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.

* Research Institute, Research and Development Division, ClassNK

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**

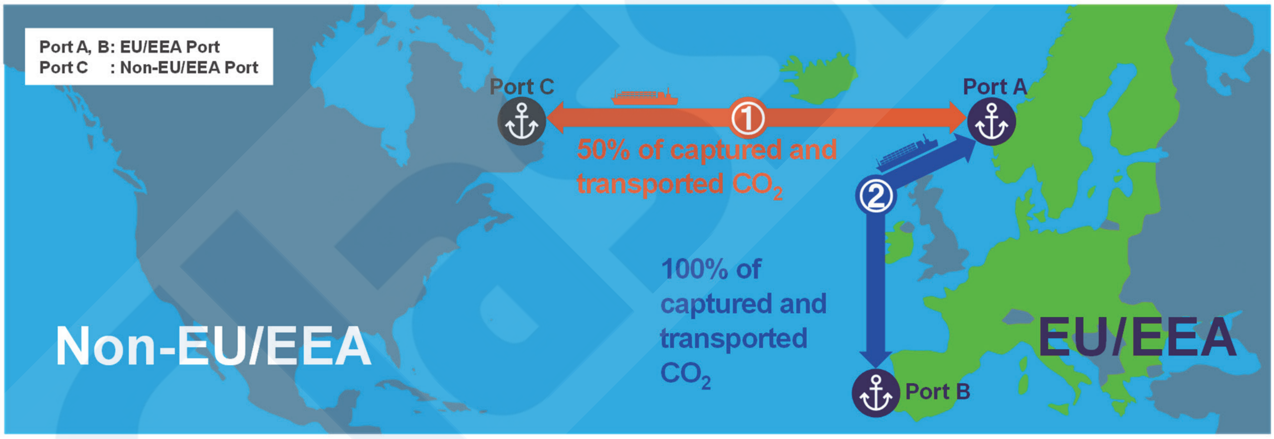

Fig. 1 CO_2 emissions excluded from EU allowances by onboard CCS

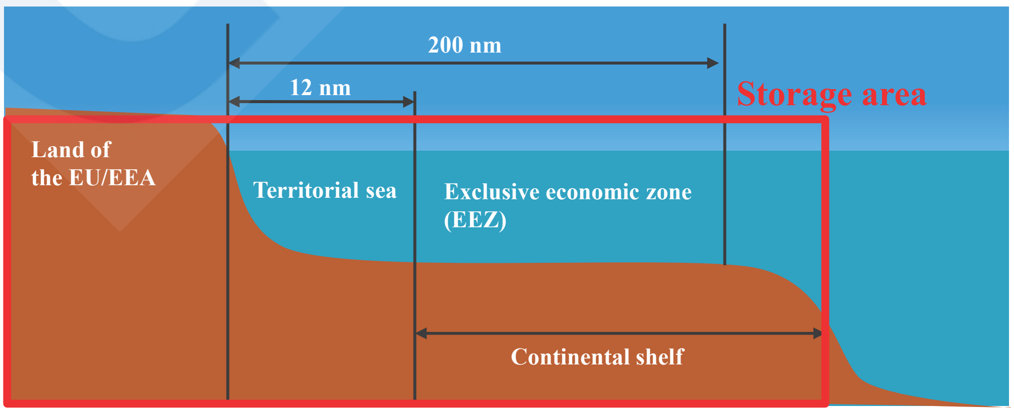

Fig. 2 Recognized CO_2 storage area in EU/EEA

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.

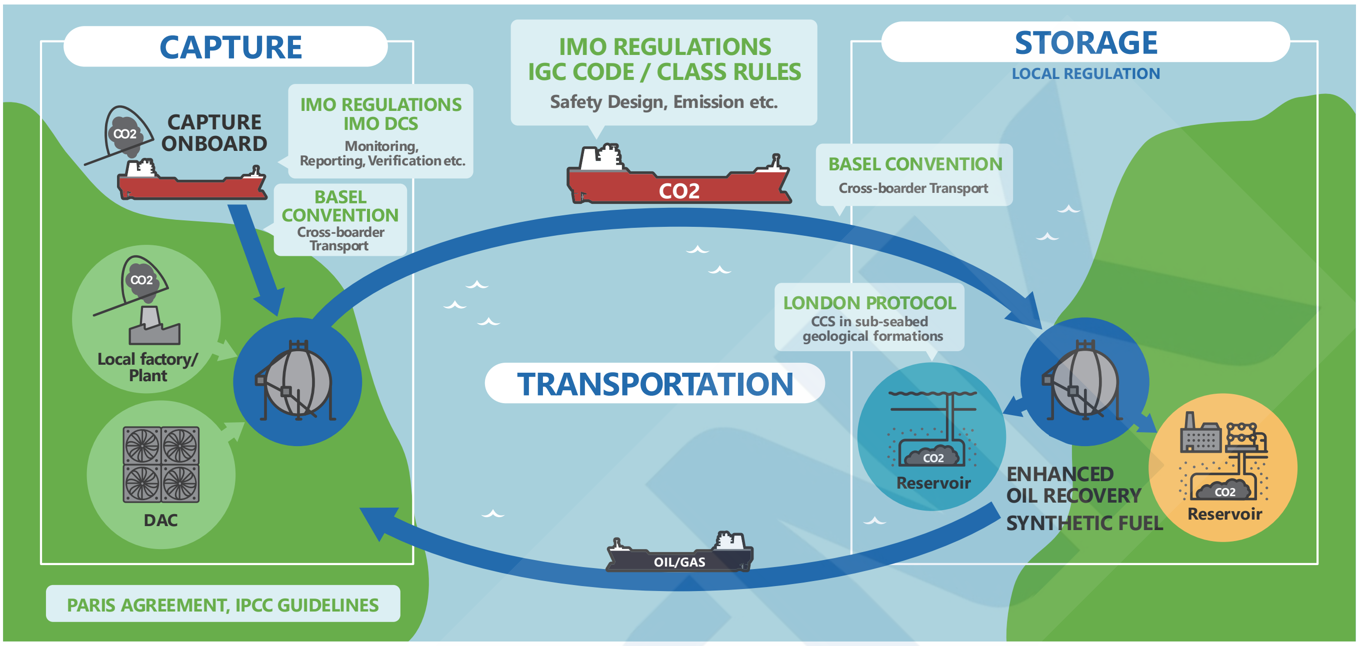

Fig. 3 Regulatory framework of value chain for captured CO_2 storage and utilization

REFERENCES

1) EU: Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community (Text with EEA relevance)

2) EU: Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 (Text with EEA relevance)

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

4) EU: Commission Delegated Regulation (EU) 2024/2620 of 30 July 2024 supplementing Directive 2003/87/EC of the European Parliament and of the Council as regards the requirements for considering that greenhouse gases have become permanently chemically bound in a product

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)

6) IMO: 2024 GUIDELINES ON LIFE CYCLE GHG INTENSITY OF MARINE FUELS (2024 LCA GUIDELINES), IMO RESOLUTION MEPC.391(81)

7) IMO: ANNEX 8 WORK PLAN ON THE DEVELOPMENT OF A REGULATORY FRAMEWORK FOR THE USE OF ONBOARD CARBON CAPTURE AND STORAGE (OCCS), MEPC 83/17