDITIONAL REQUIREMENTS FOR CRANES USED FOR PERSONNEL TRANSFERS (no important revisions)
	(For Japanese flag ships) Annex 1.1.1-10 ADDITIONAL REQUIREMENTS FOR CRANES USED FOR PERSONNEL TRANSFERS **(new)**
Part 2 ANCHOR HANDLING WINCHES **(new)**	Chapter 1 GENERAL

Before amendment

Guidance for Cargo Handling Appliances
Chapter 1 GENERAL
Chapter 2 SURVEYS
Chapter 3 DERRICK SYSTEMS
Chapter 4 CRANES
Chapter 6 LOOSE GEAR
Chapter 7 MACHINERY, ELECTRICAL INSTALLATIONS AND CONTROL ENGINEERING SYSTEMS
Chapter 8 CARGO LIFTS AND CARGO RAMPS
(For foreign flag ships) Annex 1.1.1-3 ADDITIONAL REQUIREMENTS FOR CRANES USED FOR PERSONNEL TRANSFERS

4.1 Lifting Appliances (Part 1)

4.1.1 Application and Definitions (Chapter 1)

The scope of application was amended as shown in Table 5 to conform to Regulation 3-13, Chapter II-1 of the SOLAS Convention, and the limitation of application to power operated cargo handling appliances was deleted. Since Japanese flag ships also conform to Japanese domestic laws and regulations, the object ships are different from those subject to the rules for foreign flags ships.

Here, lifting appliances outside the scope of application were specified in accordance with Regulation 3-13, Chapter II-1 of the SOLAS Convention. In this requirement, “integrated mechanical equipment for opening and closing hold hatch covers” means equipment having a mechanical structure consisting of a folding or side-rolling type hatch cover. In addition, it should be noted that when life-saving launching appliances conforming to the LSA Code are subject to application of the requirements for lifting appliances, when they are also used to retrieve cargo.

In application of the requirements of Regulation 3-13, Chapter II-1 of the SOLAS Convention, the requirements and timing of application differ depending on the installation date of the lifting appliance. Therefore, the Society's Rules also specify these requirements according to the divisions shown in Table 6 in the text of the Rules. The requirements related to design, construction and installation are applied to lifting appliances installed on or after 1 January 2026 (see Note 2 of Table 6). However, the requirements related to operational testing, thorough examinations, inspections, operation and maintenance are applicable on and after 1 January 2026, irrespective of the installation date of the lifting appliance. In particular, it needs to be noted that thorough examinations are to be witnessed by a "competent person" (e.g., a ClassNK surveyor). For lifting appliances with a safe working load (SWL) of less than 1 000 kg, the extent of application of the requirements for design, construction, installation and load testing is left to the discretion of the Administration. The Society also confirms the judgements of the Administrations with each Administration and posts this information on the ClassNK website, where can be accessed by interested parties [6]. Note also that the requirements for operational testing, thorough examinations, inspections, operation and maintenance are applied irrespective of the discretion of the Administration.

Definitions have been amended to be consistent with Regulation 2, Chapter II-1 of the SOLAS Convention and the related guideline MSC.1/Circ.1663. Before amendment, the Rules for Cargo Handling Appliances used the terms "cargo handling appliances" (lifting appliances and loose gear), "lifting appliances" (cargo gears and cargo ramps) and "cargo gears" (derrick systems, cranes, cargo lifts, etc. for the loading and unloading cargo) only for foreign flag vessels, and the handling of cargo ramps and other appliances was different in the Rules for foreign and Japanese flag ships. However, in accordance with Regulation 3-13, Chapter II-1 of the SOLAS Convention, those terms were unified as "lifting appliances," and cargo ramps were included in lifting appliances, limited to those that open/close or turn while loaded with cargo. In addition, other definitions in MSC.1/Circ.1663, etc. (such as "competent person," etc.) have also been included.

Table 5　Amendments of scope of application

After amendment	Before amendment
(For foreign flag ships) Applicable to lifting appliances and loose gear installed on the following ships: (1) Passenger ships engaged on international voyages (including high-speed crafts) (2) Cargo ships not less than 500 gross tonnage engaged on international voyages (same as above)	(For foreign flag ships) Applicable to power operated lifting appliances
(For Japanese flag ships) Applicable to lifting appliances and loose gear installed on ships not less than 300 gross tonnage, except passenger ships	(For Japanese flag ships) Applicable to following power operated lifting appliances: (1) Lifting appliances and loose gear with a safe working load (SWL) of not less than 1 000 kg installed on ships not less than 300 gross tonnage, excluding passenger ships (2) Cargo ramp equipment
(For both foreign and Japanese flag ships) The following lifting appliances are outside the scope of application: (1) Lifting appliances installed on ships certified as MODU (2) Lifting appliances used on offshore construction ships which comply with standards acceptable to the Administration (3) Integrated mechanical equipment for opening and closing hold hatch covers (4) Life-saving launching appliances complying with the LSA code	(For both foreign and Japanese flag ships) (New)

Table 6　Differences in application of requirements by installation date of lifting appliances

Installation date	Requirement	Timing of application
Before 1 January 2026 [1)]	Based on Part 1, load tests, thorough examinations, marking of SWL (documentary evidence is to be provided and kept onboard the ship)	Before first special survey after 1 January 2026
	Based on Part 1, operational testing, thorough examinations, inspections, operation and maintenance	On or after 1 January 2026
On or after 1 January 2026 [1) 2)]	Based on Part 1, Design, construction and installation, load tests, thorough examinations, marking of SWL (documentary evidence is to be provided and kept onboard the ship)	Before first use
	Based on Part 1, operational testing, thorough examination, inspection, operation and maintenance	On or after 1 January 2026

1) For lifting appliances with a safe working load (SWL) of less than 1 000 kg, the extent of application of requirements related to design, construction and installation and load tests is to be determined by the Administration.

2) Lifting appliances installed on or after 1 January 2026 means:
a) Lifting appliances installed on a ship of which the keel was laid, or in a similar stage of construction, on or after 1 January 2026
b) For ships other than those in the above a) (including ships constructed before 1 January 2009), lifting appliances having a contractual delivery date (or the actual delivery date in the absence of a contractual delivery date) on or after 1 January 2026

4.1.2 Timing of Surveys (Chapter 2)

In line with Regulation 3-13, Chapter II-1 of the SOLAS Convention and MSC.1/Circ.1663, the term “annual thorough survey” was amended to “thorough examination”. As the timing of thorough examinations, since these examinations are now under Chapter II-1 of the SOLAS Convention, the timing of examinations which had formerly followed the requirements of ILO C152 (i.e., a timing not to exceed 12 months from the date of completion of the previous annual thorough survey) was amended to the timing of the annual survey and interim survey in Safety Construction surveys (i.e., the timing of annual surveys and interim surveys of the classification survey, which are similar in terms of practical work). In addition, the timing is also specified to be after the load test. No substantial changes were made in the timing of the load tests.

To avoid the possibility of duplication of thorough examinations based on the SOLAS Convention and ILO C152, when a thorough examination is to be conducted in accordance with ILO C152, MSC.1/Circ.1663 recognizes verification, by examination of the records, that a thorough examination was properly conducted and completed at the timing of an annual survey or interim survey of the ship. Therefore, a related provision, making it possible to respond to this requirement by application, was also included in the Society’s Rules.

Postponement of the timing of thorough examinations are no longer recognized when a thorough examination is carried out at the timing of an annual survey or interim survey of the ships. This is because extensions of annual surveys and interim surveys of the ships are not recognized. However, since the timing of the thorough examination becomes the same timing as the annual survey or interim survey, a window of 3 months after the anniversary date is considered. Therefore, there is no substantial change from the previous practice. When a thorough examination is carried out at the timing according to ILO C152 by application, there may be cases where the examination deadline is extended by 3 months, as in the past. On the other hand, load tests must be carried out at a timing not to exceed 5 years from the date of completion of the previous load test. Thus, if a load test is carried out at the timing of a special survey of classification society, it may exceed the 5-year limit. In this case, careful attention must be paid when applying for an extension, since the approval of the Administration is required.

4.1.3 Inoperative Lifting Appliances and Loose Gear, Designation as Out-of-Service (Chapter 2)

When a deficiency that affects the operational safety of a lifting appliance or loose gear is discovered in a thorough examination in accordance with the requirements of MSC.1/Circ.1663, use of that lifting appliance or loose gear is to be prohibited until the deficiency is rectified (until that time, the device is to be marked as “not to be used,” and its status is to be recorded in the survey records etc.). This requirement also specifies actions to be taken by the ship’s master to reduce the risk of inoperative lifting appliances and loose gear (e.g., lashing, marking as inoperative, record-keeping).

4.1.4 Load Test (Chapter 2)

The requirements for load tests of lifting appliances and loose gear were amended in accordance with the requirements of

MSC.1/Circ.1663. For cases where the safe working load (SWL) of a lifting appliances is 100 tonnes or more, the load to be used in the load test was changed from the former "load as considered appropriate by the Society" to "1.1 times the safe working load (SWL)." However, in actual practice, there is no change because 1.1 times SWL was also used before the amendment. On the other hand, in accordance with JIS F 3421, load tests of loose gear had been performed with different test loads for loose gear with and without a becket. For compatibility with international standards and clarification of the handling, this requirement was amended in accordance with MSC.1/Circ.1663 so that tests are to be performed using the same test load with or without a becket.

For lifting appliances and loose gear intended for open-sea operations, this requirement specifies that the test load must be to the satisfaction of the Administration, taking into account dynamic loads such as ship motion (rolling, pitching) and waves, as a requirement that considers designs to withstand use under more severe environments (e.g., designs based on EN 13852-2, API Spec 2C, etc.).

When information concerning the safe working load (SWL) is not documented and design information is not available, for example, in case the manufacturer of an existing lifting appliance (installed prior to 1 January 2026) no longer exists, etc., this requirement stipulates that the test load is to be determined based on the SWL nominated by the ship owner or ship management company, to the satisfaction of the Administration.

4.1.5 Assignment and Marking of Safe Working Load and Certificates (Chapter 9)

In accordance with MSC.1/Circ.1663, this requirement specifies that diagrams of the permissible maximum loads over the entire range of use are to be displayed in a position where they are clearly visible to the operator. For example, for cranes, it is assumed that the diagram is a performance curve showing the slewing radius (outreach) on the X-axis and the Safe Working Load (SWL) on the Y-radius, and is displayed in a position within the field of view from the control panel or in the operating cabin. (As supplemental information, the boom length, boom angle, etc. are also included in some cases.)

Although not directly related to MSC.1/Circ.1663, for stamping of the SWL, the former requirement had stipulated use of a weld bead and paint or other methods recognized by the Society to be equivalent. However, to make it clear that marking by punch marks is also recognized, the expression "weld bead and paint" was deleted. The former rules had stipulated that the height of the characters marked on lifting appliances and loose gear is to be not less than 77 mm. However, this provision was amended by limiting the requirement to derricks, since it is only applied to derricks in ILO C152. In addition, requirement for marking of loose gear was amended to content requiring marking corresponding to the type of loose gear.

When the test load of a lifting appliance is determined based on the SWL nominated by the ship owner or the ship management company, as mentioned at the end of section 4.1.4 above, in accordance with MSC.1/Circ.1696, a factual statement for the load test is to be issued in place of the standard load test certificate, based on the fact that the potential safety of the appliance (materials, design strength, etc.) is different from those of lifting appliances verified by examination of drawings, etc. in the design, manufacture and installation stages.

4.1.6 Operation, Maintenance, Inspection and Operational Testing (Chapter 10)

The fact that proper implementation of operation, maintenance, inspections and operational testing is important for reducing accidents involving lifting appliances has been pointed out by the related Administrations and industry groups since development of international standards for lifting appliances began. Therefore, in view of its importance, the requirements of MSC.1/Circ.1663 were incorporated as-is, as matters to be observed by ship owners and ship operators responsible for ship operation.

For operation and maintenance manuals, the requirements formerly specified in Chapter 9 were moved to Chapter 10, accompanying the establishment of the new Chapter 10.

4.2 Anchor Handling Winches (Part 2)

4.2.1 Application and Definitions (Chapter 1)

In the rules for both Japanese flag ships and foreign flag ships, the scope of application was specified as anchor handling winches and loose gear installed on ships not less than 500 gross tonnage engaged in international voyages, so as to be consistent with Regulation 3-13, Chapter II-1 of the SOLAS Convention. As in the case of lifting appliances, under Regulation 3-13, Chapter II-1 of the SOLAS Convention, the requirements and timing of application differ depending on the date of installation of the anchor handling winch. Therefore, in the Society's Rules, this point was also specified separately depending on the installation date, as shown in Table 7. Here, it should be noted that the requirements for operational testing, thorough examinations, inspections, operation and maintenance apply from 1 January 2026, irrespective of the installation date of the anchor handling winch, as in the case of lifting appliances.

The definitions were amended for consistency with Regulation 2, Chapter II-1 of the SOLAS Convention and the related guideline MSC.1/Circ.1662. The definition of "anchor handling winch" is "any winch for the purpose of deploying, recovering and repositioning anchors and mooring lines in subsea operations" (SOLAS II-1/Reg.2.31). This term is different from windlasses and mooring winches used in mooring the ship itself, in that it refers to winches used to deploy, etc. the anchors and mooring lines of other vessels. Working winches installed in the forward part of the aft working deck of an anchor handling vessel (AHV) generally fall under this definition (Fig. 1). Classification by type of anchor (drag, pile, suction, etc.) is not assumed.

Table 7 Differences in applied requirements by installation date of anchor handling winches

Installation date	Requirements	Timing of Application
Before 1 January 2026	Based on Part 2, Periodic survey (functional confirmation), thorough examination	Before first special survey after 1 January 2026
	Based on Part 2, Operational testing, thorough examination, inspection, operation and maintenance	On or after 1 January 2026
On or after 1 January 2026 [1]	Design, construction and installation, testing and thorough examination, where deemed applicable under Part 2 and the Administration	Before first use
	Based on Part 2, operational testing, thorough examination, inspection, operation and maintenance	On or after 1 January 2026

1) Anchor handling winches installed on or after 1 January 2026 means:

a) Anchor handling winches installed on a ship of which the keel was laid, or in a similar stage of construction, on or after 1 January 2026

b) For ships other than those in the above a) (including ships constructed before 1 January 2009), anchor handling winches having a contractual delivery date (or the actual delivery date in the absence of a contractual delivery date) on or after 1 January 2026

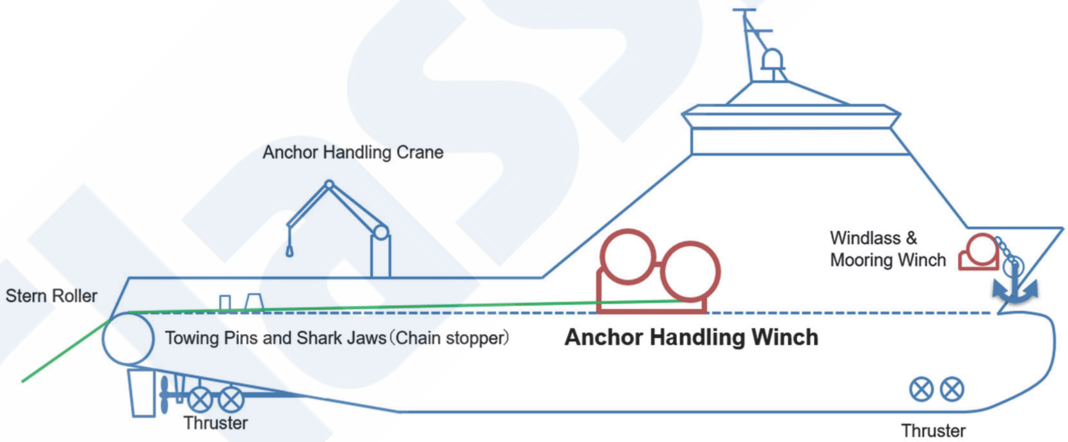

Fig. 1 Image of arrangement of anchor handling winch

4.2.2 Arrangement, Construction and Materials (Chapter 1)

Chapter 8, Part O of Rules for the Survey and Construction of Steel Ships specifies requirements for anchor handling vessels. However, the requirements for the arrangement and construction of anchor handling winches were moved to Part 2 of the Rules for Lifting Appliances and Anchor Handling Winches. Although no clear requirements were provided for materials, the range of the minimum limits considered necessary for safety was specified in accordance with the requirements of Part 1 "Lifting Appliances."

4.2.3 Surveys (Chapter 2)

General requirements related to preparations for surveys, etc. were specified in accordance with Part 1 "Lifting Appliances." In accordance with MSC.1/Circ.1662, the content is the same as that of the requirements in Part 1 "Lifting Appliances," and the handling of out-of-service anchor handling winches and loose gear, inoperative anchor handling winches, associated equipment and loose gear was specified.

The types of surveys may be classified as registration surveys (registration survey during construction, registration survey of anchor handling winches not built under Survey) and periodical surveys for maintaining registration (thorough examination, periodical test (annual survey), occasional survey, unscheduled survey). Among the registration surveys and periodical surveys for maintaining registration, the timing of thorough examinations and periodical test is as shown in Table 8. The timing of occasional surveys and unscheduled survey is the same as in Part 1 “Lifting Appliances.”

As the content of the surveys, in line with the requirements of Part 1 “Lifting Appliances” and MSC.1/Circ.1662, registration surveys, thorough examinations and periodical tests are stipulated as shown in Table 9. Commissioning tests are tests which are conducted after an anchor handling winch is installed on a ship. Among these tests, a load test at a load that exceeds the maximum line pull force is assumed. However, since the maximum line pull force of some anchor handling winches exceeds 400 tonnes, depending on the winch, it is assumed that there may be cases where the test cannot be conducted because the necessary test environment cannot be prepared, etc. Therefore, it is considered necessary to clarify the handling of this test in the future, based on the possibility of executing the test.

Table 8 Timing of registration surveys and periodical surveys for maintaining registration (thorough examinations, periodical tests)

Survey category 1	Survey category 2	Timing
Registration survey	Registration survey during construction	When applying for registration
	Registration survey of anchor handling winches not built under Survey	
Periodical surveys for maintaining registration	Thorough examinations	At time of the following class surveys (Part B, Rules) • Registration survey • Annual survey [1], intermediate survey [1], special survey
	Periodical tests	At time of the following class surveys (Part B, Rules) • Annual survey [1], intermediate survey [1], special survey

1) In place of an actual survey, this requirement may also be satisfied by examination of operation test records.

Table 9 Content of registration surveys and periodical surveys for maintaining registration (thorough examinations, periodical tests)

Survey category 1	Survey category 2	Examination of drawings	Survey (inspection)
Registration survey	Registration survey during construction	<u>Drawing to be submitted for approval:</u> • General arrangement of anchor handling winch • Construction drawing of anchor handling winch • Drawings of fittings • Arrangement of loose gear • List of loose gear • Construction drawing of drive gears • Power system diagram • Drawings of operation and control mechanisms • Drawings of safety devices • Drawings of protective devices • Other drawings and documents deemed necessary by the Society <u>Documents to be submitted for reference:</u> • Specification for anchor handling winch • Calculation sheets or check sheets relevant to drawings and documents for approval • Anchor handling winch operation and maintenance manual	<u>Surveys in work:</u> • Workmanship of anchor handling winches and loose gear is to be examined and ascertained to be in good order • Tests specified in Part K of the Rules (where necessary) • Tests specified in Part M of the Rules (where necessary) • Nondestructive testing (where necessary) • Shop trials of driving gears • Operational tests of safety and protective devices (including braking test and electric power source cutoff test) • Others test deemed necessary by the Society <u>Commissioning test:</u> • Functional testing and operational testing under light load • Overload tests • Emergency release and residual brake holding force test • Static bollard pull test (only when used for towing) • Brake holding test (can also be demonstrated by calculation) • Function test of whole winch systems

Survey category 1	Survey category 2	Examination of drawings	Survey (inspection)
		• Commissioning test procedure • Asbestos-free declarations and supporting documents • Other drawings and documents deemed necessary by the Society	Thorough examination: • According to the content of periodical surveys for maintaining registration
	Registration survey of anchor handling winches not built under Survey	In principle, same as registration survey during construction	In principle, same as registration survey during construction
Periodical surveys for maintaining registration	Thorough examinations	None	Anchor handling winch: • Thorough examination by visual examination ➢ Structural members ➢ Connections between structural members and hull structure ➢ Installations of drive system ➢ Safety devices and protective devices ➢ Markings and validity of the relevant certificates ➢ Provision of operation and maintenance manuals on board the ship • Surveys considered necessary by the Surveyor ➢ Measurement of plate thickness, nondestructive testing, open-up examination ➢ Operational testing of safety and protective devices Loose gear: • Thorough examination by visual examination ➢ Wires throughout their full length ➢ Chains, rings, hooks, shackles, swivels, clamps, etc. ➢ Marking of SWL and identifying symbols marking of loose gear and validity of the relevant certificates • Open-up examination when considered necessary by Surveyor
	Periodical tests	None	• Operational testing and functional testing of all equipment as recommended by the manufacturer

4.2.4 Design of Anchor Handling Winches (Chapter 3)

The design requirements (and some inspection items) for anchor handling winches and their associated equipment were assumed in accordance with the requirements of MSC.1/Circ.1662. Some of the requirements of Chapter 8, Part O of Rules for the Survey and Construction of Steel Ships were also moved and incorporated in the Rules for Lifting Appliances and Anchor Handling Winches. The main requirements are as shown in Table 10.

Table 10 Design requirements (including some inspection items) of anchor handling winches and associated equipment

Requirement item	Content of requirement	Supplementary explanation
Speed control and handling	• Should be capable of hoisting and lowering in a controlled manner. • Should be provided with adjustable speed control between the minimum and maximum speeds. • Should be designed to pay out the wire by moving the control lever away from the operator, and to heave in by pulling the control lever towards the operator. • Should be permanently marked with signs indicating the operating direction. • The control lever should be a "hold-to run" type that automatically returns to the neutral position when released by the operator.	MSC.1/Circ.1662 Para.3.1.2
Tension control	• Should be equipped with tension control to prevent overloading. • Should be equipped with a means of measuring tension for display of tension at the control station.	MSC.1/Circ.1662 Para.3.1.3
Overload alarm and monitoring	• Should be provided with continuous load monitors and an audible and visual overload alarm. • The overload alarm should be programmable for lower levels of load. (Pre-overload alarm)	MSC.1/Circ.1662 Para.3.1.4
Control stations	• The main control station should be in a position on the navigation bridge with a clear view of the deck area. • If the view is obstructed, cameras or video monitoring equipment may be used as supplementary devices. • Where a winch is controlled from more than one control station, an arrangement for preventing simultaneous control is to be provided. • Each control station should be provided with the following: ➢ Means of two-way communication with the main control station ➢ Arrangement to prevent inadvertent actuation ➢ Adequate protection for personnel ➢ Sufficient lighting (not less than 320 Lux)	MSC.1/Circ.1662 Para.3.1.5
Spooling device	Anchor handling winches should be equipped with remotely operated spooling devices.	MSC.1/Circ.1662 Para.3.1.6
Emergency release	• Should be designed to facilitate safe and controlled emergency release under both normal and dead-ship conditions. • Controls for actuation of emergency release should be conducted in the main control station (the emergency release function may also be available from the local control station). • Should be protected against unintentional activation. • The emergency release should be design considering restrictions on the wire pay-out speed due to inertia and any restrictions due to onboard arrangements. • Instructions for the operation of the emergency release should be clearly displayed at the navigation bridge and locally at the winch. • After emergency release, an inspection should be carried out, and any damage should be rectified.	MSC.1/Circ.1662 Para.3.1.7
Chain stopper	• Chain stoppers (including wire stoppers) should be provided. • Should be equipped with an audible alarm that activates when the stopper is engaged or disengaged. • Should be equipped with an emergency release that functions under all conditions, including the dead-ship condition (also including disengagement of pins, etc. that can cause entanglement of the wire during release). • Emergency release should be designed for remote operation. • Should be protected against unintentional activation. • Instructions for operation of the emergency release should be clearly displayed at the navigation bridge and locally on the emergency release control mechanism side. • After an emergency release, the chain stopper system should be inspected, and any damage should be rectified.	MSC.1/Circ.1662 Para.3.1.8.1

Requirement item	Content of requirement	Supplementary explanation
Winch brake	• The winch brake is to be provided with a means of controlling power braking (regenerative brake, dynamic brake, etc.) capable of maintaining control at low speeds. • Brakes are to be applied automatically upon loss of power and whenever the winch lever is returned to the neutral position.	Moved from 8.5.3, Part O of the Rules
Power supply	• When the power supply for an anchor handling winch is the same as the power supply for propulsion equipment (shaft generators, shaft power take-offs (PTO, etc.), independent redundant power supply is to be provided. • The power supply is to have sufficient capacity for operation of the anchor handling winch, so that ship maneuverability performance is not degraded during winch operation (anchor handling, towing).	Moved from 8.5.4, Part O of the Rules

4.2.5 Operation, Maintenance, Inspection and Operational Testing (Chapter 4)

As in Chapter 1 "Lifting Appliances," the matters to be observed by the ship owners or ship operators responsible for ship operation are specified. For the content of the Rules for Lifting Appliances and Anchor Handling Winches, the provisions of MSC.1/Circ.1662 were incorporated without modification.

4.2.6 Installations Character

Accompanying the new establishment of requirements for anchor handling winches in the Rules for Installations, "AHW" was added to Chapter 3 of the Regulations for Classification and Registry of Ships as a new installations character.

5. CONCLUSION

With the aim of preventing accidents involving onboard lifting appliances and anchor handling winches and improving the safety of seamen, Regulation 3-13, Chapter II-1 of the SOLAS Convention and the related guidelines were finally enacted after a lengthy study of the establishment of internationally-unified standards. Following this, further improvement in the safety of onboard lifting appliances and anchor handling winches is expected, based on mandatory requirements established by the Administrations. On the other hand, there are also uncertainties regarding the actual operation of these regulations, including the objects and timing of application of the requirements, the response to the existing ILO C152, test conditions, etc. In the future, the Society will continue its efforts to clarify the requirements through amendment of the ClassNK Rules, to enable smooth compliance of the equipment concerned with the requirements of the SOLAS Convention. In addition to revisions of the ClassNK Rules, the Society will also share information whenever appropriate through ClassNK Technical Information [7) 8) 9)] and special pages [6)] of the Society website, and will promptly share information when additional information is obtained from the Administrations, the IMO, IACS and others. Inquiries regarding the application of the Society's rules will continue to be handled by our Materials and Equipment Department (concerning rules related to lifting appliances), Machinery Department (concerning rules related to anchor handling winches), and Survey Department (concerning survey-related matters), and stakeholders are kindly invited to seek clarification from these departments as needed.

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3) IMO: MSC.1/Circ1663, GUIDELINES FOR LIFTING APPLIANCES, 2023
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Cost Simulation Based on IMO's Mid-term GHG Reduction Measures

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1. INTRODUCTION

The international shipping sector is currently at a major turning point, facing the strengthening of greenhouse gas (GHG) emission reduction regulations led by the International Maritime Organization (IMO) and the European Union (EU). These regulations are not merely frameworks for achieving international environmental goals, but also elements that directly affect corporate strategies and the entire life cycle of ships. The choice of fuels, operational costs, and investment decisions for newbuilding or retrofitting are expected to be subject to the evolution of these regulatory frameworks. Under the IMO's proposed Mid-term measures currently under discussion, a progressive reduction in the GHG intensity of marine fuels will be required.

At the second extraordinary session of the Marine Environment Protection Committee (MEPC/ES.2) held in October 2025, discussions on the adoption of the Mid-term measures were postponed for one year due to differing views among the Member States. Although no agreement was reached, the overall direction toward maritime decarbonization as indicated by the IMO remains unchanged. This means that the industry will continue to be required to implement comprehensive GHG reduction measures, including fuel transition, under a global framework. Consequently, measures focusing solely on improving energy efficiency will no longer be sufficient to comply with future regulations. Medium- to long-term preparations, including the transition to alternative fuels, will be indispensable.

Against this background, it is increasingly important for the shipping industry to conduct economic assessments that comprehensively consider both fuel selection and regulatory compliance costs. Under this new framework, it will be essential to assess in advance the economic implications of fuel transition when formulating future strategies.

This paper utilizes ClassNK's cost simulation tool to analyze the potential impact of the IMO's Mid-term measures, with a particular focus on the cost implications arising from regulatory compliance, and outlines fundamental concepts for strategic assessment. It should be noted that the actual cost impact may vary significantly depending on future discussions at the IMO. The simulation results presented herein are based on assumptions established by ClassNK using information available at the time of publication, and are subject to change if underlying assumptions such as fuel prices, supply volumes, or GHG intensity are altered. Therefore, this paper should be regarded as an illustration of scenario analysis using ClassNK's simulation tool.

2. REGULATORY COST ASSESSMENT

The IMO's Mid-term measures are designed not only to encourage the transition to low- and zero-emission fuels, but also to account for the GHG emissions throughout the entire life cycle of fuels from fuel production to end use. Unlike previous regulations that focused only on emissions from combustion, the new framework aims to achieve actual emission reductions across the entire fuel supply chain, including production, transportation, storage, and use. In this context, the IMO's Mid-term measures represent a comprehensive regulatory approach to decarbonization across both ship operation and the broader energy value chain. Accordingly, to correctly understand the regulatory costs under the IMO's Mid-term measures, it is essential to grasp the concept of "Well-to-Wake (WtW)," which serves as the new evaluation framework. The specific assessment boundaries and calculation methods are described below.

(1) Concept of Well-to-Wake Emissions

The existing IMO regulations on CO2 emission reduction have primarily targeted direct emissions from onboard fuel combustion, that is, Tank-to-Wake (TtW) emissions. In contrast, under the IMO's Mid-term measures, GHG emissions are evaluated comprehensively across all stages of the fuel life cycle from production (Well) to combustion (Wake). Therefore, even if a fuel emits no GHG during combustion, it may still have high total emissions if fossil-based energy or raw materials are used in its production process. On the other hand, fuels such as e-fuels, which are produced using electricity derived from renewable energy and CO2 captured by direct air capture (DAC) can achieve a significant reduction in emissions across their entire life cycle. Thus, the production pathway of a fuel has a direct impact on the associated regulatory cost. This is one of the key characteristics of the IMO's Mid-term measures.

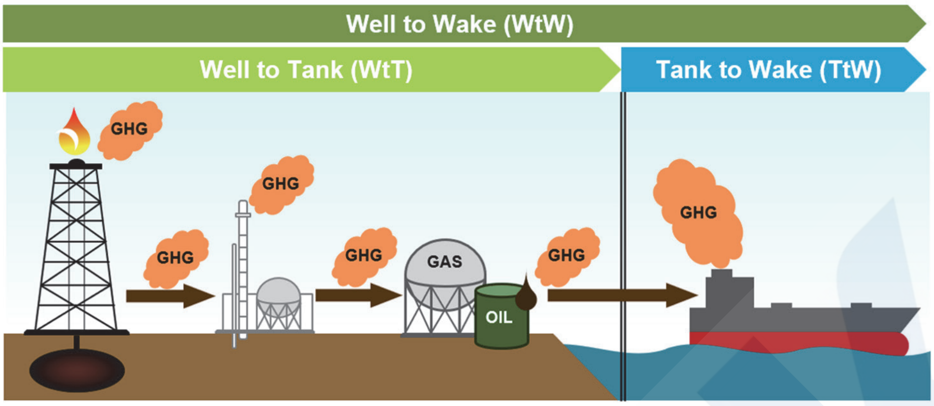

Fig. 1 Conceptual image of GHG emissions in the marine fuel life cycle

(2) Calculation of GHG Intensity

A representative indicator of a fuel's environmental performance is its GHG intensity, defined as the amount of life-cycle GHG emissions per unit of energy. As illustrated in Fig. 2, the GHG intensity of a single fuel can be calculated based on its emission conversion factor and lower calorific value.

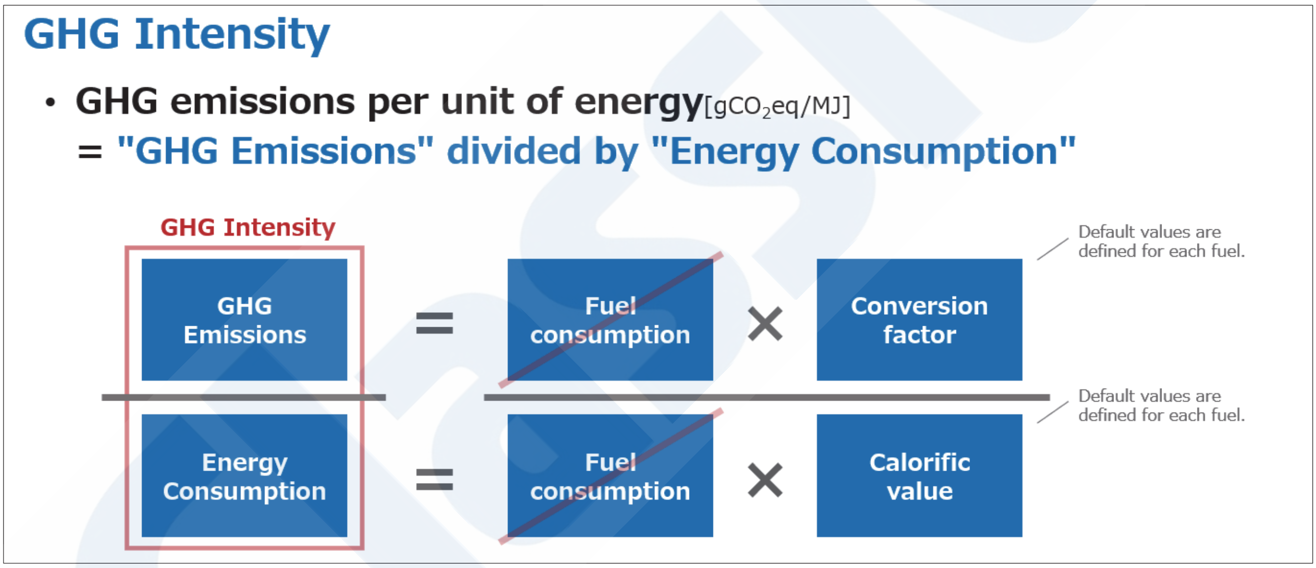

Fig. 2 Calculation of GHG intensity

However, since ships use multiple fuels in actual operation, rather than a single fuel, the average GHG intensity should be calculated as a weighted average based on the proportion of energy consumed from each fuel. For example, as shown in Fig. 3, if a ship uses equal amounts of energy derived from heavy fuel oil (HFO) and biodiesel (B100) with GHG intensities of 95.48 gCO2eq/MJ and 22.12 gCO2eq/MJ, respectively, the combined average GHG intensity is approximately 60.22 gCO2eq/MJ.

This means that even ships which mainly use conventional heavy fuel oils can reduce their overall GHG intensity below the regulatory target values by partially introducing low-carbon fuels such as B30, B100, or e-fuels. Partial introduction of low-carbon fuels offers flexibility in coping with uncertainties in fuel availability and price fluctuations, making it a practical mid-term transitional approach.

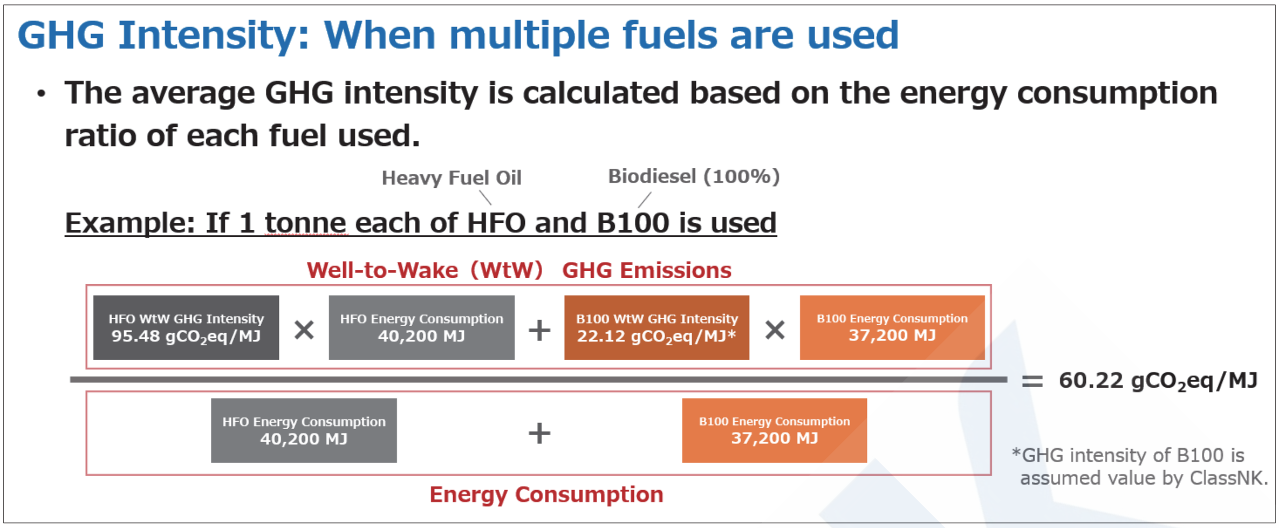

Fig. 3 Calculation of GHG intensity when multiple fuels are used

(3) GHG Intensity of Each Fuel

The LCA Guidelines developed by the IMO define a total of 128 fuel supply pathways, and default GHG intensity values can be calculated for each. However, at present, the default values for many fuels have not yet been finalized. For reference purposes, Fig. 4 provides approximate Well-to-Wake GHG intensity values for representative fuels. As shown in this figure, there are substantial differences in GHG intensity among various fuels. For example, the GHG intensity of low-sulfur heavy fuel oil (LSHFO) is approximately 95 gCO2eq/MJ, and decreases to about 77 gCO2eq/MJ for LNG (combustion system: diesel slow), 76 gCO2eq/MJ for biofuel B30, and 22 gCO2eq/MJ for B100. Synthetic fuels such as e-methanol and e-ammonia are expected to reach even lower levels of around 10 to 13 gCO2eq/MJ, while fossil-based grey methanol has a higher intensity of about 103 gCO2eq/MJ, exceeding that of heavy fuel oil. These results indicate that Well-to-Wake GHG intensity can vary significantly depending on the energy sources and feedstocks used in the production process, even for the same type of fuel.

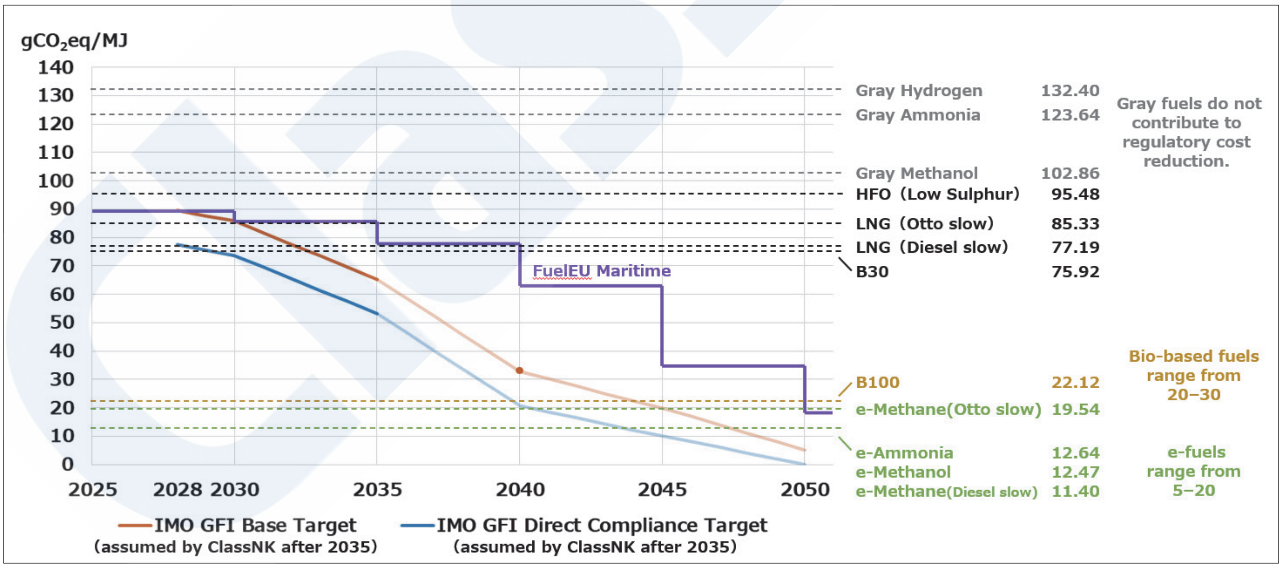

Fig. 4 Approximate Well-to-Wake GHG intensity and regulatory targets for various fuels

(4) Structure of Regulatory Costs and Optimization

Compliance with the regulations by paying contributions is also a key component of the IMO's Mid-term measures. Under this system, when a ship's actual GHG intensity exceeds the target, a contribution is paid in proportion to the excess amount. The amount of the contribution is calculated as shown in Fig. 5. For the period up to 2030, the proposed contributions are 100 USD/t-CO2eq for the excess above the Direct Compliance Target (Tier 1), and 380 USD/t-CO2eq for the excess above the Base Target (Tier 2).

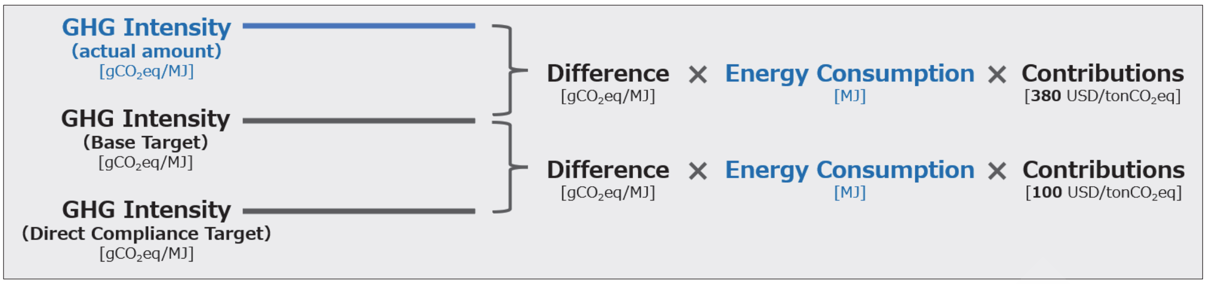

Fig. 5 Calculation method for contributions

Under this framework, there are two main elements by which the cost burden can be reduced through voluntary efforts:

(a) Reduction of annual GHG intensity (use of low-carbon fuels)

(b) Reduction of annual energy consumption (improvement of fuel efficiency)

Optimization of these factors will be the key to cost control and maintaining competitiveness in the coming years. While the introduction of low-carbon fuels is attracting attention as a primary compliance measure, the options actually available to ships remain limited. Therefore, in addition to fuel transition, improvements in operational efficiency and energy efficiency, that is, fuel efficiency improvement, will become an increasingly important element.

3. COST IMPACT OF THE MID-TERM MEASURES

In order to estimate the potential cost impacts associated with the IMO's Mid-term measures, in this chapter, a representative 64,000 DWT bulk carrier was assumed as the model vessel, and a cost projection was made assuming continued use of conventional fuel over the coming decades. The underlying assumptions applied in this estimation, which are kept constant through 2050, are as follows.

- Annual fuel consumption: 5,000 tons of HFO
- Fuel price: 500 USD/ton
- Contribution unit price:
  - Tier 1 (Direct Compliance Target exceedance): 100 USD/ton-CO2eq
  - Tier 2 (Base Target exceedance): 380 USD/ton-CO2eq
- Assessment period: 2025-2050

As shown in Fig. 6, assuming that fuel prices remain constant, the annual cost in 2025 is estimated to be approximately USD 2.5 million. However, due to the progressive strengthening of the IMO's Mid-term measures, regulatory costs are expected to rise year by year, surpassing fuel costs in the early 2030s. In particular, the additional contributions associated with exceeding the Base Target (Tier 2) have a significant impact, with total costs projected to increase by +102 % in 2035 compared to 2025, +202 % in 2040, and ultimately +280 % by 2050. In other words, if ships continue to use heavy fuel oil, regulatory costs are expected to substantially increase overall operating expenses, and could fundamentally alter the existing fuel cost structure. This outcome indicates that the IMO's Mid-term measures will serve as a strong price signal to accelerate the transition to low carbon fuels. Without fuel transition, rising regulatory costs in proportion to GHG emissions will rapidly undermine the economic advantage of conventional fuels. In particular, in segments such as bulk carriers and tankers, where the combined amount of fuel expenses and contributions under the IMO's Mid-term measures accounts for the majority of operating costs, the impact on the profitability of shipowners and operators will be direct and significant. As a result, a comprehensive restructuring of cost management strategies, including the introduction of alternative fuels, improvement of fuel efficiency, and management of contributions and potential refunds, will be indispensable.

As shown in Fig. 7, regulatory costs tend to increase roughly in proportion to fuel consumption. According to the estimate for 2028, assuming continuing use of heavy fuel oil, ships with higher fuel consumption, such as large container ships and Very Large Ore Carriers (VLOCs), will face a significantly higher burden, exceeding USD 15 million per year in some cases. In contrast, for small- and medium-sized vessels with lower fuel consumption (for example, Handy size bulk carriers and small container ships), the absolute amount of regulatory cost remains relatively limited, but will still be non-negligible in terms of operating profitability.

These results indicate that although the impact of the IMO's Mid-term measures will vary depending on the ship type and size, improving fuel performance and operational efficiency is a common challenge for all vessels. In particular, it is imperative that ships with high fuel consumption prioritize countermeasures such as introduction of alternative fuels and optimization of operation.

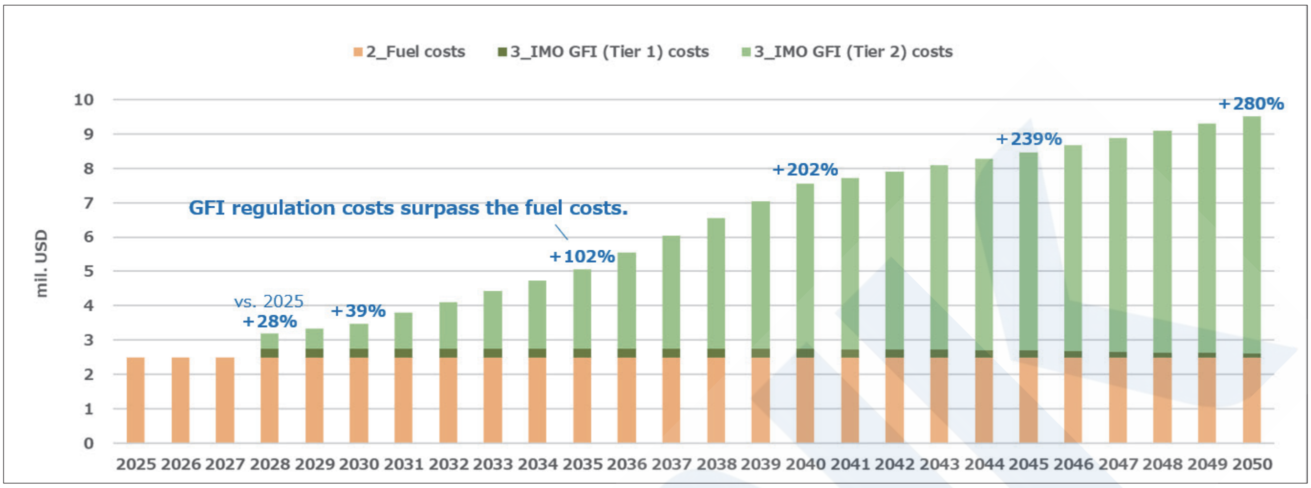

Fig. 6 Estimated cost trend assuming continuing use of conventional fuel oil

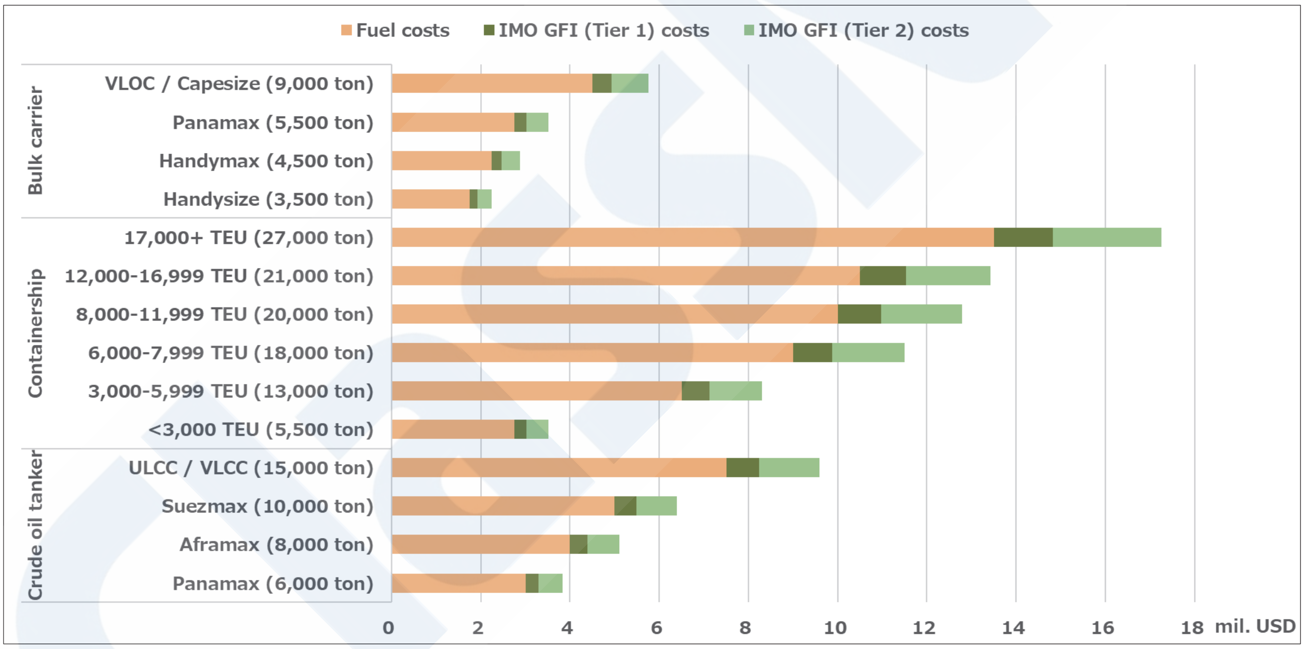

Fig. 7 Estimated regulatory cost by ship type and size in 2028

4. MEASURES FOR REDUCING COSTS

This chapter examines various measures aimed at reducing regulatory costs, focusing on their underlying concepts and effectiveness based on specific case examples. Under the IMO's Mid-term measures, the contribution burden linked to the GHG intensity of fuels will be introduced as a new cost component. Consequently, initiatives that combine economic efficiency with environmental performance, such as improving operational efficiency and introducing low carbon fuels, will become increasingly important. This chapter highlights three representative approaches, fuel efficiency improvement, slow steaming, and the use of multiple fuels, and clarifies how each measure affects the overall cost structure of ship operation through case studies.

4.1 Improvement of Fuel Efficiency

Under the IMO's Mid-term measures, improving fuel efficiency should be the primary step to mitigate cost increases.

Compared with fuel switching or conversion to alternative fuels, fuel efficiency improvement can deliver immediate and tangible benefits with relatively limited capital investment. This case study assumes a vessel consuming 5,000 tons of HFO annually, and evaluates the impact of a 5 % improvement in fuel efficiency, which corresponds to reducing annual fuel consumption to 4,750 tons. The results are presented in Fig. 8. A 5 % improvement in fuel efficiency directly reduces fuel costs through lower fuel consumption, while simultaneously reducing the regulatory costs imposed in proportion to GHG emissions. In other words, improving fuel efficiency is a highly cost-effective approach that reduces both fuel costs and regulatory costs at the same time. Over a cumulative period of 13 years up to 2040, the total cost savings resulting from a 5 % improvement in fuel efficiency are as follows:

- Fuel cost reduction: approx. USD 1,625,000
- Regulatory cost reduction: approx. USD 1,617,042

The combined effect of these measures are expected to result in a total cost reduction of approximately USD 3.24 million by 2040. These results confirm that the reduction in regulatory costs achieved through efficiency improvements can be almost equivalent to the savings in fuel costs.

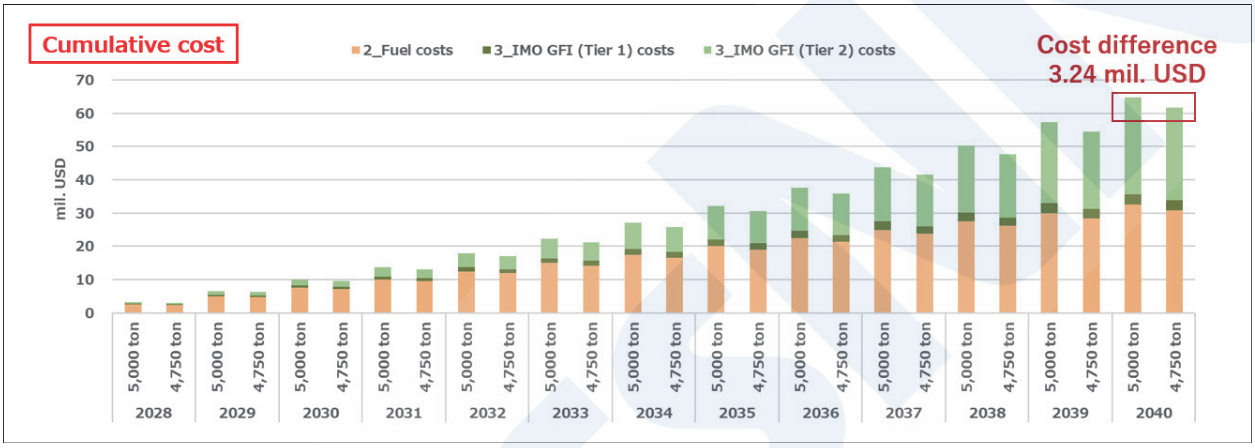

Fig. 8　Cost reduction effect through fuel efficiency improvement

4.2　Slow Steaming

As a specific measure to improve fuel efficiency, the effect of slow steaming, which can be implemented immediately, is examined. Reducing vessel speed also reduces fuel consumption, not only reducing GHG emissions but also decreasing regulatory costs. For this reason, slow steaming is regarded as an effective and practical option for the short to medium term. In this case study, a fleet of 10 bulk carriers was analyzed to compare the effects of operating at reduced speeds over an eight-year period from 2028 to 2035. The fuel price was assumed to be 500 USD per ton, and the estimates were made considering differences in sailing days and fuel consumption. When the operating speed was reduced to 10.45 knots from 11.5 knots, it was found that both the fuel costs and regulatory costs of the entire fleet could be minimized:

- Normal operation (11.5 knots × 10 ships): Total cost = Approximately USD 704 million
- Slow steaming (10.45 knots × 11 ships): Total cost = Approximately USD 675 million

Since slow steaming reduces operational efficiency, one additional vessel would be required to maintain the same transport volume over the same period. However, the analysis takes into account the total fleet cost, including vessel capital expenditure, and as noted above, resulted in an overall cost reduction of approximately 29 million USD. This indicates that the economic and environmental benefits gained from reduced fuel consumption outweigh the moderate loss in operational efficiency.

Fig. 9　Cost reduction effect of slow steaming for an entire fleet

4.3　Use of Multiple Fuels

Under the IMO's Mid-term measures, the life cycle GHG intensity of fuels is subject to regulation. If high GHG intensity fuels such as heavy fuel oil (HFO) continue to be used, regulatory costs will increase cumulatively, in addition to fuel prices. By partially using fuels with lower GHG intensities, it is possible to suppress emission-related costs while optimizing the overall operating cost. In this case study, a vessel consuming 5,000 tons of HFO per year is assumed, and the cost trend is estimated for a scenario in which the proportion of biodiesel (B30) used in place of HFO is gradually increased in order to achieve the Base Target. The assumptions applied are as follows:

- Annual fuel consumption: 5,000 tons
- Fuel price: HFO = 500 USD/ton, B30 = 746.7 USD/ton
- Assessment period: 2028-2040

In 2028, the scenario begins with a 30 % share of B30, and the proportion is gradually increased thereafter. From 2033 onward, B30 becomes the primary fuel used. The estimation results shown in Fig. 10 indicate that the introduction of low carbon fuels is not merely an environmental countermeasure, but also an economically rational option in the medium to long term. In particular, fuels such as biodiesel, which can utilize existing infrastructure, allow a smooth transition when used together with heavy fuel oil, and contribute to the reduction of regulatory costs. Furthermore, if the price of biofuels decreases in the future, they could provide a clear cost-saving advantage compared with operation using heavy fuel oil alone. Therefore, combined use of fuels can be regarded as a practical and effective transitional step under the IMO's Mid-term measures.

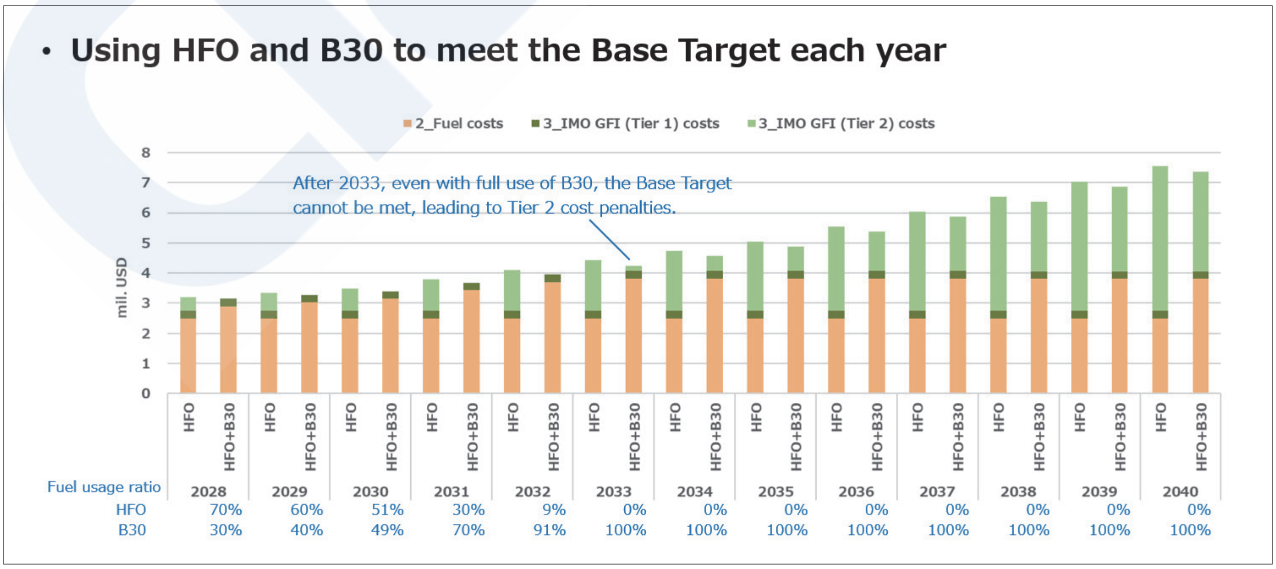

Fig. 10　Cost reduction by combined use of fuels meeting the annual Base Target

5. CLASSNK SERVICES

To appropriately address GHG emission reduction regulations such as the IMO's Mid-term measures, EU-ETS, and FuelEU Maritime, it is essential to conduct a comprehensive cost simulation that takes into account not only the compliance costs associated with these regulations but also changes in shipbuilding costs and fuel costs resulting from fuel transition.

ClassNK provides the "ClassNK Fleet Cost Simulation" service to support clients in conducting such complex and comprehensive cost assessments. This service combines the "ClassNK Fleet Cost Calculator" with customized simulation reports that present fleet-wide cost projections through clear graphs and tables. The Fleet Cost Calculator covers not only compliance costs associated with the IMO's Mid-term measures, EU-ETS, and FuelEU Maritime, but also shipbuilding costs and fuel costs, providing a comprehensive basis for long-term fleet strategy planning. The tool also allows flexible customization of assumptions such as fuel prices, the timing of vessel replacement, energy-efficiency improvement rates, and emission factors according to user requests.

Through simulations and analytical support that account for fuel transition, ClassNK assists companies in formulating effective decarbonization strategies and making informed investment decisions for the future.

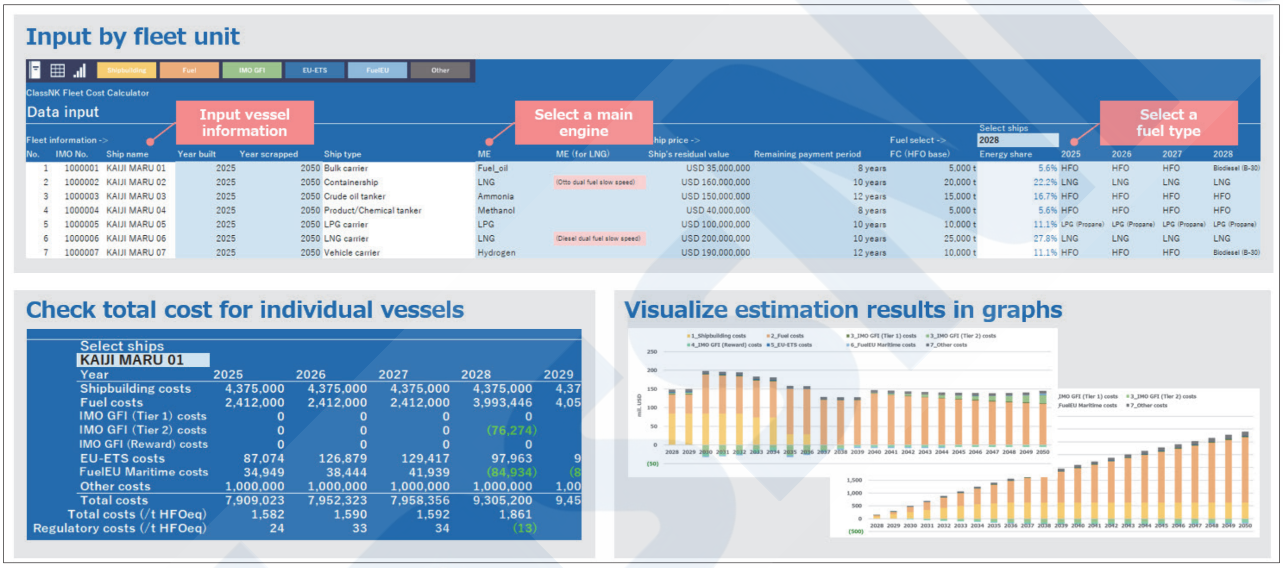

Fig. 11 Interface image of the ClassNK Fleet Cost Calculator

6. CONCLUSION

With the introduction of the IMO's Mid-term measures, the choice of fuel and fuel efficiency performance are expected to have a direct impact on the asset value of ships and on investment decisions. In the years ahead, factors such as the ability to use specific fuels and the relative efficiency of ship performance are likely to become key determinants of market value. From an investment perspective, companies are increasingly evaluated based on the clarity of their decarbonization strategies, and such evaluations may in turn influence ship prices and financing conditions.

On the operational side, fleet deployment planning and cost management are expected to become more complex than ever. Whether optimized ship operations, fuel procurement, and bunkering strategies are in place will have a direct bearing on profitability. To effectively control total costs, close coordination across the entire supply chain, including all relevant stakeholders, will be essential.

As part of future preparations, continuous monitoring of developments in the relevant regulations is essential. In addition, however, companies should also conduct simulations to assess the economic feasibility of conventional and alternative-fuel vessels, as well as the potential impacts on charter rates and freight levels. It will be important for stakeholders to develop a common view of the future outlook to ensure a smooth transition and maintain competitiveness following the implementation of the IMO's Mid-term measures.

ClassNK will continue to assist industry stakeholders in taking practical actions by providing up-to-date information and cost simulation services that reflect the latest international trends. Through these efforts, the Society aims to further promote the decarbonization of the global maritime sector.

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Research on Carbon Reduction Strategies for Operating Small-and Medium-Sized Bulk Carriers

Wenyu XU*, Nan WANG**

1. INTRODUCTION

The shipping industry, although responsible for less than approximately 3% of global CO_2 emissions[1)], faces mounting pressure to decarbonize. In June 2021, the International Maritime Organization (IMO) introduced a mandatory Carbon Intensity Indicator (CII) rating requirement for existing vessels. Ships receiving lower ratings must implement improvements or risk operational restrictions. In July 2023, the 80th session of the IMO's Marine Environment Protection Committee (MEPC) revised its greenhouse gas (GHG) reduction strategy, setting a net-zero emissions target for around 2050[2)]. In April 2025, MEPC 83 approved the IMO Net-Zero Framework draft, establishing basic and direct compliance objectives. Should a vessel's annual GHG Fuel Intensity (GFI) exceed targets, shipowners must purchase remedial units to offset the compliance deficit[3)]. This creates dual compliance obligations, CII and GFI, for operational vessels.

Bulk carriers constitute over 40% of the global commercial fleet by deadweight. Small-and medium-sized bulk carriers represent nearly 80% of the bulk fleet by vessel count, with over 99% reliant upon conventional fuels. The fleet's average age is at its eldest since 2010, with more than two-thirds of bulkers aged over 10 years old. Clarksons forecasts a rise in bulk carriers with D/E CII ratings—from 31% today to over 40% by 2026. That would downgrade over 1,000 vessels in just one year. Whilst mature energy-saving technologies (e.g., energy-saving appendages, low-friction coatings, propeller retrofits) are widely adopted, newer solutions such as wind-assisted propulsion, air lubrication systems, and carbon capture are being trialed on some bulk carriers[4)].

Retrofitting for alternative fuels remains challenging for small/medium bulkers due to their variable, unscheduled "tramp" routes. Without the magic of the ever-scaling Hammer of Thor, at this moment, it is "mission impossible" for alternative fuel storage capacity planning, unlike container ships which have fixed port rotations and established retrofit precedents. Bunkering infrastructure for alternative fuels is still under-developed and unevenly distributed. Despite years of LNG dual-fuel vessels operations, only around 210 ports worldwide currently offer LNG bunkering, over 50% of which are in Europe, while Africa, South America, and Oceania collectively account for less than 5%. Methanol and ammonia bunkering capabilities are even scarcer. Even with ample affordable green fuel supplies, global bunkering accessibility remains limited at this moment. Additionally, concerns over fuel system reliability and operational management persist. No operational bulk carrier has undergone dual-fuel retrofitting to date. Thus, there is significant market demand for reliable, cost-effective decarbonization pathways for aging small/medium bulk carriers without resorting to alternative fuel retrofits.

2. IMO REGULATORY FRAMEWORK FOR CARBON EMISSIONS FROM OPERATIONS

The operational carbon intensity rating system, effective January 2023, calculates annual attained CII for vessels >5,000 GT as:

$$\text{Attained CII} = \frac{\sum_j FC_j \times C_{Fj}}{\text{DWT} \times \text{D}} \tag{1}$$

where:

j is the fuel type;

FC_j is the consumption of fuel j in ton;

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** Nantong COSCO KHI Ship Engineering CO., LTD.

CF_j is the carbon conversion factor for fuel j in tonCO_2 / tonFuel;

DWT is the deadweight of the bulk carrier at full load draft in ton;

D is the sailing distance in the reporting period in nautical miles.

The required annual operation CII value for ships to be reduced against the CII reference line, and the formulas are calculated as:

$$\text{CII reference line} = \text{a} \times \text{DWT}^{-c} \tag{2}$$

$$\text{Required annual operation CII} = (1 - \frac{\text{z}}{100}) \times \text{CII reference} \tag{3}$$

where: a = 4745, c = 0.622 for bulk carriers;

z is a general reference to the reduction factors for the required annual operational CII of ship types from year 2023 to 2030, as specified in Table 1.

Table 1 Reduction factor for the CII relative to the reference line

Year	2023	2024	2025	2026	2027	2028	2029	2030
Reduction factor	5%	7%	9%	11%	13.625%	16.25%	18.875%	21.5%

Based on a comparison between the attained CII values and the required annual operation CII values, vessels will be assigned ratings from A to E. A ship rated as D for three consecutive years or rated as E in one year shall duly undertake the planned corrective actions in accordance with the revised Ship Energy Efficiency Management Plan (SEEMP).

To achieve the target of net-zero greenhouse gas (GHG) emissions around 2050, the draft “IMO Net-Zero Framework” was proposed at MEPC 81 in March 2024, and approved at MEPC 83 in April 2025. This framework will require ships to progressively reduce their Greenhouse Gas Fuel Intensity (GFI) value, over the full life-cycle of fuels, each year. Vessels failing to meet GFI targets will incur compliance deficits, necessitating economic measures to balance these deficits. The attained annual GFI of a ship in a given year shall be calculated as follows:

$$\text{GFI}_{attained} = \frac{\sum_j GFI_j \times Energy_j}{Energy_{total}} \tag{4}$$

where:

GFI_j, expressed in gCO_{2eq}/MJ , is the GHG intensity, expressed on a well-to-wake basis of a fuel type j;

$Energy_j$, expressed in MJ, refers to the energy consumption of fuel type j by the ship in the reporting period;

$Energy_{total}$ expressed in MJ, refers to the total amount of energy used by the ship in the reporting period.

The target annual GFI (GFI_T) of a ship shall consist of two tiers: a basic target annual GFI and a direct compliance target annual GFI. The GFI_T shall be calculated as follows:

$$\text{GFI}_T = (1 - \frac{\text{Z}_T}{100}) \times \text{GFI}_{2008} \tag{5}$$

where:

GFI_{2008} is the GFI reference value equivalent to 93.3 gCO_{2eq}/MJ (well-to-wake), representing the average GFI of international shipping in the year 2008;

Z_T is the annual GFI reduction factors to ensure continuous improvement of the ship’s GFI, consisting of both an annual reduction factor for the base target and for the direct compliance target, the values of which are shown in Fig. 1. The 2040 Z_T for the Base target shall be set at 65%.

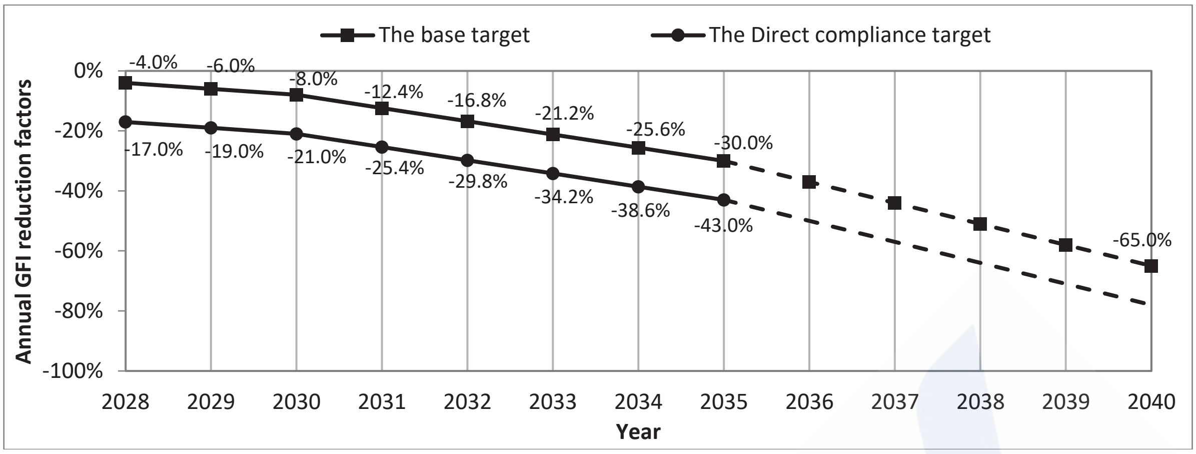

Fig. 1 Annual GFI reduction factors for the target annual GFI relative to the GFI reference value

Fig. 1 shows that the direct compliance target consistently requires a reduction 13% greater than the base target in the same year, through to 2035. If this differential persists from 2035 to 2040, the GFI compliance targets exhibit a "first accelerating, then decelerating" trend: from 2028 to 2030, the GFI annual reduction rate is 2.0%; from 2031 to 2035, the reduction increases to 4.4%; from 2036 to 2040, the figure will rise to 7.0% to achieve the base target of a 65% reduction by 2040. Beyond 2040, it would slow to approximately 2.2–3.5% annually, aligning with the IMO's net-zero goal for year 2050.

At the end of each reporting period, if the attained annual GFI is below the Direct Compliance Target, the ship shall be considered in direct compliance and be eligible to receive Surplus Units (SUs). These SUs may be transferred to other vessels, banked for use in the following two calendar year reporting periods, or voluntarily cancelled. If the attained annual GFI is below the Base Target but above the Direct Compliance Target, the ship shall balance the Tier 1 compliance deficit by purchasing Tier 1 Remedial Units (RUs). If the attained annual GFI is greater than the Base Target, a Tier 2 compliance deficit arises in addition to that of the Tier 1. The ship can balance its Tier 2 compliance deficit through one of three approaches: transferring SUs from other vessels, using banked SUs from the vessel's previous two years, or purchasing Tier 2 Remedial Units.

3. EMISSION REDUCTION MEASURES FOR EXISTING BULK CARRIERS

By the end of 2024, approximately 40% of global ocean-going vessels have been equipped with at least one kind of energy-saving device[5)]. The authors categorize the primary energy-saving and emission-reduction measures for mainstream ship types into the following six categories, as demonstrated in Table 2[6)-11)].

Table 2 Energy saving and emission reduction measures for medium/small bulk carriers

Pathways	Energy Saving Measures	Energy Saving Effect
Hydrodynamic Energy Saving	Energy-saving devices before/after propeller	~2~9%
	Low - Resistance Coatings	~2~5%
	Optimize the propeller	~2~7%
Operations Management	Speed and Route Optimization	Less than 5%
	Trim Optimization	Less than 2%
Clean Energy	Install Wind Power System	~3% for A Single Rotor
Machinery	Install Shaft Generators	~3%
Onboard carbon capture	Install Carbon Capture System (CCS)	Depending on capture rate
Alternative Fuels	Blended Biofuels	Depending on blending rate of Biofuels
	Retrofit LNG, Methanol, Ammonia fuel system	Depending on the proportion of available and affordable renewable fuels used.

On bulk carriers currently in service, the most widely applied measures primarily include low-friction antifouling paints, and energy-saving devices (ESDs) installed both fore and aft of propellers. In addition, propeller retrofitting also produces a significant reduction in emissions. Since 2008, the global commercial fleet has progressively reduced operating speeds, in order to reduce costs and as a mechanism to control supply-side capacity. By 2014, the average speed of bulk carriers had dropped below 11.5 knots. Although there was a brief, minor rebound in 2021, 11.5 knots was still the ceiling for the average sailing speed of bulk carriers. Subsequently the average speed has continued to decline to just above 10.7 knots recently. To achieve better ship performance, in the past three years, over 1,000 bulk carriers have undergone propeller replacements during dry-docking.

Other measures such as machinery optimization, installation of CCS, and software-based energy efficiency monitoring solutions have reportedly been explored by manufacturers. However, authenticated performance data remains scarce, with limited implementation track records observed on operational bulk carriers to date.

Among alternative fuels, biofuels have garnered significant attention from ship owners. However, according to DNV's 2025 Biofuels Whitepaper, over 99% of global biofuel production is allocated to road transportation. The remaining supply must also accommodate the larger appetite of the aviation industry, which generates higher CO_2 emissions, leaving a severely limited supply for shipping. Currently, biofuel bunkering is available at just 24 ports worldwide, with none in Africa or South America.

Therefore, energy-efficient solutions for currently operational bulk carriers remain severely constrained.

4. TECHNICAL ASSESSMENT OF CII-COMPLIANT CARBON-CUTTING SOLUTIONS FOR 10-YEAR-OLD KAMSARMAX BULK CARRIERS

4.1 Calculation Examples

We undertake our investigation based on a 2016-delivered KAMSARMAX bulk carrier as the case vessel, for which the shipowner has kindly shared its 2024 operational results as shown in Table 3.

Table 3 Annual operation statistic for target vessel

Average Speed (kn)	Cruise Range (nm)	LSHFOC (t)	MDOC (t)	CII Rating
12.5	62700	5840	540	C

Based on the operational data above, it can be found that without implementing emission reduction measures, the CII rating of this ship will decline in the coming years. Since the IMO has not specified future reduction factors for CII and GFI, in order to estimate the CII rating and GFI compliance costs for the target ship over the course of its remaining operational life cycle, whilst also controlling variables, the following assumptions provided in Table 4 were adopted for our analysis.

Table 4 The calculation assumptions and definitions in entire operational lifecycle of the target vessel

Parameters	Assumptions
Ship Operation Cycle	The vessel has an operational life of 25 years and will operate until 2040.
CII reduction factor	From 2031 to 2040, the CII requirements become more stringent, decreasing by 3.5% annually.
GFI reduction factor	From 2035 to 2040, the difference between the direct compliance target and the basic compliance target is 13%. From 2035 to 2040, the annual reduction factor for both direct compliance and basic compliance is 7%.
Cost of fuel	Low-sulfur heavy fuel oil: \$520 per ton; Diesel: \$600 per ton; 100% biodiesel: \$1500 per ton. Assumption: Fuel prices remain unchanged from 2025 to 2040.
GFI fee	The price for Tier 1 Remediation Units is \$100/tonCO_{2eq}, and for Tier 2 Remediation Units the price is \$380/ton CO_{2eq}.
Energy Saving Effect	Silicone-based low-friction paint: 5%; Propeller retrofit: 6%; Single wind rotor: 3%
GFI Value	LSHFO: 95.48 gCO_{2eq}/MJ; MGO: 93.93 gCO_{2eq}/MJ; Biofuel: 15 gCO_{2eq}/MJ (assumed)
Direct Extra Cost	Organic silicone paint addition: USD 0.3 million; Propeller modification: USD 0.4 million; Single wind rotor: USD 1.5 million; Carbon capture retrofit: USD 6 million.
Annual Cost	Annual costs cover the initial equipment investment, yearly fuel costs, GFI compliance fees, and similar expenses, and excluding the costs of equipment maintenance, the cost of after CO_2 captured off-hire losses during retrofitting, freight revenue losses due to speed reduction. Neglect the influences on DWT (equipment number, if any) when installation of CCS or Wind rotors.
Total Cumulative Cost	Accumulated annual cost from 2025 to the statistical year.

The GFI compliance costs of this ship are shown in Fig. 2, on the basis of the above assumptions, maintaining unchanged fuel consumption while continuing to use Low Sulphur Heavy Fuel Oil (LSHFO). From 2028, payments for both Tier-1 and Tier-2 deficits will be required. Among these, Tier-1 deficit costs are relatively lower, with cumulative payments of around USD 4 million from 2028 to 2040. Meanwhile Tier-2 deficit costs are significantly higher and increase annually, accounting for about 95% of the total GFI compliance costs in 2040. The combined Tier-1 and Tier-2 deficit costs during the 2028–2040 period will substantially exceed the vessel's original newbuilding price.

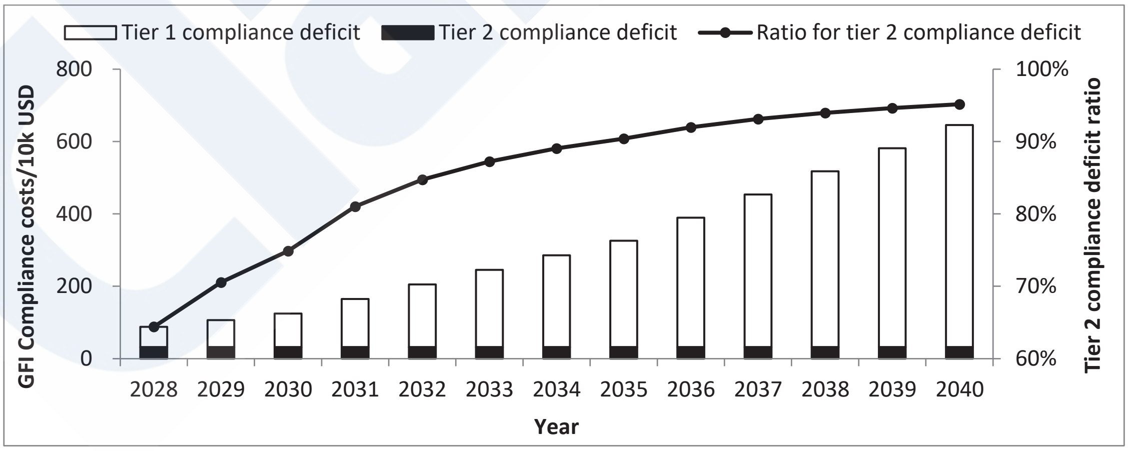

Fig. 2 IMO fuel compliance costs for the target vessel from 2028 to 2035

Fig. 3 illustrates the required reduction in fuel consumption ratio for this vessel to maintain a CII rating of Class C throughout its operational cycle. In 2030, the vessel needs to reduce its fuel consumption by approximately 10%, compared to 2024. By 2035, this fall in annual fuel consumption needs to reach 30% compared to 2024, and by 2040 reach 50% below levels. Therefore, to satisfy the CII rating requirements in different phases, a staged approach implementing various measures is necessary to achieve compliance. We adopt a three-phase "progressive" retrofit strategy for this vessel, based on the CII reduction factor and

GFI annual reduction rate, as well as the availability of biofuels in the market and the maturity of carbon capture technologies: Phase 1 retrofit measures are implemented from 2025 to 2030, Phase 2 from 2031 to 2035, and from 2036 to 2040 for Phase 3.

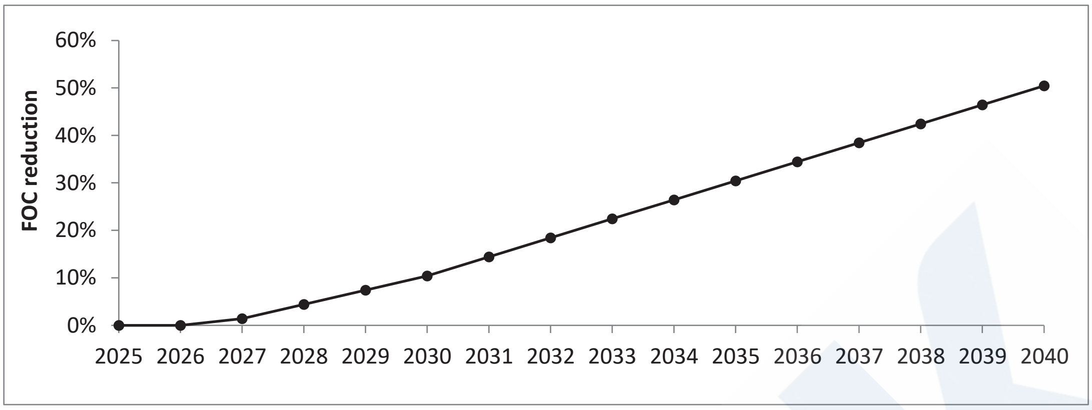

Fig. 3 The proportion of fuel consumption reduction to meet CII Class C requirements for the target vessel

4.2 Retrofit Plans for Phase I

Phase I, the reduction factors for CII and GFI are relatively small, offering a wider range of feasible emission reduction solutions. Priority in this phase is given to speed reduction as the mitigation strategy. As shown in Table 3, the vessel's average speed in 2024 is approximately 12.5 knots. Considering that the main engine requires a minimum load over 40% for prolonged continuous operation, the minimum average operational speed after slow steaming is about 11.5 knots. Table 5 compares the CII ratings under reduced speed scenarios for 2025–2030.

Table 5 Comparison of CII ratings after Phase I speed reduction

Year	Keep original speed		Case 0-Reduced Speed	
	Average Speed/kn	CII rating	Average Speed/kn	CII rating
2025	12.5	C	12.5	C
2026	12.5	C	12.5	C
2027	12.5	D	12.3	C
2028	12.5	D	11.9	C
2029	12.5	D	11.5	C
2030	12.5	D	11.5	D

By slowing down, our vessel will maintain a C rating from 2025 to 2029. However the CII rating will drop to D in 2030 as any further reduction in speed is no longer possible. Whilst reduced speed can cut down fuel consumption and GFI compliance deficit costs, if port time and other non-sailing periods are not shortened, the reduction in average speed will reduce the annual sailing distance and consequently reduce the revenue of the vessel.

Based on speed reduction, other emission reduction measures can be combined to lessen the GFI compliance costs. Given that energy-saving devices, such as a Semi-duct system and a Rudder bulb system have already been installed on this vessel during the newbuilding stage, Table 6 selects emission reduction measures suitable for this vessel. While not covering all optional measures, the analytical approach applies equally to other reduction solutions.

Table 6 Comparison of emission reduction measures in Phase 1 for the target vessel

Case	Measures of Emission Reduction	Emission Reduction Effect	Initial Investment
Case 1	Silicone Based Low Resistance Paints together with Optimization of Propeller	Comprehensive Energy Saving Achievement: 11%	~USD 0.7million
Case 2	Install 3 rotor sails and take advantage of meteorological Navigation.	Comprehensive Energy Saving Achievement: 9%	~USD 5 million
Case 3	Install a Carbon Capture and Storage System	Maximum Carbon Capture Rate of 30%	~USD 6 million
Case 4	Blended Biofuels	Depends on Biofuel Blending Ratio	The retrofitting costs are negligible

In Table 6, Case 1 assumes a speed reduction with a dry docking commencing at the beginning of 2026, including silicone antifouling, repainted every 5 years; Case 2 assumes a speed reduction, with dry docking and rotor sail retrofitting commencing in early 2026; Case 3 and Case 4 are both based on a speed reduction and aim to reduce GFI compliance deficit costs, with retrofits beginning in 2028. In Case 3, the annual carbon capture rate is fixed at 30%. In Case 4, a mix of biofuels is used to ensure the annual attained GFI meets the GFI base target line, avoiding the Tier 2 compliance deficit. Table 7 compares the CII ratings under different cases, and Fig. 4 shows the comparison of annual cumulative costs for each of the cases.

Table 7 The comparison of CII ratings in Phase 1 for the target vessel

Year	Case 0	Case 1	Case 2	Case 3	Case 4	
	CII rating	CII rating	CII rating	CII rating	CII rating	Biofuel blending Ratio
2025	C	C	C	C	C	0%
2026	C	C	C	A	C	0%
2027	C	C	C	A	C	0%
2028	C	C	C	A	C	8%
2029	C	C	C	A	C	10%
2030	D	C	C	A	C	13%

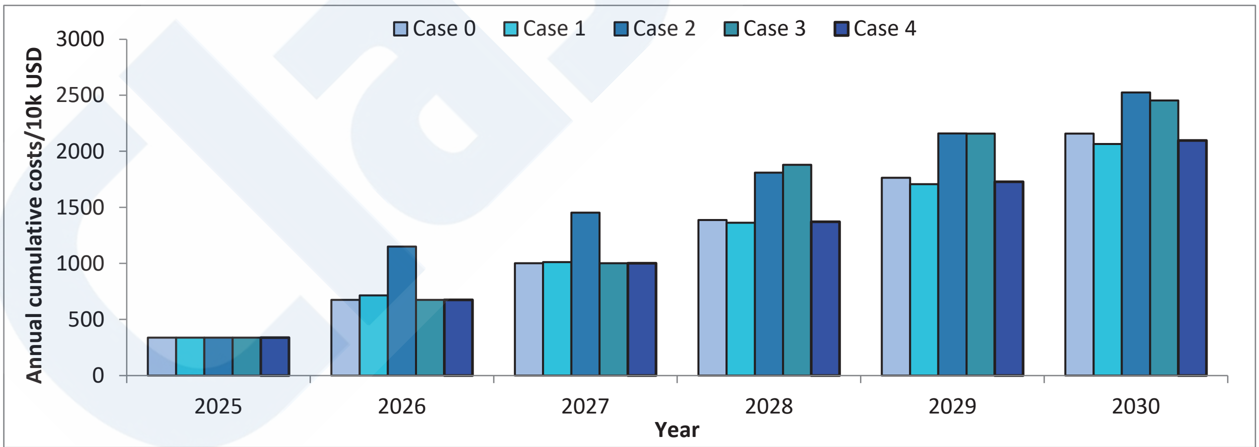

Fig. 4 Comparison of total cumulative costs in Phase 1 for different cases

Combining Table 7 and Fig. 4, it can be observed that in terms of CII ratings, implementing nothing but a speed reduction, will see the CII rating will drop to Class D in 2030. In contrast, the CII rating for Case 1 to 4 can all meet the Class C criteria. Among them, after the installation of CCS, the CII ratings are Class A every year.

Regarding the total cumulative costs, Case 1 is implemented from 2026 to 2028, which has an total cumulative cost lower than Case 0 by 2028, indicating that the static payback period of Case 1 is less than three years. By 2030, the total cumulative cost of Case 3 (the installation of CCS), is less than Case 2 (the installation of three sets of Rotor sails). This indicates that, under the given assumptions, a carbon capture system (CCS) is more cost-effective than wind-assisted technology. Additionally, Case 4 has the lowest operational cost in Phase 1.

4.3 Retrofit Plans for Phase II

In the second phase, CII ratings and GFI compliance requirements become even stricter, with the annual reduction rate of the CII reduction factor increasing from 2.65% to 3.5% and the annual rate of the GFI reduction factor increasing from 2.0% to 4.4%. Table 8 compares the CII ratings for all cases in this phase.

Table 8 The comparison of CII ratings in Phase II for the target vessel

Year	Case 0	Case 1	Case 2	Case 3	Case 4	
	CII rating	CII rating	CII rating	CII rating	CII rating	Biofuel blending Ratio
2031	D	C	D	A	C	18%
2032	E	D	D	B	C	23%
2033	E	D	D	C	C	29%
2034	E	E	E	C	C	34%
2035	E	E	E	C	C	39%

Table 8 indicates that conventional energy-saving methods cannot enable compliance with a CII Rating of C. Only adopting a carbon capture system (CCS) or using biofuels can guarantee compliance. Among these cases, Case 4 meets the GFI basic target while still achieving a CII Rating of C. However, the bio-fuel blending ratio progressively increases, rising to 39% in the year 2035.

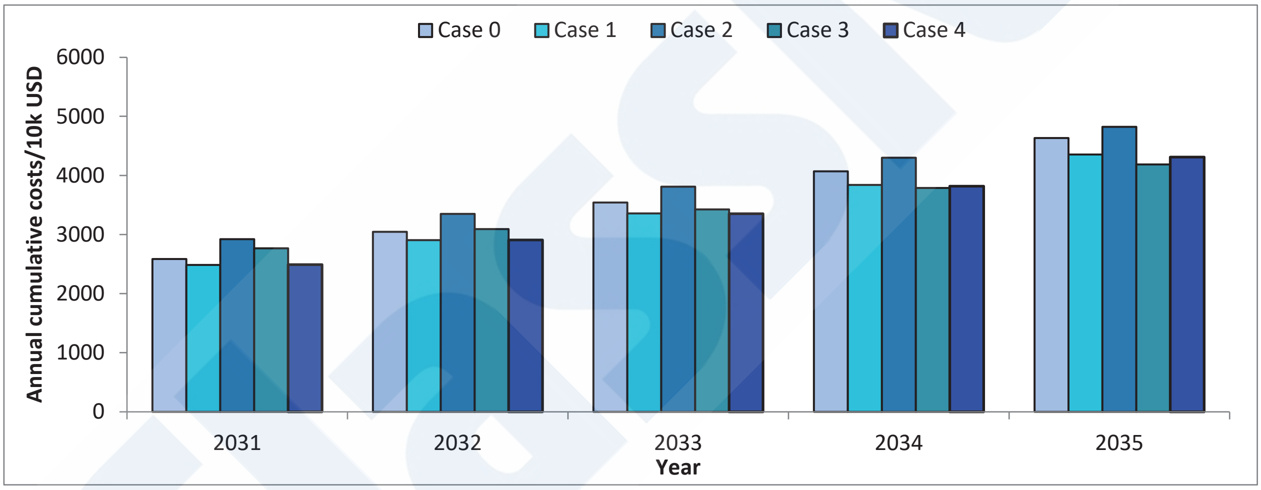

Fig. 5 Comparison of total cumulative costs in Phase II for different cases

Fig. 5 presents a comparison of the annual cumulative costs under different cases from 2031 to 2035. The results indicate that prior to 2034, of all of the energy conservation and emission reduction measures, Case 4 always enjoys the lowest total cumulative cost. After 2034, however, the cost advantage of installing CCS starts to be realized, emerging as the plan with the lowest total cumulative cost amongst these cases.

4.4 Retrofit Plans for Phase III

The compliance requirements for Phase III of GFI become more stringent, with the annual reduction rate of 7%, which is higher than the annual reduction rate for CII. Table 9 compares the CII ratings of different cases within this phase. Due to the configuration of auxiliary engines and boilers in the subject vessel, the maximum possible carbon capture rate for Case 3 is 30%, while Case 4 meets the basic target requirements of GFI by blending a certain proportion of biofuel. Fig. 7 compares the annual costs in different cases.

Table 9 The comparison of CII ratings in Phase III for the target vessel

Year	Case 0	Case 1	Case 2	Case 3	Case 4	
	CII rating	CII rating	CII rating	CII rating	CII rating	Biofuel blending Ratio
2031	E	E	E	D	C	48%
2032	E	E	E	E	B	57%
2033	E	E	E	E	A	65%
2034	E	E	E	E	A	74%
2035	E	E	E	E	A	82%

Table 9 shows that only Case 4 can maintain the CII rating requirements, but the biofuel blending ratio at this stage is extremely high. Furthermore, since the GFI reduction rate is significantly higher than the CII reduction rate, Case 4 could achieve a B or even an A CII rating while meeting the basic GFI compliance target. Case 3 has a carbon capture rate capped at 30%, so it cannot further improve its CII rating. In terms of total cumulative costs, the results in Fig. 6 show that installing a carbon capture system is the most economically beneficial option at this stage.

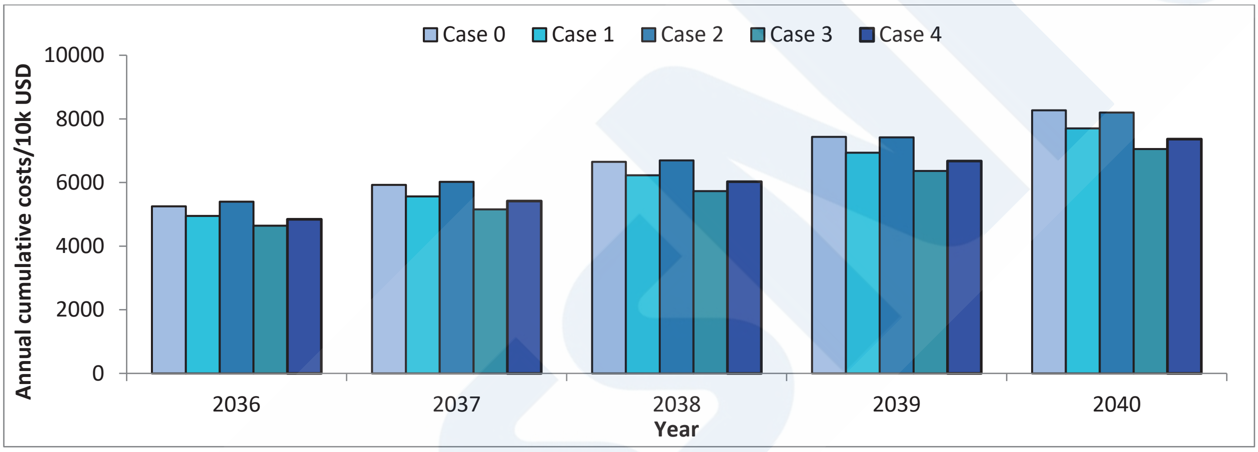

Fig. 6 Comparison of total cumulative costs in Phase III for different cases

4.5 Combined Emission Reduction Solution

Based on the segmented analysis of the previous three phases, we have consolidated the emission reduction pathways from all stages to determine a solution that technically maintains a CII rating Class C, while minimizing total cumulative costs throughout the vessel's operational life cycle. In the Combined Solution, based on the application of silicone anti-fouling paint during the dry docking period, the limitation of the CCS system's capture rate at 30%, and the B24 Biofuel blend currently most popular (24% biofuel blend ratio) as the calculation conditions. Table 10 presents the emission reduction measures and CII rating of the Combined Solution and compares it with the solution that involves a conversion to renewable methanol (Case 5).

Table 10　Comparison of Combined Solutions for emission reduction measures and CII ratings for the target vessel

Year	Combined Solution 1		Combined Solution 2		Case 5	
	Measures	CII	Measures	CII	Measures	CII
2025	No retrofit	C	No retrofit	C	No retrofit	C
2026	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization	C	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization	C	Speed Reduction	C
2027		C		C		C
2028		C		C	Speed Reduction + Renewable Methanol	C
2029		C		C		C
2030		C		C		C
2031	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization + CCS (Capture rate:30%)	A	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization + Blended Biofuel (B24)	C		C
2032		A		C		C
2033		B		C		C
2034		B		C		C
2035		C		C		C
2036	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization + CCS (Capture rate:30%) + Blended Biofuel (B24)	C	Speed Reduction + Silicone anti-fouling paint + Propeller Optimization + Blended Biofuel (B24) + CCS (Capture rate:30%)	A		C
2037		C		B		B
2038		C		C		A
2039		C		C		A
2040		D		D		A

In Table 10, the primary distinction between Combined Solution 1 and Combined Solution 2 lies in their implementation sequence: Combined Solution 1 prioritizes installing the carbon capture system before adopting biofuel, whereas Combined Solution 2 employs biofuel first, followed by the installation of a carbon capture system. Case 5 performs a methanol dual-fuel retrofit in 2028 to reduce GFI compliance deficit costs, with the renewable methanol usage ratio set so as to satisfy the annual GFI base compliance target. Results indicate that under a 30% carbon capture rate and maximum 24% biofuel blend ratio, both Combined Solutions 1 and 2 achieve CII ratings of C or higher in all years except 2040 (rated D), which satisfy the IMO's CII rating requirements. Case 5, utilizing renewable methanol at GFI base compliance target, which meets CII requirements (C or higher). However, Case 5 requires the proportion of renewable methanol to surge dramatically from 7% in 2028 to 80% by 2040!

Fig. 7 compares the annual cumulative costs of the two Combined Solutions. Case 0 represents the scenario considering only a speed reduction without other emission reduction measures. The results show that by 2040, the total cumulative costs of both Combined Solutions are lower than Case 0. Specifically, the total cumulative cost of Combined Solution 1 is over $5 million lower than that of Combined Solution 2. However, prior to 2035, the total cumulative cost of Combined Solution 1 consistently remains higher than that of Combined Solution 2. Therefore, if the vessel operates for 25 years, installing a carbon capture system early in the period could be considered to reduce annual costs. Conversely, if the owner plans to sell the vessel at 20 years of age, or if the vessel will not engage in ocean-going transport, just using biofuel without installing the CCS system can allow the ship to meet the CII rating requirements and reduce operating costs. Case 5, which uses renewable methanol and results in total cumulative costs by 2040 that are not only higher than Case 0, but also higher than the two Combined Solutions. This indicates that under current assumptions, using renewable methanol on operational vessels is not economically viable.

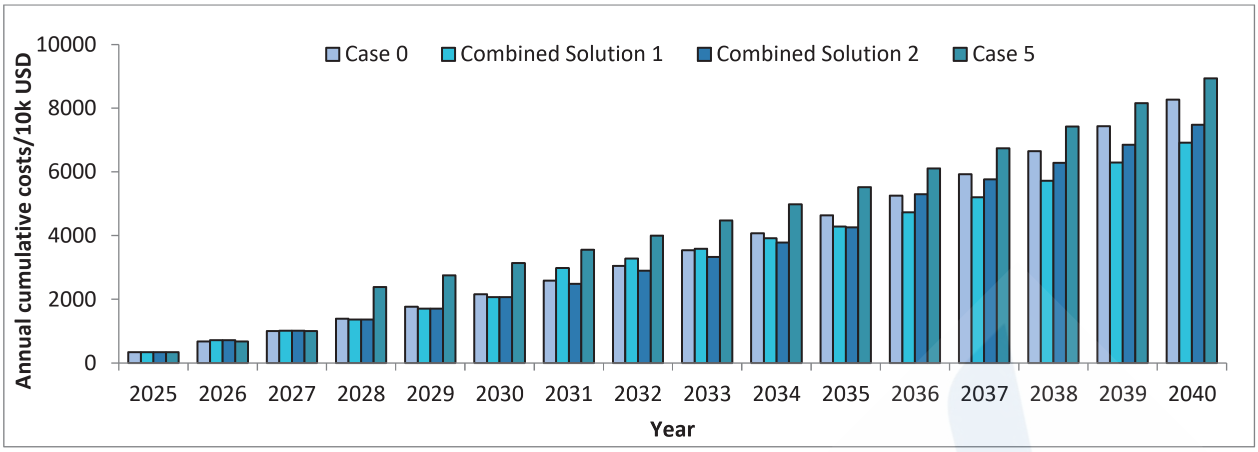

Fig. 7 Comparison of total cumulative costs for the target vessel within her operational lifecycle

5. EMISSION REDUCTION PLANS FOR MEDIUM/SMALL BULK CARRIERS IN OPERATION LIFECYCLE

Based on the analysis of retrofit schemes for the 10-year-old KAMSARMAX bulk carrier with a current CII rating of C, a feasible "step-by-step" retrofit solution has been developed, as illustrated in Fig. 8. The horizontal axis represents the retrofit measures applicable at each year in the process. The corresponding research methodology has also been validated on an 11-year-old ULTRAMAX bulker.

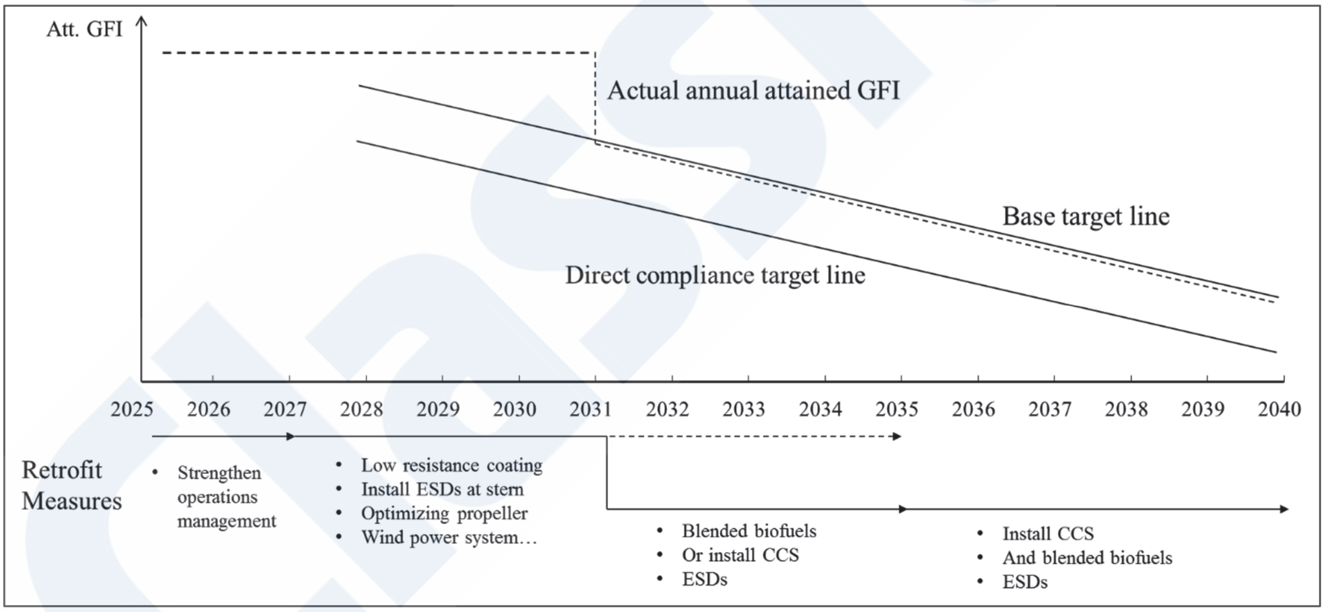

Fig. 8 'Gradual' retrofit plan for medium/small bulk carriers within their operation lifecycle

6. CONCLUSIONS

Currently, no single measure can perfectly meet IMO decarbonization requirements both technically and commercially. This study also validates its approach based on numerous assumptions. Although many boundary conditions of these assumptions may change in the coming future, the "step-by-step" emission reduction approach can be extended to other existing Bulk carriers. The conclusions are found to be as follows:

(1) Medium and small bulk carriers of a certain age can achieve lifecycle compliance without converting to a new source of propulsion.

(2) Operational vessels should prioritize emission reduction technologies with identifiable effects and affordable costs.

(3) Improving the "inherent" energy efficiency of the vessel outperforms adopting alternative clean energy sources.

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Recent Topics at IMO

— Outline of Discussion at IMO Committees —

External Affairs Department, Research and Development Division, ClassNK

1. INTRODUCTION

This article introduces recent topics discussed at International Maritime Organization (IMO). At the previous issue, a summary of the topics discussed at 82nd Marine Environment Protection Committee (MEPC 82) held in October 2024 and 109th Maritime Safety Committee (MSC 109) held in December 2024 was provided.

This article provides a summary of the decisions taken at 83rd Marine Environment Protection Committee (MEPC 83) held from 7 to 11 April 2025 and 110th Maritime Safety Committee (MSC 110) held from 18 to 27 June 2025 as below. This article is based on the summary issued as ClassNK Technical Information No. TEC-1354 and No. TEC-1363.

2. OUTCOMES OF MEPC 83

2.1 Reduction of Greenhouse Gas (GHG) Emissions from Ships

Draft regulations on the mid-term measures for reduction of greenhouse gas (GHG) have been approved.

At MEPC 80 in 2023, the IMO adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships (2023 IMO GHG Strategy), which sets out the IMO's levels of ambition (see Table 1) including the aim to reach net-zero GHG emissions from international shipping by or around 2050. Further discussions continued in developing "Mid-term measures for reduction of GHG emissions" for achieving the levels of ambition set out in the 2023 IMO GHG Strategy. At this session, MEPC 83 approved draft regulations on the mid-term measures and also held discussions on the review of short-term measures etc.

Table 1 Levels of ambition adopted at MEPC 80

Target year	Levels of ambition and indicative checkpoints (as of 2023)
2030	• To reduce CO_2 emissions per transport work by at least 40% (compared to 2008) • To reduce total annual GHG emissions by at least 20% (striving for 30%) (compared to 2008) • Uptake of zero GHG emission fuels etc. to represent at least 5% of the energy used (striving for 10%)
2040	• To reduce total annual GHG emissions by at least 70% (striving for 80%) (compared to 2008)
2050	• To reach net-zero GHG emissions by or around 2050 at the latest

2.1.1 Mid-Term Measures for Reduction of GHG Emissions

At this session, the draft amendments to MARPOL Annex VI on the mid-term measures was approved, comprising the concepts of "regulating GHG fuel intensity of the fuel used by a ship (GFI regulations)" and "accelerating decarbonization through the IMO Net-Zero Fund" as the two pillars. The draft amendments were circulated for adoption by MEPC (Circular Letter No. 5005); and if they are adopted at the extraordinary session of MEPC in October 2025, then the amendments will enter into force at the earliest in March 2027.

The summary of the mid-term measures approved at this session is as follows.

2.1.1.1 Regulating GHG Fuel Intensity of the Fuel Used by a Ship (GFI Regulations)

For ships of 5,000 GT and above engaged in international voyages, the GHG fuel intensity (GFI) of the fuel used, i.e. the GHG emissions per unit of energy from the fuel used, will be regulated. These regulations are drafted for implementation by January 2028. By progressively tightening the required GFI values, the consequential acceleration in decarbonization of ship fuels and reduction in GHG emissions from ships are expected.

The GFI regulations set two levels of targets, "Base Target" and "Direct Compliance Target" as below, with different reduction levels from the average GHG intensity of fuel used in international shipping in 2008, which was 93.3 gCO_2eq/MJ (see Fig. 1).

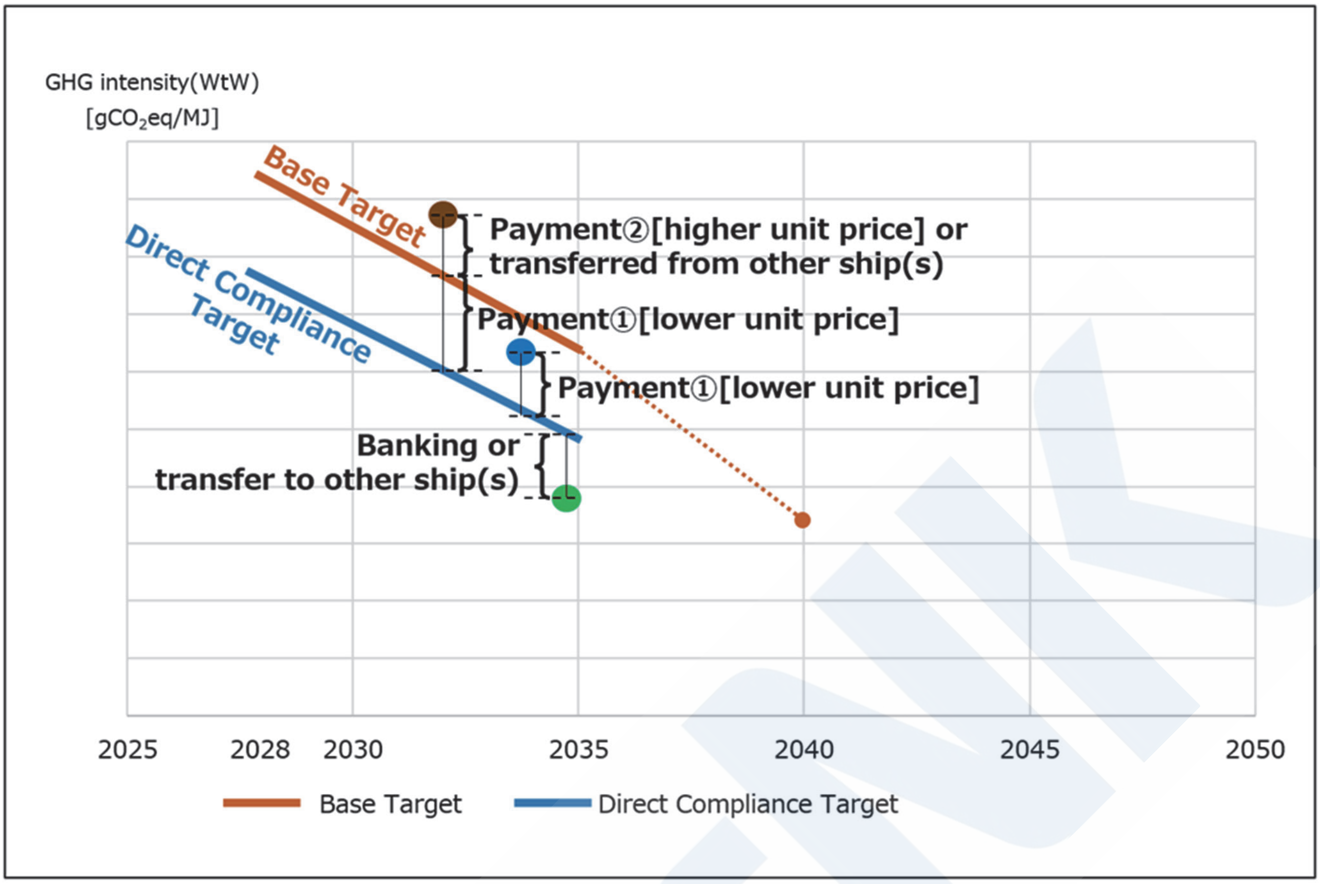

Fig. 1 2-tier GFI values【Illustrative purpose】

Base Target: Based on the 2008 reference GHG intensity value (93.3 gCO2eq/MJ), Base Target annual values are set to achieve 4% reduction in 2028, 8% reduction in 2030, and 30% reduction in 2035. In addition, 65% reduction from the 2008 reference value in 2040 is also stipulated.

Direct Compliance Target: Based on the 2008 reference GHG intensity value (93.3 gCO2eq/MJ), Direct Compliance Target annual values are set to achieve 17% reduction in 2028, 21% reduction in 2030, and 43% reduction in 2035.

If a ship is in direct compliance by utilizing fuels such as zero-emission fuels, the ship will be eligible to receive surplus units equal to its positive compliance balance, which can be transferred to another ship to balance that ship's "base target" compliance deficit or banked for use in the following reporting periods (up to two calendar years after the calendar year of its issuance).

If the ship is not in direct compliance but meets the "base target", a deficit corresponding to the GHG emission exceeding the "direct compliance target" (i.e. Payment ①) shall be paid to the IMO Net-Zero Fund.

If the ship does not meet the "base target", the deficit corresponding to the GHG emission exceeding the "base target" (i.e. Payment ②) shall be paid in addition to Payment ① to the IMO Net-Zero Fund or otherwise receive surplus units from other ships to balance the compliance.

The unit price of Payment ①, to be collected and utilized for disbursements such as rewarding "accelerating the uptake of Zero or Near-Zero GHG emission technologies, fuels and/or energy sources (ZNZs) " (refer to 2.1.1.2) etc., is set relatively less expensive. On the other hand, the unit price of Payment ②, to be taken in a sense of penalty, is set relatively more expensive.

Further work to be pursued by MEPC includes development of guidelines related to calculation of GHG fuel intensity and verification scheme of fuels etc. so as to set out detailed procedures prior to the entry into force of the GFI regulations.

2.1.1.2 Accelerating Decarbonization through the IMO Net-Zero Fund

The aforementioned payments from the GFI regulations will be collected by the IMO Net-Zero Fund to be established. The fund will disburse collected revenue for the purposes such as rewards for the use of ZNZs or supporting the energy transition of developing countries, in particular least developed countries (LDCs) and small islands developing States (SIDS), etc.

Accelerating the uptake of ZNZs

Ships of 5,000 GT and above engaged in international voyages and using ZNZs may receive rewards for partial reimbursement of the costs associated with the use of such fuels. This is expected to accelerate the early transition to ZNZs.

A threshold for the GHG intensity of the fuel is set out in the regulations. The specific scale of this reward will continue to be discussed at MEPC.

2.1.2 Review of Short-Term Measures for Reduction of GHG

MARPOL Annex VI prescribes that a review of the EEXI (Energy Efficiency Existing Ship Index) and CII (Carbon Intensity Indicator) rating regulations, introduced by IMO as short-term measures, shall be completed by 1 January 2026 to assess their effectiveness.

At the previous session, a consolidated list of challenges and gaps in the short-term measures was developed, which is used as the base document for ensuing discussions. The tasks were then categorized into two phases by the relevant Correspondence Group: priority tasks to be completed by 2026; and tasks to be pursued continuously beyond 2026. At this session, discussions focused on the priority tasks aimed for completion by 2026.

2.1.2.1 Amendments to the CII Reduction Factors Guidelines (G3)

Under the CII rating scheme, the annual CII reduction factor used to determine the required annual operational CII has been set to increase by 2% each year until 2026. However, the reduction factors beyond 2027 were to be decided in the review of the short-term measures.

At this session, discussions were held on the reduction factors for the period after 2027. As a result, it was agreed that the reduction factor would increase by 2.625% annually, reaching 21.5% by 2030. Accordingly, amendments to the “Guidelines on the CII reduction factors (G3)” were adopted. The annual CII reduction factors through 2030 are shown in Table 2.

Table 2 Annual CII reduction factors through 2030

Year	CII reduction factor (relative to 2019)
2023	5 %
2024	7 %
2025	9 %
2026	11 %
2027	**13.625 %**
2028	**16.250 %**
2029	**18.875 %**
2030	**21.500 %**

These reduction factors are aligned with the level of ambition of the 2023 IMO GHG Strategy to reduce CO2 emissions per transport work by at least 40% by 2030, compared to 2008.

2.1.2.2 Amendments to the Guidelines for Development of SEEMP

IMO Ship Fuel Consumption Database (IMO DCS), from 1 January 2026, introduces additional reporting items such as the total fuel oil consumption by each fuel-consuming equipment and the total fuel consumption during non-operational (non-voyage) periods.

At this session, the amendments to the “Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)” were adopted, providing clear definitions for the terms “under way” and “not under way”.

2.1.2.3 Accessibility to the IMO DCS Database

The IMO DCS data reported annually to the IMO is utilized by the IMO Secretariat to analyze the effectiveness of GHG emission reduction efforts by the maritime industry. By anonymizing and publicly disclosing this data, more diverse and in-depth analyses are expected to become possible.

At this session, draft amendments to Regulation 27 of MARPOL Annex VI were approved, enabling the following with respect to the access to the IMO DCS data.

- Access by Parties to non-anonymized data for all ships
- Public user access to anonymized data for all ships

Consideration of revisions to the relevant guidelines will follow in order to enhance the data anonymization measures.

2.1.3 Practical Application of the Guidelines on Life Cycle GHG Intensity of Marine Fuels (LCA Guidelines)

Low and zero carbon fuels such as hydrogen, ammonia and biomass-based fuels are expected to become widely used in the future to decarbonize ships, and there is a growing interest in GHG emissions from the whole life cycle of these fuels, from their production to distribution stages in addition to the combustion of the fuel.

At MEPC 80, the IMO adopted Guidelines (LCA Guidelines) that specify the methodology for calculating the GHG fuel intensity of fuels used on ships over their whole life cycle from feedstock extraction to processing, fuel production, transport, bunkering and onboard use, as well as default values for the GHG fuel intensity for various fuels. While the IMO at MEPC 81 adopted the amendments to the Guidelines, the default values of GHG fuel intensity for only five types of marine fuel, e.g. fossil based heavy fuel oil and biofuels, were set out, needing for further work in order to put the Guidelines into practical applications.

At this session, based on the scientific review and advice provided by GESAMP working group on life cycle GHG intensity of marine fuels (GESAMP-LCA WG), the IMO agreed to the procedures for proposing and reviewing default values of GHG fuel intensity. It was also agreed to continue discussions on improving the emission calculation methodology, sustainability criteria and certification of GHG intensity in the LCA Guidelines.

2.1.4 Measurement of Methane and Nitrous Oxide Emissions from Ships and Onboard Carbon Capture and Storage

In addition to CO_2 emitted upon fuel combustion, emissions of methane (CH_4) and nitrous oxide (N_2O) are also gaining increased attention as they are considered as greenhouse gases (GHG) with global warming effects. At MEPC 81, a Correspondence Group was established and began discussing relevant topics: methods for measuring methane and nitrous oxide emissions from ships; and a regulatory framework for the use of onboard carbon capture and storage (OCCS), which reduces GHG emissions from ships through the separation, capture, and storage of CO_2.

At this session, the “Guidelines for Test-Bed and Onboard Measurements of Methane and/or Nitrous Oxide Emissions from Marine Diesel Engines” was adopted. Moreover, the IMO developed a work plan on the development of a regulatory framework for the use of the OCCS, including consideration of legal barriers and the development of guidelines on testing, survey, and certification of the OCCS. It was agreed that these agenda items require further study and that the Correspondence Group is re-established to continue discussions on these issues.

2.1.5 Amendments to the Guidelines on Survey and Certification of EEDI

The calculation of the EEDI (Energy Efficiency Design Index) requires determination of the ship’s speed based on speed trial results, assuming calm weather conditions with no wind or waves. The current “Guidelines on Survey and Certification of the EEDI” refers to the ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials 2017, 2021 or 2022 (hereafter referred to as the ITTC Procedure) or ISO 15016:2015 for determining ship speed taking into account the external effects (wind, current, waves, shallow water, displacement, water temperature and water density).

Given the amendments to the ITTC Procedure and ISO 15016 in 2024 and 2025 respectively, MEPC 83 adopted the amendments to the “Guidelines on Survey and Certification of the EEDI” to refer to the amended 2024 ITTC Procedure and ISO 15016:2025.

In addition, ISO 15016:2025 will be applied to sea trials conducted on or after 1 May 2026, in recognition of the need to allow adequate time for preparation in accordance with the updated standard.

ClassNK is in the process of updating the progressive speed trial analysis software “PrimeShip-GREEN/ProSTA” to ensure compliance with ISO 15016:2025.

2.2 Air Pollution

2.2.1 Addition of North-East Atlantic Ocean as Nitrogen Oxides (NOx), Sulphur Oxides (SOx) and Particulate Matter (PM) Emission Control Area (ECA)

Regulation 13 of MARPOL Annex VI specifies the NOx emission regulations for marine diesel engines installed on board ships. Regulation 13.6 designates NOx Emission Control Areas (ECA), in which the NOx Tier III emission limit is applied.

Regulation 14 of MARPOL Annex VI sets out control measures to reduce emissions of SOx and PM from ships, where the sulphur content in fuel oil used has been limited to 0.50% in open sea area since 2020. Regulation 14.3 designates SOx and PM ECAs, in which the sulphur content in fuel oil used is further limited to 0.10%.

The following sea areas have been designated as ECAs so far (Table 3):

Table 3　Sea areas designated as ECAs

Sea area	Type of ECA	
	NOx	Sox and PM
North America	✓	✓
US Caribbean Sea	✓	✓
Baltic Sea	✓	✓
North Sea	✓	✓
Mediterranean Sea		✓
Canadian Arctic Waters	✓	✓
Norwegian Sea	✓	✓

At this session, draft amendments to MARPOL Annex VI were approved, newly designating the North-East Atlantic Ocean (see Fig. 2) as ECA.

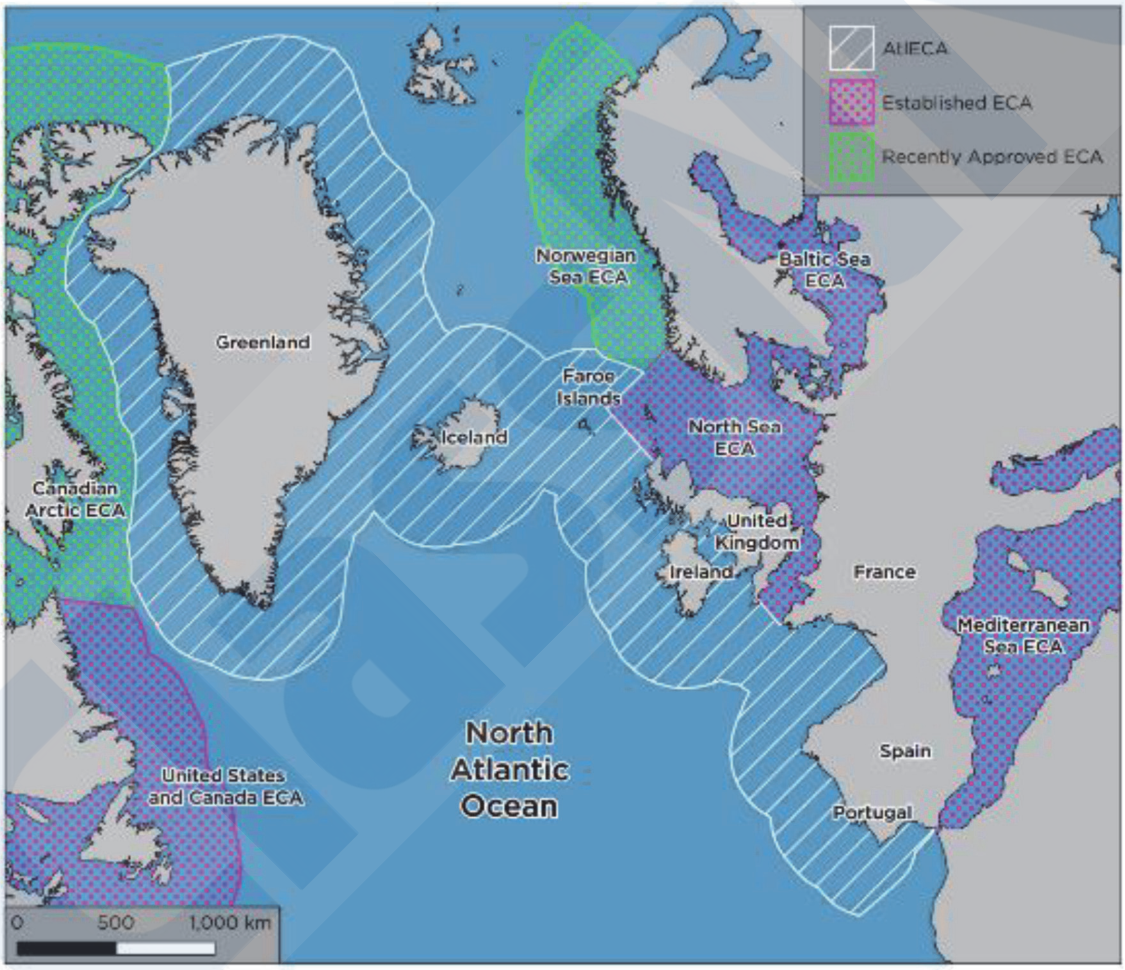

Fig. 2　Illustration of the North-East Atlantic ECA

Assuming the adoption of the draft amendments at the extraordinary session of MEPC in October 2025 with the application date of March 2027, it is expected that the sulphur content in fuel oil used for ships operating in North-East Atlantic ECA will be limited to 0.10% at the earliest from March 2028. Furthermore, the NOx Tier III emission limit will be applied to the following ships operating in North-East Atlantic ECA:

- Ships for which the building contract is placed on or after 1 January 2027
- In the absence of a building contract, ships the keels of which are laid or which are at a similar stage of construction on or after 1 July 2027
- Ships delivered on or after 1 January 2031

2.2.2 Revision of SCR Verification Guidelines

Selective Catalytic Reduction (SCR) systems for NOx emission reduction need to be certified in accordance with the "2017 Guidelines for SCR Systems".

At this session, the revised "2025 Guidelines for SCR Systems" was adopted, which clarifies the methods for monitoring catalyst condition and degradation. The amended guidelines are applicable to the following SCR systems:

- SCR systems installed on ships the keels of which are laid or which are at a similar stage of construction on or after 1 November 2025
- SCR systems installed on ships the keels of which are laid or which are at a similar stage of construction before 1 November 2025, which have a contractual delivery date of SCR systems to the ship on or after 1 May 2026 or, in the absence of a contractual delivery date, the actual delivery of the SCR system to the ship on or after 1 May 2026

2.3 Others

2.3.1 Carriage of Blends of Biofuels by Conventional Bunker Ships

The "Interim Guidance on the Carriage of Blends of Biofuels and MARPOL Annex I Cargoes by Conventional Bunker Ships" was approved, which allows transportation of blends of not more than 30% by volume of biofuel by conventional bunker ships (i.e. oil tankers as defined in Regulation 1.5 of MARPOL Annex I that are engaged in the transport and delivery of fuel oil for use by ships).

2.3.2 In-Water Cleaning of Ships' Biofouling

The "Guidance on In-water Cleaning of Ships' Biofouling" was approved, which sets out guidance for operationalizing in-water cleaning operations for minimizing transfer of invasive aquatic species attached to ships' hull, including specifications and performance standards for in-water cleaning systems and guidance for planning and conducting in-water cleaning operations.

2.3.3 Amendments to the Guidelines for the Development of the Inventory of Hazardous Materials

With respect to the restriction of the use of cybutryne as anti-fouling system since January 2023, the use or non-use of cybutryne is required to be recorded in the Inventory of Hazardous Materials (IHM) in accordance with the "2023 Guidelines for the Development of the Inventory of Hazardous Materials" adopted at MEPC 80.

At this session, the amendments to the "2023 Guidelines for the Development of the Inventory of Hazardous Materials" were adopted, clarifying the threshold values of cybutryne in anti-fouling system coating samples, either taken from wet paint containers or taken directly from hull.

2.3.4 Review of BWM Convention

When BWM Convention entered into force in 2017, it was agreed to monitor the application and to review the effectiveness of the Convention through the experience building phase (EBP), and the review work has been conducted based on the Convention Review Plan (CRP) approved at MEPC 80, which comprises the list of issues that need to be finalized.

At this session, with the aim to finalize the draft amendments to the BWM Convention and BWM Code by MEPC 84 in spring 2026 in line with the work plan, it was agreed to continue the work at the Correspondence Group. Assuming the approval of the draft amendments at MEPC 84 followed by adoption at MEPC 85 in autumn 2026, the amendments are expected to enter into force in summer 2028 at the earliest.

2.4 Amendments to Mandatory Instruments

2.4.1 Amendments to NOx Technical Code on Certification of Marine Diesel Engines Subject to Substantial Modification, etc.

The amendments to the NOx Technical Code 2008 were adopted, which includes the onboard NOx certification procedures for marine diesel engines subject to substantial modifications or being certified to a Tier to which the engine was not certified at the time of its installation. These amendments clarify the onboard NOx certification process for marine diesel engines, which went under a modification for reasons such as environmental measures for GHG emission reduction. The amendments will enter into force on 1 September 2026.

The Parties were further invited to consider early application of these amendments.

2.4.2 Amendments to NOx Technical Code on NOx Regulations for Marine Diesel Engines

The amendments to the NOx Technical Code 2008 were adopted, which includes the procedures for demonstrating compliance of "off-cycle" NOx emissions (specific area within the power or torque and speed area of a marine engine to which NOx emission measurement is not required under the current Convention, but still within the limit area of the not to exceed zone that the engine is certified to operate within under steady-state conditions) and NOx regulations applicable to marine diesel engines with multiple engine operational profiles. These amendments may lead to an increased number of load points for NOx emission tests and additional submission of technical documents related to NOx emission characteristics by engine manufacturers, etc. The amendments will enter into force on 1 March 2027.

The new requirements apply to a new parent engine to which EIAPP Certificates are issued on or after 1 January 2028. In the case of an engine family or engine group for which the parent engine was certified prior to 1 January 2028, the new requirements apply when an EIAPP Certificate is issued for the relevant member engine on or after 1 January 2030.

3. OUTCOMES OF MSC 110

3.1 Adopted Mandatory Requirements

Mandatory requirements were adopted at MSC 110 as follows:

(1) Amendments to SOLAS Chapter II-2 and V

Amendments to SOLAS regulation II-2/11 to correct the wording regarding structural integrity and amendments to regulation V/23 regarding pilot transfer arrangements. In addition, the performance standards for pilot transfer arrangements, which are made mandatory by the amended regulation V/23, were also adopted. It was also agreed to invite a voluntary early implementation at that time.

For details regarding pilot transfer arrangements, please refer to section 3.7.

(2) Amendments to HSC Code

Amendments to 1994 HSC Code and 2000 HSC Code regarding the numbers of lifejackets for infants and adults.

3.2 Approved Mandatory Requirements

The following mandatory requirements were approved at this session and are expected to be adopted at MSC 111 to be held in May 2026.

(1) Amendments to IP Code

Amendments to Part IV of IP Code to change the assumed mass of each industrial personnel from 75 kg to 90 kg in the ship stability calculation.

(2) Amendments to 2011 ESP Code

Amendments to 2011 ESP Code regarding Remote Inspection Technique (RIT). This includes the procedures for certification of a firm engaged in close-up survey of hull structures using RIT. In addition, the guidelines on the use of RIT will be in place by the entry into force of the amendments to the 2011 ESP Code, to ensure a standardized and safe approach of the use of RIT.

(3) Amendments to 1988 Load Lines Protocol

Amendments to 1988 Load Lines Protocol regulation 25 regarding guard rails. If adopted by MSC 111, ships the keels of which are laid, or which are at a similar stage of construction on or after 1 January 2028 will be required to have guard rails with 3 bars and openings not exceed 230 mm below the lowest course of the guard rails and 380 mm at the other courses, regardless of the location of the guardrail.

(4) Amendments to LSA Code

Amendments to LSA Code regarding the arrangement to test the release system under load without launching the free-fall lifeboat into the water.

(5) Amendments to SOLAS Chapter V and HSC Code

Amendments to SOLAS Chapter V and HSC Code to allow the VHF Data Exchange System (VDES), which has function of VHF data exchange in addition to Automatic Identification System (AIS), to install ships as an alternative to AIS. In addition, the performance standards for shipborne VDES are expected to be approved at MSC 111.

3.3 Approval of Unified Interpretations (UIs), Guidelines and Guidance etc.

The following unified interpretations (UIs), guidelines, guidance and etc. were approved during MSC 110.

3.3.1 UIs

(1) Unified interpretation of SOLAS regulation II-1/12.6.2

Unified interpretation of SOLAS regulation II-1/12.6.2 to clarify remotely controlled valve complying with the SOLAS regulation.

(2) Unified interpretation of 6.1.1.3 and 6.1.2.2 of the LSA Code

Unified interpretation of 6.1.1.3 and 6.1.2.2 of the LSA Code to accept manual hoisting up of a dedicated rescue boat for cargo ships from stowed position.

(3) Unified interpretation of SOLAS regulation II-2 and the HSC Code

Unified interpretation of SOLAS regulation II-2/10.11.2.2 and 7.9.4 of the HSC Code regarding the permissible values of perfluorooctane sulfonic acid (PFOS) in fire-extinguishing media and procedures for Verification.

(4) Unified interpretation of the FSS Code

Unified interpretation of 2.4.2.2 of chapter 9 of the FSS Code regarding the acceptable spacings of combined smoke and heat detectors.

(5) Unified interpretation of SOLAS regulation II-1/3-13.2.4

Unified interpretation of SOLAS regulation II-1/3-13.2.4 regarding the factual statement for existing non-certified lifting appliances including sample format.

3.3.2 Guidelines and Guidance etc.

(1) Interim guidelines for emergency towing arrangements on ships other than tankers

Interim guidelines for emergency towing arrangements on ships other than tankers to specify strength, safety factor, type approval, prototype test, etc. for towing arrangements.

(2) Revised guidelines for construction, installation, maintenance and inspection/survey of means of embarkation and disembarkation

Amendments to guidelines for construction, installation, maintenance and inspection/survey of means of embarkation and disembarkation (MSC.1/Circ.1331) to add requirements for the side net, which is an alternative to the safety net, and the revision of the test procedure of accommodation ladder to be conducted every five years.

3.4 Consideration of Requirements for Maritime Autonomous Surface Ships (MASS)

In the recent development of MASS, it has been discussed at MSC on an international instrument of MASS (MASS Code). Non-mandatory MASS Code mainly on goal and functional requirements for items such as safety, operation, security, etc. is currently under consideration.

At this session, chapters other than Chapter 4 “TERMINOLOGY AND DEFINITIONS”, Chapter 5 “CERTIFICATE AND SURVEY”, Chapter 8 “OPERATIONAL CONTEXT”, Chapter 9 “SYSTEM DESIGN”, Chapter 10 “SOFTWARE PRINCIPLES” and Chapter 15 “HUMAN ELEMENT” were finalized.

Also, regarding Chapter 15 “Human Element” (including Chapters 5, 8, 9 and 10), its finalization will proceed based on the outcome of the discussions in due course. In the future work, the non-mandatory MASS Code is scheduled to be finalized at MSC 111in 2026, and thereafter, it is planned to be developed as a mandatory code with a view to adoption by 2030.

At this time, the structure of the non-mandatory MASS Code will be as follows.

Part 1: Introduction (purpose and application of the code, etc.)

Part 2: Main principles for MASS and MASS functions (certificate and survey, approval process, risk assessment, operational context, human element, etc.)

Part 3: Goals, functional requirements and expected performance (specified for each item such as safety of navigation and remote operations)

3.5 A Safety Regulatory Framework to Support the Reduction of GHG Emissions from Ships Using New Technologies and Alternative Fuels

At MSC 107, identification and updating a list of new technologies and alternative fuels to reduce greenhouse gas (GHG) emissions and their technical assessment, as well as a review of safety obstacles and gaps in the current IMO instruments that may impede the use of the alternative fuel or new technology, were initiated.

At this session, based on the recommendations to address each of the identified barriers and gaps in current IMO instruments reported by the correspondence group, amendments to conventions or cords, development of guidelines, etc. are instructed to each sub-committee.

For example:

・Develop safety requirements for onboard carbon capture and storage systems on ships (CCC)

- Develop requirements for the Safety of Ships Using Lithium-ion Battery Installations (SSE)
- Update the Code of Safety for Nuclear Merchant Ships (Resolution A.491(XII)) (SDC)
- Develop Interim guidelines for the Safety of Ships Using Wind Propulsion and Wind Assisted Power (SDC)

The discussion on nuclear power was limited to safety at this session, and cooperation with the International Atomic Energy Agency (IAEA), legal status, relationships with other treaties such as the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and environmental impact will be discussed at the future session.

3.6 Cyber Risk Management

In view of the growing importance of cyber security on board ships and the need for security risk countermeasures, resolution MSC.428(98) on maritime cyber risk management and the non-mandatory guidelines (MSC-FAL.1/Circ.3/Rev.3) for reference in the implementation of this resolution have been developed.

At the previous session, it was agreed to initiate discussions to further develop cybersecurity standards for ships and port facilities as next steps to enhance maritime cybersecurity.

At this session, based on the report of the related working group, it was agreed to develop a non-mandatory cybersecurity Code of which requirements are goal-based and include risk management. As the development of the Code would be subject to the approval of a future session of the committee, preliminary work on the Code will be undertaken by an informal group of experts.

3.7 Amendments to SOLAS Regulation V/23 regarding Pilot Transfer Arrangements

SOLAS regulation V/23 requires to provide ships engaged in the course of which pilots may be employed with pilot transfer arrangements. Requirements regarding pilot transfer arrangements have been revised several times, and current requirements have applied since 2012. Even after the revision, fall accidents caused by improper maintenance and installation had occurred. Therefore, consideration of new safety measures had been commenced at MSC 104 held in 2021 and amendments to SOLAS regulation V/23 and the Performance Standard for Pilot Transfer Arrangements were adopted at this session.

The followings are the key points to pay special attention to.

- Pilot ladders and manropes shall be removed from service, within 36 months after the date of manufacture or within 30 months after the date of being placed into service, whichever comes first. (Part D)
- At least one spare pilot ladder and one spare set of manropes shall be carried on board the ship. (Part D)
- A pilot ladder and manropes shall be type-approved by the Administration as complying with these performance standards. (Part F)
- All strong points, shackles and securing ropes shall have a breaking strength of not less than 48 kN (currently, not less than 24 kN is required). (Part A)
- If a pilot ladder is to be stowed on a winch drum, the drum diameter shall be not less than 0.16 m and the drum shall be provided with sunken securing points. (Part C)

This amendment will be applied on or after 1 January 2028, noting that IMO Circular was issued to invite a voluntary early implementation. Pilot transfer arrangements for existing ships will also be required to comply with these requirements.

For specific inspection procedures and other details regarding this amendment will be provided in ClassNK Technical Information separately in due course.

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