Technical Report

ISO/TR 27929

Transportation of CO_2 by ship

Transport de CO_2 par bateau

First edition
2024-10

Reference number
ISO/TR 27929:2024(en)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword ..... **v**

Introduction ..... **vi**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 Abbreviations **3**

5 Regulatory regime for maritime and inland waterways for CO_2 transportation **3**
5.1 General 3
5.2 Maritime governance 4
5.3 Technical safety regime for maritime transportation of liquid CO_2 5
5.4 Greenhouse gas emissions 6
5.5 Trading and cross-border transportation 6

6 Ship transport of CO_2 ..... **7**
6.1 General 7
6.2 CO_2 cargo transport conditions 7
6.2.1 General 7
6.2.2 Low pressure 8
6.2.3 Medium pressure 8
6.2.4 Elevated pressure 8
6.2.5 Density effects 9
6.2.6 Solid state CO_2 (dry ice) 9
6.3 Cargo tank design 9
6.3.1 Cargo tank design considerations 9
6.3.2 Tank material 10
6.3.3 Novel materials 10
6.3.4 Design pressure 11
6.3.5 Insulation 11
6.4 CCS ship transport concepts 11
6.4.1 General 11
6.4.2 Ship terminal to terminal 12
6.4.3 Barge terminal to terminal (inland waterways) 12
6.4.4 Offshore floating storage and injection unit (FSIU) 12
6.4.5 Offshore injection unit 12
6.4.6 Offshore direct injection 13
6.5 Multi Gas and dedicated carriers 13
6.5.1 General 13
6.5.2 Existing ship conversion 13
6.6 Ship design 13

7 Properties of CO_2, CO_2 streams and mixing of CO_2 streams influencing the ship transportation **13**
7.1 Thermodynamic properties of CO_2 and CO_2 composition 13
7.2 CO_2 impurities and trace components 15
7.2.1 Common impurities 15
7.3 Flexibility and mixing of CO_2 streams from different sources 16

8 Ship operation **17**
8.1 Ship and terminal modes of operation 17
8.2 Compatibility and interface 17
8.3 Cargo operations 18
8.3.1 Responsibilities 18
8.3.2 Manifold operations 18
8.3.3 Loading operations 18
8.3.4 Offloading operations 19

8.4 Cargo management ... 19
8.4.1 General ... 19
8.4.2 Cargo tank preparation ... 19
8.4.3 Cargo voyage management ... 19
8.4.4 Cargo losses ... 20
9 Technical gaps and development ... 20
9.1 Applicability and precision of existing requirements ... 20
9.2 Identification of additional relevant requirements such as practices onshore ... 20
9.3 Qualification and process for new technology ... 21
9.4 Gaps and need for development ... 21
10 Safety and risks ... 21
10.1 Health, safety and environment (HSE) ... 21
10.1.1 Toxicity and asphyxiation ... 21
10.1.2 Hazards of liquid CO_2 ... 22
10.2 Measures to mitigate risks ... 22
10.2.1 Gas detection ... 22
10.2.2 Emergency shut down ... 22
10.2.3 Emergency release system ... 22
10.3 Special risks with liquid CO_2 as ship cargo ... 22
10.3.1 Solid formation ... 22
10.3.2 Material integrity ... 22
10.3.3 Electrostatic charge ... 23
11 Quantification and verification of CO_2 cargo ... 23
11.1 General ... 23
11.2 Quantification and measurement ... 23
11.2.1 General ... 23
11.2.2 Cargo measurement ... 23
11.2.3 CO_2 quality ... 24
11.2.4 Co-mingling ... 24
11.2.5 Onboard carbon capture ... 24
11.3 Verification ... 24
12 Summary status and development needs for CO_2 ship transportation for CCS value chains ... 24
Bibliography ... 26

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation, and geological storage*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In a carbon dioxide capture and storage (CCS) value chain, the main means for transportation of CO_2 from an emitter to storage are by ships or by pipelines. Transportation of gas in liquid state is well established in the shipping industry and has been done for decades. However, liquid CO_2 is different from other gases carried by ships and poses new challenges for both ship design and ship operation. Compatibility along the value chain is an essential element in the development of CCS. It is important to have a common understanding of how different aspects, such as cargo temperature and pressure, can influence the ship design and ship operation.

The purpose of this document is to support consistency and compatibility in the design of CCS value chains and address important areas where future development and standardization can add value. This document will discuss CO_2 ship types, ship logistics and interface-specific aspects related to the safe and reliable design and operation of CO_2 ships.

Transportation of liquified gas on ships is governed by the regulations, codes and conventions drawn up under the International Maritime Organization (IMO) which is referred to under United Nations Convention on the Laws of the Sea (UNCLOS). Ships carrying CO_2 are regulated by the IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), which serves as the main technical regulation for CO_2 carriers under the International Convention for the Safety of Life at Sea (SOLAS).

Ship transportation of CO_2 is currently limited to commercial trade for small-scale use in industries such as the food or beverage industries and is served by a handful of small ships. However, the evolving industry around CCS will demand transportation volumes of a different magnitude and involve development of new ship designs and ship logistics concepts. These are introducing a need for knowledge-sharing related to type of transportation concepts, CCS value chain compatibility, technical and operational reliability and the safety of CO_2 carriers.

Quantification, verification and reporting along the different elements in the CCS value chain will become important. This document describes limitations and challenges to them and how they can be done onboard the ship.

In this document, CO_2 means a captured CO_2 stream, including potential impurities following the capture process, if not otherwise explicitly referred to as pure CO_2.

Transportation of CO_2 by ship

1 Scope

This document provides insights into the essential aspects of CO_2 shipping and provides basic descriptions of how the CO_2 carrier and technology therein is technically integrated with the CCS value chain. It also includes a description of specific challenges of transporting CO_2 as cargo, how this differs from other gases transported by ships today, and how this influences the ship design and operation. Finally, this document introduces how CO_2 ships are regulated within the existing international maritime regulatory framework. This document's main focus is on the technical aspects of CO_2 shipping. Commercial, liability and financial aspects are intentionally kept out of this document. However, general reference to commercial impact is made where relevant.

This document focuses on the ship transportation of CO_2 between loading and offloading facilities where the system boundaries are at the ship manifold equipment that connects the ship to the other components in the value chain. In the document, the basis for the description of ship operation is transportation between two shore-based terminals. A high-level description of other relevant interfaces is given on a conceptual level as this has impact on the ship design. However, any further description of potential solutions upstream and downstream from the CO_2 carrier is outside the scope. This document also gives a high-level description of the physical properties of CO_2 streams at the conditions relevant for shipping and how relevant impurities can impact the ship and ship operation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
barge
floating unit carrying freight on canals, rivers and in ports, either under its own power or towed by another

3.2
cargo containment system
arrangement for containment of the cargo including, where fitted, a primary and secondary barrier, associated insulation and any intervening spaces, and adjacent structure, if necessary, for the support of these elements

Note 1 to entry: See Reference [9].

3.3
convention
written agreement between countries

Note 1 to entry: Conventions form a major part of maritime affairs governed by the International Maritime Organization (IMO).

3.4
CO_2 carrier
cargo ship or barge constructed or adapted and used for the carriage of CO_2 as cargo

3.5
CO_2 stream
stream consisting overwhelmingly of carbon dioxide

[SOURCE: ISO 27917: 2017, 3.2.10]

3.6
dynamic positioning system
equipment and system that is used for keeping a vessel at a given position using the thruster and propulsion of the vessel to compensate for the environmental loads, including waves, wind, current, etc.

3.7
export location
location where the ship loads the CO_2 for transport to the import location

3.8
flag state
jurisdiction under whose laws the ship is registered

3.9
heat ingress
transfer of heat from the surroundings into the cargo

3.10
heel
liquid cargo maintained at the bottom of the tank on the return voyage to maintain cargo tank temperature

3.11
import location
location where the ship offloads the CO_2 that is transported from the export location

3.12
inland waterway
natural or artificial navigable inland body of water, or system of interconnected bodies of water, used for transport, such as lakes, rivers or canals

3.13
intermediate storage
storage of CO_2 volumes before being loaded to a ship and storage after being offloaded from the ship

3.14
multi-lobe
bi-lobe
tri-lobe
cargo tanks which consist of two (bi-lobe) or three (tri-lobe) lobes where lobes represent cylinder segments partly merged and connected by a common bulkhead

3.15
muster area
location where the crew assemble in the event of an emergency

3.16
riser
flexible pipe that connects an offshore well to a ship or floating offshore unit

3.17
ship master
person in charge of the ship, its crew and any passengers or cargo it is carrying, on the water and in port

3.18
territorial seas
areas which extend up to 12 nautical miles from the baseline of a country's coastal line

3.19
triple point
temperature and pressure at which three phases (gas, liquid and solid) of a substance coexist in thermodynamic equilibrium

3.20
two-phase flow
simultaneous flow of gas and liquid

3.21
vapour return
connection between ship and terminal for vapour exchange to ensure pressure equilibrium between the shore storage tanks and the ship cargo tanks

3.22
vapour-liquid equilibrium
state where a substance's liquid and vapour phases are in equilibrium

4 Abbreviations

CO_2	carbon dioxide
CCS	carbon dioxide capture and storage
ESD	emergency shut down
FSIU	floating storage and injection unit
IGC Code	International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organization
LNG	liquified natural gas
LPG	liquefied petroleum gas
NIST	National Institute of Standards and Technology
OCIMF	Oil Companies International Maritime Forum
SIGTTO	Society of International Gas Tanker and Terminal Operators
SOLAS	International Convention for the Safety of Life at Sea
UNCLOS	United Nations Convention on the Law of the Sea
IACS	International Association of Classification Societies
ES-TRIN	European Standard — Technical Requirements for Inland Navigation vessels

5 Regulatory regime for maritime and inland waterways for CO_2 transportation

5.1 General

International and national shipping are subject to an extensive and stringent set of laws and regulations which are enforced by international, regional and national regulatory bodies. Considering the large number

of stakeholders and the significant environmental and economic impact the maritime industry has on the society, regulations are developed to enable cooperation between stakeholders and to promote and improve safety, security, efficiency and to prevent marine and atmospheric pollution by ships.

Marine transportation of liquefied gases, including CO_2 in bulk by dedicated gas carriers, is well regulated with proven and high safety standards developed by IMO and other governmental and industry organizations. Considering the increased focus on CCS, it is however expected that laws and regulations for maritime transportation of CO_2 will be further developed.

General description of the maritime governance scheme is explained in 5.2. It is followed by a description of the main regulatory regime for CO_2 carriers.

5.2 Maritime governance

International shipping involves vessels which operate across the oceans as well as territorial seas and exclusive economic zones. Other vessels are limited to coastal and inland waterways transport within territorial waters covered by the jurisdictions of a single state or multiple states. Maritime shipping is a mature industry with well-established international governance institutions; however, the regulatory scheme can be different depending on the area and type of operation. A generic overview of the maritime governance scheme and stakeholders involved in maritime shipping is shown in Figure 1.

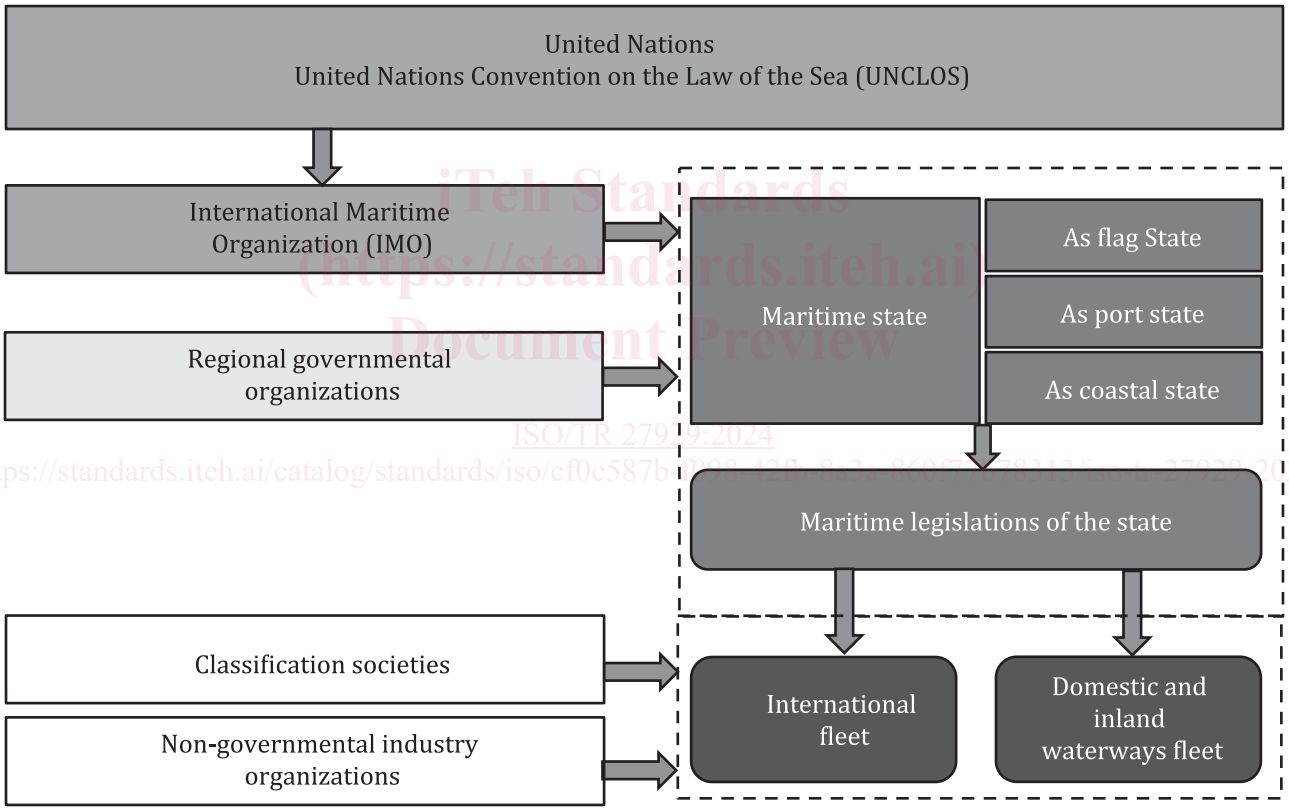

Figure 1 — Governance and stakeholders in maritime shipping

The governance of the ocean emerges from the United Nations. UNCLOS lays down a comprehensive regime of law and order in the world's oceans and seas by, *inter alia*, defining the maritime geographical jurisdiction, including the coastal states' sovereignty over their respective maritime zones.

IMO is a specialized agency under the United Nations that develops conventions containing detailed regulations to safety, security and environment, with the intention of establishing a global minimum standard for the shipping industry. Under IMO, more than 60 conventions, codes and regulations have been developed which serve the basis for the implementation in the legislations of the individual member states.

Regional governmental organizations can develop additional regulations which apply for specific geographical areas or member states. The European Union (EU) is an example of a regional governmental organization which through its regulations and directives aim at ensuring common standards among the EU member states.

The regulations developed by IMO or any other governmental organization are upon ratification implemented into the national laws of the ratifying states. The flag states enforce the regulations for ships registered under their flag. Port states exercise port state control on ships visiting their ports based on domestic laws, to ensure the ship's condition and equipment are in compliance with the provisions of international conventions and that the ship is safely manned and operated pursuant to applicable international law. Flag and port states can introduce additional regional or domestic regulations which apply within their jurisdiction.

Within the convention framework set by IMO and the regulations set by flag states, the classification societies play an important role as independent governance actors. The major classification societies form the International Association of Classification Societies (IACS), which works together with the industry and maritime regulators to ensure that the legislative framework is supported and enhanced by the practical implementation of classification rules. IACS has an observer role in IMO which allows them to provide support and advise to the IMO process. The classification societies develop and maintain technical rules and standards for the construction and operation of ships, and carry out classification, certification and verification services, as well as surveys to ensure compliance with the standards. The classification is the basis for the registration with the flag state and is required by IMO for international voyages. The classification standards are generally internationally recognized and in compliance with international maritime regulations.

The classification societies can, on behalf of a flag state administration, undertake statutory certification to the extent the society has been authorized to do so by the individual flag state administration. Statutory certification includes among others approval, surveys, and the issuance of statutory certificates.

Other non-governmental organizations such as International Chamber of Shipping (ICS), International Association of Independent Tanker Owners (INTERTANKO), Oil Companies International Maritime Forum (OCIMF), Society of International Gas Tanker and Terminal Operators (SIGTTO), are also important stakeholders in maritime shipping. These are industry organizations with the aim of sharing experiences, addressing common problems and establishing a framework of standards, guidelines, and best practices for the industry. Publications from these organizations often become industry standards and are important for ensuring standardization particularly regarding operational compatibility and safety. Several of these organizations have consultative status in IMO.

Considering the sovereignty of the territorial seas and internal waters as laid down in UNCLOS, the coastal states are not bound by the framework issued by IMO and other organizations when forming the legislative framework for ships operating within the territory of the state, unless the instruments are ratified by the individual states. Hence, the regulatory framework which is basis for the national legislations can differ from that of international shipping. Many states do however use the international legislative framework as a basis for their national frameworks, potentially with modifications and adjustments as found relevant depending on the type of ship and trade, the operational area, etc. regional (e.g. bi-lateral or multi-lateral) requirements and agreements can apply to specific operational areas within the territories of two or more states. One example is the regulations applicable for the inland waterways system in Europe, which is described in more detail in 5.3.

5.3 Technical safety regime for maritime transportation of liquid CO_2

The carriage of liquid CO_2 onboard ships for international trade is governed pursuant to the IMO framework and by the provisions in the SOLAS, and is further detailed in mandatory codes, depending on the mode of transport. The regulations distinguish between the carriage of the product in packaged form, e.g. as modular tank containers on cargo ships, and the carriage of the product in bulk on dedicated gas carriers as explained in more detail in the following. Carriage of product in package form is regulated by the International Maritime Dangerous Goods Code (IMDG) while the carriage of product in bulk on dedicated gas carriers is regulated by the IGC Code.