GUIDE FOR

FUEL CELL POWER SYSTEMS FOR MARINE AND OFFSHORE APPLICATIONS
NOVEMBER 2019

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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Foreword

ABS recognizes the increasing use of fuel cells in the marine and offshore industries and their benefits. A fuel cell is a device that converts chemical energy from a fuel into electricity through an electrochemical reaction of the fuel with oxygen or other oxidizing agent. Fuel cells differ from batteries by requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas a battery's available chemical energy is fixed by the amount of chemicals in the battery. Fuel cells can produce electricity continuously as long as fuel and oxygen are supplied, and there are many types of fuel cell designs. Most consist of an anode, cathode and an electrolyte that allows positively charged hydrogen ions to move from the anode to the cathode side of the fuel cell. The main benefits are increased energy efficiency, low to zero emissions and reduced noise levels.

It is anticipated that because of increasingly stricter air emissions legislation and other local air quality controls, fuel cells may play an important role in the future. Accordingly, this Guide has been developed to provide guidance for the design, evaluation, and construction of support systems for use of fuel cells on ships and may be applied to all types of vessels.

The requirements in this Guide have been developed considering the IMO Draft Interim Guideline to the IGF Code pertaining to fuel cells. It is recognized that when the Draft Interim Guidelines are finalized, the Guide will be updated.

The applicable edition of the ABS *Rules for Building and Classing Marine Vessels* is to be used in association with this Guide.

This Guide becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

GUIDE FOR

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CONTENTS

SECTION 1 General

1 Introduction

A fuel cell is a device that continuously converts an oxidizing fuel (hydrogen, methane, etc.) into electricity and water through an electrochemical reaction. ABS recognizes the application of fuel cell technology in the marine and offshore industries and its benefits of improved energy efficiency and reduced emissions as well as reduced noise levels. The main distinction among fuel cell types is the electrolyte, and thus they are classified by such. Fuel cells have a variety of applications such as providing electrical power in remote areas, and can be used to power underwater vehicles, vessels and offshore units.

This Guide has been developed to provide requirements for the design, construction, testing and survey of vessels utilizing fuel cells. The Guide is focused on the safe use of fuel cell systems and arrangements for propulsion and auxiliary systems.

2 Application

This Guide is applicable to marine and offshore assets designed, constructed, or retrofitted with a fuel cell using a gaseous fuel as well as liquid fuels. Where a fuel cell power system is to be installed, it is to comply with the requirements in this Guide and is to be verified by ABS.

This Guide is applicable to fuel cell power systems used for auxiliary and main electric power systems onboard vessels, offshore, floating production installations (FPIs), etc.

When Type Approval for a fuel cell power system is requested, applicants should contact ABS for the approval process. For ABS Type Approval Program requirements, refer to 1-1-4/7.7, Appendix 1-1-A3, and Appendix 1-1-A4 of the ABS *Rules for Conditions of Classification (Part 1)*. See Section 2, Table 1 for certification details. Alternative certification schemes are also available in 1-1-A3/5.5 of the ABS *Rules for Conditions of Classification (Part 1)*.

This document makes reference to the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)* and SOLAS. When Fuel cell power systems are installed in other marine and offshore applications, similar requirements will apply.

3 Scope

For emerging fuel cell technologies currently under development or types not listed, consideration may be given on a case by case basis.

This Guide is intended for the design, installation, and survey of fuel cells power systems. This covers fuel cells, fuel reformers, fuel stacks, modules, fuel systems, storage systems, preparation rooms, safety systems, monitoring control, testing, certification, etc.

In addition to the requirements listed in this guide, designs of liquid fuel systems with flashpoints above 60°C are to adhere to Part 4, Chapter 6 of the *Marine Vessel Rules*. Liquid fuel systems with a low flashpoint equal to or below 60°C and gaseous fuels are to be designed in accordance with appropriate requirements in Part 5C, Chapter 13 of the *Marine Vessel Rules*.

4 Classification Symbols and Notations

Upon Owner's request, the optional notation **FC-E (Essential Service)**, **FC-NE (Non-Essential Service)** may be granted once the fuel cell installation has complied with the requirements of this Guide.

Fuel cell power systems designed, tested and surveyed in compliance with the requirements in this Guide and relevant Rules may be assigned with a classification notation based on the features as defined below.

4.1 FC-E (Essential Services) Notation

Where a vessel is arranged to use the fuel cell power system for essential services (primary and secondary) or emergency services, the system is designed, constructed and tested in accordance with this Guide. See also 2/5.2 of this Guide.

4.2 FC-NE (Non-essential Services) Notation

Where a vessel is arranged to use the fuel cell power system for non-essential services, the system is designed, constructed and tested in accordance with this Guide except with the requirements as per 2/5.2 of this Guide.

4.3 Associated Notations

If the fuel cell is intended for installation on a Gas Carrier or a Gas Fueled Ship, the notations **LFFS** or **GFS** will be assigned in association with **FC-E** or **FC-NE** notation for specific ship type. (e.g. **LFFS(FC-E)**) with descriptive letters introduced in the record identifying the specific low flashpoint fuel used (Methanol/Ethanol/Methane/Propane/Butane/Ammonia/Hydrogen).

5 Definitions

5.1 Block and Bleed Valve

A *Block and Bleed Valve* is an arrangement of two valves located in series in a piping system with a third valve that vents that portion of the gas fuel piping that is between the two valves in series.

5.2 Certified Safe Type

Certified Safe Type means electrical equipment that is certified safe by a competent, independent testing laboratory based on a recognized standard. See also 4-8-3/13 of the *Marine Vessel Rules*.

5.3 Control Station

Control stations are those spaces in which the vessel's radio or main navigating equipment or the emergency source of power is located, or where the fire recording or fire control equipment is centralized. Spaces where the fire recording or fire control equipment is centralized are also considered to be a fire control station. See also 4-7-1/11.21 of the *Marine Vessel Rules*.

5.4 ESD

ESD is Emergency Shutdown.

5.5 Essential Services

For definition of essential services, see 4-8-1/7.3.3 of the ABS *Rules for Building and Classing Marine Vessels*, and see 4-1-1/3.5 of the ABS *Rules for Building and Classing Mobile Offshore Units.*

5.6 Fuel Cell

A Fuel Cell is a source of electrical power in which the chemical energy of a fuel is converted directly into electrical and thermal energy by electrochemical oxidation

5.7 Fuel Cell Stack

A Fuel Cell Stack is an assembly of cells, separators, cooling plates, manifolds and a supporting structure that electrochemically converts, typically, hydrogen rich gas and air reactants to DC power, heat and other reaction products.

5.8 Fuel Cell Module

A Fuel Cell Module is an assembly incorporating one or more fuel cell stacks and other main and, if applicable, additional components, which is intended to be integrated into a power system

5.9 Fuel Cell Power Installation

Fuel Cell Power Installation means the fuel cell power system and other components and systems required to supply electrical power to the ship. It may also include ancillary systems for the fuel cell operation.

5.10 Fuel Cell Power System

Fuel Cell Power System means fuel cell(s), fuel reformers if fitted and associated piping systems. A typical fuel cell power system is shown in Section 1, Figure 1

Note:

Subject to the specific fuel cell technology, not all components are applicable, and the configuration may vary.

5.11 Fuel Cell Space

Fuel Cell Space means a space containing elements of the fuel cell power system.

5.12 Fuel Containment System

A Fuel Containment System is the arrangement for the storage of fuel including tank connections. It includes, where fitted, a primary and secondary barrier, associated insulation and any intervening spaces, and adjacent structure, if necessary, for the support of these elements. If the secondary barrier is part of the hull structure, it may be a boundary of the fuel storage hold space.

The spaces around the fuel tank are defined as follows:

- Fuel storage hold space is the space enclosed by the ship's structure in which a fuel containment system is situated. If tank connections are located in the fuel storage hold space, it will also be a tank connection space;
- Interbarrier space is the space between a primary and a secondary barrier, whether or not completely or partially occupied by insulation or other material; and
- Tank connection space is a space surrounding all tank connections and tank valves that is required for tanks with such connections in enclosed spaces.

5.13 Fuel Input

Fuel Input is the amount of natural gas, hydrogen, methanol, liquid petroleum gas, propane, butane, distillate fuel or other material containing chemical energy entering the fuel cell power system while it is working at the specified operating conditions.

5.14 Fuel Preparation Space (room)

Fuel preparation space (room) is any space or room containing equipment for fuel preparation purposes, such as fuel pumps, fuel valve train, heat exchangers and filters.

5.15 Fuel Reformer

A Fuel Reformer is the arrangement of all related fuel reforming equipment for processing gaseous or liquid primary fuels to reformed fuel for use in fuel cells.

5.16 Hazardous Area

A Hazardous Area is an area in which an explosive gas atmosphere is, or may be expected to be, present in quantities such as to require special precautions for the construction, installation and use of equipment. See also IEC 60079-10-1 and 5/2 of this Guide.

Hazardous areas are divided into zones 0, 1 and 2 as defined below:

5.16.1 Zone 0

Zone 0 is an area in which an explosive gas atmosphere is present continuously or for long periods or frequently.

5.16.2 Zone 1

Zone 1 is an area in which an explosive gas atmosphere is likely to occur in normal operation occasionally.

5.16.3 Zone 2

Zone 2 is an area in which an explosive gas atmosphere is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

5.16.4 Enclosed Space

Enclosed Space means any space within which, in the absence of forced ventilation, the ventilation will be limited and any explosive atmosphere will not be dispersed naturally.

5.17 Non-Hazardous Area

Non-hazardous Area means an area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment.

5.18 High Pressure Piping

High Pressure Piping means gas fuel piping with a maximum working pressure greater than 10 bar.

5.19 IGF Code

The *IGF Code* is the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels.

5.20 LEL

LEL is the lower explosive limit.

5.21 CH_2, CGH_2

CH_2 or CGH_2 is compressed hydrogen.

5.22 LH_2

LH_2 is liquefied hydrogen.

5.23 MARVS

MARVS stands for maximum allowable relief valve setting.

5.24 Recognized Standard

A *Recognized Standard* is an international or national standard acceptable to ABS.

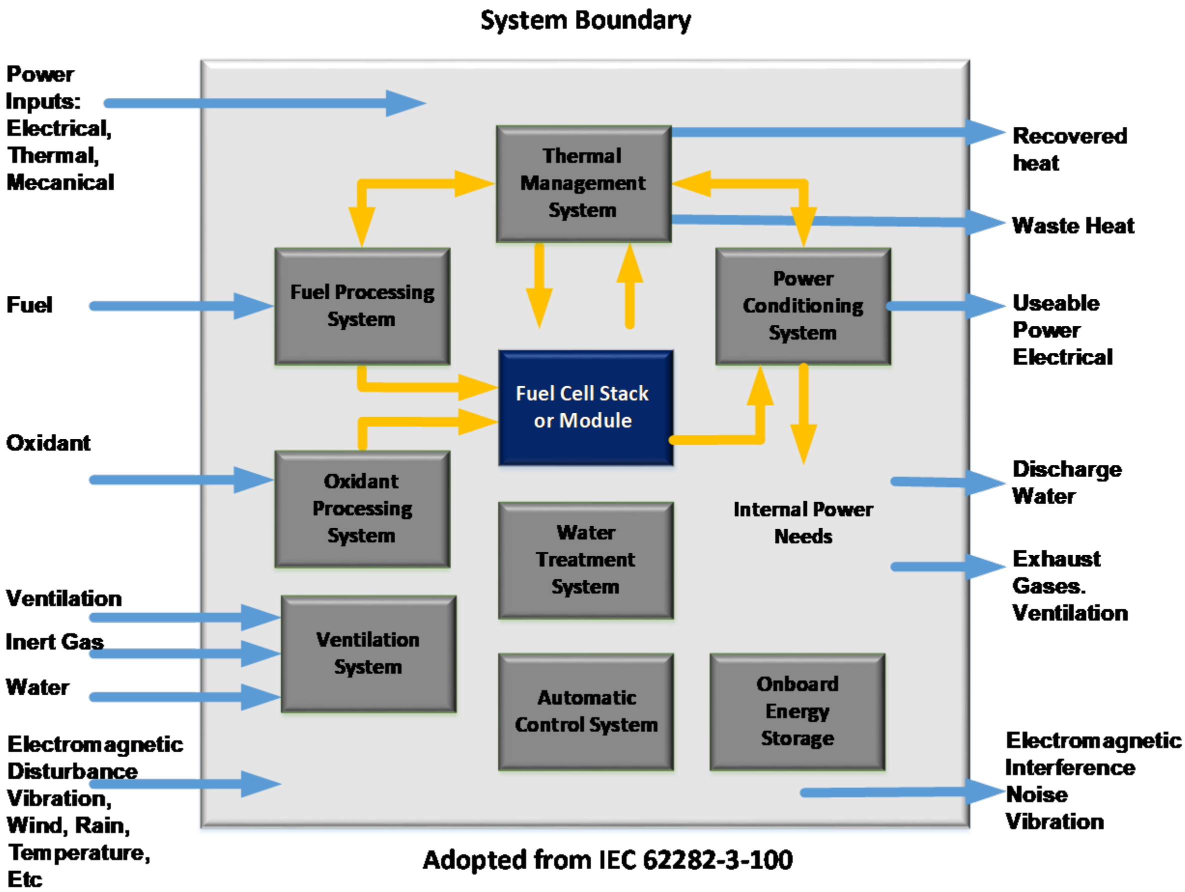
5.25 Reformed Fuel

Reformed fuel is the hydrogen rich gas generated in the fuel reformer.

5.26 Primary Fuel

Primary Fuel is the fuel supplied to the fuel cell power system.

FIGURE 1
Fuel Cell Power Systems



6 Environmental Conditions

The fuel cell power systems are to be suitable for inclinations and environmental conditions found in marine and offshore installations such as those mentioned in 4-1-1/Table 7 and 4-1-1/Table 8 of the *Marine Vessel Rules*.

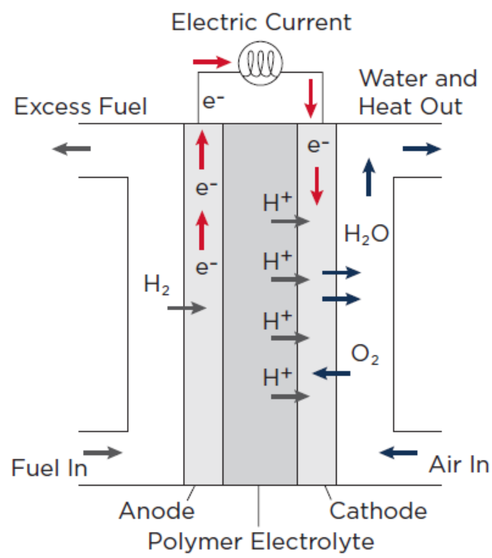
In addition to Section 6 of this Guide, the requirements of Sections 4-9-1 and 4-9-2, as appropriate, of the *Marine Vessel Rules* are also applicable to all vessels with equipment for control, monitoring and safety systems associated to the fuel cell power system. Where vessels request special notations (such as **ACC**, **ACCU**, and **ABCU** in *Marine Vessel Rules*), this equipment is to be designed to successfully withstand the test conditions stipulated in 4-9-9/Table 1 of the *Marine Vessel Rules*, as applicable.

7 Fuel Cell Characteristics

7.1 General Description and operation

As depicted in Section 2, Figure 2 below, a fuel cell consists of a negative electrode (anode) and a positive electrode (cathode), an electrolyte, a fuel and oxygen (air) system, electrical terminals and ancillary devices. A fuel such as hydrogen is fed to the anode and air is fed to the cathode. A catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external electric circuit to power a load. The protons journey through the electrolyte to the cathode, where they unite with oxygen (from the air) and electrons to produce heat and water.

FIGURE 2
Typical Proton Exchange Membrane (PEM) Fuel Cell



7.2 Fuel Cell Types

The main difference among fuel cell types is the electrolyte. Therefore, fuel cells are generally classified by the type of electrolyte utilized. Some main types of fuel cells available today include Proton Exchange Membrane, Alkaline, Phosphoric Acid, Molten Carbonate and Solid Oxide fuel cells (See Section 1, Table 1).

i) *Proton Exchange Membrane (PEM) Fuel Cells*. PEMs use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks or reformers (a device that extracts pure hydrogen from hydrocarbon or alcohol fuels). PEM fuel cells operate at relatively low temperatures, typically less than 120°C (248°F) and typically use a noble-metal catalyst (platinum) to separate the hydrogens electrons and protons.

ii) *Alkaline Fuel Cells (AFC)*. AFCs use a solution of potassium hydroxide in water as the electrolyte and can use a variety of nonprecious metals as a catalyst at the anode and cathode. AFCs operate at temperatures between 100°C and 250°C (211°F and 482°F). The oxidant supplied to an AFC must be pure oxygen as carbon dioxide (CO_2) can negatively affect the performance of AFCs.

iii) *Phosphoric Acid Fuel Cells (PAFC)*. PAFCs use liquid phosphoric acid as an electrolyte which is contained in a Teflon-bonded silicon carbide matrix and porous carbon electrodes containing a platinum catalyst. PAFCs operate at temperatures between 150°C and 220°C (302°F and 428°F). PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than other fuel cell types.

iv) *Molten Carbonate Fuel Cells (MCFC)*. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Nonprecious metals can be used as catalysts at the anode and cathode. MCFC operates at 600°C to 700°C (1112°F and 1292°F). MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming.

v) *Solid Oxide Fuel Cells (SOFC)*. SOFCs use a hard, non-porous ceramic compound as the electrolyte. SOFCs operate at 650°C to 1000°C (1202°F to 1,830°F). High-temperature operations remove the need for a precious-metal catalyst such as platinum. SOFCs reform fuels internally, which enables the use of a variety of fuels such as natural gas, biogas, and gases made from coal.

TABLE 1
Fuel Cell Type

Type	*Mobile Ion*	*Operating Temperature*	*Applications and Notes*
Proton Exchange Membrane (PEM)	H^+	30-120°C	Vehicles and mobile applications, and for lower power CHP (Combine Heat Power) systems
Alkaline (AFC)	OH^-	100-250°C	Used in space vehicles, (e.g., Apollo, Shuttle)
Phosphoric Acid (PAFC)	H^+	150-220°C	Large numbers of 200-kW CHP (Combine Heat Power) systems in use
Molten Carbonate (MCFC)	CO_3^{2+}	600-700°C	Suitable for medium- to large-scale CHP (Combine Heat Power) systems, up to MW capacity
Solid Oxide (SOFC)	O^{2-}	650-1000°C	Suitable for all sizes of CHP (Combine Heat Power) systems, 2 kW to multi-MW

7.3 Fuels Used in Fuel Cell Applications

i) Fuel cells can utilize a variety fuels either directly or as a fuel requiring reformation. Each of the fuels has its own operational requirements. This includes safety systems, storage, and handling, etc. Section 1, Table 2 below lists some low flash point fuels and other fuel examples for use and applicable references in addition to this Guide.

ii) In addition to the requirements referenced above, the selected fuel is to be evaluated as part of the required Risk Assessment as specified in 2/3 of this Guide.

TABLE 2
References for example Fuels

Fuels for use in Fuel Cell	*Fuel Containment System*	*Material and General Piping System*	*Fire Safety Systems*	*Electrical System*	*Control, Monitoring and Safety Systems*
Methane (Natural Gas)	5C-13-6 of MVR	5C-13-7 of MVR	5C-13-11 of MVR	5C-13-14 of MVR	5C-13-15 of MVR
Propane, Butane	Section 3 of this Guide	2/2.2.2 and 3/4 of this Guide	Section 4 of this Guide	Section 5 of this Guide	Section 6 of this Guide
Methyl Alcohol (Methanol)	Section 3 of this Guide	2/2.2.2 and 3/4 of this Guide	Section 4 of this Guide	Section 5 of this Guide	Section 6 of this Guide
Ethyl Alcohol (Ethanol)	Section 3 of this Guide	2/2.2.2 and 3/4 of this Guide	Section 4 of this Guide	Section 5 of this Guide	Section 6 of this Guide
Ammonia	Section 3 of this Guide	2/2.2.2 and 3/4 of this Guide	Section 4 of this Guide	Section 5 of this Guide	Section 6 of this Guide
Hydrogen	Section 3 of this Guide	2/2.2.2 and 3/4 of this Guide	Section 4 of this Guide	Section 5 of this Guide	Section 6 of this Guide

8 Alternative Design

Fuel cell power systems may comply with the requirements of alternative design, in lieu of the specific requirements in this Guide, subject to such a design being determined to ABS as not less effective or safe. The alternative design is to be demonstrated as specified in Annex to MSC.1/Circ.1455 (Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments) and approved by ABS. However, ABS may allow operational methods or procedures to be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment, or type thereof subject to approval of the Flag Administration. Additional requirements may be imposed by ABS on those alternative designs to meet the intent of this Guide and the IGF Code. In all cases, the fuel cell power systems are subject to design review, survey during construction, tests, and trials, as applicable, by ABS to verify compliance with the alternative design.

9 Data and Plans to be Submitted

Plans and specifications covering the ship arrangements are to be submitted, in addition to the requirements contained in each of the individual sections and are, as applicable, to include:

9.1 General Arrangement

i) General arrangement

ii) Fuel storage arrangement

iii) Fuel supply system arrangements

iv) Fuel bunkering station arrangements

v) *v.* Fire protection arrangement

vi) Hazardous area classification plan

vii) Fuel cell space's geometrical shapes (to demonstrate ability to minimize the accumulation of gases).

9.2 Risk Assessment of the System

i) A risk assessment method in accordance with an appropriate standard is to be identified and agreed upon by ABS. The fuel cell power system integrator or the supplier are to submit the proposed method. The submitter is to include relevant data from system suppliers.

ii) The risk assessment is to identify and evaluate the hazards associated with each function of the fuel cell power system throughout its lifecycle.

iii) Based on the risk assessment results, a revised system category may have to be agreed among ABS and the system integrator or the supplier.

iv) Safety risk assessment is to address the items as stipulated in 2/3.2 of this Guide.

v) The risk assessment is to include the necessary parameters for the safe and effective operation of the control, monitoring and safety systems (see also Section 6, Table 1).

9.3 Fuel Cell Submissions

i) Fuel cell principle, design and capacity (e.g., total fuel cell stack rating output, in kW) calculation for intended application

ii) Fuel cell physical environment and operating conditions including the following:

- Electrical power input, output
- Fuel input: type, volume, rate, temperature, supply pressure
- Water input, when required for the operation of the fuel cell power system: quantity, temperature, supply pressure

- Vibration, shock and bump limits
- Handling, transportation, and storage
- System purging

iii) Maintenance schedule and procedures for fuel cell replacement

iv) Manufacturer's recommendation regarding fuel cell service life (e.g. fuel cell stack components) and inspection cycles

v) Fuel cell full range of service conditions as specified by the manufacturer

9.4 Fuel Containment System Submissions

The following specifications, plans, and detailed arrangements of the fuel containment system and its components are to be submitted:

i) General arrangement of the fuel containment system

ii) Fuel containment system structure, including the installation of supports and accessory supports

iii) Specifications and plans of the insulation system and calculations for the heat balance, as applicable

iv) Loading and unloading systems, venting systems, and gas-freeing systems, as well as a schematic diagram of the remote controlled valve system

v) Details and installation of the safety valves and relevant calculations of their relieving capacity, including backpressure

vi) Details of the electrical equipment installed in the fuel containment area and of the electrical bonding of the fuel tanks and piping

vii) Welding procedures, stress relieving and non-destructive testing plans

viii) Fuel tank capacity

Additionally, the following calculations and analyses applicable to the specifications, plans, and detailed arrangements of the fuel containment system and its components are to be submitted for review:

a) Design loads and structural analyses for the fuel storage tank(s) together with complete stress analysis, as applicable, of the hull and fuel containment system including sloshing analysis. If the tanks are designed, manufactured and tested as per a recognized standard by a third party, appropriate documentation is also to be provided to ABS for review.

b) Fuel tank pressure accumulation calculation.

9.5 Material and Piping System Submissions

The following material specifications, plans, and detailed arrangements of the piping systems and their components are to be submitted:

i) Material specifications and design for piping, valves and associated components

ii) Piping systems arrangements are to include details of piping and associated components, design pressures, temperatures and insulation, where applicable

iii) Weld procedures, stress relieving and non-destructive testing plans

iv) Details and installation of the safety valves and relevant calculations of their relieving capacity

v) Vent piping system for the fuel gas supply

vi) Arrangement of air supply system, including filter

vii) Details of testing procedure of piping and associated components *viii)* Arrangement and design of drip trays

9.6 Ventilation System Submissions

i) Details of the ventilation system indicating the vent pipe sizes and height of the openings above the main deck

ii) Ventilation system for fuel pump rooms, compressor rooms, fuel preparation rooms, fuel storage (when in enclosed spaces) rooms, and other hazardous areas

iii) Detailed arrangement of the ventilation ducting for fuel pipes, and fuel storage tank, if applicable

iv) Detailed arrangements of the mechanical ventilation system including calculation of gross volume capacity

9.7 Gas Detection System Submissions

i) Arrangement and location of the permanently installed gas detector system for fuel supply pump room, compressor and fuel preparation room

ii) Arrangement of the gas freeing and purging system

iii) Specifications of gas detectors including alarm devices

9.8 Fuel Cell Control Monitoring and Safety System Submissions

i) Details and installation of the various monitoring and control systems, including the fuel level measuring devices in the tanks and the temperatures in the containment system including the following:

- Fuel cell fuel tank monitoring and alarm system
- Fuel cell fuel compressor control, monitoring alarm system
- Fuel cell fuel supply control, monitoring and alarm system

ii) Arrangement of emergency shutdown system (ESD)

9.9 Fire Detection and Extinguishing Systems Submissions

i) An approved fixed fire detection and alarm system

ii) Plans of the piping system for the fire main and the fire protection of fuel cell space

iii) Location arrangements of portable fire extinguishers

iv) Arrangement drawings showing required details of the spaces, (e.g., large fuel cell spaces are to be arranged with a smooth ceiling sloping up towards the ventilation outlet, etc.)

v) Documentation showing that the bulkhead (i.e., fuel cell space) has sufficient strength to withstand a worst-case explosion

vi) Detailed installation arrangements of personnel protective equipment (i.e., eyewash, safety showers, safety glasses, etc.).

9.10 Electrical Systems Submissions

i) Fuel cell power system electrical schematic drawings (block diagram with system interface) such as electrical one-line diagram that depicts the electrical power system and the point of coupling of the fuel cell power system

ii) Details of electrical equipment arrangement, and its wiring system in any hazardous areas

iii) A list/booklet identifying all electrical equipment installed in the hazardous area zones and particulars for that equipment (Manufacturers name, hazardous area classification, certification, etc.) as per 4-8-1/5.3.2 and 4-8-4/27.13 of the *Marine Vessel Rules* *iv)* Detailed diagram of main power, auxiliary power, alarm, control power including distribution system

v) Documents verifying the transient frequency and voltage during the operations, as applicable

vi) In addition to above, the following plans and data are to be submitted for Fuel Cells powering essential services notation:

- One-line diagrams of propulsion control system for fuel cell power supply, circuit protection, alarm, monitoring, safety and emergency shutdown systems including list of alarm and monitoring points
- Arrangement details of essential services (primary and secondary) and emergency services that supply electrical power for propulsion and steering and the safety of the vessel
- Plans showing the location of propulsion controls and their monitoring stations
- Arrangements and details of the propulsion control console or panel including schematic diagram of the system therein
- Load analysis, covering all operating conditions of the vessel, such as normal seagoing, cargo handling, harbor maneuvering, dynamic positioning, emergency operation, etc.

9.11 Emergency Shutdown Systems (ESD) Submissions

i) Details of disconnection arrangement (such as ESD, stop buttons, etc.)

ii) Emergency shutdown arrangement of bunkering system

iii) Emergency shutdown arrangement of fuel supply system

9.12 Test Plan Submissions

A Test Plan is to be submitted during the plan review process. The test plan is to identify all equipment, fuel cell power systems and the recommended method of performing the tests or trials. See also 7/5.2 of this Guide.

10 Certification

Fuel cell power systems are to be certified at the manufacturer's facility in accordance with Section 1, Table 3 below. This table also provides the applicability of the certification requirements for certain equipment and components as referred to in Part 4, Part 5C and their applicable Chapters and Sections of the *Marine Vessel Rules*. See also notes under this Table.

TABLE 3
Fuel Cell and Certification

System, Equipment, Component	*ABS Certification(4)*	*ABS Type Approval Tier (See Appendix 1-1-A4 of ABS Rules for Conditions of Classification)*	*Standards*	*Rule Reference (Marine Vessel Rules)*	*Section of this Guide*
Fuel Cell Modules	Required	4/5	IEC 62282-2		2/4
Fuel cell power system	Required(1)	4/5	IEC 62282-3 Series		2/5
Pipe, Valves and Fitting	Required(2)	4/5		4-6-1, 4-1-1/Table 6, 5C-13-16	3/4
Pressure Vessels	Required	4/5		4-4-1, 4-1-1/Table 5	2/2.2.1

System, Equipment, Component	*ABS Certification[(4)]*	*ABS Type Approval Tier (See Appendix 1-1-A4 of ABS Rules for Conditions of Classification)*	*Standards*	*Rule Reference (Marine Vessel Rules)*	*Section of this Guide*
Hydrogen Storage Tank	Required	4/5		4-4-1, 4-1-1/Table 5	3/8.3
Fuel Cell Control and monitoring system	Required	4/5	IEC 62282-3 Series		Section 6
Electrical Equipment	Required	4/5		4-8-3, 4-1-1/Table 3	Section 5
Rotating Machines	Required	4/5		4-8-3, 4-1-1/Table 3	3/10
Fixed Fire and Gas detection system	Required	4/5		4-7-3, 4-1-1/Table 4, 5C-13-11, 5C-13-15	Section 4
Ships Bunker Hoses	Required[(3)]	4/5		5C-13-8/3.2	3/9.3

Notes:

1 Fuel cell power systems having a net electrical output of 100 kW or greater are required to be certified by ABS. (See Note 4). For fuel cell power systems having a net electrical output of less than 100 kW, the manufacturer is to certify the standard to which it is designed, fabricated and tested to, and to report the results of the tests conducted.

2 Where indicated as 'required' in 4-6-1/Table 2 of the *Marine Vessel Rules*, the piping component is to be certified by ABS. This involves design approval of the component, as applicable, and testing in accordance with the standard of compliance at the manufacturer's plant. Such components may also be accepted under the Type Approval Program

3 Bunker hose assemblies are to be burst tested to an international standard to demonstrate they are able to withstand a pressure not less than five (5) times its design pressure without indication of failure or leakage subject to the satisfaction of the attending Surveyor.

4 ABS Certification means plan review, and surveys' attendance during construction and after installation to verify to itself that a vessel, structure, item of material, equipment or machinery is in compliance with the Rules, Guides, standards or other criteria of ABS and to the satisfaction of the attending Surveyor.

11 Onboard Documentation

11.1 General

At a minimum, the following drawings and data are to be kept on board for reference by the operator for system operation and troubleshooting, maintenance, repair and safety

i) Operations and Maintenance Manual for Fuel cell power system (fuel cell module, instrumentation, control and monitoring)

ii) Fuel cell power system Maintenance Schedule

iii) Fuel cell power system Functional Testing Schedule

iv) Safety Training for Fuel

v) Possible safety critical scenarios including fire and explosion

vi) Drill and emergency exercises conduction (regular intervals)

12 Operation and Maintenance Manual

12.1 Operation Manual

The operating manual is to denote the safety measures provided and detail proper procedures for the set-up and use of the fuel cell power system. Particular attention is to be given to the safety measures provided and the anticipated methods of operation.

The operations manual is to include a section on the hazards of the fuel cell power system.

Where the operation of equipment can be programmed, detailed information on methods of programming, equipment required, program verification and additional safety procedures (where required) is to be provided.

The instructions are to give information on airborne noise emissions by the fuel cell power system, either the actual value or a value established using measurements made on an identical fuel cell power system.

The operating manual is to identify in an orderly manner the different sub-systems and components of the fuel cell power system. See also A1/2.

12.2 Maintenance Manual

The maintenance manual is to detail proper procedures for the adjustment, servicing, preventive inspection, and repair of the fuel cell. Recommendations on maintenance/servicing records are to be part of the maintenance manual. Where methods for the verification of proper operation are provided (for example, software testing programs), the use of such methods are to be detailed.

The manual is to contain clearly defined, legible and complete instructions for the following, at a minimum:

i) Instructions for starting and shutting down the fuel cell power system depicting illustrations and locations of all relevant components.

ii) Specifications for the frequency of filter change or cleaning and the dimensional size and type of filter for replacements. These instructions are to provide directions for removal and replacement of filters and pictorially illustrate and denote all components supplied by the manufacturer referred to in the instructions for removal and replacement of filters.

iii) Caution to users regarding electrical components that may retain residual voltage/energy after shutdown, and method(s) to properly dissipate the voltage/energy to a safe level.

iv) Recommended methods for periodic cleaning of necessary parts.

v) Instructions for lubrication of moving parts, including type, grade and amount of lubricant.

vi) Instructions for examining the fuel cell power system installation to confirm

- Any intake or exhaust openings are clear and free of obstructions;
- There are no obvious signs of physical deterioration of the fuel cell power system or its support (i.e., base, frame, or cabinet).

vii) Periodic examination of the venting system, gas detection system, and related functional parts.

viii) Calibration of gas detectors

ix) A replacement parts list, including information necessary for ordering spare or replacement parts.

x) Instructions that the area surrounding the fuel cell power system must be kept clean and free of combustible materials, gasoline and other flammable vapors and liquids.

xi) Instructions and schedule for neutralizing condensate, if appropriate.

The maintenance manual is to also provide a list of all regular and routine maintenance activities to be performed on the fuel cell power system components and indicate the necessity and minimum frequency for these examinations.

Maintenance and repair procedures are to consider the fuel containment system and adjacent spaces.

In-service survey, maintenance and testing of the fuel containment system are to be carried out in accordance with the inspection/survey plan (see 1/9.12 and 7/5.2).

The inspection/survey plan for the liquefied gas fuel containment system is to be developed and approved by ABS.

The procedures and information are to include maintenance of electrical equipment installed in explosion hazardous spaces and areas. The inspection and maintenance of electrical installations in explosion hazardous spaces are to be performed in accordance with a recognized standard.

SECTION 2 Fuel Cell Design Requirements

1 Design Principles

1.1 General

The fuel cell space is to be regarded as a machinery space of Category A and categorized according to SOLAS Chapter II-2 for fire protection purposes. The fire extinguishing system is to be compatible with the specific fuel and fuel cell technology proposed. ABS may allow alternative fire safety measures if equivalence is demonstrated by a risk assessment considering the fuels used subject to approval of the Flag Administration.

The fuel cell space is to be designed to mitigate hazards to lower hazardous levels under all operational conditions. Due to the possibility of hydrogen leaks within the fuel cell stacks, the fuel cell space is to be classified as a hazardous area Zone 1 (refer to 5/3.2 i) of this Guide). Therefore, equipment or components installed in this space are to be of a certified safe type in order to minimize the probability of a gas explosion in such a fuel cell space.

When an alternative design is proposed, the equivalence of such an alternative design is to be demonstrated in accordance with 1/8 of this Guide.

The Fuel cell power system is to be designed such that failure of any of the system's components will not cause unsafe operation of the process or its control systems, emergency control systems or safety systems.

Risk Assessment (i.e., HAZID, HAZOP, FMEA, see 2/3) is to be used to determine that any component failure will not result in the complete loss of control, the unsafe shutdown of the process or equipment, or other undesirable consequences. IACS Rec. 146 may be referred to for the application of acceptable and recognized techniques and means to document the risk assessment.

The vessel electrical system is to be so arranged that, in the event of the loss of the fuel cell(s) power system(s) in service, the electrical supply to equipment necessary for propulsion and steering and for the safety of the vessel will be maintained or restored in accordance with the provision in 4-8-2/3.11.2 or 4-8-2/3.11.3 of the *Marine Vessel Rules*. See also 2/5.2i) and 2/5.2ii) of this Guide.

2 Materials

2.1 General

Materials in general are to comply with the requirements of the ABS *Rules for Materials and Welding (Part 2)*.

The use of materials within the fuel cell power installation are to be suitable for the intended application and are to comply with recognized standards.

The use of combustible materials inside the fuel cell power system are to be minimized. However, the use of combustible materials may be acceptable for sealing and electrical insulating purposes subject to ABS approval.

2.2 Material Requirements for Specific Fuels

2.2.1 Hydrocarbon Gas

Materials used in gas tanks, gas piping, process pressure vessels and other components in contact with cryogenic liquids or gases are to be in compliance with Section 5C-13-7 of the *Marine Vessel Rules*.

The use of alternative materials not covered by Section 5C-13-7 of the *Marine Vessel Rules* may be accepted provided such materials are approved in connection with the design and that they are verified or tested by a Surveyor, as applicable, as complying with the approved specifications.

2.2.2 Hydrogen Gas

Materials used in all components in contact with hydrogen are to be resistant to hydrogen embrittlement and hydrogen attack. A material is not to be used unless data is available showing that it is suitable for the planned service conditions. In case of any doubt the material can be subjected to hydrogen embrittlement susceptibility testing (as per ISO 11114-4) to evaluate material suitability before use.

2.2.3 Ammonia Gas

Materials used in all components in contact with ammonia are not to contain copper, zinc, cadmium or alloys of these materials. Components of rubber or plastic materials likely to be exposed to ammonia are not to be used.

3 Fuel Cell Power System Risk Assessment

3.1 General

A risk assessment is to be conducted to identify risks arising from the use of fuels (methyl/ethyl alcohol, hydrogen, etc.) affecting the structural strength or the integrity of the ship, safety of crew on board, and preservation of the environment. Consideration is to be given to the hazards associated with physical layout, operation and maintenance following any reasonably foreseeable failure. The risks are to be analyzed using acceptable and recognized risk analysis techniques. Loss of function, component damage, fire, explosion and electric shock are to be considered as a minimum. The analysis should identify risks that can be eliminated wherever possible. Risks which cannot be eliminated are to be mitigated as necessary. Identification of risks, and the means by which they are mitigated, are to be documented to the satisfaction of ABS and to the flag Administration if required.

For data and plans submissions see 1/9.2 of this Guide.

3.2 Risk Assessment

i) The primary objective of the risk assessment is to identify risks and uncertainties associated with the proposed fuel cell power system design and its installation on a vessel. The risk assessment is to be conducted to evaluate the design as a whole, encompassing the general arrangement of where and how the fuel cell is integrated into the vessel design.

ii) The use of risk assessment techniques should be discussed with ABS prior to performing the risk assessment. The risk assessment is to be carried out in accordance with the ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*, ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification* or other ABS-recognized industry standards (such as IEC 60812).

iii) Several risk assessment techniques may be applied. At the early design stages, a Hazard Identification (HAZID) technique may be conducted to identify potential hazards that could result in consequences to personnel, the environment, and assets. The Hazard and Operability (HAZOP) study may also be conducted in order to identify and evaluate hazards that may represents risks to personnel or equipment. A Failure Mode and Effects Analysis (FMEA) may also be used to demonstrate that any single failure will not lead to an undesirable event.

All foreseeable hazards, their causes, consequences (local and global effects), and associated risk control measures are to be documented. The fuel cell power system risk assessment report is to be submitted for review, and at a minimum is to address the following issues, as applicable:

- Strong exothermic reaction of reformer material
- Internal leakage in Fuel Cell Module
- High energy collision with potential to penetrate a Liquid Hydrogen tank
- Rupture of CH_2/CGH_2 tank containment system
- Leakage of hydrogen gases, any fuels gases
- Failure of fuel pressure reduction
- Failure of the electrical power output conditioning system
- Thermal runaway of onboard energy buffer
- Loss of inert gas system
- Issues associated with storage of hydrogen as fuel, such as vicinity the other equipment, corrosion, extreme high temperature, etc.
- Toxicity potential and risk of oxygen deficiency or other negative impacts on crew health due to fuels (i.e., methyl/ethyl alcohol, ammonia, etc.) and inert gases
- Safe handling, stowage, marking and carriage of flammable, toxic, and other dangerous substances
- Sufficient capacity of each drip tray to provide that the maximum amount of spill can be handled
- Special consideration of closed or semi-enclosed bunkering station with mechanical ventilation; ABS may require a special risk assessment
- The causes and consequences of release of fuel. The consequences of any release of fuel are to be minimized, while providing safe access for operation and inspection
- Safe handling and containment arrangement for excess fuel (e.g. in the fuel cell stack) where there is no recirculation to the fuel processing system
- Arrangement of any fixed and/or portable fire extinguishing systems
- Permanently installed gas detectors at ventilation inlets to accommodation and machinery spaces
- Arrangement and the number of personnel protective equipment (i.e., eyewash, safety shower, safety glasses, canister mask, etc.)
- Risks associated with gases "heavier than air" (eg: propane, butane or other gases)

4 Fuel Cell Module

4.1 General

The fuel cell module is to be designed, type and/or routine tested, and certified for compliance with IEC 62282-2 or other recognized standards by ABS or a competent, independent testing laboratory.

In addition, the module is to comply with appropriate requirements for installation in a marine environment as documented in 1/6.

5 Fuel Cell Power System

5.1 General Requirements

i) Accessible parts of the fuel cell power system are to have no sharp edges, sharp angles or rough surfaces likely to cause injury.

ii) The easily accessed parts of the fuel cell power system are to be designed and constructed to prevent slipping, tripping or falling hazards.

iii) The fuel cell power system, components and fittings are to be designed and constructed so that they are stable enough, under the foreseen operating conditions for use without risk of overturning, falling or unexpected movement. Otherwise, appropriate means of anchorage are to be incorporated and indicated in the instructions.

iv) The moving parts of the fuel cell power system are to be designed, built and arranged to avoid hazards or, where hazards persist, fixed with guards or protective devices in such a way to prevent all risk of contact.

v) The various parts of the fuel cell power system and their linkages are to be so constructed that, when used normally, no instability, distortion, breakage or wear can occur that is likely to impair safety.

vi) The fuel cell power system is to be designed, constructed and/or equipped so that risks due to gases, liquids, dust or vapors released during the operation or maintenance of a fuel cell power system are avoided.

vii) All parts are to be securely mounted or attached and rigidly supported. The use of shock-mounts is permitted when suitable for the application.

viii) All safety shutdown system components, whose failure may result in a hazardous event, as identified by the risk analysis noted in 2/3, are to be recognized, certified or separately tested for their intended usage.

ix) The manufacturer is to take steps to eliminate any risk of injury caused by contact with, or proximity to, external surfaces of the fuel cell power system enclosure, handle, grips or knobs at high temperatures.

5.2 Essential Service (FC-E Notation)

When the Owner requests the optional notation **FC-E**, the requirements of the *Marine Vessel Rules* 4-8-2/3.11 are to be met.

5.3 Standards

For functional safety, the required installation level, performance level or the class of test and control function are to be determined and designed in accordance with following standards:

- IEC 62282-3-100, applicable to marine power safety systems
- IEC 62282-3-200 for operational and environmental aspects of stationary fuel cell power systems performance

SECTION 3 **Ship Arrangements and Installation Requirements**

1 General

1.1 Application

The requirements specified in this Section provide general guidance on ship arrangements and system designs with fuel cell power systems. There are further requirements contained in each of the individual Sections of this Guide such as the fuel storage, fuel bunkering and fuel supply systems. Refer to the requirements in each Section as well as the results of risk assessment.

There are certain specific requirements in this Section 3 for specific fuels that are as identified in the subsections accordingly.

1.2 Plans and Data to be Submitted

Plans and specifications covering the ship arrangements are to be submitted as detailed in 1/9.1 as well as the requirements contained in each of the individual Sections, as applicable.

2 Location and Separation of Spaces

2.1 Fuel Cell Compartment/Space

2.1.1 Fuel Cell Space as Machinery Space Category A

The fuel cell compartment/space is to be regarded as a Category A machinery space according to SOLAS Chapter II-2, and IGF Code. Additionally, the space is to be bounded by "A-60" class divisions on all sides adjoining control stations, evacuation stations, escape routes, accommodation spaces, stairways, corridors and machinery spaces. The fire-extinguishing system is to be suitable for use with the specific fuel and fuel cell technology proposed. ABS may allow any alternative fire safety measures if the equivalence of the measure is demonstrated by a risk assessment considering the characteristics of fuels for use subject to approval of the Flag Administration.

2.1.2 Fuel Cell Space Concept

In order to minimize the probability of a gas explosion in a fuel cell space, this is to be designed to mitigate hazards to lower hazardous levels under all operation conditions. Due to the nature of hydrogen leaks within the fuel cell stacks, the fuel cell space is to be classified as a hazardous area Zone 1 (refer to 5/3.2i) of this Guide). Therefore, equipment or components installed in this space are to be of a certified safe type.

When an alternative design is proposed, the equivalence of such an alternative design is to be demonstrated in accordance with 1/8 of this Guide.

2.2 Arrangements of Fuel Cell Spaces

2.2.1 Fuel Cell Space

i) Fuel cell power installations are to be designed for automatic operation and equipped with all the monitoring and control facilities required for safe operation of the system.

ii) Fuel cell spaces are to be designed to safely contain fuel leakages and be provided with suitable leakage detection systems.

iii) The shut-down of the fuel cell power system is to be possible from an easily accessible location outside the fuel cell space.

iv) Means are to be provided to safely remove the fuel from the fuel cell power system.

v) Means are to be provided to put the fuel cell power system into a safe state for maintenance and shutdown.

vi) For the auxiliary systems of the fuel cell power system where fuel may leak directly into a system medium (e.g., cooling water), such auxiliary systems are to be equipped with appropriate gas extraction and detection measures fitted as close as possible after the media outlet from the system in order to prevent gas dispersion. The gas extracted from the auxiliary system media is to be vented to a safe location on the open deck.

vii) The reforming equipment, if fitted, may be an integrated part of the fuel cell assembly or arranged as an independent structural unit with reformed fuel piping connected to the fuel cell(s). Evaporation of liquefied gases is not covered by the fuel reforming process.

viii) Notwithstanding the ventilation provisions of this Section, fuel cell spaces are to be gastight.

2.2.2 Fuel preparation rooms and pumps

i) Fuel preparation rooms are to be located outside Category A machinery spaces with ventilation of at least 30 air changes per hour. These rooms are to be gas tight and liquid tight to surrounding enclosed spaces and vented to open air.

ii) Hydraulically powered pumps that are submerged in fuel tanks are to be arranged with double barriers preventing the hydraulic system serving the pumps from being directly exposed to fuels. The double barrier is to be arranged for detection and drainage of eventual fuel leakage.

iii) All pumps in the fuel system are to be protected against running dry (i.e., protected against operation in the absence of fuel or service fluid). All pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with relief valves. Each relief valve is to be in closed circuit (i.e., arranged to discharge back to the piping upstream of the suction side of the pump and to effectively limit the pump discharge pressure to the design pressure of the system).

3 Arrangement of Entrances and Other Openings

3.1 General

i) Direct access is not to be permitted from a non-hazardous area to a hazardous area. Where such openings are necessary for operational reasons, an air lock which complies with the requirements of 3/3.3 of this Guide are to be provided.

ii) For fuel cell spaces, the above i) requirement is to be determined based on the fuel cell space concept as per 3/2.1.2.

iii) Fuel preparation rooms are to have independent access direct from the open deck, where practicable. Where a separate access from open deck is not practicable, an air lock complying with the requirements of 3/3.3 of this Guide is to be provided.

iv) Access to fuel equipment units not normally accessed is to be by bolted gastight manholes or covers. Technical provisions are to be made so that access to the units is not possible before the unit is safely shut down, isolated from the fuel system, drained and the atmosphere is confirmed gas-free.

3.2 Fuel Tanks and Fuel Containment Systems

i) Fuel tanks and surrounding cofferdams are to have suitable access from the open deck where practicable, for gas-freeing, cleaning, maintenance and inspection

ii) For fuel tanks or surrounding cofferdams without direct access from the open deck, the entry space is to comply with the following conditions:

- The entry space is to be fitted with an independent mechanical extraction ventilation system, providing a minimum of 10 air changes per hour. A low oxygen alarm and a gas detection alarm are to be fitted.
- The entry space is to have sufficient open area around the fuel tank hatch for efficient evacuation and rescue operation.
- Direct entry from accommodation spaces, service spaces, control stations and machinery spaces are not permitted.
- Entry from cargo spaces may be accepted depending upon the type of cargo if the area is cleared of cargo and no cargo operations are undertaken during tank entry.

iii) The area around independent fuel tanks are to be sufficient to carry out evacuation and rescue operations.

iv) For safe access, horizontal hatches or openings to or within fuel tanks or surrounding cofferdams are to have a minimum clear opening of 600 mm by 600 mm that allows the hoisting of an injured person through it. For access through vertical openings providing main passage through the length and breadth within fuel tanks and cofferdams, the minimum clear openings are not to be less than 600 mm by 800 mm at a height of not more than 600 mm from bottom plating unless gratings or footholds are provided. Smaller openings may be accepted provided evacuation of an injured person through it can be demonstrated.

3.3 Air Locks

i) An air lock is a space enclosed by gastight bulkheads with two gastight doors spaced at least 1.5 m and not more than 2.5 m apart. Unless subject to the requirements of the International Convention on Load Lines, the door sills are not to be less than 300 mm in height. The doors are to be self-closing without any holding back arrangements.

ii) Air locks are to be mechanically ventilated at an overpressure relative to the adjacent hazardous area or space.

iii) Air locks are to have a simple geometrical form. They are to provide free and easy passage, and are to have a deck area not less than 1.5 m^2. Air locks are not to be used for any other purposes or for storage.

iv) An audible and visual alarm system to give a warning on both sides of the air lock is to be provided to indicate if more than one door is open.

v) For non-hazardous spaces with access from hazardous spaces below deck where the access is protected by an airlock, upon loss of underpressure in the hazardous space, access to the space is to be restricted until the ventilation has been reinstated. Audible and visual alarms are to be given at a manned location to indicate both loss of pressure and opening of the airlock doors when pressure is lost.

vi) Essential equipment required for safety are not to be de-energized and are to be of a certified safe type. This may include lighting, fire detection, public address and general alarms systems.

vii) Electrical equipment which is not of the certified safe type for propulsion, power generation, maneuvering, anchoring and mooring, as well as the emergency fire pumps, are not to be located in spaces protected by air locks.

4 Piping Design

4.1 General

i) The design pressure is not to be less than 1 MPa, except for open-ended pipes where it is not to be less than 0.5 MPa. The design pressure P in the formula for t_o in 3/4.2 below is the maximum gauge pressure to which the system may be subjected in service, taking into account the highest set pressure on any relief valve on the system.

ii) For pipes made of materials other than steel, the allowable stress is to be considered by ABS on a case-by-case basis provided that a recognized standard has been used.

iii) Fuel pipes and all the other piping needed for a safe and reliable operation and maintenance are to be color marked in accordance with a standard.

iv) All fuel piping and independent fuel tanks are to be electrically bonded to the ship's hull. Electrical conductivity is to be maintained across all joints and fittings. Electrical resistance between piping and the hull are to be a maximum of 10^6 Ohm.

v) Piping other than fuel supply piping and cabling may be arranged in the double wall piping or duct provided that they do not create a source of ignition, or compromise the integrity of the double pipe or duct. The double wall piping or duct is to only contain the piping or cabling necessary for operational purposes.

vi) Filling lines to fuel tanks are to be arranged to minimize static electricity by minimizing the free fall distance into the fuel tank.

4.2 Piping System Component Requirements

The following requirements are applicable to piping system components. ABS may consider other approaches based on a case-by-case basis provided that a recognized standard has been used.

4.2.1 Piping Scantlings

4.2.1(a)

The wall thickness of pipes is not to be less than:

$$t = \frac{t_o + b + c}{1 - \frac{a}{100}} \quad \text{mm}$$

where

t_o = theoretical thickness, determined by the following formula:

$$= \frac{P \cdot D}{2K \cdot e + P} \quad \text{mm}$$

with

P = design pressure, in MPa, referred to in 3/4.1i)

D = outside diameter, in mm

K = allowable stress, in N/mm^2, referred to in 3/4.2.1(b)

e = efficiency factor equal to 1.0 for seamless pipes and for longitudinally or spirally welded pipes, delivered by approved manufacturers of welded pipes, which are considered equivalent to seamless pipes when nondestructive testing on welds is carried out in accordance with recognized standards. In other cases, an efficiency factor of less than 1.0, in accordance with recognized standards, may be required, depending on the manufacturing process

b = allowance for bending, in mm. The value of b is to be chosen so that the calculated stress in the bend, due to internal pressure only, does not exceed the allowable stress. Where such justification is not given, b is to not be less than:

= $\frac{D \cdot t_o}{2.5 \cdot r}$ mm

r = mean radius of the bend, in mm

c = corrosion allowance, in mm. If corrosion or erosion is expected, the wall thickness of the piping is to be increased over that required by the other design requirements.

a = negative manufacturing tolerance for thickness, %

4.2.1(b)

For pipes, the allowable stress K to be considered in the formula for t_o in 3/4.2.1(a) is the lower of the following values:

$\frac{R_m}{2.7}$ or $\frac{R_e}{1.8}$

where

R_m = specified minimum tensile strength at room temperature, in N/mm^2

R_e = specified minimum yield stress at room temperature, in N/mm^2. If the stress-strain curve does not show a defined yield stress, the 0.2% proof stress applies.

4.2.1(c)

Where necessary for mechanical strength to prevent damage, collapse, excessive sag or buckling of pipes due to superimposed loads, the wall thicknesses are to be increased over that required by 3/4.2.1(a) or, if this is impracticable or would cause excessive local stresses, these loads are to be reduced, protected against, or eliminated by other design methods. Suchsuperimposed loads may be due to: supports, ship deflections, liquid pressure surge during transfer operations, the weight of suspended valves, or reaction to loading arm connections.

4.2.1(d)

High pressure fuel piping systems are to have sufficient constructive strength. This is to be confirmed by stress analysis, and taking into account the following:

i) Stresses due to the weight of the piping system

ii) Acceleration loads when significant

iii) Internal pressure and loads induced by hogging and sagging

4.2.2 Flexibility of Piping

The arrangement and installation of fuel piping is to provide the necessary flexibility to maintain the integrity of the piping system in actual service situations, taking potential for fatigue into account.

4.2.3 Joining Details for Flanges, Valves and Fittings

4.2.3(a)

Fuel Piping is to be joined by welding except:

i) For approved connections to shut off valve and expansion joints, if fitted

ii) For other exceptional cases specifically approved by ABS

4.2.3(b)

The following direct connections of pipe length without flanges may be considered *i)* Butt-welded joints with complete penetrations at the root

ii) Slip-on welded joints with sleeves and related welding having dimensions in accordance with recognized standards are to only be used in pipes having an external diameter of 50 mm or less.

iii) Screwed connections, in accordance with recognized standards, are to only be used for piping with an external diameter of 25 mm or less.

4.2.3(c)

Welding, post-weld heat treatment, radiographic testing, dye penetrating testing, pressure testing, leakage testing and non-destructive testing are to be performed in accordance with recognized standards. Butt welds are to be subject to 100% non-destructive testing, while sleeve welds are to be subject to at least 10% liquid penetrant testing (PT) or magnetic particle testing (MT).

4.2.3(d)

All valves and expansion joints used in high-pressure fuel systems are to be approved according to a recognized standard acceptable to ABS.

4.2.3(e)

Where flanges are used they are to be of the welded neck or slip-on type. Socket welds are not to be used in nominal sizes above 50 mm.

4.2.3(f)

Expansion of piping are to normally be allowed for by the provision of expansion loops or bends in the fuel piping system.

4.2.3(g)

Piping connections are to be joined in accordance with 3/4.2.3(b) in above but for other exceptional cases ABS may consider alternative arrangements.

4.2.4 Drip Trays

4.2.4(a)

Drip trays are to be fitted where leakage and spills may occur, particularly in way of single wall pipe connections.

4.2.4(b)

Each tray is to have a sufficient capacity to handle the maximum amount of spill according to the risk assessment.

4.2.4(c)

Each drip tray is to be provided with means to safely drain spills or transfer spills to a dedicated holding tank. Means for preventing backflow from the tank are to be provided.

4.2.4(d)

The holding tank is to be equipped with a level indicator and alarm and is to be inerted at all times.

4.3 Hydrogen Piping Requirements

Hydrogen piping systems are to be designed in accordance with recognized standards. The fabrication, assembly, erection, inspection, examination and testing of hydrogen piping systems are to be performed in accordance with a recognized standard (i.e. ASME B31-12, Hydrogen Piping and Pipelines) acceptable to ABS. To minimize the potential for leaks and allow for their easy detection are to be defined in the Risk Assessment.

5 General System Requirements

The following requirements apply to system design and ship's arrangements installed with fuel cell power systems. These are closely related to the Risk assessment approach, see 2/3 of this Guide.

i) The safety, reliability and dependability of the systems are to be equivalent to that achieved with new and comparable conventional oil-fueled main and auxiliary machinery.

ii) The probability and consequences of fuel-related hazards are to be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of fuel leakage or failure of the risk reducing measures, necessary safety actions are to be initiated.

iii) The design philosophy is to confirm that risk-reducing measures and safety actions for the fuel installation do not lead to an unacceptable loss of power.

iv) Hazardous areas are to be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the ship, persons on board, and equipment.

v) Equipment installed in hazardous areas are to be minimized to that required for operational purposes and are to be suitably and appropriately certified.

vi) Unintended accumulation of explosive, flammable or toxic vapor and liquid concentrations are to be prevented.

vii) System components are to be protected against external damage.

viii) Sources of ignition in hazardous areas are to be minimized to reduce the probability of fire and explosions.

ix) Safe and suitable fuel supply, storage and bunkering arrangements are to be provided, capable of receiving and containing fuel in the required state without leakage.

x) Piping systems, containment and over-pressure relief arrangements that are of suitable design, material, construction and installation for their intended application are to be provided.

xi) Machinery, systems and components are to be designed, constructed, installed, operated, maintained and protected to provide safe and reliable operation.

xii) Suitable control, alarm, monitoring and shutdown systems are to be provided to provide safe and reliable operation

xiii) Fixed fuel vapor and/or leakage detection suitable for all relevant spaces and areas are to be arranged.

xiv) Fire detection, protection and extinction measures appropriate to the hazards concerned are to be provided.

xv) Commissioning, trials and maintenance of fuel systems and fuel utilization machinery are to satisfy the goals of safety, availability and reliability.

xvi) The technical documentation is to permit an assessment of the compliance of the system and its components with the applicable Rules, guidelines, design standards use and the principles related to safety, availability, maintainability and reliability.

xvii) A single failure in a technical system or component is not to lead to an unsafe condition.

6 Fuel Supply System to Consumers

6.1 General

i) The fuel piping system is to be separate (independent and separated) from all other piping systems.

ii) The fuel supply system is to be arranged so that the consequences of any release of fuel will be minimized, while providing safe access for operation and inspection. The causes and consequences of fuel releases are to be subject to special consideration within the risk assessment in 2/3 of this Guide.

iii) The piping system for fuel transfer to the consumers is to be designed so that a failure of one barrier will not lead to a leak from the piping system into the surrounding area, causing danger to the persons on board, the environment or the ship.

iv) Fuel lines are to be installed and protected so as to minimize the risk of injury to persons on board in case of leakage.

6.2 Double Wall Piping Requirements for Fuel Supply System

The following requirements apply to any low flash point or gaseous type of fuels:

i) Fuel piping in general is to be located in well-ventilated spaces, and as far as practicable to be fully welded.

ii) Fuel piping is not to pass directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention. In cases where fuel piping needs to be routed through accommodation spaces, the fuel piping is to be double walled and led through a dedicated duct. The ducts are to be of substantial construction and be gas tight and watertight.

iii) All piping containing fuel passing through enclosed spaces are to be double walled. Such double walled piping is not required in cofferdams surrounding fuel tanks, or in spaces or units not normally accessed or fuel preparation-rooms or other fuel treatment spaces considered as hazardous.

iv) When liquid hydrogen pipe is used the vacuum insulated pipe type is to be considered provided that its design and installation is in accordance with recognized standards, and appropriate documentation is submitted to ABS.

v) The outer pipe or ducts are to be gas tight and watertight.

vi) The outer pipe in the double walled fuel pipes are to be dimensioned for a design pressure not less than the maximum working pressure of the fuel pipes. As an alternative the calculated maximum built up pressure in the duct in the case of an inner pipe rupture may be used for the dimensioning of the duct.

vii) Ventilation requirements as documented in 3/10.5.

6.3 Redundancy of Fuel Supply System for Alcohol Fuels and Diesel Fuels

i) Propulsion and power generation arrangements, together with fuel supply systems are to be arranged so that a failure in fuel supply does not lead to an unacceptable loss of power.

ii) Two fuel service tanks for each type of fuel used on board necessary for propulsion and vital systems of equivalent arrangements are to be provided. Each tank is to have a capacity sufficient for continuous rating of the propulsion plant and normal operating load at sea of the generator plant for a minimum period of 8 hours. Other arrangements with the same level of redundancy may be accepted by ABS.

7 Fuel Tank

7.1 General

i) Fuel tanks are to be located in such a way that the probability of damage following a collision or grounding is minimized taking into account the safe operation of the ship and other hazards.

ii) Tanks containing fuel are not to be located within accommodation spaces or machinery spaces.

iii) Fuel tanks located on open decks are to be protected against mechanical damage.

iv) Fuel tanks on open decks are to be surrounded by coamings, with spills collected in a dedicated holding tank.

v) Integral fuel tanks are to be surrounded by protective cofferdams, except on those surfaces bound by bottom shell plating, other fuel tanks or the fuel preparation room.

vi) Fuel tanks on open decks are to be surrounded by coamings, and spills are to be collected in a dedicated holding tank, as applicable (e.g., for liquid fuels).

vii) Proposals for alternative fuel tank location criteria, including locations adjacent to accommodation, service or control stations, will be considered on a case-by-case basis. Consideration will be made using an appropriate risk assessment, and is to cover subjects such as protective location, fire protection, lifesaving appliance equipment and evacuation arrangements.

7.2 Fuel Tank Operation

i) In accordance with 1/11 of this Guide, detailed instruction manuals are to be provided onboard covering operations, safety and maintenance requirements and occupational health hazards relevant to the use of fuel.

ii) Fuel tank operation aspects of the manuals are to include but are not be limited to instructions for pumping bunker fuel, stripping tanks, inerting, warming up/cooling down procedures, venting and means for avoiding stratification/rollover, as applicable.

8 Fuel Tank Design

8.1 Independent Fuel Tanks

i) Independent fuel tanks are to be secured to the ship's structure. The arrangement for supporting and fixing the tanks is to be designed for the maximum expected static and dynamic loads as well as the maximum expected acceleration loads, taking into account the ship characteristics and the position of the tanks.

ii) Independent tanks may be accepted on open decks or in enclosed spaces.

iii) Independent tanks are to be fitted with

- Mechanical protection of the tanks depending on location and cargo operations
- Drip tray arrangements for leak containment and water spray systems for emergency cooling, if located on an open deck.
- If located in an enclosed space, the space is to meet the requirements of 3/10 and Section 4.

iv) Independent tanks are to be constructed and tested according to the following:

- The storage used for fuel are to be designed and tested in accordance with applicable Section 5C-13-6 or 5C-13-16 of the *Marine Vessel Rules*.

8.2 Portable Fuel Tanks

i) The design of the tank is to comply with 3/8.1 above. The tank support (container frame or truck chassis) is to be designed for the intended purpose.

ii) Portable fuel tanks are to be located in dedicated areas fitted with:

- Mechanical protection of the tanks depending on location and cargo operations;
- If located on an open deck: drip tray arrangements for leak containment and water spray systems for emergency cooling; and
- If located in an enclosed space: the space is to meet the requirements of 3/10 and Section 4.

iii) Portable fuel tanks are to be secured to the deck while connected to the ship systems. The arrangement for supporting and fixing the tanks are to be designed for the maximum expected static and dynamic loads as well as the maximum expected acceleration loads, taking into account the ship characteristics and the position of the tanks.

iv) Consideration is to be given to the ship's strength and the effect of the portable fuel tanks on the ship's stability.

v) Connections to the ship's fuel piping systems are to be made by means of approved flexible hoses suitable for the fuel or other suitable means designed to provide sufficient flexibility.

vi) Arrangements are to be provided to limit spilled fuel in case of inadvertent disconnection or rupture of the non-permanent connections.

vii) The pressure relief system of portable tanks is to be connected to a fixed venting system.

viii) Control and monitoring systems for portable fuel tanks are to be integrated in the ship's control and monitoring system. Safety system for portable fuel tanks are to be integrated in the ship's safety system (e.g., shutdown systems for tank valves, leak/vapor detection systems).

ix) Safe access to tank connections for the purpose of inspection and maintenance are to be provided.

x) When connected to the ship's fuel piping system

- Each portable tank is to be capable of being isolated at any time
- Isolation of one tank is to not impair the availability of the remaining portable tanks
- The tank is not to exceed its filling limits

8.3 Fuel Tank Monitoring

Fuel tanks are to be monitored and protected against overfilling as required by 6/2.1 of this Guide.

9 Fuel Bunkering System and Distribution System

9.1 General

Fuel bunker systems are to be designed such that any leakage from the piping system cannot cause danger to persons onboard, the environment (such as damaging spills onto water, and air emissions including pollutants, toxic gases. etc.) or the ship.

9.2 Fuel Bunkering Station

i) The bunkering station is to be located on the open deck so that sufficient natural ventilation is provided. Closed or semi-enclosed bunkering stations are to be subject to special consideration with respect to requirements for mechanical ventilation.

ii) Entrances, air inlets and openings to accommodation, service and machinery spaces and control stations are not to face the bunkering connection.

iii) Closed or semi-enclosed bunkering stations are to be surrounded by gastight boundaries against enclosed spaces.

iv) Bunkering lines are not to pass directly through accommodation, control stations or service spaces. Bunkering lines passing through non-hazardous areas in enclosed spaces are to be double walled or located in gas-tight ducts.

v) Arrangements are to be made for safe management of fuel spills. Coamings and/or drip trays are to be provided below the bunkering connections together with a means of safely collecting and storing spills. This could be a drain to a dedicated holding tank equipped with a level indicator and alarm. Where coamings or drip trays are subject to rainwater, provisions are to be made to drain rainwater overboard.

vi) Showers and eye wash stations for emergency usage are to be located in close proximity to areas where the possibility for accidental contact with fuel exists. Emergency showers and eye wash stations are to be operable under all ambient conditions.

9.3 Ship's Bunker Hoses

i) Bunker hoses are carried onboard; they are to be suitable for the fuel used and certified to a minimum bursting pressure of 5 times the normal working pressure.

ii) Means are to be provided for draining any excess fuel from the bunkering hoses upon completion of fueling.

iii) Where fuel hoses are to be carried on board, arrangements are to be made for safe storage of the hoses. Hoses are to be stored on the open deck or in a storage room with an independent mechanical extraction ventilation system, providing a minimum of 6 air changes per hour.

9.4 Fuel Bunkering Manifolds

The bunkering manifold is to be designed to withstand the external loads encountered during bunkering. The connections at the bunkering station are to be of dry-disconnect type and equipped with an additional safety dry break-away coupling or self-sealing quick release. The couplings are to be of a standard type.

9.5 Fuel Bunkering System

i) Fuel bunker piping arrangements between the bunkering manifold and the fuel storage tank are to be in accordance with the requirements of 3/4 of this Guide.

ii) Means are to be provided for draining any fuel from the bunkering pipes upon completion of operation.

iii) Means are to be provided to inert bunker lines and make them gas free.

iv) In the bunkering line, as close to the connection point as possible, there is to be a manually operated stop valve and a remotely operated shutdown valve arranged in series. Alternatively, a combined manually operated and remote shutdown valve may be provided. Operation of this remotely operated valve is to be possible from the bunkering control station.

v) Here bunkering pipes are arranged with a crossover, suitable isolation arrangements are to be provided that fuel cannot be transferred inadvertently to the ship side not in use for bunkering.

9.6 Emergency Shutdown System

The ship is to be fitted with a bunkering Emergency Shutdown (ESD) system operable from both the ship and the bunker supply facility. This is to allow a rapid and safe shutdown of the bunker supply system without the release of liquid or vapor.

9.7 Control and Monitoring

The monitoring and safety shutdowns for the fuel bunkering system are to be in accordance with Section 6, Table 1 of this Guide.

9.8 Gas Detection System

Monitoring and safety system functions are to be provided in accordance with Section 6, Table 1 of this Guide.

10 Ventilation System

10.1 General

i) Any ducting used for the ventilation of hazardous spaces is to be separate from that used for the ventilation of non-hazardous spaces. The ventilation is to function at all temperature and environmental conditions the ship will be operating in. Electric ventilation fan motors are not to be located in ventilation ducts for hazardous spaces unless the motors are certified for the same hazardous zone as the space served.

ii) Design of ventilation fans serving spaces where vapor from fuels may be present is to fulfill the following:

a) Ventilation fans are not to produce a source of vapor ignition in either the ventilated space or the ventilation systems associated with the space. Ventilation fans and fan ducts, in way of fans only, are to be of non-sparking construction.

- Impellers or housings of non-metallic material, due regard being paid to the elimination of static electricity
- Impellers and housings of non-ferrous metals
- Impellers and housings of austenitic stainless steel
- Impellers of aluminum alloys or magnesium alloys and a ferrous (including austenitic stainless steel) housing on which a ring of suitable thickness of non-ferrous materials is fitted in way of the impeller, due regard being paid to static electricity and corrosion between ring and housing
- Any combination of ferrous (including austenitic stainless steel) impellers and housings with not less than 13 mm tip design clearance

b) In no case is the radial air gap between the impeller and the casing to be less than 0.1 of the diameter of the impeller shaft in way of the bearing but not less than 2 mm. The gap need not be more than 13 mm.

c) Any combination of an aluminum or magnesium alloy fixed or rotating component and a ferrous fixed or rotating component, regardless of tip clearance, is considered a sparking hazard and is not to be used in these locations.

d) Protection screens of not more than 13 mm (0.5 in.) square mesh are to be fitted in the inlet and outlet of ventilation openings on the open deck to prevent the entrance of foreign objects into the fan casing.

iii) Ventilation systems required to avoid any vapor accumulation are to consist of independent fans, each of sufficient capacity, unless otherwise specified in this Guide. The ventilation system is to be of a mechanical exhaust type, with extraction inlets located as to avoid accumulation of vapor from leaked fuel in the space.

iv) Air inlets for hazardous enclosed spaces are to be taken from areas which, in the absence of the considered inlet, would be non-hazardous. Air inlets for non-hazardous enclosed spaces are to be taken from non-hazardous areas at least 1.5 m away from the boundaries of any hazardous area. Where the inlet duct passes through a more hazardous space, the duct is to be gas-tight and have over-pressure relative to this space.

v) Air outlets from non-hazardous spaces are to be located outside hazardous areas.

vi) Air outlets from hazardous enclosed spaces are to be located in an open area which, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.

vii) The required capacity of the ventilation plant is normally based on the total volume of the room. An increase in required ventilation capacity may be necessary for rooms having a complicated form.

viii) Ventilation ducts are to have the same area classification as the ventilated space.

ix) Non-hazardous spaces with entry openings to a hazardous area are to be arranged with an air-lock and be maintained at overpressure relative to the external hazardous area. The overpressure ventilation is to be arranged according to the following

a) During initial start-up or after loss of overpressure ventilation, and before energizing any electrical installations not certified safe for the space in the absence of pressurization, it is to:

- Proceed with purging (at least 5 air changes) or confirm by measurements that the space is non-hazardous.
- Pressurize the space.

b) Operation of the overpressure ventilation is to be monitored and in the event of failure of the overpressure ventilation:

- An audible and visual alarm is to be given at a manned location
- If overpressure cannot be immediately restored automatically or preprogrammed, disconnection of electrical installations according to a recognized standard in the non-hazardous space is to be performed.

x) Non-hazardous spaces with entry openings to a hazardous enclosed space are to be arranged with an air lock and the hazardous space is to be maintained at underpressure relative to the non-hazardous space. Operation of the extraction ventilation in the hazardous space is to be monitored and in the event of failure of the extraction ventilation, the following is to be provided:

a) An audible and visual alarm is to be given at a manned location

b) If underpressure cannot be immediately restored automatically or preprogrammed, disconnection of electrical installations according to a recognized standard in the non-hazardous space is to be performed.

In addition, there are specific ventilation requirements in each individual Section of this Guide. Refer to the requirements in each Section.

10.2 Fuel Cell Space

i) Fuel cell spaces are to be equipped with a mechanical ventilation system of the extraction type providing effective ventilation of the complete space, also taking into consideration the density of potentially leaking fuel gases.

ii) The ventilation rate in fuel cell spaces are to be sufficient to dilute the gas/vapor concentration to below the flammable range in all leakage scenarios, including the fuel released upon pipe rupture with consideration for automatic detection and line shutoff processes that limit the release duration.

iii) Any ducting used for the ventilation of fuel cell spaces is not to serve any other space.

iv) Ventilation ducts from spaces containing reformed fuel piping or release sources are to be vertical or steadily ascending and without sharp bends to avoid any opportunity for gas to accumulate.

v) Two fans are to be installed for the ventilation of the fuel cell space with 100% capacity each. Both fans are to be supplied from separate circuits. In case of loss of ventilation or loss of negative pressure in the fuel cell space the fuel cell power system is to carry out an automatic, controlled shutdown of the fuel cell and isolation of the fuel supply.

10.3 Fuel Preparation Rooms

i) Fuel preparation rooms are to be fitted with an effective mechanical forced ventilation system of extraction type. During normal operations the ventilation capacity is to provide at least 30 air changes per hour.

ii) The number and power of the ventilation fans are to be such that the capacity is not reduced by more than 50% if a fan with a separate circuit from the main switchboard, or emergency switchboard, or a group of fans with common circuit from the main switchboard or emergency switchboard is inoperable.

iii) Ventilation systems for fuel preparation rooms and other fuel handling spaces are to be in operation when pumps or other fuel treatment equipment are working.

10.4 Bunkering Station

Bunkering stations that are not located on the open deck are to be suitably ventilated so that any vapor released during bunkering operations will be exhausted outside. If the natural ventilation is not sufficient, the bunkering stations are to be subject to special consideration with respect to requirements for mechanical ventilation.

10.5 Ducts and Double Pipes

i) The annular space between inner and outer pipe are to have mechanical ventilation of an underpressure type, with a capacity of a minimum 30 air changes per hour, and be ventilated to open air. Appropriate means for detecting leakage into the annular space are to be provided. The double wall enclosure is to be connected to a suitable draining tank allowing the collection and the detection of any possible leakage.

ii) Inerting of the annular space may be accepted as an alternative to ventilation. Appropriate means of detecting leakage into the annular space are to be provided. Suitable alarms are to be provided to indicate a loss of inert gas pressure between the pipes.

iii) The ventilation system for double wall piping and ducts is to be independent of all other ventilation systems.

iv) The ventilation inlet for the double wall piping or duct is to always be located in a non-hazardous area, in open air, away from ignition sources. The inlet openings are to be fitted with a suitable wire mesh guard and protected from ingress of water.

11 Fuel Leakage

11.1 General

i) The propulsion and fuel supply system are to be designed so that safety actions after any fuel leakage do not lead to an unacceptable loss of power.

ii) Fuel cell spaces are to be designed to safely contain and exhaust fuel leakages and are to be provided with suitable leakage detection systems.

iii) If fuel leakage is detected in the ducting enclosure or the annular spaces of the double walled bunkering lines, an audible and visual alarm and emergency shutdown of the bunkering valve is to automatically be activated.

iv) If a leak leading to a fuel supply shutdown occurs, the fuel supply is not to be operated until the leak has been found and addressed. Instructions to this effect are to be placed in a prominent position in the fuel cell space.

v) Fixed fuel vapor and/or leakage detection suitable for all spaces and areas concerned, arranged to automatically shutdown the fuel supply, and disconnect all electrical equipment or installations not of a certified safe type, is to be provided.

vi) Drip trays are to be provided where leakage and spills may occur in accordance with 3/4.2.4 of this Guide.

vii) The fuel cell space is to have an independent deck drain or no deck drain at all.

12 Fuel Cell Exhaust System

12.1 General

i) Exhaust gases from the fuel cell power systems are not to be combined with any ventilation systems and are to be led to the open air.

ii) Fuel cell exhaust air and exhaust gas outlets are to be regarded as Zone 1 hazardous areas.

SECTION 4 Fire Safety

1 General

1.1 Application

i) The fire safety system is to be suitable for use with the specific fuel and fuel cell technology proposed. ABS may allow any alternative fire safety measures if equivalence is demonstrated by a risk assessment considering the fuels used.

ii) Fuel cell spaces are to be designed to provide a geometrical shape that minimizes the accumulation of gases or formation of gas pockets.

iii) Fuel cell spaces bulkhead are to have sufficient strength to withstand the effects of a local gas explosion in either space, without affecting the integrity of the adjacent space and equipment within that space. Documentation showing that the bulkhead has sufficient strength to withstand a worst-case explosion is to be submitted for review.

2 Structural Fire Protection

i) For the purposes of fire protection, fuel preparation rooms are to be regarded as Category A machinery spaces.

ii) Any boundary of accommodation including navigation bridge windows, service spaces, control stations, machinery spaces, and escape routes facing fuel tanks on open deck are to have a fire integrity class of A-60. This may be waived, provided that a minimum safe distance between the above spaces and the fuel tank space has been determined, and that appropriate documentation is submitted to ABS for consideration.

iii) The fire integrity of fuel tank cofferdam boundaries facing high fire risk spaces such as machinery spaces and similar are to be separated by a cofferdam of at least 900 mm with insulation of A-60 class.

iv) The bunkering station is to be separated by A-60 class divisions between Category A machinery spaces, accommodations, control stations and high fire risk spaces except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, and sanitary and similar spaces where the boundary may be reduced to class A-0.

3 Fire Extinguishing

3.1 General

The fire-extinguishing system is to be suitable for use with the specific fuel and fuel cell technology proposed and included in the Risk Assessment. Spaces such as fuel cell, fuel containment, fuel preparation room, bunkering station, etc., are to be fitted with a suitable Fixed Fire Extinguishing System (FFES) recommended by the vendor and appropriate to the fuel chemistry used in those spaces. The FFES is to adequately consider the potential fire loads involved. Technical validation of the system is to be carried out in accordance with the procedures outlined in the ABS *Guidance Notes on Alternative Design and Arrangements for Fire Safety* and sufficient documentation to verify the same is to be submitted along with arrangements and details of the system for review.

3.2 Fire Main

When the storage tank is located on the open deck, isolating valves are to be fitted in the fire main in order to isolate damaged sections of the fire main. Isolation of a section of fire main is not to deprive the fire line ahead of the isolated section from the supply of water.

3.3 Machinery Spaces and Pump Room

i) Machinery spaces and fuel preparation rooms where fuel pumps are arranged are to be protected by an approved fixed fire extinguishing system in accordance with SOLAS Reg.II-2/10 and the FSS Code. In addition, the fire extinguishing medium used is to be suitable for the specific fuel.

ii) An approved alcohol resistant foam system covering the tank top and bilge area under the floor plates are to be arranged for Category A machinery spaces and fuel preparation rooms containing the specific fuels.

iii) Regardless of the requirements in *i)* and *ii)* above, fire extinguishing systems used for specific fuels may be arranged based on the risk assessment.

3.4 Firefighting Systems for Methyl/Ethyl Alcohol-based Fuels

The following requirements are to be applicable in general to methyl/ethyl alcohol-based fuels.

i) Where fuel tanks are located on the open deck, there is to be a fixed firefighting system of alcohol resistant aqueous film forming foam (ARAFFF) type. The system is to be operable from a safe position. The system is to fulfil the requirements in Chapter 14 of the FSS Code.

ii) The ARAFFF type foam is to be able cover the area below the fuel tank where a large spill of fuel can be expected to spread.

iii) The bunker station is to have a fixed fire extinguishing system of ARAFFF type and a portable dry chemical powder extinguisher or an equivalent extinguisher, located near the entrance of the bunkering station.

iv) Where fuel tanks are located on the open deck, there is to be a fixed water spray system for diluting eventual large spills, cooling and fire prevention. The system is to cover exposed parts of the fuel tank.

v) A fixed fire detection and fire alarm system complying with Fire Safety System Code is to be provided for all compartments containing the specific fuel system (see 4/5 of this Guide).

vi) Suitable detectors are to be selected based on the fire characteristics of the fuel. Smoke detectors are to be used in combination with detectors which can detect methanol/ethanol fire.

3.5 Personnel Safety Equipment use of Ammonia as a Fuel

The following safety equipment is to be provided and stored in a readily accessible location outside the fuel cell space and is to be in addition to the equipment required by 4-7-3/15.5 of the *Marine Vessel Rules*:

i) At least two sets of ammonia protective clothing, including refrigerant gas mask, helmet, boots and gloves.

ii) Two or more power driven air compressors, to recharge breathing apparatus cylinders.

4 Fire Detection and Alarm Systems

i) A fixed fire detection and fire alarm system complying with the Chapter 9 of International Code for Fire Safety Systems is to be provided for all compartments containing the fuel system.

ii) Suitable detectors are to be selected based on the fire characteristics of the fuel. Smoke detectors are to be used in combination with detectors which can detect fire.

iii) The fire detection system in machinery spaces containing the fuel and rooms containing independent tanks for fuel storage are to give audible and visual alarms.

iv) Required safety actions at the fire detection in the fuel cell spaces are given in Section 6, Table 1.

SECTION **5 Electrical Systems**

1 General

1.1 Application

i) The electrical requirements in this Section supplement the requirements of Part D of SOLAS Chapter II-1 and Part 4, Section 8 of the *Marine Vessel* Rules.

ii) Electrical equipment is not to be installed in hazardous areas unless essential for operational purposes or safety enhancement.

iii) Where electrical equipment is installed in hazardous areas it is to be selected, installed and maintained in accordance with standards at least equivalent to those acceptable to the Organization (i.e., IEC 60079 series and IEC 60092-502, as applicable).

iv) Cable penetrations are to satisfy the requirements regulating the dispersion of gas.

v) The lighting system in hazardous areas is to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and are to be located in a non-hazardous area.

vi) The installation of the electrical equipment units is to provide the safe bonding to the hull of the units themselves.

vii) Hoses, transfer arms, piping and fittings provided by the delivering facility used for bunkering are to be electrically continuous, suitably insulated and are to provide a level of safety compliant with recognized standards.

2 Area Classification

i) Area classification is a method of analyzing and classifying the areas where these explosive gas atmospheres may occur. The object of the classification is to allow the selection of electrical equipment able to be operated safely in the defined areas.

In order to facilitate the selection of the appropriate electrical equipment and the design of suitable electrical installations, hazardous areas are divided into Zones 0, 1 and 2 according to the principles of the standards IEC 60079-10 and guidance and informative examples given in IEC 60092-502.

ii) Means are to be provided for protection of the fuel cell installation against short circuits and flow of reverse current.

3 Hazardous Area Zones

3.1 Hazardous Area Zone 0

Hazardous Area Zone 0 includes:

i) The interiors of buffer tanks, reformers, pipes and equipment containing low flashpoint fuel or reformed fuel, any pressure-relief pipework or other venting.

3.2 Hazardous Area Zone 1

Hazardous Area Zone 1 includes:

i) Fuel cell space.

ii) Areas on the open deck or semi- enclosed spaces on deck, within 3 m of any reformed fuel or purge gas outlets, or fuel cell space ventilation outlets.

iii) Fuel cell exhaust air and exhaust gas outlets.

iv) Areas on open deck or semi-enclosed spaces on deck, within 1.5 m of fuel cell space entrances, fuel cell space ventilation inlets and other openings into Zone 1 spaces.

v) Areas on open deck or semi-enclosed spaces within 3 m in which other sources of release of reformed fuel are located.

3.3 Hazardous Area Zone 2

Hazardous Area Zone 2 includes:

i) Areas within 1.5 m surrounding open or semi-enclosed spaces of Zone 1 as specified above if not otherwise specified in this standard.

ii) Air locks.

3.4 Ventilation Duct and Other Spaces

i) Ventilation ducts are to have the same area classification as the ventilated space.

ii) Areas and spaces other than those mentioned in this Section are to be subject to special consideration. The principles of the IEC standards are to be applied.

iii) For gas detectors requirements in ventilation ducts and other spaces, please see 6/3.1, as appropriate.

4 Certified Safe Equipment

4.1 General

Certified safe equipment is equipment intended for installation in hazardous areas where flammable or explosive gases, vapors, or dust are normally or likely to be present. The equipment is to be type-tested and certified by a competent, independent testing laboratory for complying with IEC Publication 60079 series or other recognized standard, and rated according to its enclosure and the types of flammable atmosphere in which it is safe to install. If desired, the manufacturer may have such equipment type approved (see 1-1-A3/1 of the ABS *Rules for Conditions of Classification (Part 1))*.

4.2 Flammable Gas Groups and Temperature Classes

Certified safe equipment is to be rated for the flammable atmosphere in which it is safe to install. Each flammable atmosphere is to be identified with respect to the flammable gas, vapor or dust and its auto-ignition temperature; the latter being used to limit the maximum permissible external surface temperature of the equipment. The following tables show the typical flammable gas groups and the temperature classes as in IEC Publication 60079-20:

Representative Gas	*Gas Group*	*Temperature Class*
Methane (Natural Gas)	IIA	T1
Propane, Butane	IIA	T2
Methyl Alcohol (Methanol)	IIA	T2
Ethyl Alcohol (Ethanol)	IIB	T2

Representative Gas	*Gas Group*	*Temperature Class*
Ammonia	IIA	T1
Hydrogen	IIC	T1

5 Emergency Shutdown

5.1 General

In general, arrangements are to be provided for the disconnection or shutdown, either selectively or simultaneously, of all electrical equipment and devices, including the emergency generator, except for the services listed in accordance with the applicable sections of the *Marine Vessel Rules (MVR)* and the *Mobile Offshore Units (MOU) Rules*, from the emergency control stations (see 5/5.2 below). Initiation of the above shut-downs may vary according to the nature of the emergency. A recommended shut down sequence is to be provided in the vessel's operating manual.

To address risks associated with technical faults and inadvertent operations of the emergency shutdown, each vessel is to develop a detailed plan for recovery and restoration of operation after operation of each level of ESD.

If limit values determined for the control process, e.g. temperature, pressure, or voltage, which may lead to hazardous situations, the fuel cell power system are to be automatically shut down and interlocked by an independent protective device.

For emergency shutdown arrangement submissions please see 1/9.8 ii), 1/9.11 and 3/9.6.

5.2 Manual Emergency Shutdown

The means of manual emergency shutdown of fuel cell power system is to be provided the following locations as fitted:

a) Navigating bridge

b) Continuously manned central control station

c) Fire control station

d) Inside the Fuel Cell Space

6 Inspection and Maintenance

6.1 General

i) The procedures and information are to include maintenance of electrical equipment that is installed in explosion hazardous spaces and areas. The inspection and maintenance of electrical installations in explosion hazardous spaces are to be performed in accordance with a recognized standard. (e.g., IEC 60092-502 and IEC 60079-17).

ii) An inspection and maintenance manual is to be prepared for electrical equipment that is installed in explosion hazardous spaces and areas in accordance with Sections 9 and 10 of IEC 60092-502.

6.2 Documentation

The inspection and maintenance manuals for the equipment are to be provided. They are to be kept updated and available in a location known to the operating personnel. The inspection and maintenance manual is to include, but not limited to:

i) Zone classification of areas and, if included, the equipment protection level (EPL) required for each location.

ii) For gases: equipment group (IIA, IIB or IIC) and temperature class requirements. Please note that some IEC Standards (i.e., 60079-0, 60079-1) address a double marking can be applied to specific gas groups (i.e., IIB+H2 for hydrogen).

iii) Equipment characteristics (e.g., temperature ratings, type of protection, IP rating, corrosion resistance).

iv) Records sufficient to enable the explosion protected equipment be maintained in accordance with its type of protection.

v) Copies of previous inspection records.

vi) Copies of the additional initial inspection records.

vii) All electrical equipment located in hazardous areas and in the spaces which may become hazardous on loss of pressurization are to be, together with any associated safe-area apparatus required for the protection of the equipment, listed on a schedule. The schedule is to include the following details:

- Location
- Zonal classification of location
- Type of equipment
- Manufacturer
- Type reference
- Test authority and certificate number, or, reference and date of manufacturer's declaration
- Type of protection
- Apparatus group
- Temperature class
- Ambient temperature range for which equipment is suitable
- Ingress protection (IP) rating

6.3 Qualification of Personnel

i) The necessary basic training for the inspection and maintenance of installations covered by this standard are to be carried out only by experienced personnel.

ii) Documentation verifying compliance with 5/6.2 are to be made available to the Surveyor upon request.

SECTION 6 Control, Monitoring and Safety Systems

1 General

1.1 Application

i) The control system for the fuel cell power system may be connected to an integrated control system or be a stand-alone system. See Section 6, Table 1 for list of fuel cell monitoring requirements.

ii) The overall system design is to be based on single-fault criteria. The system is to be designed such that a single fault of a component will not lead to serious consequences.

iii) Suitable instrumentation devices are to be fitted to allow a local and a remote reading of essential parameters to provide safe management of the whole fuel-gas system including bunkering.

iv) At least one bilge well with a level indicator is to be provided for each enclosed space where an independent storage tank without a protective cofferdam or secondary barrier is located. Alarms are to be given at a high level in the bilge well. The leakage detection system is to trigger an alarm and safety functions in accordance with Section 6, Table 1.

v) For tanks not permanently installed in the ship, a monitoring system is to be provided that is equivalent for the permanently installed tanks. Liquid leakage detection is to be installed in the protective cofferdams or secondary barrier space surrounding the fuel tanks, in all ducts around fuel pipes, in fuel preparation rooms, and in other enclosed spaces containing single walled fuel piping or other fuel equipment.

vi) Chemical reactions, such as those that occur during fuel reforming or within the fuel cell, are to be monitored (e.g., by means of temperature, pressure or voltage monitoring).

vii) If limit values determined for the process (e.g., temperature, pressure, voltage) which may lead to hazardous situations are exceeded, the fuel cell power system is to be automatically shut down and interlocked by an independent protective device

viii) Computer based systems where used for control, monitoring and safety systems are to comply with the applicable provisions of Section 4-9-3 of the *Marine Vessel Rules.*

2 Control and Monitoring System

2.1 Bunkering and Fuel Tank Monitoring

The following requirements apply to any fuel (liquid or vapor state) The gauging device types are to be selected as appropriate.

2.1.1 Level Indicators for Fuel Tanks

i) Each fuel tank is to be fitted with level gauging devices, arranged to provide a level reading whenever the fuel tank is operational. The devices are to be designed to operate throughout the design pressure range of the fuel tank and at temperatures within the fuel operating temperature range.

ii) Unless necessary maintenance can be carried out while the fuel tank is in service, two level gauging devices are to be installed.

2.1.2 Overflow Control

i) Each fuel tank is to be fitted with a visual and audible high level alarm. These are to be able to be function tested from outside the tank and can be common with the level gauging system, but are to be independent of the high-high level alarm.

ii) An additional sensor (high-high level) operating independently of the high liquid level alarm is to automatically actuate a shutoff valve in a manner that will both avoid excessive liquid pressure in the bunkering line, and prevent the fuel tank from becoming liquid full.

iii) The high and high-high level alarm for the fuel tanks are to be visual and audible at the location at which gas-freeing by water filling of the fuel tanks is controlled, given that water filling is the preferred method for gas-freeing.

2.2 Bunkering Control

2.2.1 Application

i) Control of the bunkering is to be from a remote location. At this remote location:

- Tank pressure and tank level are to be capable of being monitored.
- Remote control valves required by 3/9.6 and 4/4 of this Guide are to be capable of being operated from this location. Closing of the bunkering shutdown valve is to be possible from the control location for bunkering and from another safe location.
- Overfill alarms and automatic shutdown are to be also be indicated at this location.

ii) If the ventilation in the ducting enclosure or annular spaces of the double walled bunkering lines stops, an audible and visual alarm is to be provided at the bunkering control location.

iii) Where bunkering lines are enclosed in double pipes or ducts, the ventilation is to be in accordance with 3/10.5.

iv) If fuel leakage is detected in the ducting enclosure or the annular spaces of the double walls of the bunkering lines, an audible and visual alarm and emergency shutdown of bunkering valve are to automatically be activated.

2.3 Fuel Pump Monitoring

i) Fuel pumps are to be fitted with audible and visual alarms the following locations:

a) Navigation bridge

b) Engine control room

c) Fuel preparation room

ii) As a minimum, the alarms are to indicate low fuel input pressure, low fuel output pressure, high fuel output pressure and fuel pump operation.

2.4 Fuel Cell Condition Monitoring

i) All operating conditions are to be monitored to verify they are within the acceptable design range specified by the manufacturer.

ii) A failure mode and effect analysis examining all possible faults affecting the fuel cell operation and safety are to be carried out. Based on the outcome of the analysis, the extent of the monitoring and control are to be decided. As a minimum the following items are to typically be monitored, as applicable:

a) Cell voltage

b) Cell voltage deviations

c) Exhaust gas temperature

d) Fuel Cell temperature

e) Electric current

Other typical monitoring that should be considered:

a) Air flow

b) Air pressure

c) Cooling medium flow, pressure, temperature (if applicable)

d) Fuel flow

e) Fuel temperature

f) Fuel pressure

g) Gas detection based on the risk assessment

h) Water system level

i) Water system pressure

j) Water system purity

k) Parameters necessary to monitor lifetime/ deterioration.

iii) The fuel cell power system is to be arranged for manual remote emergency stop from the following locations:

a) Cargo control room (relevant for cargo ships only)

b) Navigation bridge

c) Engine control room

d) Fire control station

iv) The fuel cell operation condition indicators (see above *ii*)) are to be fitted on the navigation bridge, the engine control room and the maneuvering platform, as appropriate.

3 Gas Detection System

3.1 Location

i) Generally, gas detectors are not required in spaces where fuel piping is completely ducted.

ii) The number of detectors in each space are to be considered taking into account the size, layout and ventilation of the space.

iii) Independent gas detector systems are to be fitted for each required fuel supply system.

iv) The detection equipment is to be located where vapor may accumulate and/or in the ventilation outlets.

v) Fuel vapor detection equipment is to be designed, installed and tested in accordance with a recognized standard.

vi) An audible and visible alarm is to be activated at a fuel vapor concentration of 20% of the lower explosion limit (LEL). The safety system is to be activated at 40% of LEL at two detectors. Please refer to Section 6, Table 1 for identification of locations calling for a minimum of two gas detectors.

vii) The gas detection system is to initiate audible and visual alarms distinct in both respects from the alarms of any other system not indicating gas, so that the alarms are heard and observed at the following locations as fitted:

a) Navigating bridge

b) Continuously manned central control station

c) Fire control station

d) Control location for bunkering

e) Locally

When the navigating bridge is unmanned the alarm is to sound in a place where a responsible member of the crew is on duty.

viii) Fuel vapor detection required by this Section is to be continuous and without delay.

ix) Permanently installed gas detectors are to be fitted in:

a) All ventilated annular spaces of the double walled fuel pipes

b) Machinery spaces (i.e., fuel cell space, etc.) containing fuel piping, fuel equipment or consumers

c) Fuel preparation rooms

d) Other enclosed spaces containing fuel piping or other fuel equipment without ducting

e) Other enclosed or semi-enclosed spaces where fuel vapors may accumulate

f) Airlocks

g) g. Cofferdams surrounding fuel tanks

h) At ventilation inlets to accommodation and machinery spaces if required based on the risk assessment required in 2/3.1 of this Guide

4 Fire Detection System

4.1 General

Fire detection in machinery spaces containing the fuel and rooms containing independent tanks for fuel storage are to be give audible and visual alarms.

5 Ventilation System

5.1 General

Any loss of the required ventilating capacity (see ventilation system, 3/10 of this Guide for specific spaces) is to be give an audible and visual alarm on the navigation bridge, in a continuously manned central control station or fire control station, as well as locally.

6 Fuel Supply System

6.1 General

i) If the fuel supply is shut off due to activation of an automatic valve, the fuel supply is not to be opened until the reason for the disconnection is ascertained and the necessary precautions taken. A readily visible notice giving instruction to this effect is to be placed at the operating station for the shut-off valves in the fuel supply lines.

ii) If a fuel leak leading to a fuel supply shutdown occurs, the fuel supply is not to be operated until the leak has been found and addressed. Instructions to this effect are to be placed in a prominent position in the machinery space.

iii) Pumps and fuel supply are to be arranged for manual remote emergency stop from the following locations as applicable:

a) Navigation bridge

b) Cargo control room

c) Engine control room

d) Fire control station

e) Adjacent to the exit of fuel preparation spaces

TABLE 1
Monitoring of Fuel Cells Power System

Parameter(1)	*Alarm*	*Automatic Shutdown of Tank Valve*	*Automatic Shutdown of Master Fuel Valve*	*Automatic Shutdown of Bunkering Valve*	*Comments*
High level fuel tank	X			X	See 6/2.1.1i)
High, high level fuel tank	X			X	See 6/2.1.1ii) & 6/2.2.1i)
Loss of ventilation in the annular space in the bunkering line	X			X	See 6/2.2.1ii)
Gas detection in the annular space in the bunkering line	X			X	See 6/2.2.1iii)
Loss of ventilation in ventilated areas	X				See 6/5
Manual shutdown				X	See 6/2.2.1i)
Vapor detection in cofferdams surrounding fuel tanks. One detector giving 20% of LEL	X				See 6/3.1ix)g)
Vapor detection in crankcase and above stuffing box	X				See 6/3.1ix)e)
Vapor detection in air locks	X				See 6/3.1ix)f)
Vapor detection in cofferdams surrounding fuel tanks. Two detectors giving 40% of LEL(2)	X	X		X	See 6/3.1ix)g)
Vapor detection in other area	X				See 6/3.1ix)a), b), c), d) and h)
Vapor detection in ducts around double walled pipes, 20% LEL	X				See 6/3.1vi)

Parameter[1]	*Alarm*	*Automatic Shutdown of Tank Valve*	*Automatic Shutdown of Master Fuel Valve*	*Automatic Shutdown of Bunkering Valve*	*Comments*
Vapor detection in ducts around double walled pipes, 40% of LEL[2]	X	X	X		See 6/3.1vi) Two gas detectors to give min 40 % LEL before shutdown
Liquid leak detection in annular space of double walled pipes	X	X	X		See 6/1.1v)
Liquid leak detection in Machinery space	X	X			See 6/1.1v)
Liquid leak detection in pump-room	X	X			See 6/3.1vi)
Liquid leakage detection in protective cofferdams surrounding fuel tanks	X				See 6/3.1vi)
Fire detection in fuel cell space	X				See 4/5iii)
Air Lock	X				See 3/3.3iv)
Emergency Shutdown	X	X	X	X	See 3/9.6, & 5/5

Notes:

1 The risk assessment method used is to include any other necessary parameters for the safe and effective operation of the control, monitoring and safety system.

2 Refer to 6/3.1vi).

SECTION 7 Surveys During Construction

1 General

This Subsection pertains to surveys during fabrication at the manufacturer's facility and installation and testing of fuel cell systems onboard. For surveys at the manufacturer's facility, the scope of the survey will be confined to only those items that are supplied by the manufacturer.

2 Surveys at Manufacturer's Facility

See Section 1, Table 3 of this Guide for certification requirements of fuel cell and associated systems. Survey requirements for equipment components and packaged units at the manufacturer's facility are summarized in the relevant sections of the applicable Rules/Guides.

i) The manufacture, testing, inspection and documentation of the fuel cell system is to be in accordance with applicable ABS Rules, Recognized standards and the requirements given in this Section.

ii) In addition, fuel cell systems operating on liquid fuels, except for Hydrogen, Methanol and Ethanol, with a flashpoint equal or below 60°C and gaseous fuels are to be constructed and tested in accordance with the requirements of Part 5C, Chapter 13 of the *Marine Vessel Rules,* as applicable.

3 Tests for Control, Monitoring and Safety System

3.1 General

i) Equipment in association with control, monitoring and safety systems of propulsion machinery, propulsion boilers, vital auxiliary pumps and the electrical power generating plant including its prime mover for vessels and offshore installations are to be performance tested in accordance with 4-9-9/Table 1 of the *Marine Vessel Rules*, as applicable.

ii) Indications of parameters necessary for the safe and effective operation of the control, monitoring and safety system are to be tested and verified according to Section 6, Table 1, as applicable.

4 Marking and Labelling

4.1 General

The fuel cell power system should be marked and provided with a data plate. Marking and mounting are to be durable and suitable for the application.

4.2 Marking

The fuel cell power system is to bear a data plate or combination of adjacent labels located in an easily accessible location when the fuel cell power system is in a normally installed position. The marking is to clearly state any restrictions on use.

The data plate/label is to include the following information:

- Manufacturer's name (with trademark), and location
- Manufacturer's model number or trade name

- Serial number of the fuel cell power system and year of manufacture
- Electrical input, as applicable (voltage/type of current/frequency/phase/power/consumption)
- Electrical output (voltage/type of current/frequency/phase /rated power/power factor; kVA)
- Fuel type to be used by the fuel cell power system
- Range of fuel supply pressure
- Fuel consumption at rated power (kW)
- Range of ambient temperatures (minimum and maximum) within which the fuel cell power system is intended to operate in degrees Celsius
- Suitable location for use: indoor or outdoor
- Warnings for alerting personnel to the potential for personal injury or equipment damage and requirements to follow installation and operation instructions.

4.3 Marking of Components

i) All user serviceable parts are to be identified to match the fuel cell power system drawings in the user manual.

ii) Warning signs are to be appropriately placed to identify electrical hazards, contents from drain valves, hot components and mechanical hazards. Preference should be given to the use of standard symbols given in ISO 3864-2.

iii) Control devices, visual indicators and displays (particularly those related to safety) used in the man-machine interface are to be clearly marked with regard to their functions either on or adjacent to the item. Preference should be given to the use of standard symbols given in IEC 60417 and ISO 7000.

4.4 Documentation

i) The manufacturer is to provide the information necessary for safe installation, operation, and servicing of the fuel cell power system and is in particular to draw attention to any restrictions on use. The information is to be provided in the form of technical documents such as drawings, diagrams, charts, tables and instructions, and these are to be on suitable data medium and language.

ii) The installation manual is to provide the installer with all the information necessary for the preliminary work of setting-up the fuel cell power system.

iii) The fuel cell power system is only to be installed in areas with sufficient ventilation.

5 Onboard Testing

5.1 General

Onboard testing is to verify that the specified functionality has been achieved with all systems in operation.

i) Onboard testing is to verify that correct functionality has been achieved with all systems in operation.

ii) All systems in this Guide are to be examined and tested to the satisfaction of the attending Surveyor in accordance with the approved plans.

5.2 Test Plans

i) Commissioning Test Plan

A Test Plan is to be submitted to ABS at the start of the plan review process. The test plan is to identify all equipment and systems, listing performance tests or trials. Additionally, the control, monitoring and safety system are to be tested and verified according to Section 6, Table 1, as applicable.

ii) Inspection/ Survey Plan

An inspection/survey plan for the fuel containment system is to be developed and approved by ABS. The inspection/survey plan is to identify components/systems to be examined and/or validated during surveys throughout the fuel containment system's life and, in particular, any necessary in-service inspections, maintenance and testing that was considered when selecting the fuel containment system design parameters .

5.3 Initial Survey

5.3.1 Surveys During Installation

i) As far as deemed necessary, weld nondestructive examination tests and records of nondestructive examinations are to be reviewed.

ii) All certified safe systems and instrumentation and control panels are to be verified to be in compliance with approved drawings.

iii) Piping systems are to be visually examined and pressure-tested, as required by the *Marine Vessel Rules*. Pressure tests conducted on Class I piping systems (see 4-6-1/5 TABLE 1 of the *Marine Vessel Rules*) should preferably be recorded on test charts for the duration of their tests.

iv) Electrical wiring and connections are to be in accordance with Part 4, Chapter 8 of the *Marine Vessel Rules* and checked for continuity and proper workmanship.

v) Instrumentation is to be tested to confirm proper operation as per its predetermined set points.

vi) Pressure relief and safety valves installed on the unit are to be tested.

5.3.2 **Surveys During Trials**

During the initial trials, the fuel cell power system is to be confirmed for its satisfactory operation, including associated controls, alarms and shutdowns. The tests are to be conducted in accordance with the testing procedure as per 7/5.2.

SECTION 8 Surveys After Construction

1 General

The fuel cell power systems are to be maintained in satisfactory condition. This section pertains to periodical surveys after construction for the equipment described in Section 1 to Section 6 of this Guide. Surveys should follow requirements in 8/2 as appropriate.

2 Survey Intervals

2.1 Annual Survey

An Annual Survey of a vessel fitted with fuel cell equipment, and installed classed systems covered by 1/4 of this Guide is to be carried out within three (3) months before or after each annual anniversary date of the crediting of the previous Special Periodical Survey or original construction date. For vessels on Continuous Survey, all Continuous Survey requirements for those parts (items) due are generally to be completed each year. The Annual Survey will not be credited and the Certificate of Classification will not be endorsed unless Continuous Survey items that are due or overdue at the time of the Annual Survey are either completed or granted an extension.

2.2 Special Periodical Survey

A Special Periodical Survey of fuel cell equipment, associated systems covered by 1/4 of this Guide is to be completed within five years after the date of construction or after the crediting date of the previous Special Periodical Survey. The fifth Annual Survey must be credited as a requirement of the Special Periodical Survey. The interval between Special Periodical Surveys may be reduced by the Committee.

The Special Periodical Survey may be commenced at the fourth Annual Survey and be continued with completion by the fifth anniversary date. Where the Special Periodical Survey is commenced prior to the fourth Annual Survey, the entire survey is to be completed within fifteen (15) months if such work is to be credited to the Special Periodical Survey.

A Special Periodical Survey will be credited as of the completion date of the survey but not later than five years from date of construction or from the date recorded for the previous Special Periodical Survey. If the Special Periodical Survey is completed within three (3) months prior to the due date, the Special Periodical Survey will be credited to agree with the effective due date. Special consideration may be given to Special Periodical Survey requirements in unusual cases. Consideration may be given for extensions of Rule required Special Periodical Surveys under exceptional circumstances.

2.3 Continuous Survey Program

At the request of the Owner, and upon approval of the proposed arrangements, a system of Continuous Surveys may be undertaken, whereby the Special Periodical Survey requirements are carried out in regular rotation to complete all of the requirements of the particular Special Periodical Survey within a five-year period. The proposed arrangements are to provide for survey of approximately 20% of the total number of survey items during each year of the five-year period. Reasonable alternate arrangements may be considered as recommended by the manufacturer.

Generally, each part (item) surveyed becomes due again for survey approximately five (5) years from the date of the survey, and the due parts (items) are generally to be completed each year. For Continuous

Surveys, a suitable notation will be entered in the *Record* and the date of the completion of the cycle published.

ABS may withdraw its approval for Continuous Survey if the Surveyor's recommendations are not complied with.

2.4 Survey Based upon Preventative Maintenance Techniques

A properly conducted approved program of preventative-maintenance/condition-monitoring plan may be credited as satisfying the requirements of Special Continuous Survey. This plan must be in accordance with Appendix 7-A1-14 "Surveys Based on Preventative Maintenance Techniques" of the ABS *Rules for Survey After Construction (Part 7)*.

2.5 Survey for Existing Vessels installing Fuel Cell Systems

All vessel subjected to modifications and retrofits with fuel cell power systems as detailed in this Guide are to be examined and tested in accordance with the approved plans to verify compliance and to the satisfaction of the attending Surveyor .

2.6 Surveys

2.6.1 Annual Survey

The following items are to be carried out at annually:

i) Fuel containment system is to be surveyed in accordance with the approved testing plan (see 7/5.2.ii) of this Guide).

ii) *Logbooks/Records*, The logbooks and operating records are to be examined with regard to correct functioning of the gas detection systems, liquid fuel /gas systems, tracking the fuel cells operation hours, etc. The hours per day of the re-liquefaction plant, gas combustion unit, as applicable, the boil-off rate, and nitrogen consumption (for membrane containment systems) are to be considered together with gas detection records.

iii) *Operating and Maintenance Instruction Manuals*, The manufacturer/builder instructions and manuals covering the operations, safety and maintenance requirements and occupational health hazards relevant to fuel storage, fuel bunkering, and fuel supply and associated systems for the use of the fuel, are to be confirmed as being available on board the vessel.

iv) *Control, Monitoring and Safety Systems*

a) Gas detection and other leakage detection equipment in compartments containing fuel storage, fuel bunkering, and fuel supply equipment or components or associated systems, including indicators and alarms listed in Section 6, Table 1 as applicable, is to be confirmed in satisfactory operating condition. Recalibration of the gas detection systems is to be verified in accordance with the manufacturers' recommendations.

b) Verification of the satisfactory operation of the control, monitoring and automatic shutdown systems of the fuel supply and bunkering systems listed in Section 6, Table 1 as applicable.

c) Operational test, as far as practicable, of the shutdown of ESD protected machinery spaces.

v) *Fuel Handling Piping, Machinery and Equipment,* Piping, hoses, emergency shut-down valves, remote operating valves, relief valves, machinery and equipment for fuel storage, fuel bunkering, and fuel supply such as venting, compressing, refrigerating, reliquefaction, heating, cooling or otherwise handling the fuel are to be examined, as far as practicable. Means for inerting is to be examined. Stopping of pumps and compressors upon emergency shutdown of the system is to be verified as far as practicable.

vi) *Ventilation System.* Examination of the ventilation system, including portable ventilating equipment where fitted, is to be made for spaces containing fuel storage, fuel bunkering, and fuel supply units or components or associated systems, including air locks, pump rooms, compressor rooms, fuel preparation rooms, fuel valve rooms, control rooms and spaces containing gas burning equipment. Where alarms, such as differential pressure and loss of pressure alarms, are fitted, these should be operationally tested as far as practicable.

vii) *Drip Trays*. Portable and fixed drip trays and insulation for the protection of the ship's structure in the event of leakage are to be examined.

viii) *Hazardous Areas*. Electrical equipment and bulkhead/deck penetrations including access openings in hazardous areas are to be examined for continued suitability for their intended service and installation area.

ix) Fire Protection and Fire Extinguishing Equipment. The required fire protection and fire extinguishing system contained in areas and spaces where fuel storage, fuel bunkering, and fuel supply are fitted are to be examined and operationally tested, in so far as practicable.

x) *Electrical Bonding*. Electrical bonding arrangements in hazardous areas, including bonding straps where fitted, are to be examined.

xi) *Fuel Storage, Bunkering and Supply Systems*.

The following are to be examined, so far as applicable. Insulation need not be removed, but any deterioration or evidence of dampness is to be investigated:

a) Fuel Storage

- External examination of the storage tanks including secondary barrier if fitted and accessible.
- General examination of the fuel storage hold place.
- Internal examination of tank connection space.
- External examination of tank and relief valves.
- Verification of satisfactory operation of tank monitoring system.
- Examination and testing of installed bilge alarms and means of drainage of the compartment.
- Testing of the remote and local closing of the installed main tank valve.

b) Fuel Bunkering System

- Examination of bunkering stations and the fuel bunkering system.
- Verification of satisfactory operation of the fuel bunkering control, monitoring and shutdown systems.

c) Fuel Supply System

- Examination of the fuel supply system during working condition as far as practicable.
- Verification of satisfactory operation of the fuel supply system control, monitoring and shut-down systems.
- Testing of the remote and local closing of the master fuel valve for each engine compartment.

2.6.2 Special Survey

In addition to the above annual survey items, the following items are to be carried out during the special survey:

i) *Fuel Handling and Piping*. All piping for fuel storage, fuel bunkering, and fuel supply such as venting, compressing, refrigerating, liquefying, heating storing, burning or otherwise handling the fuel and liquid nitrogen installations are to be examined. Removal of insulation from the piping and opening for examination may be required. Where deemed suspect, a hydrostatic test to 1.25 times the Maximum Allowable Relief Valve Setting (MARVS) for the pipeline is to be carried out. After reassembly, the complete piping is to be tested for leaks. Where water cannot be tolerated and the piping cannot be dried prior to putting the system into service, the Surveyor may accept alternative testing fluids or alternative means of testing.

ii) *Fuel Valves*. All emergency shut-down valves, check valves, block and bleed valves, master gas valves, remote operating valves, isolating valves for pressure relief valves in the fuel storage, fuel bunkering, and fuel supply piping systems are to be examined and proven operable. A random selection of valves is to be opened for examination.

iii) *Pressure Relief Valves*

a) *Fuel Storage Tank Pressure Relief Valves.* The pressure relief valves for the fuel storage tanks are to be opened for examination, adjusted, and function tested. If the tanks are equipped with relief valves with non-metallic membranes in the main or pilot valves, such non-metallic membranes are to be replaced.

b) *Fuel Supply and Bunkering Piping Pressure Relief Valves.* Pressure relief valves for the fuel supply and bunkering piping are to be opened for examination, adjusted, and function tested. Where a proper record of continuous overhaul and retesting of individually identifiable relief valves is maintained, consideration will be given to acceptance on the basis of opening, internal examination, and testing of a representative sampling of valves, including each size and type of liquefied gas or vapor relief valve in use, provided there is logbook evidence that the remaining valves have been overhauled and tested.

c) *Pressure/Vacuum Relief Valves*. The pressure/vacuum relief valves, rupture disc and other pressure relief devices for interbarrier spaces and hold spaces are to be opened, examined, tested and readjusted as necessary, depending on their design.

iv) *Electrical Equipment*

a) Examination of electrical equipment to include the physical condition of electrical cables and supports, intrinsically safe, explosion proof, or increased safety features of electrical equipment.

b) Functional testing of pressurized equipment and associated alarms.

c) Testing of systems for de-energizing electrical equipment which is not certified for use in hazardous areas.

d) An electrical insulation resistance test of the circuits terminating in, or passing through, the hazardous zones and spaces is to be carried out.

v) *Safety Systems.* Gas detectors, temperature sensors, pressure sensors, level indicators, and other equipment providing input to the fuel safety system are to be tested to confirm satisfactory operating condition.

a) Proper response of the fuel safety system upon fault conditions is to be verified.

b) Pressure, temperature and level indicating equipment are to be calibrated in accordance with the manufacturer’s requirements.

vi) *Fuel Storage Tanks.* Fuel storage tanks are to be examined in accordance with an approved test plan. Liquefied gas fuel storage tanks are to be examined based upon IACS Recommendation No. 148.

APPENDIX 1 Operation Manual Sample

1 Introduction

Technical documentation is to contain an operation manual detailing proper procedure for set-up and use of the fuel cell power system. Particular attention is to be given to safety measures provided and to any improper methods of operation that are anticipated.

Where the operation of the fuel cell power system can be programmed, detailed information on methods of programming, equipment required, program verification and additional safety procedures (where required) are to be provided.

The manuals are to include, but not be limited to, the operational procedures for the loading, storage, operation, maintenance, and inspection of systems for gas or liquid fuels to minimize the risk to personnel, together with details of required personal protective equipment and the occupational health hazards relevant to the use of gas as a fuel.

2 Recommended Contents of Operation Manual

A detailed ship's operation manual is to clearly indicate and/or include, but is not limited to, the following

- Start-up and operational procedure
- Fuel cell module specification and general characteristics
- Sequence of operation(s)
- Frequency of inspection
- Normal and emergency shut-down procedures
- Storage procedure and conditioning
- Bunkering procedure
- Maintenance and repair procedures
- Functional testing plan for automation and control system
- Maintenance and function testing plan details of all components and instrumentations
- General notes and prohibited operation; information on the physical environment (for example, range of ambient temperatures for operation, vibration, noise levels, atmospheric contaminants) where appropriate
- Procedures for making the area safe for hot work on or near fuel systems
- Installation procedure (handling, transportation, preparation, fixing method of the module, connection method of gas and coolant piping, connection method of the electric line and sensors and circuit diagram(s)
- Bunkering procedure including the maximum transfer rate at all stages and volume to be transferred
- Pre-bunkering operations/verification all necessary requirements and documented in the bunker safety checklist
- Communication devices used in bunkering

APPENDIX 2 References

1 ABS

ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)*

ABS *Rules for Building and Classing Mobile Offshore Units (MOU Rules)*

ABS *Rules for Building and Classing Facilities on Offshore Installation (Facilities Rules)*

ABS *Guide for Dynamic Positioning Systems*

ABS *Guide for Use of Lithium Batteries in the Marine and Offshore Industries*

ABS *Guidance Notes on Alternative Design and Arrangements for Fire Safety*

ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*

ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification*

ABS *Advisory on Hybrid Electric Power Systems*

2 IEC Standards

IEC 60034-1[ed12] Rotating Electrical Machines

IEC 60079-2[ed6] Explosive atmospheres – Part 2: Equipment protection by pressurized enclosure "p"

IEC 60079-7[ed4] Explosive atmospheres – Part 7: Equipment protection by increased safety "e"

IEC 60079-10-1 Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres

IEC 60079-20 Explosive atmospheres – Part 20-1: Material characteristics for gas and vapor classification – Test methods and data

IEC 62282-1:2013 Terminology

IEC 62282-2:2012 Fuel cell modules

IEC 62282-3-100:2012 Stationary fuel cell power systems – Safety

IEC 62282-3-200:2016 Stationary fuel cell power systems – Performance test methods

IEC 62282-3-300:2012 Stationary fuel cell power systems – Installations

IEC 62282-7-1:2017 Single cell test methods for polymer electrolyte fuel cell (PEFC)

IEC 62282-7-2:2014 Single cell and stack performance tests for solid oxide fuel cells (SOFC)

IEC 60092-502 Electrical Installations in Ships

3 Other References

ASME B31.12, Hydrogen Piping and Pipelines

ISO 15649, Petroleum and natural gas industries — Piping

NFPA 2 - 2011 Edition, Hydrogen Technologies Code

IMO International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code)

IMO CCC5/3 Amendments to the IGF Code and Development of Guidelines for Low-Flashpoint Fuels

IEC/ISO 31010 Risk management – Risk assessment techniques

Annex to MSC.1/Circ.1455 (Guidelines for the Approval of Alternative and Equivalents as provided for in Various IMO Instruments)