財團法人驗船中心
CR CLASSIFICATION SOCIETY

GUIDELINES FOR SHIPS USING HYDROGEN AS FUEL

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April 2025

REVISION HISTORY

(This version supersedes all previous ones.)

Revision No.	Editor	Date (yyyy-mm)
001	Rules Section	2025-04

GUIDELINES FOR SHIPS USING HYDROGEN AS FUEL

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Abbreviations

ANSI	American National Standards Institute
AIAA	American Institute of Aeronautics and Astronautics
ASME	American Society of Mechanical Engineers
CCC	IMO Sub-Committee on Carriage of Cargoes and Containers
CCTV	Closed Circuit Television
ESD	Emergency Shutdown
FSS Code	International Code for Fire Safety Systems
FMEA	Failure Modes and Effects Analysis
IACS	International Association of Classification Societies
IEC	International Electrotechnical Commission
IGF Code	International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organization
ISO	International Organization for Standardization
KHKS	Koatsu Gas Hoan Kyoukai Standards
NASA	National Aeronautics and Space Administration
SOLAS	International Convention for the Safety of Life at Sea

Chapter 1 Introduction

1.1 Introduction

1.1.1 The purpose of the Guidelines for Ships Using Hydrogen as Fuel (hereinafter referred to as "the Guidelines") is to provide an standard for the safety of ships using hydrogen as fuel. The basic philosophy of the Guidelines is to provide provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using hydrogen as fuel in order to minimize the risk to the ship, its crew and the environment. Throughout the development of the Guidelines it was recognized that the provisions therein must be based on sound naval architectural and engineering principles and the best understanding of operational experience, field data and research and development.

1.1.2 The Guidelines follow the goal-based approach (MSC.1/Circ.1394/Rev.2) by specifying goals and functional requirements for each section forming the basis for the design, construction and operation of ships using hydrogen as fuel. The current version of the Guidelines includes provisions to meet the functional requirements for hydrogen as fuel. The Guidelines address areas identified as needing a special consideration for the use of hydrogen as fuel. The Guidelines have been closely aligned with the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code), as amended.

1.1.3 While the Guidelines have been developed based on available information at the present time, they will be revised periodically in line with discussions at the International Maritime Organization (IMO) and the rapid development of new technologies.

1.1.4 Based on a comparative study with the general requirements for ships using natural gas as fuel stipulated in Chapters 2 to 16 of the Guidelines for Ships Using Gases or Other Low-Flashpoint Fuels (hereinafter referred to as "the LFFS Guidelines"), the Guidelines establish additional requirements according to the properties and hazards of hydrogen fuel in addition to those general requirements.

Chapter 2 General

2.1 General

The provisions of Chapter 2 of the LFFS Guidelines shall apply for the general requirements. Additional requirements are provided below.

2.2 Application

2.2.1 The Guidelines apply to ships using hydrogen as fuel. In the case of liquefied gas bulk carriers that use hydrogen cargo as fuel, the provisions of CR17.23 in the Guidelines for Ships Carrying Liquefied Gases in Bulk shall apply.

2.2.2 Ships subject to the Guidelines must implement alternative designs in accordance with section 2.3 of the LFFS Guidelines, demonstrate that such designs provide a level of safety equivalent to that of ships using natural gas as fuel (as stipulated in the LFFS Guidelines), and obtain approval from the competent authority.

2.2.3 The Guidelines are intended for ships subject to International Convention for the Safety of Life at Sea (SOLAS), but in cases where this is difficult for small ships, etc., part of the provisions of the Guidelines can be applied with mitigation if the Society deems that the purpose and functional requirements of the relevant requirements are met and that the safety is equivalent to the requirements of the relevant chapters.

2.2.4 Ships equipped with a fuel cell power system must also comply with the Guidelines for Fuel Cell Installation in addition to the Guidelines.

2.3 Definitions

2.3.1 Unless otherwise specified, the definitions provided in the LFFS Guidelines apply. Additional definitions specific to hydrogen fuel are given below:

(a) "Compressed hydrogen" refers to hydrogen in the gaseous state under pressure exceeding atmospheric pressure.

(b) "Deflagration" refers to the phenomenon where a flame propagates through a flammable mixture at a speed below the speed of sound without causing a shock wave.

(c) "Detonation" refers to the phenomenon where the rapid thermal expansion of gas combusts at a speed exceeding the speed of sound, accompanied by a shock wave.

(d) "Hydrogen" refers to the substance with the chemical formula H_2, and when referred to as hydrogen in the Guidelines, it represents either the gaseous or liquid state, or both.

(e) "Inerting" refers to the process of providing a non-combustible environment by adding inert, compatible gases to the environment, which may be carried in pressure vessels or produced on board the ship or supplied from an external source.

2.4 Submission of Plans and Documents

In addition to those stipulated in 1.3.1 of Part II, 4.3.2 and 5.3 of Part III and 1.5 of Part IV of the Rules for Steel Ships and the LFFS Guidelines, the following plans and documents must be submitted:

- Risk assessment report required by 4.2.1
- Explosion impact assessment report required by 4.3.2
- Gas dispersion analysis report required by 6.4.5
- Radiant heat transfer analysis report required by 6.4.6
- Material selection report required by 7.4.2
- Failure mode and effects analysis (FMEA) report for single failure required by 9.2
- Design pressure evaluation report for explosion required by 9.4
- Equipment selection report for technical certification required by A1.2 of Annex 1

Chapter 3 Goal and Functional Requirements

3.1 General

The provisions of Chapter 3 of the LFFS Guidelines shall apply for the goal and functional requirements.

Chapter 4 General Requirements

4.1 General

The provisions of Chapter 4 of the LFFS Guidelines shall apply for the general requirements. Additional requirements are provided below.

4.2 General Requirements

4.2.1 Ships subject to the Guidelines shall apply the LFFS Guidelines. In the LFFS Guidelines, "natural gas" should be read as "hydrogen gas" and "liquefied natural gas" as "liquefied hydrogen".

4.2.2 When applying the LFFS Guidelines, additional requirements for ships using hydrogen as fuel are specified in this chapter. If these additional requirements conflict with any provisions of the LFFS Guidelines, the additional requirements shall take precedence.

4.3 Limitation of Explosion Consequences

4.3.1 An explosion in any space containing any potential sources of release and potential ignition sources is not to disrupt the proper functioning of pressure relief systems or ventilation systems. Note this is applicable to all spaces containing stored hydrogen, fuel preparation equipment, piping systems, consumers and ventilation ducting or ventilation equipment.

Note:
Consideration is to be given for any space where hydrogen explosions may occur for explosion-resistant structural protection such as reinforced steel bulkheads and decks, energy absorbing structural arrangements, or the integration of barricade structures.
Double wall fuel pipes are not considered as potential sources of release.

4.3.2 Enclosed spaces where hydrogen leakage may occur must undergo quantitative analysis (e.g., explosion analysis) to understand the impact of explosions.

4.4 Risk Assessment

4.4.1 The risk assessment must consider the entire system related to hydrogen fuel, focusing on the prevention of leaks and the effectiveness of countermeasures. Potential ignition characteristics and their impacts must also be evaluated. The following hazards and considerations related to hydrogen must be particularly considered, though not limited to:

(a) Loss of function of component

(b) Leaks

(c) Explosion

(d) Ignition sources

(e) Self-ignition

(f) Delayed ignition

(g) Fire

(h) Bunkering stations

(i) Vent masts

(j) Enclosed spaces

(k) Fire prevention and extinguishing equipment

(l) Gas and fire detection equipment

(m) Control, alarm, and safety systems

(n) Ventilation

(o) Condensation of air

(p) Component damage

Note:
See IACS (International Association of Classification Societies) Recommendation No.146 Risk Assessment as Required by the IGF Code.
Where these requirements and the risk assessment are to support application under the IGF Code Alternative Design criteria and application of SOLAS II-1/55, such application is subject to agreement by the flag Administration, and application of the guidelines referenced by SOLAS II-1/55 footnote to MSC.1/Circ.1212, or associated guidelines MSC.1/Circ.1455.

4.4.2 Equipment related to hydrogen fuel may require safety verification based on risk assessment, depending on the novelty of their operating conditions and design specifications. The selection of equipment requiring safety verification must be carried out in accordance with Annex 1.

Chapter 5 Ship Design and Arrangement

5.1 General

The provisions of Chapter 5 of the LFFS Guidelines shall apply for the ship design and arrangement. Additional requirements are provided below.

5.2 General Requirements

5.2.1 Fuel containment tanks must be installed on open decks to prevent the accumulation of leaked hydrogen. If these tanks are placed in enclosed spaces or below deck areas, a risk assessment must be conducted to verify their safety. The evaluation must specifically consider at least the following points:

(a) Potential minor leaks
The presence of minor leaks to be considered must be determined based on the type of tank.

(b) Explosion relief

(c) Isolation from other compartments

(d) Hazardous area plans

(e) Emergency actions for leaks, fire, and explosions

(f) Access through airlocks from non-hazardous to hazardous areas

(g) Monitoring by Closed Circuit Television (CCTV)

5.2.2 Arrangement and protection of fuel pipes

Fuel pipes must be arranged as far as possible from hot surfaces and electrical equipment or other locations where arcs or ignition sources may be present.

5.2.3 Design of machinery spaces

The Emergency Shutdown (ESD) protected machinery spaces specified in 5.4.1(2) of the LFFS Guidelines cannot be applied.

5.2.4 Design of fuel conditioning spaces

Equipment for fuel conditioning must be installed on open decks to prevent the accumulation of leaked hydrogen. If this equipment is placed in enclosed spaces or below deck areas, a risk assessment must be conducted to verify its safety. The evaluation must specifically consider at least the points listed in section 5.2.1.

Chapter 6 Fuel Containment Systems

6.1 General

The provisions of Chapter 6 of the LFFS Guidelines shall apply for the fuel containment systems. Additional requirements are provided below.

6.2 Functional Requirements

6.2.1 Liquefied hydrogen fuel containment systems must be designed to ensure that leaks from the tanks or their connections do not pose a risk to the ship, crew, or environment. The potential hazards specifically related to liquefied hydrogen include, but are not limited to, the following:

(a) Generation of liquefied air

(b) Generation of high-concentration oxygen areas

6.3 General Requirements

6.3.1 If there is concern about equipment and piping systems being damaged by solid particles of residual inert gas in the fuel pipes and tanks, appropriate equipment such as filters should be installed in the fuel piping system. Additionally, safe maintenance procedures should be established for when clogging occurs and documented in the fuel handling manual as required by 18.4.2.1 of the LFFS Guidelines.

6.3.2 To properly purge the fuel equipment, fuel piping systems, and tanks, consider the necessary conditions, including the required amount and temperature, etc., of inert gas.

6.3.3 To prevent the phenomenon of deflagration transitioning to detonation, an upper limit for the permissible oxygen concentration should be set during purging operations.

6.4 Compressed Hydrogen Gas Fuel Containment Systems

6.4.1 Tanks used for storing compressed hydrogen gas must be deemed suitable by the Society.

Note:
Tanks used for storing compressed hydrogen gas should be in accordance with recognized standards such as KHKS (Koatsu Gas Hoan Kyoukai Standards, established by the High Pressure Gas Safety Institute of Japan), ISO etc., and be confirmed that they can be adopted to ships.

6.4.2 Thermal-operated safety devices, such as pressure relief devices activated by heat, must be designed to ensure rated capacity.

Additionally, such devices must be deemed suitable by the Society.

6.4.3 Vent pipes must be securely fixed to account for the reaction forces during the operation of pressure relief devices.

6.4.4 In cases where multiple fuel tanks are installed, means must be provided to determine from which fuel tank hydrogen is leaking.

6.4.5 In preparation for hydrogen leakage, an emergency response procedure must be developed and included in the fuel handling manual required by 18.4.2.1 of the LFFS Guidelines.

6.5 Pressure Relief Devices

6.5.1 In vacuum-insulated tanks, the capacity of pressure relief devices and associated piping must be provided based on the results of risk assessment, considering the deterioration of vacuum insulation performance due to a single damage or the heat load on the tank when exposed to fire.

6.5.2 Where there is a possibility of atmospheric air condensing and dripping due to the release of low-temperature hydrogen gas, drip trays must be provided in locations where structural damage to the hull or effects of leakage may occur.

6.5.3 Vent pipes must be designed to prevent the transition from fire in the vent mast section to detonation through deflagration (considering factors such as the ratio of pipe length to diameter and inactivation, but not limited to these).

6.5.4 Regarding vent masts for the release of low-temperature hydrogen gas, appropriate measures must be taken to prevent blockage due to the accumulation of ice formed from moisture in the air.

6.5.5 Gas diffusion analysis considering anticipated venting scenarios must be conducted to determine the appropriate size and placement of vent masts.

6.5.6 Vent masts must be positioned to ensure that radiant heat from vent fires does not affect the crew inside the ship or surrounding structures.

6.6 Inert Gas Arrangements

Appropriate inert gas is to be chosen according to the expected operating temperature ranges of the hydrogen fuel contained in the systems to be inerted. For example, for hydrogen systems operating above the liquefication temperature of nitrogen, -196°C, nitrogen gas may be used as an inerting gas.
For temperatures below the liquefication point of nitrogen, helium may be considered.

Machinery, equipment and systems are to be certified according to the characteristics of hydrogen and any other associated chemicals used, for example nitrogen or helium used for inerting. These gas characteristics include for example, flame properties, gas diffusivity, and phase temperatures and pressures.

Note:
Hydrogen fuel systems and auxiliary systems may operate at conditions outside of standard certification parameters, for example the temperature of liquefied hydrogen at -253°C may require additional cryogenic and leak detection provisions for systems, or provisions for handling helium for the purposes of inerting or pre-cooling.

Chapter 7 Materials and General Pipe Design

7.1 General

The provisions of Chapter 7 of the LFFS Guidelines shall apply for the material and general pipe design. Additional requirements are provided below.

7.2 Functional Requirements

7.2.1 The liquefied hydrogen fuel piping system must be designed to prevent exposure of the ship, crew, and environment to danger from releases and leaks from the discharge source. In particular, potential hazards associated with liquefied hydrogen include but are not limited to the following:

(a) Condensation of liquefied air

(b) Generation of high-concentration oxygen zones

7.3 Material Requirements

7.3.1 Metallic and non-metallic materials used in fuel containment systems, fuel piping systems, etc., should be suitable for their intended use.

7.3.2 When selecting commonly available materials considering hydrogen embrittlement, low-temperature embrittlement, and hydrogen attack, recognized standards approved by the Society (e.g., ANSI (American National Standards Institute)/AIAA (American Institute of Aeronautics and Astronautics) G-095A, General High-Pressure Gas Safety Regulation Related Exemplary Standards, etc.) may be referenced and applied. It must be ensured that materials selected in accordance with appropriate standards are suitable for each usage conditions and environments (design temperature, pressure, operating stress, external environmental conditions, etc.).

Note:
Hydrogen embrittlement is a phenomenon that results in a significant reduction in material tensile strength, ductility, and fracture toughness. The initiation and severity of hydrogen embrittlement depends upon the interaction of materials used, the mechanical loading, and environmental variables.

Such deterioration in properties in turn, leads to accelerated fatigue crack growth and consequently shorter equipment life. Furthermore, if not properly accounted for material degradation due to hydrogen, can result in catastrophic unpredicted failure.

Reference can be made to IMO CCC 9-WP.3 Draft Interim Guidelines for the Safety of Ships using Hydrogen as Fuel. Although in draft format, this document contains interim guidelines for the safety of ships using hydrogen as a fuel to be adopted by the IMO Maritime Safety Committee, intended to function as an amendment to the IGF Code.

Information regarding material compatibility with hydrogen environments and effects of material exposure to hydrogen can be found in various industry references, including ANSI/AIAA G-095A-2017 Guide to Safety of Hydrogen and Hydrogen Systems, ASME B31.12 2019 Hydrogen Piping and Pipelines, and NASA (National Aeronautics and Space Administration)/TM-2016-218602 Hydrogen Embrittlement.

7.4 General Pipe Design

7.4.1 For low-temperature fuel containment systems, fuel piping systems, etc., appropriate measures such as thermal insulation must be taken to prevent the exposure of pipe surfaces to the atmosphere from dropping below -183°C in order to prevent the condensation of nitrogen or oxygen. However, if it is unavoidable to generate liquefied oxygen within the insulation or if insulation is not applied to prevent contact with liquefied oxygen, appropriate measures approved by the Society must be taken, such as the removal of nearby combustibles, ensuring ventilation to prevent the generation of high-concentration oxygen zones, and the installation of trays to catch dripping liquefied air.

7.4.2 Pipe joints should be of the fully welded type. Flange joints and screwed joints with a nominal diameter of 25A or less, or mechanical joints approved by the Society, may be used only when full penetration welded joints are not feasible.

Note:
The design, fabrication, assembly, erection, inspection, examination and testing of hydrogen piping systems are to be performed in accordance with recognized standards (e.g., ASME (American Society of Mechanical Engineers) B31-12, Hydrogen Piping and Pipelines).

Chapter 8 Bunkering

8.1 General

The provisions of Chapter 8 of the LFFS Guidelines shall apply for the bunkering.

Chapter 9 Fuel Supply to Consumers

9.1 General

The provisions of Chapter 9 of the LFFS Guidelines shall apply for the fuel supply to consumers. Additional requirements are provided below.

9.2 Fuel Supply System Safety Functions

A manually operated stop valve and a tank master valve in series, or a combined manually operated and master valve are to be fitted in every gas supply outlet of the tank, and to be located close to the tank as far as possible.

9.3 Fuel Supply Redundancy

The fuel supply system must conduct Failure Modes and Effects Analysis (FMEA) for single failures. Additionally, such FMEA must be documented based on criteria deemed appropriate by the Society.

9.4 Design of Outer Pipes and Ventilation Ducts for Gas Leakage from Inner Pipes

The space between the inner pipes and outer pipes or ducts of the fuel supply system must be equipped with a vacuum-insulated structure or an inert gas system or mechanical ventilation system.

Note:
Adoption of mechanical ventilation systems should be subject to prior agreement among relevant parties for each ship.

Chapter 10 Power Generation including Propulsion and Other Fuel Consumers

10.1 General

The provisions of Chapter 10 of the LFFS Guidelines shall apply for the power generation including propulsion and other fuel consumers.

Chapter 11 Fire Safety

11.1 General

The provisions of Chapter 11 of the LFFS Guidelines shall apply for the fire safety. Additional requirements are provided below.

11.2 Fire Extinguishing

11.2.1 Category A Machinery spaces, fuel storage hold spaces and fuel preparation rooms where hydrogen fueled consumers or fuel supply systems are located are to be protected by an approved fixed fire-extinguishing system in accordance with SOLAS Chapter II-2 Regulation 10 and the FSS Code(International Code for Fire Safety Systems). Where hydrogen is used as the primary fuel, the extinguishing media used in the space is to be dry powder or carbon dioxide. In addition, the fire-extinguishing medium used is to be suitable for the extinguishing of hydrogen fires.

11.2.2 The quantity of dry powder or carbon dioxide for fixed gas fire-extinguishing systems is to be addressed by the risk assessment.

Chapter 12 Explosion Prevention

12.1 General

The provisions of Chapter 12 of the LFFS Guidelines shall apply for the explosion prevention. Additional requirements are provided below.

12.2 Explosion Prevention

12.2.1 Hazardous locations

The classification of hazardous locations must be verified based on IEC 60079-10, gas diffusion analysis, and other relevant analyses.

Note:

Based on the verification of hazardous location classification according to IEC 60079-10, the hazardous locations classified in 12.5 of the LFFS Guidelines (Zones 0 to 2) may be modified as necessary.

Chapter 13 Ventilation

13.1 General

The provisions of Chapter 13 of the LFFS Guidelines shall apply for the ventilation. Additional requirements are provided below.

13.2 Tank Connection Space

The number and capacity of ventilation devices in the tank connection space must be such that if fans powered independently from the main switchboard or emergency switchboard, or a group of fans powered from a common circuit from the main switchboard or emergency switchboard, fail, the total ventilation capacity does not fall below 50% of the total required capacity.

Chapter 14 Electrical Installations

14.1 General

The provisions of Chapter 14 of the LFFS Guidelines shall apply for the electrical installations. Additional requirements are provided below.

14.2 Explosive Limit and Electrical Equipment Standards for Hydrogen

For the purposes of application of IEC standards and selection of electrical equipment, hydrogen has an IEC lower explosive limit (LEL) of 4.0% and an upper explosive limit (UEL) of 75.0%, respectively. Electrical equipment is to meet ISO/IEC 60079-20 group IIC class T1 standards and NEC/CEC Group B standards.

Chapter 15 Control, Monitoring, and Safety Systems

15.1 General

The provisions of Chapter 15 of the LFFS Guidelines shall apply for the control, monitoring and safety systems. Additional requirements are provided below.

15.2 General Requirements

Compartments where liquefied hydrogen fuel piping is located must have means for promptly detecting liquefied hydrogen leaks and hydrogen gas leaks.

Chapter 16 Manufacture, Workmanship and Testing

16.1 General

The provisions of Chapter 16 of the LFFS Guidelines shall apply for the manufacture, workmanship and testing. Additional requirements are provided below.

16.2 General Requirements

16.2.1 For fuel containment systems and fuel piping systems that may come into contact with hydrogen, it must be ensured that the selected materials do not experience harmful reductions in strength and toughness due to the effects of hydrogen.

16.2.2 Welding procedure approval test for fuel tanks, process pressure vessels, and secondary barriers

For fuel containment systems and fuel piping systems that may come into contact with hydrogen, it must be ensured that the selection of welding materials and welding procedures does not lead to harmful reductions in strength and toughness due to the effects of hydrogen.

16.2.3 Welding procedure approval test for pipes

In the welding procedure approval test for pipes, measures must be taken based on the provisions for fuel tanks specified in 16.2.2.

Annex 1 Safety Verification of Machinery and Equipment

A1.1 General

As stipulated in 3.1.2(b) of the Guidelines, some machinery and equipment related to hydrogen fuel may require safety verification based on a risk assessment specific to the individual equipment, depending on the novelty and complexity of its operating conditions and design specifications. This safety verification is achieved by obtaining technology qualification for the equipment subject to be accepted or approved by the Society.

A1.2 Selection of Equipment

Machinery and equipment subject to technical qualification is to be screened based on discussion with relevant parties and the Society, taking into account their operating conditions and design specifications. Generally, machinery and equipment that meets the following criteria A1.2.1 and A1.2.2 should be subject to technology qualification. For such equipment, a risk assessment will be conducted and approved by the Society.

A1.2.1 The machinery or equipment has novel technology elements and a complex design (not a simple system).

A1.2.2 Based on A1.2.1, it is determined that existing Rules of the Society are insufficient for verifying the safety of the machinery or the equipment.