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Inland Transport Committee

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Working Party on the Transport of Dangerous Goods

Joint Meeting of Experts on the Regulations annexed to the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN)
(ADN Safety Committee)

Forty-third session
Geneva, 22-26 January 2024
Item 4 (b) of the provisional agenda
Implementation of the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN): special authorizations, derogations and equivalents

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Request for a recommendation on the use of hydrogen fuel cells for the propulsion of the vessel "Rhenus Mannheim"

Transmitted by the Government of the Netherlands

Annexes to document ECE/TRANS/WP.15/AC.2/2024/33

Annex I

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Datum: 20.1.2023 Rev04

Description of the
Rhenus
H2-System
with
Fuel Cell 800 kW (400kW)
and
500 bar H2-Storage Tank
Rev04

Projekt Overview

The “Rhenus Mannheim I+II” will be a 193,50m x 11.45m container convoy to service the container terminals along the Rhine till Mannheim/Wörth. For this purpose, it shall be able to carry dangerous goods without limitation.

The motor vessel will be outfitted with a fuel cell with a nominal power of 800kW, initially equipped with only 400kw. The reduced initial power installation is planed due to the unknown hydrogen supply situation to ensure the service even without H2. The fuel cells are running on pressurized hydrogen which will be stored in up to 20’’ swappable containers. The fuel cell is part of a hybrid electric powertrain where the main energy will be provided by Stage V Diesel generators. The power generation is located at the bow of the motor vessel. The deckhouse is dived into tree decks: on the tanktop the generators are located. On main deck the switchboards and electric distribution will be take place and in a separated area, designed as semi enclosed space, the fuel cells. On top of the deckhouse locations for up to four 20’’ containers to store the Hydrogen. Most of the piping and gas handling equipment will be at the free deck to ensure natural ventilation.

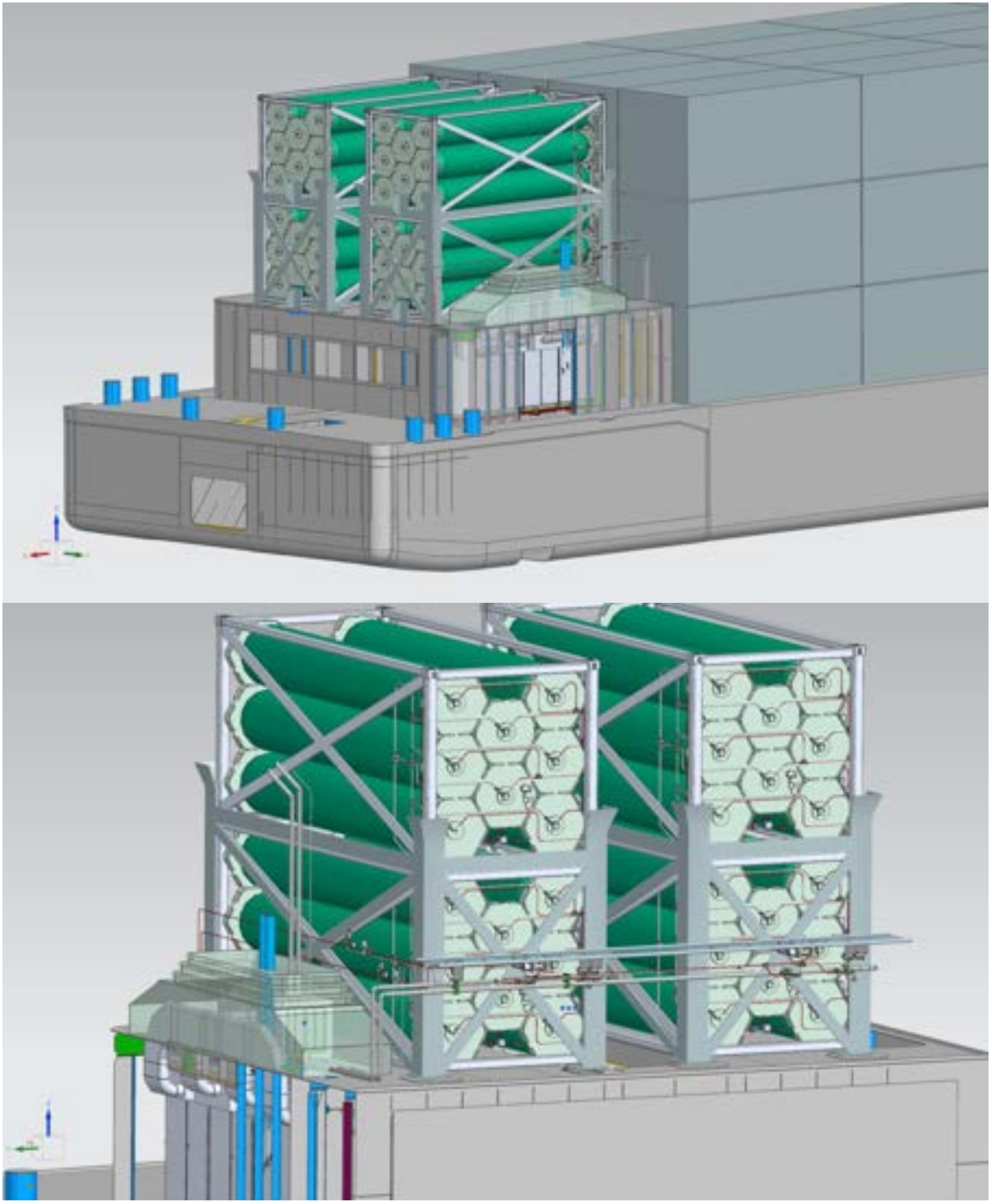
Content overview

1. Over all view H2 System on Deck
2. Exchange container 20 feet, 500 bar, approx. 500 kg installed on deck
3. Connection coupling: The 20 feet container is connected without pressure.
   Overlap and leakage free connection.
4. First stage: GHU with excess flow valve
   PT1 & TT1 => HP leakage detection procedure (P1 = 20 … 500 bar)
   PT2 & TT2 => LP leakage detection procedure (P2 = 8 … 12 bar)
5. Double Block & Bleed Valve: for draining in case of emergency
6. Second stage: pressure control unit before fuel cell
   (P1 = 8…12bar / P2 = 4…6bar)
7. Fuel cell system 200 kW x 2
8. GoController with ISO 26262-2 certified software
9. P&ID
10. ATEX zones plan
11. Pipeline & fittings

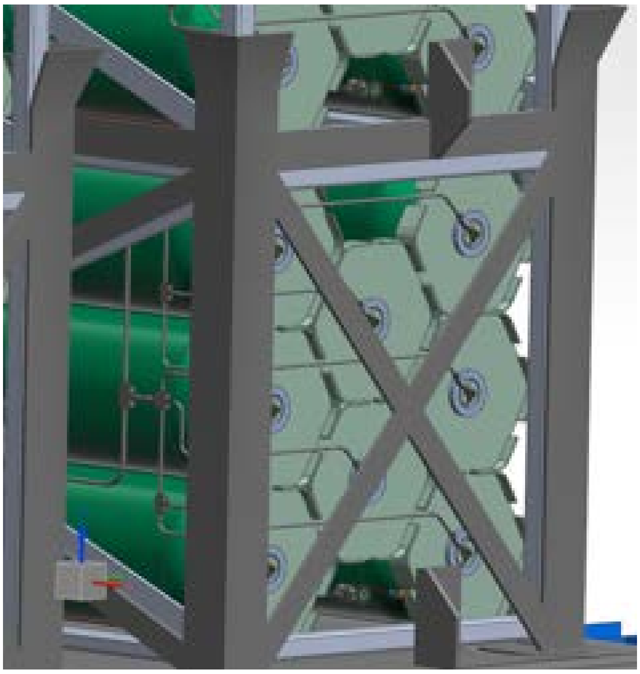
1.) Overall view H2 System on Deck

P&ID of H2 System
must be printed in A3 minimum (attached)

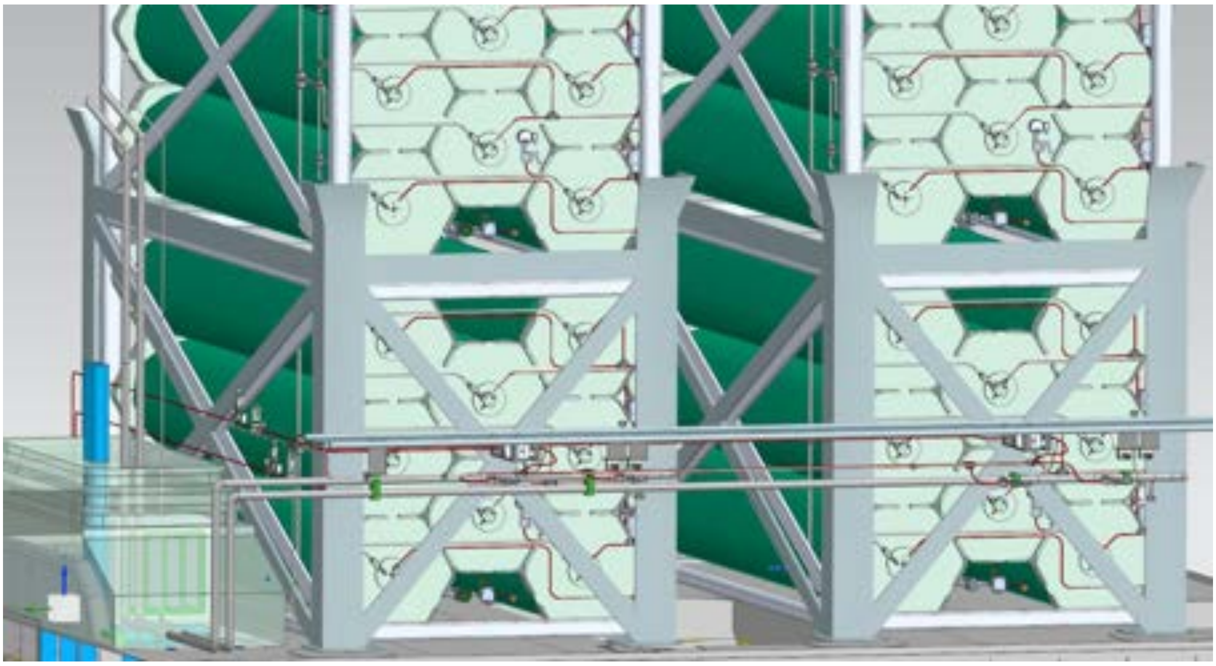
View of installation of 4 x h2-cartridges on deck



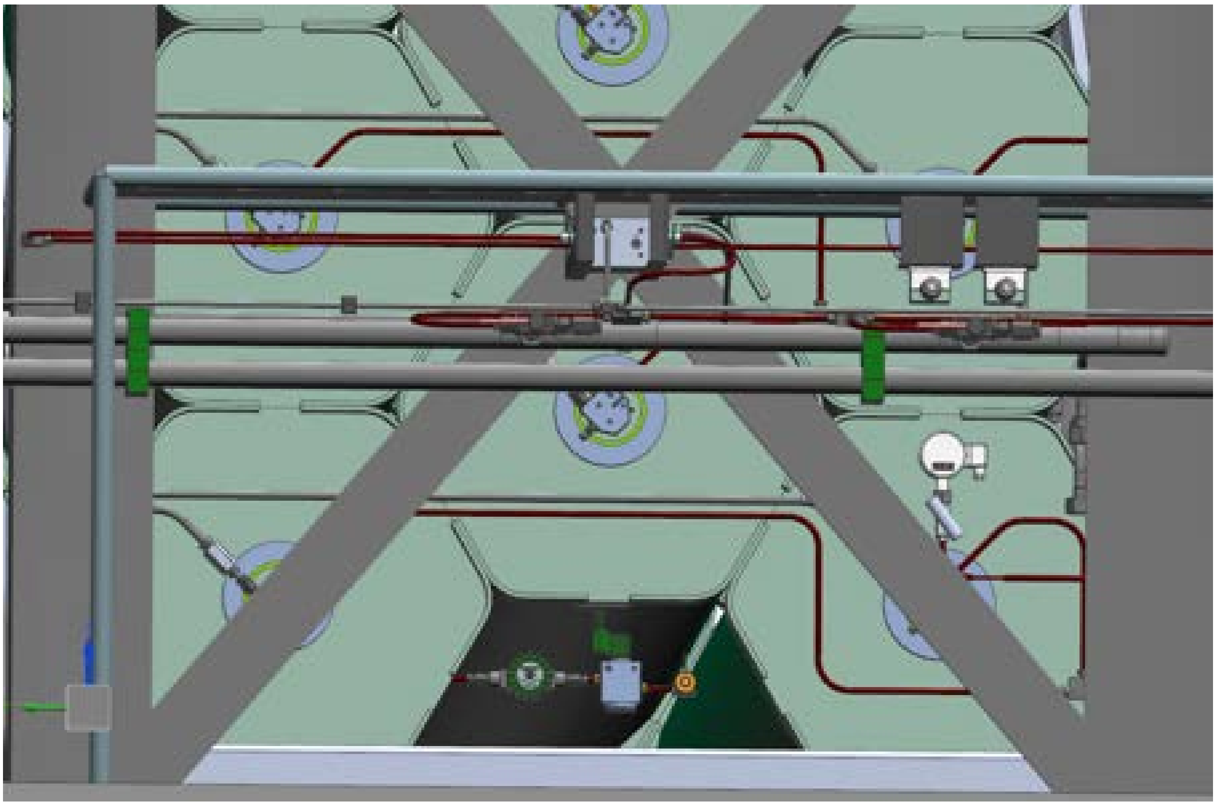
View of Cartridge Guiding structure with fillingpreventer on frontside



View of connection bridge with GHU



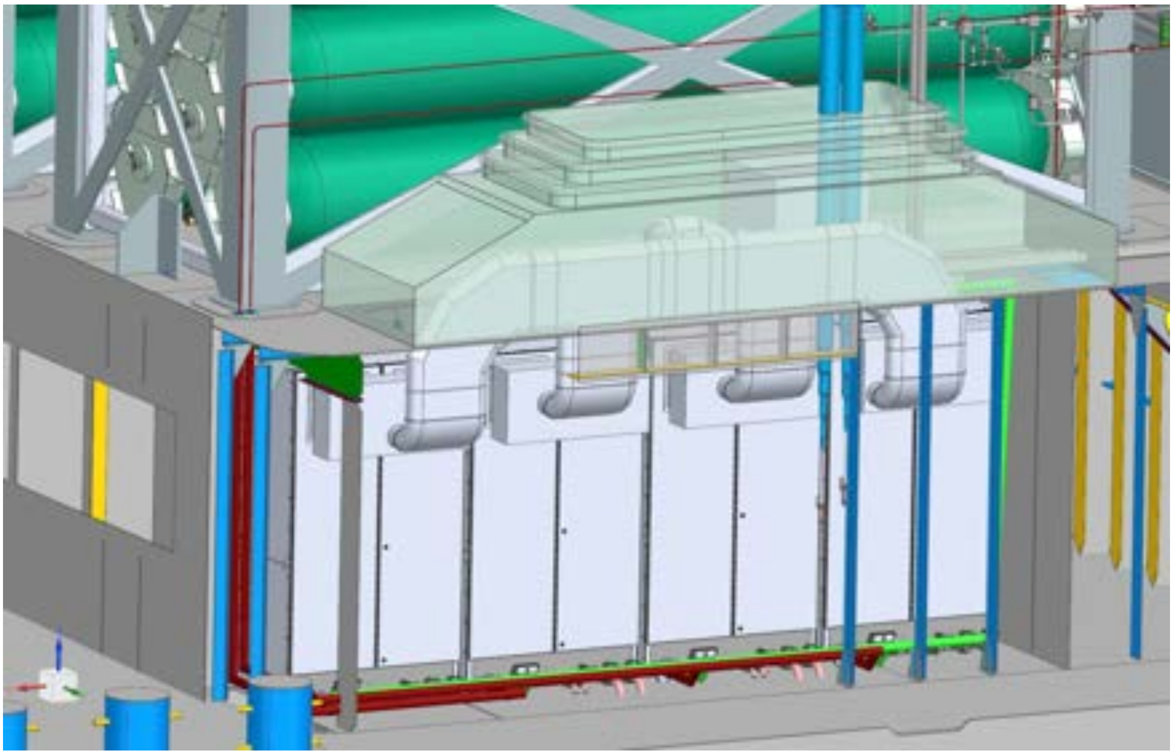
View of GHU



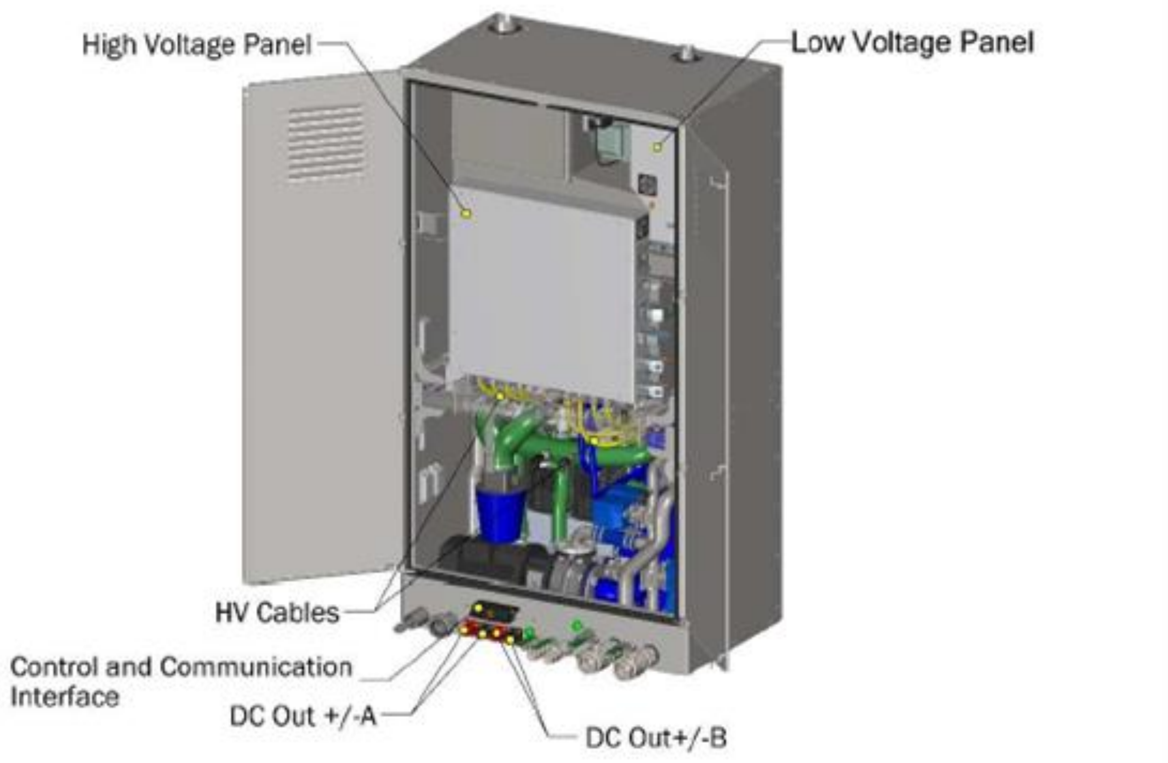
View of Fuel cell Room

We can install up to 800 kw Fuel Cell per Fuel cell room

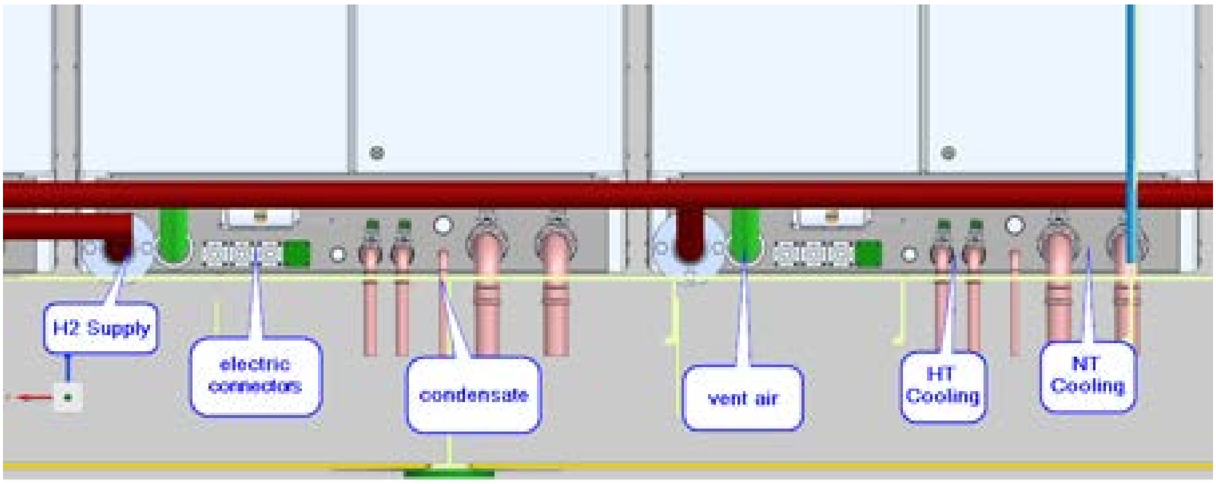
At the first step 2 x 200 KW = 400 KW of fuel cell power will be installed.



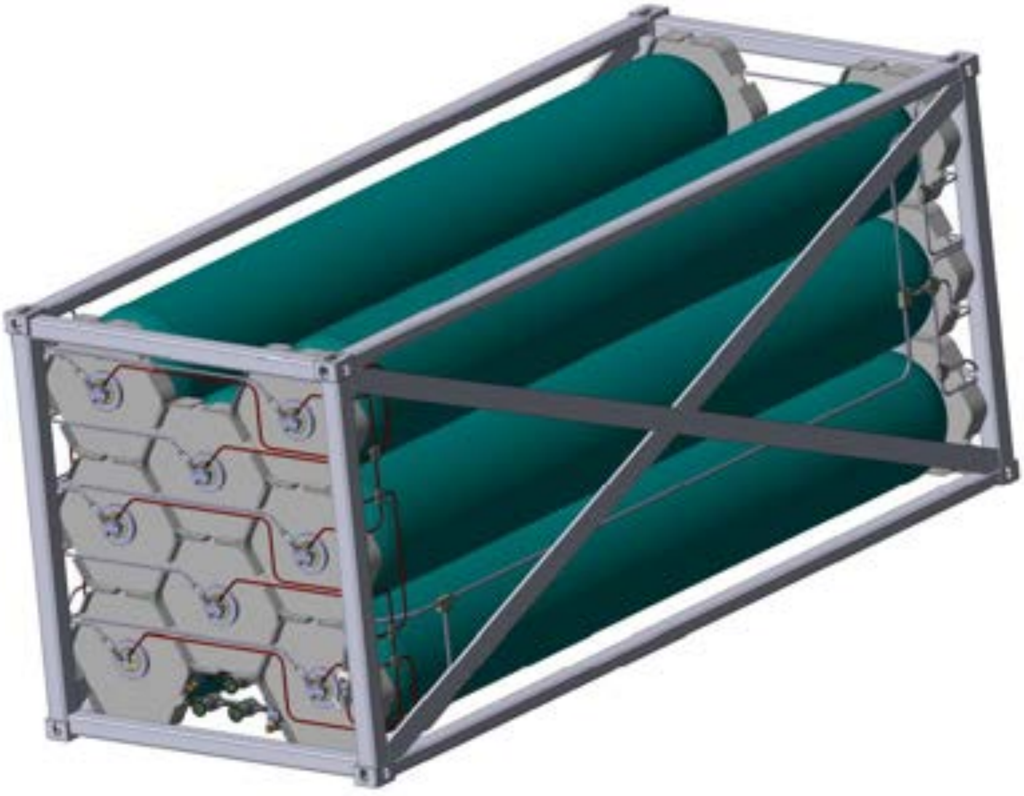
Fuel cell Solution based on Ballard FC-Wave 200 KW Module



Connections at the foot of the cabinet



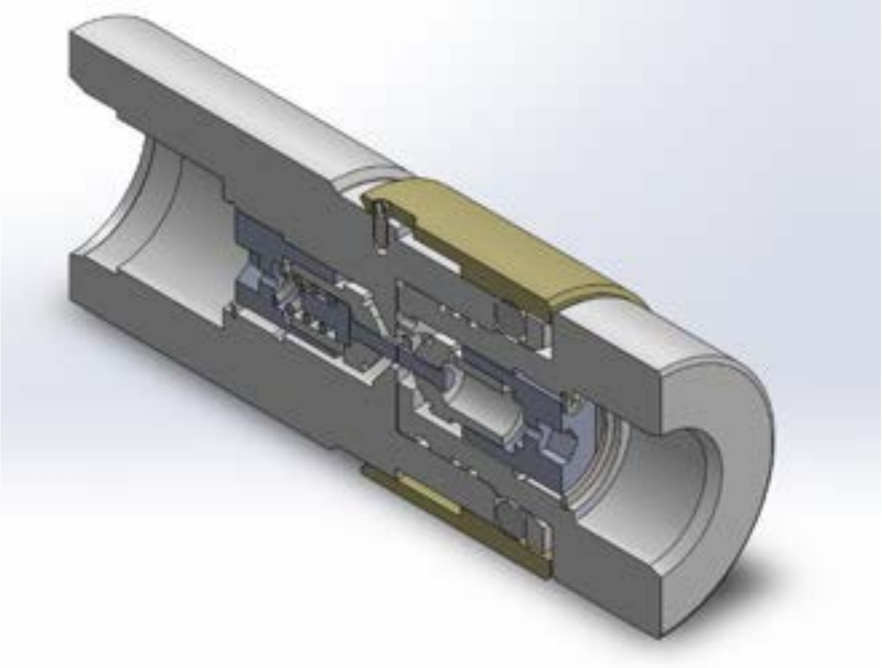
2.) Exchange cartridge, 20 feet, 500 bar, approx. 520 kg mounted on deck



Pressure = 500 bar
Weight = approx. 13.500 kg
Quantity of H2 = 520 kg
Segments: 4 segments, ON/OFF Valve pneumatic or electrically activated per segment
Refuelling Line: 1 x refuelling connectors
H2 supply line: 1x connection manual ON/OFF valve, gauge for each segment,
1 x outlet with special quick connector, dead room free
H2 vent line: TPRD (activated at 110° C), 1x main H2 supply manual valve ON/OFF valve, solenoid valve.
Controller Unit, with shock- an angle-senor
Attached P&ID
The frame is constructed to be able to put up to 2 (3 if necessary) one above the other (stackable).

3.) H2 - Quick -Connection coupling: 20 feet Cartridge

The refuelling connector has a special design, which allows to connect first being tight and after is fixing the connection.



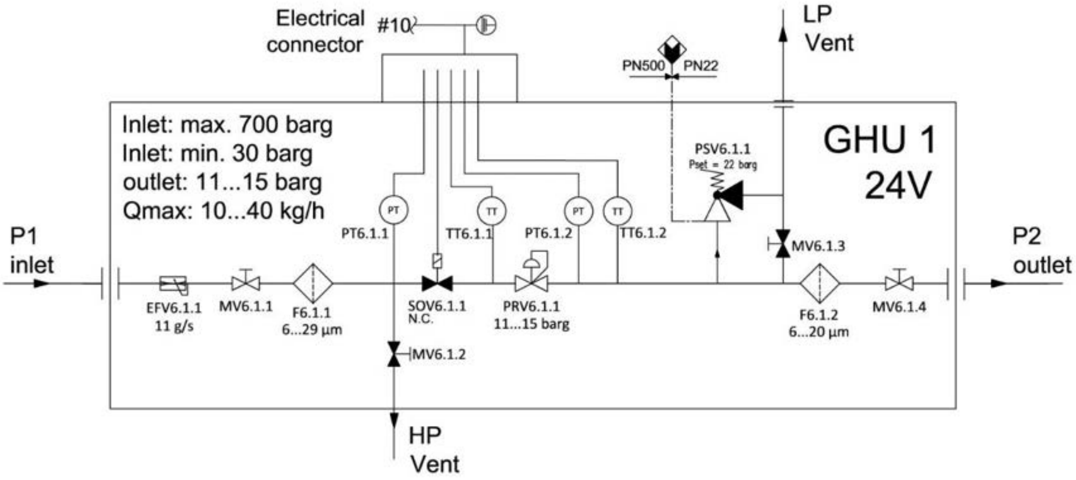
Confidential Drawing of the quick coupling connector

During disconnecting of the coupling, the outcoming H2 gas (is nearly close to zero, which means that no hazardous area is around this connector.
For security reasons the connector is not connected being under pressure.
This solution is patented.

4.) First stage: GHU with Excess Flow Valve

The Gas Handling Unit, called GHU, is an integrated valve block, which contains multiple functions. The GHU is mounted as close as possible to the cartridges. Minimizing the length of high-pressure pipeline on deck of the ship. We have foreseen 2 x GHU, to have a fully usable redundancy on the hydrogen system. One GHU can supply enough hydrogen for both fuel cells of 200 KW.

P&ID of Gas Handling Unit



1. **Excess Flow Valve [EFV 1.1]:**
   If a pipeline rupture happens after the GHU, this device automatically shuts down the hydrogen supply line, even before the solenoid valve or the controller can detect this pressure drop and the leakage.

2. **Manual Valve [MV1.1]:**
   To shut down the hydrogen supply line for maintenance reasons or other reasons.

3. **Filter [F1.1]:**
   Filter with a filtration level of approx. 5 to 29 µm. Protection filter so in case of particles coming out of the hydrogen tank system are captured before the come into the fuel cell.

4. **Pressure Gauge [PG1.1]:**
   Pressure gauge which allows the user to see, whether there is pressure on the pipeline or not.

5. **High Pressure Transmitter [PT1.1]:**
   High pressure sensor to measure the pressure on the high-pressure system.
   In combination with the temperature sensor, we have a dedicated leak detection procedure which makes it possible to detect even very small leakages of on several PPM of H_2. PT1.1 & TT1.1 => HP leak detections procedure (P1 = 20 … 500bar).
   This also allows to determine the status of technical tightness of the high pressure and low-pressure system.

6. **Manual Valve [MV 1.2]:**
   Double functional needle valve. This needle valve can be used venting needle for maintenance and for inerting with N_2 in case of maintenance. It is connected to the high-pressure venting line.

7. **ON/OFF Solenoid Valve [SOV 1.1]:**
   Sectioning on/off solenoid valve. This valve is normally closed. So in case of a problem or EMERGENCY-Stop the electricity is taken off and the solenoid valve closed within 20 to 40 msec.

8. **Temperature Sensor [TT 1.1]:**
   Temperature measurement for leak detection and for protection of the fuel cell.

9. **Pressure Regulator First Stage [PRV 1.1]:**
   First stage pressure regulator reducing from P1 max = 500/700 bar, P1 min = 20 bar to P2 = 11 … 15 bar,
   the maximum flow rate is set for 2 fuel cells of 200 KW = 400 KW = ca 40 kg/h

10. **Mid Pressure Transmitter [PT1.2]:**
    Mid pressure sensor to measure the pressure on the high-pressure system.
    In combination with the temperature sensor, we have a dedicated leak detection procedure which makes it possible to detect even very small leakages of on several PPM of H_2.
    PT1.2 & TT1.2 => mid pressure leak detections procedure (P1 = 8 … 40 bar). This also allows to determine the status of technical tightness of the high pressure and mid pressure system.

11. **Temperature Sensor [TT 1.2]:**
    Temperature measurement for leak detection and for protection of the fuel cell.

12. Safety Valve [PSV 1]:

PED approved safety valve, setting pressure P_{set} = 22 bar. To protect the mid pressure line. This allows to use PN 20 bar components after the gas handling unit.
It continues with high pressure pipeline in the direction of the fuel cell.

13. Manual Valve [MV 1.3]:

Needle valve. This needle valve can be used venting the mid pressure line for maintenance and for inerting with N2 in case of maintenance. It is connected to the mid pressure venting line.

14. Filter [F1.2]:

Filter with a filtration level of approx. 5 to 20 µm. Protection filter so in case of particles coming out of the GHU (failure break or whatever of subcomponents like seat poppet, o-seals, etc.) are captured before they come into the fuel cell.

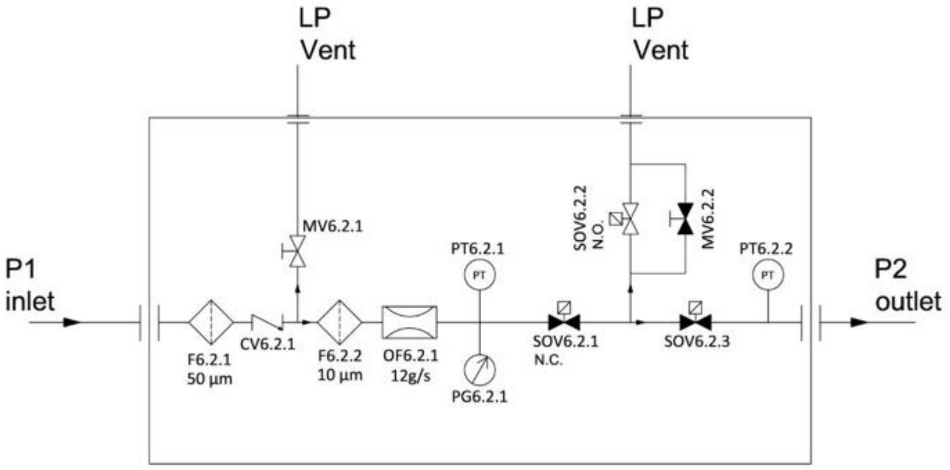
15. Manual Valve [MV 1.4]:

Needle valve. This needle valve can be used to close the mid pressure line for maintenance or in case of malfunction of the GHU.

5.) Double Block & Bleed Valve to close and empty the H2 lines in case of emergency

The double block & bleed valve is directly mounted after each GHU and allows to section on supply line from the other. In case of leakage detection, the double block & bleed valve allows to empty completely the hydrogen process lines from H2.

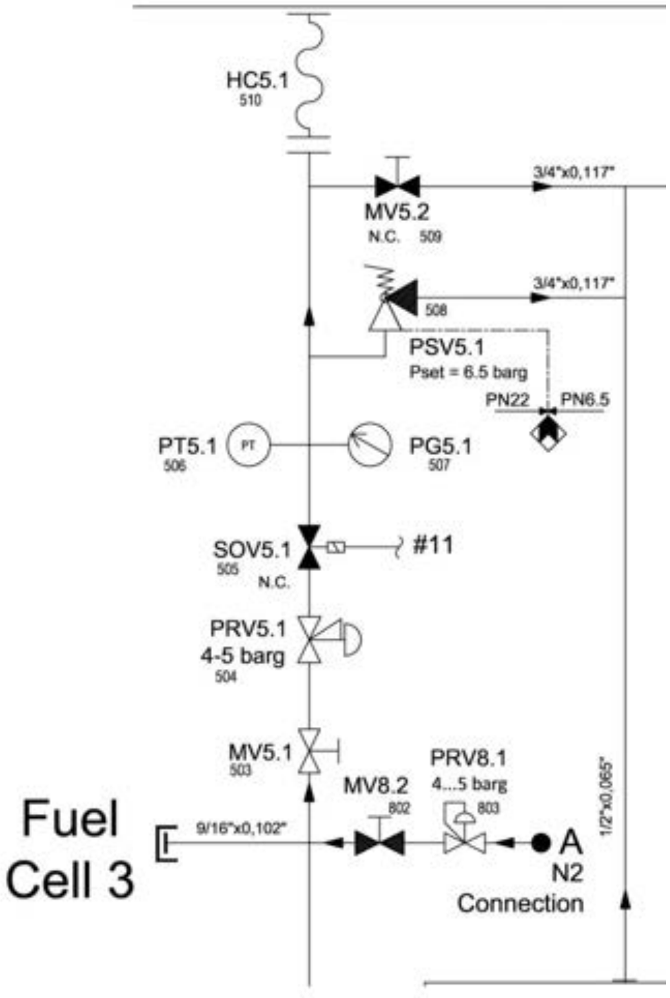
P&ID of Double Block & Bleed Valve



The Double Block & Bleed Valve consists of:
Inlet filter 50 µm
Check valve
Manual venting valve
Filter 10µm
Orifice, in order to limit the maximum flow rate to both fuel cells.
Pressure gauge and pressure transmitter, to visually see the pressure after the GHU, for maintenance.
First solenoid valve in the H2 supply line, NC.
Second solenoid valve to vent into the vent line, NO. This valve can be manually by-passed by a manual valve. This valve allows to empty the mid pressure line and, if necessary, also the high-pressure line. It ensures that in case of maintenance no mid pressure can come to the fuel cell.
Third solenoid valve in the H2 supply line, NC.
Pressure transmitter to indicate the pressure between GHU and second pressure reduction line.

6.) Second Stage: pressure reduction Line to reduce the pressure down to fuel cell

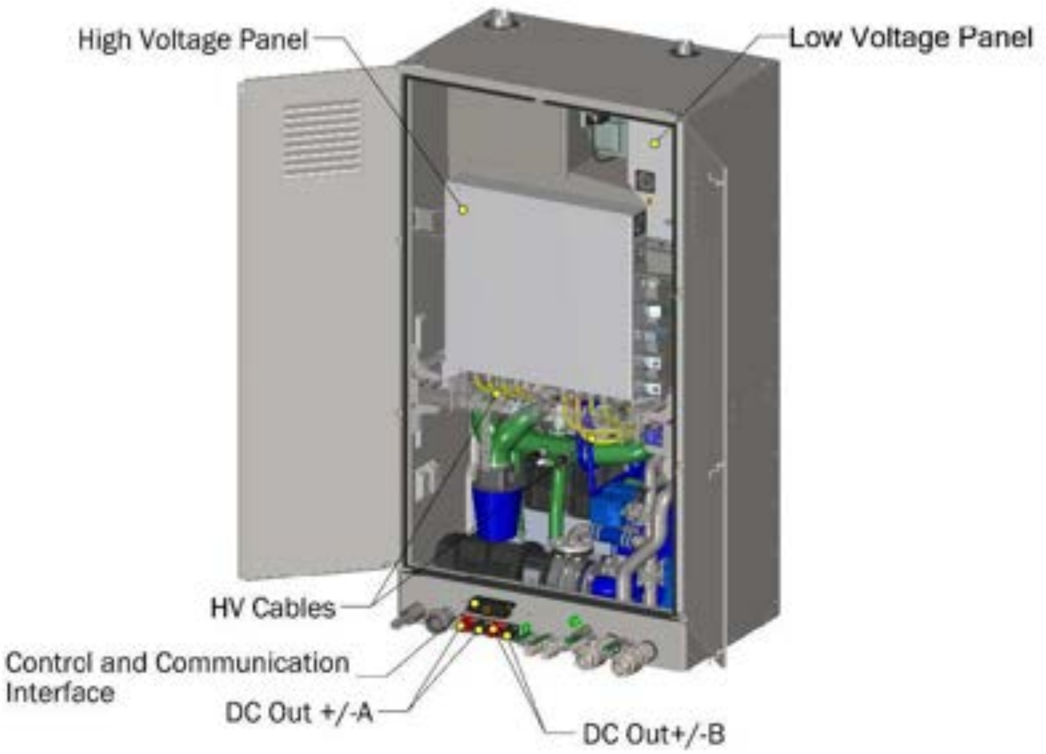
Second stage reducing to the maximum inlet pressure of the fuel cell system.
P1 = 11 ... 15 bar / P2 = 4 … 5 bar



The system can also be shutted down by the solenoid valve SOV 5.1 and emptied by the solenoid valve SOV 5.2.

7.) Fuel Cell System 200kW

200 KW fuel cell system in a closed cabinet.
The air supply line is connected to a filter, which is filtering the environment air, before it goes into the fuel cell.
DNV/Lloyd certified hydrogen System of 200 KW.



8.) Go Controller Unit

Controlling unit ISO 26262-2 certified software

1. **Tank system related**
    - Tank and other valve operations
    - Temperature and pressure survey with alarms
    - SOC calculations
    - Leak detection high pressure side
    - Leak detection low pressure side
    - Refuelling procedure
    - Communication to dispenser by Argo - Anleg
    - Communication to dispenser by LIN
    - Communication to dispenser by IR transmitter (under development)
    - Communication to vehicle by CAN control and information
    - Emergency stop handling

2. **Fuel cell/IC engine related**
    - Energy management, set point calculation, switch on/switch off
    - Battery monitoring/protection
    - System data gateway to vehicle/HMI

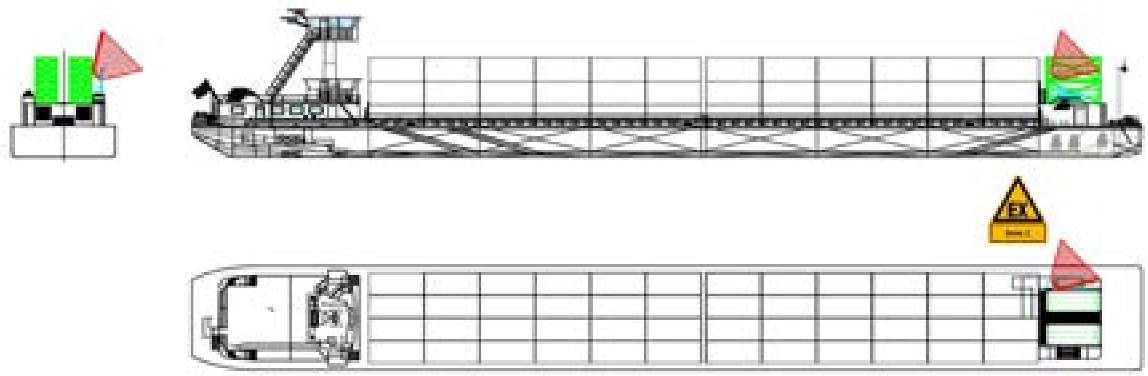
3. **Connectivity, cloud connection (WiFi, Wired Ethernet of 3/4G)**
    - Application monitoring, values, alarms, customised presentation
    - Controller management, updates, batch updates, remote bug solving
    - Predictive maintenance [under development)

9.) P&ID

P&ID Ship System H2 Supply
P&ID TankTainer

attached to this document.

10.) ATEX zones plan



attached to this document.

11.) Pipeline & fittings

The pipeline is installed on open deck.
We are using stainless steel single wall pipeline suitable for the maximum pressure of the system.
Inside the fuel cell room, we are using stainless steel double wall pipeline with leak detection.
For couplings and gas-connections, we are only using “permanent technically tight fittings”.
Each time we start the fuel cell system, we run a leak detection procedure.
We have sectioned the h2 supply to the fuel cell, so that we can detect in each section leakages.

Annex II

Hydrogen fuel cell and hybrid propulsion

Report for: RBC-2 HAZID

Name of client: Rhenus Mannheim

Report no.: 1

Project no.: 2211-0055

Revision no.: Version 1

23 January 2023

Summary

Hydrogen fuel cell and hybrid propulsion

Security classification of this Report: Commercial confidential

Report no.:	Revision no.:	Report date:
1	Version 1	23 January 2023
Prepared by: Erik Vroegrijk Senior Risk Advisor	**Reviewed by:** Alex Pedgrift Hazard, Risk & Reliability Manager	**Approved by:** Alex Pedgrift Hazard, Risk & Reliability Manager

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Document control

Revision history

Revision No.	Date	Revision
DRAFT1	17/01/2023	DRAFT Issued for client review
1	23/01/2023	Final report

The contents of this report are for the confidential information of the client and members of the Lloyd's Register Group.

List of abbreviations

ALARP	As Low As Reasonably Practicable
C&E	Cause and Effects
CAMS	Control, Alarm and Monitoring System
CCTV	Closed Circuit TeleVision
CP	Cathodic Protection
E/R	Engine Room
ERC	Emergency Release Coupling
ESD	Emergency ShutDown
FAT	Factory Acceptance Test
FiFi	Fire Fighting
FMEA	Failure Modes and Effects Analysis
FS	Functional Safety
GA	General Arrangement
GHU	Gas Handling Unit
GW	Glycol Water
HAZID	Hazard Identification
HAZOP	Hazard and Operability
H2	Gaseous hydrogen
HP	High Pressure
HSE	Health and Safety Executive
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organisation
LOPC	Loss of Primary Containment
LAH(H)	Level Alarm High (High-High)
LAL(L)	Level Alarm Low (Low-Low)
LOPA	Layer of Protection Analysis
LR	Lloyd’s Register
LSA	Life Saving Appliances

PAH(H)	Pressure Alarm High (High-High)
PAL(L)	Pressure Alarm Low (Low-Low)
PCV	Pressure Control Valve
PFD	Process Flow Diagram
P&ID	Piping & Instrumentation Diagram
PPE	Personnel Protective Equipment
PRV	Pressure Reducing Valve
PSD	Process ShutDown
PSV	Pressure Safety Valve
QRA	Quantitative Risk Assessments
RA	Risk Assessment
SCE	Safety Critical Equipment
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIMOPS	Simultaneous Operations
SIS	Safety Instrumented System
SME	Subject Matter Expert
SMS	Safety Management System
SSOW	Safe Systems of Work
STS	Ship-to-Ship
SWIFT	Structured 'What-if' Technique
SW	Sea Water
UPS	Uninterruptible Power Supply
TAH(H)	Temperature Alarm High (High-High)
TAL(L)	Temperature Alarm Low (Low-Low)
TPRD	Thermal Pressure Relieve Device
VHF	Very High Frequency
VTS	Vessel Traffic System

Standard definitions[1]

Accident	An unplanned event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.
Allision	Striking of a moving vessel against a vessel or an object that is stationary.
Collision	Striking of a moving vessel against one that is also moving.
Consequence	The outcome of an unplanned event. This considers effects on natural and human systems, i.e. lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure.
Frequency	Number of times per period that an event occurs, i.e. once per year.
Hazard	Something with the potential to threaten human life, health, property or the environment.
Mitigation	An intervention to reduce either the frequency or consequence associated with a risk, or both.
Probability	The relative frequency that an event will occur, as expressed by the ratio of the number of occurrences to the total number of possible occurrences.
Risk	The combination of the frequency and the severity of the consequence.
Strike	Unintentional contact between two or more assets.

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[1] As far as possible, definitions were taken from the UNTERM database and MSC-MEPC.2/Circ.12/Rev.2

Executive summary[2]

At the request of the Rhenus PartnerShip GmbH & Co. KG (Rhenus), Lloyd's Register (LR) EMEA's Technical Investigation Department (TID) facilitated a 2-day HAZID workshop to qualitatively assess the risks associated with their compressed hydrogen fuel cells and hybrid propulsion systems. The workshop, held on the 10th and 11th of January 2023, formed part of Stage 2 of the Risk Based Certification (RBC) process. Prior to the workshop commencing, Lloyd's Register issued a Terms of Reference (ToR) document.

The newbuilt "Rhenus Mannheim" shall be outfitted with a hydrogen fuel system as part of the hybrid power train. The use of fuel cells and the storage of pressurized hydrogen in swappable ISO 20" containers is currently not covered by ES-TRIN and / or ADN regulations. Therefore, Rhenus has requested a risk-based certification process is followed as part of the CCNR derogation. The HAZID workshop was therefore limited to the cover the design aspects for the risk-based certification. All other ship systems were assumed to follow prescriptive compliance, this included the battery systems for the hybrid propulsion.

During the HAZID workshop it was assumed that the vessel can operate on all open inland waters, will navigate predominantly inland waterways (canals & rivers), frequents busy ports and will be operated following good seamanship practises. Noting that the planned fuel cells were Marine Type Approved by DNV and consequently will have been subjected to their own risk assessment, the internal workings of the fuel cell were considered out-of-scope for this HAZID. It was assumed that any fuel cell installed onboard the Rhenus Mannheim will be Marine Type Approved. Therefore, only the fuel cell boundaries and the potential interactions of the fuel cells with systems onboard were considered during the HAZID workshop.

The participation in the HAZID workshop discussions by all attendees was good and the atmosphere collaborative. This allowed for issues to be openly discussed with viewpoints and concerns freely aired. All participants understood the status of the design well and worked hard to derive practicable recommendations to be included in the detailed design. It is duly noted that equivalently safe or safer alternatives to the recommended can be considered for approval.

The onus of monitoring and actioning the HAZID recommendations lays with the designers of the system. Keeping a dedicated action log of all recommendations is considered best practice and will often greatly assist in the approval process. The log should show how the recommendation objectives will be met, and also include sound justification for the methods used. If any methods or solutions have been discounted in the design process, it is worth noting these in the log with the associated reasoning.

In general, the risks identified in the HAZID workshop fell in-line with expectation and can, to some extent, be reasonably assumed part of normal hydrogen operations. The two highest risks were associated with dropped containers from cranes, either onto the hydrogen containers or the hydrogen container themselves. Effectively, for these highest risks there is no significant difference between the hydrogen containers being used onboard and / or being transported as ADN cargo.

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[2] Lloyd's Register and variants of it are trading names of Lloyd's Register Group Limited, its subsidiaries and affiliates. Lloyd's Register EMEA (Reg. no. 29592 R) is an Industrial and Provident Society registered in England and Wales. Registered office: 71 Fenchurch Street, London, EC3M 4BS, UK. A member of the Lloyd's Register group.

Although the design was not finalised at the time of the HAZID workshop, it is not foreseen that the implementation of the HAZID recommendations would pose a problem for the designers and builders of the system. From a risk perspective, the designers have already implemented the principles of inherent safer design and minimalization. It is duly noted that the HAZID team considered the current locations and arrangement of the hydrogen systems (storage, GHU and fuel cells), as far away as possible from the accommodation, the best possible option with consideration to alternatives and design aspects. In addition, the multiple layers of mechanical and automated control system protection are in-line with industry best practice.

Overall, the risks identified in the HAZID workshop can be considered well understood by all involved and mitigated as low as reasonably practicable

Contents

1. Introduction

At the request of the Rhenus PartnerShip GmbH & Co. KG (Rhenus), Lloyd's Register (LR) EMEA's Technical Investigation Department (TID) facilitated a 2-day HAZID workshop to qualitatively assess the risks associated with their compressed hydrogen fuel cells and hybrid propulsion systems. The workshop, held on the 10th and 11th of January 2023, formed part of stage 2 of the Risk Based Certification (RBC) process [1]. Prior to the workshop commencing, Lloyd's Register issued a Terms of Reference (ToR) document [2].

1.1 Scope

The newbuilt "Rhenus Mannheim" shall be outfitted with a hydrogen fuel system as part of the hybrid power train. The use of fuel cells and the storage of pressurized hydrogen in swappable ISO 20" containers is currently not covered by ES-TRIN and / or ADN regulations. Therefore, Rhenus has requested a risk-based certification process is followed as part of the CCNR derogation. The HAZID workshop was therefore limited to the cover the design aspects for the risk-based certification. All other ship systems were assumed to follow prescriptive compliance, this included the battery systems for the hybrid propulsion.
During the HAZID workshop it was assumed that the vessel can operate on all open inland waters, will navigate predominantly inland waterways (canals & rivers), frequents busy ports and will be operated following good seamanship practises. Noting that the planned fuel cells were Marine Type Approved by DNV and consequently will have been subjected to their own risk assessment, the internal workings of the fuel cell were considered out-of-scope for this HAZID. It was assumed that any fuel cell installed onboard the Rhenus Mannheim will be Marine Type Approved. Therefore, only the fuel cell boundaries and the potential interactions of the fuel cells with systems onboard were considered during the HAZID workshop.

Although criminal and terrorist activities were outside the scope of this risk assessment and a matter for the Flag and Port States, it was considered best practice to discuss and include any mitigative action that the crew could safely and swiftly take that would limit potential consequences.

1.2 Design information

A detailed description of the system can be found in the Design and Safety Statement (DSS) and drawings referenced in the Terms of Reference (ToR) document [2]. In summary, the hydrogen system consists of 2 to 4 hydrogen storage containers. Each of the 20 feet containers houses 8 cylinders, connected in pairs, that store hydrogen at a working pressure of 500 bar. Hydrogen is fed via a quick connection coupling to a Gas Handling Unit (GHU) that supplies the Marine Type Approved fuel cells. On deck all pipework is single walled, whereas below decks the piping shall be double-walled. The whole installation is situated in and on top of the bow superstructure, which also houses the conventional diesel generators at its lowest level. Crew accommodation and the navigation bridge are on the aft and separated by the cargo holds. The vessel will be designed to carry dangerous good in-line with the ADN Regulations.

1.3 Risk Based Certification (RBC)

Where novel and innovative designs and systems are not covered by existing, prescriptive regulations a level of safety equivalent or better than that provided by the intent of the prescriptive requirements needs to be demonstrated. The procedure for demonstrating this is outlined in IMO MSC.1/Circular.1455 – Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments – (24 June 2013) [3].

MSC.1/Circ.1455 proposes two different approaches: Either functional requirements and performance criteria have to be established for essential ship functions, which should be met by the alternative and/or equivalent design. An alternative approach is to use risk-based techniques to assess the alternative and/or equivalent design and compare it to overall risk evaluation criteria. It is proposed to follow the latter process for this project.

Lloyd's Register have developed the Risk Based Certification (RBC) procedure [1] to ensure that such studies are undertaken consistently, with an appropriate degree of rigour and in a manner consistent with the applicable Classification and Statutory requirements.

The Risk Based Certification (RBC) process consists of five stages, as shown in Figure 1.

Stage 1 Appraisal, Design and Safety Statement – Defines the novel or alternative design, identifying Classification and Statutory requirements not complied with. The safety objectives of the requirements not complied with should be understood.

Stage 2 Appraisal, Risk Assessment – Identifies the hazards associated with the novel or alternative design using a suitable Hazard Identification (HAZID) technique. The likelihood and consequences of each hazard should be determined and compared to a proposed risk acceptance criterion. Control and mitigation measures should be considered for suitability and demonstrate tolerable risks are As Low As is Reasonably Practicable (ALARP). At this stage it might be identified that further assessments are required to support this.

Stage 3 Appraisal, Revision and Supporting Studies – Follows on from recommendations made at Stage 2 regarding the requirement for further assessments to understand the risks associated with the design. These usually include the use of Quantitative Analysis. This information is used to revise the Stage 2 Assessment Report.

Stage 4 Appraisal, Final Design Assessment – Involves the detailed examination of the finalised design and should identify potential hazard and operability issues, as well as their controls.

Stage 5 Construction and In-Service Assessments – Identifies the requirements for construction, installation and commissioning of the design that has been informed and revised by the previous stages of RBC and develops the related in-service documentation.

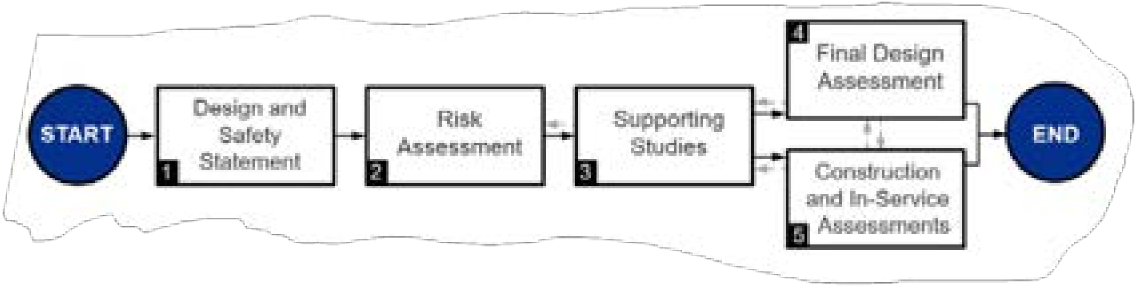

Figure 1: The Risk Based Certification (RBC) process

2. HAZID

2.1 Objectives

The objectives of the HAZID study were to:

- Identify hazards, in particular how they can be realised (what can go wrong, and how?). This considered all applicable risks, as well as unplanned and emergency scenarios related to the construction, installation, commissioning and operation of the relevant equipment and systems.
- Understand reasonably foreseeable consequences of these hazards, including the identification of loss of containment events and assess the level of risk.
- Review system safeguards and control measures to ensure suitability and understand what additional measures could be taken to eliminate or reduce the level of risk further, following ALARP principles, the detection and control of potential issues as well as suitable emergency response.
- Create a record of actions and recommendations for further supplementary work.

2.2 Methodology

The HAZID study followed a Structured What-If? (SWIFT) and checklist technique, based upon LR experience with guidance from the following sources:

BS ISO 31000: 2018, Risk Management – Principles and Guidelines	[4]
BS ISO 31010: 2019, Risk Management – Risk Assessment Techniques	[5]

The HAZID workshops were facilitated by an experienced LR Risk Specialist who also scribed the proceedings.

HAZID prompts and 'What if?' scenarios prepared prior to the workshops were applied, initiating and encouraging discussions on possible events that may lead to an unplanned event. These prompts were based upon previous experience and indicated the types of hazards that were thought to be applicable.

Identification of hazards and causes

Possible hazards were identified by applying the checklist guidewords. When a credible potential event was identified the HAZID team considered the possible causes that may lead to this.

Evaluation of consequences

The consequences of each identified hazardous scenario were analysed by the HAZID team and a discussion followed to establish the 'worst-case' reasonably foreseeable consequences.

Evaluation of safeguards and design recommendations

To obtain a coherent list of design recommendations, the HAZID team made a distinction between safeguards required by Rules and Regulations and commonly applied measures in the industry that are effectively design choices. The latter were included in the design recommendations and assumed to be implemented in the assignment of the risk ranking.

Risk Ranking

To facilitate an understanding of the level of risk associated with a particular hazard, a consequence and likelihood were assigned and compared to the risk matrix in Table 1. The chosen risk acceptance criterion reflects 'good practice' in major hazard industries regulated by governments and is recognised by the UK Health and Safety Executive (HSE) as a good basis for use.

The matrix identifies three risk zones:

High Risk (Unacceptable) - This level of risk cannot be justified and the hazard should be eliminated, substituted or controls implemented to reduce the risk to tolerable levels.

Medium Risk (Tolerable) – This level of risk can only be tolerated where it has been demonstrated to be As Low As is Reasonably Practicable (ALARP). This can be demonstrated by analysis to assess whether the implementation of risk mitigation measures is proportionate to the reduction in risk they would achieve.

Low Risk (Acceptable) – This level of risk does not need to demonstrate ALARP, however, it is good practice to implement measures to further reduce the risk where possible. The risks should be periodically reviewed to ensure they remain in this region.

To demonstrate ALARP, the High and Medium risks prompted further discussions on whether existing safeguards and the design recommendations were sufficient; or additional layers of protection needed to be identified.

🟥	Intolerable risk
🟨	Tolerable risk - ALARP
🟩	Broadly acceptable

				Consequence				
				C1	**C2**	**C3**	**C4**	**C5**
				Minor Injury	Major injury	One fatality or multiple major injuries	2-10 Fatalities	11+ Fatalities
Likelihood	**L7**	Extremely Likely	≤10^{0} to $10^{-1}/_{y}$	🟨	🟥	🟥	🟥	🟥
	L6	Very Likely	≤10^{-1} to $10^{-2}/_{y}$	🟨	🟥	🟥	🟥	🟥
	L5	Likely	≤10^{-2} to $10^{-3}/_{y}$	🟨	🟨	🟥	🟥	🟥
	L4	Unlikely	≤10^{-3} to $10^{-4}/_{y}$	🟩	🟨	🟨	🟥	🟥
	L3	Very Unlikely	≤10^{-4} to $10^{-5}/_{y}$	🟩	🟩	🟨	🟨	🟥
	L2	Extremely Unlikely	≤10^{-5} to $10^{-6}/_{y}$	🟩	🟩	🟨	🟨	🟥
	L1	Remote	≤$10^{-6}/_{y}$	🟩	🟩	🟩	🟨	🟨

Table 1: Risk acceptance criteria

2.3 Attendance

The HAZID workshop sessions attendance has been recorded in Table 2.

Name	Company	Function	Role	10/12/23	11/12/23	Qualifications / Experience
Erik Vroegrijk	LR TID	Senior Risk Advisor	Facilitator & Scribe	yes	yes	https://www.linkedin.com/in/erik-vroegrijk-12490713/
Rik de Bosscher	LR TID	Lead Integrity Engineer	SME	yes	yes	https://www.linkedin.com/in/rik-de-bosscher-3479b26/
Carlo Russo	LR TID[1]	Fire & Safety Lead	SME	yes	yes	https://www.linkedin.com/in/carlorusso1/
Matteo Roiaz	LR TID[1]	Electrotechnical Specialist	SME	yes	yes	https://www.linkedin.com/in/matteo-roiaz-a75a54140/
Robert Graf-Potthoff	Rhenus	Ship owner & operator	SME	yes	yes	https://www.linkedin.com/in/robert-graf-potthoff-b1bb27184/
Herbert Berger	Rhenus	Ship owner & operator	SME	yes	yes	https://www.linkedin.com/in/herbert-berger-680090a2/
Harm Backx	Den Breejen	Shipyard	SME	yes	yes	https://www.linkedin.com/in/harm-backx-60993568/
Stef Loffeld	Den Breejen	Shipyard project manager	SME	yes	yes	https://www.linkedin.com/in/stef-loffeld-491a5439/
Ben de Rooy	Den Breejen	Shipyard	SME	no	no	
Fabian Klumb	Buchloh	Ship designer	SME	yes	yes	https://www.linkedin.com/in/fabian-klumb-b095ba113/
Max Kolkman	Buchloh	Ship designer	SME	yes	yes	https://www.linkedin.com/in/max-kolkmann-a82553216/
Patrick Höving	Buchloh	Ship designer	SME	yes	yes	https://www.linkedin.com/in/patrick-h%C3%B6ving-219409200/
Ronald Hamstra	EMS	Electrical installation	SME	yes	yes	
Jan Andreas	Argo - Anleg	Managing Director	SME	yes	yes	https://www.linkedin.com/in/jan-andreas-3b50705b/
Ria Pabst	Argo - Anleg	Plant designer	SME	yes	yes	
Pim Geurts	LR RTSO	Senior Specialist Fire & Safety	Observer	yes	yes	
Bas Joormann	LR RTSO	Principal Specialist	Observer	yes	yes	
Mark Nijhoff	LR RTSO	Lead Technical Specialist	Observer	yes	yes	https://www.linkedin.com/in/mark-nijhoff-55406a26/
Annelies van Dijk	Ministerie I&W	Binnenvaart en vaarwegen	Observer	yes	no	
Joris Reinders	ILT	Senior Inspecteur	Observer	yes	yes	https://www.linkedin.com/in/joris-reinders-05263a62/
[1] *Working on behalf of LR TID, contracted to LR TTSO, not involved with Class Approval*						

Table 2: HAZID workshop attendance record

3. HAZID results

3.1 Considerations and assumptions

As outlined in the scope, the HAZID workshop considered only the systems associated with the compressed hydrogen storage and supply for power generation using fuel cells. Further, only the fuel cell interfaces, integration and interactions were discussed. All other systems onboard the Rhenus Mannheim were assumed to fall under existing prescriptive regulations.

Although already in an advanced stage of design, further detailed engineering will be required to finalise the system ready for installation. Where during the detailed design equivalently safe alternatives are identified, these can be implemented with an associated safety justification, without necessarily impacting the aim of the HAZID recommendations.

3.2 Risk ranking

In total 40 hazards were identified and their associated risks ranked under the assumption that all design recommendations would be implemented and all design safeguards adhered to, see Table 3. In total, 10 hazards fell into the "tolerable risk" category, for which the ALARP principle should be demonstrated.

Full HAZID worksheet available in Appendix 1.

🟥	Intolerable risk
🟨	Tolerable risk - ALARP
🟩	Broadly acceptable

				Consequence				
				C1	**C2**	**C3**	**C4**	**C5**
				Minor Injury	Major injury	One fatality or multiple major injuries	2-10 Fatalities	11+ Fatalities
Likelihood	**L7**	Extremely Likely	$\leq 10^{0}$ to $10^{-1}/_{y}$	🟨	🟥	🟥	🟥	🟥
	L6	Very Likely	$\leq 10^{-1}$ to $10^{-2}/_{y}$	🟨	🟥	🟥	🟥	🟥
	L5	Likely	$\leq 10^{-2}$ to $10^{-3}/_{y}$	🟨	🟨	🟥	🟥	🟥
	L4	Unlikely	$\leq 10^{-3}$ to $10^{-4}/_{y}$	🟩 7	🟨 1	🟨	🟥	🟥
	L3	Very Unlikely	$\leq 10^{-4}$ to $10^{-5}/_{y}$	🟩 2	🟩 1	🟨 1	🟨 1	🟥
	L2	Extremely Unlikely	$\leq 10^{-5}$ to $10^{-6}/_{y}$	🟩 1	🟩 3	🟨 7	🟨	🟥
	L1	Remote	$\leq 10^{-6}/_{y}$	🟩 11	🟩	🟩 5	🟨	🟨

Table 3: HAZID risk rankings

The highest "C4-L3" risk ranking (1 identified) was associated with the potential for a large, heavy load to be dropped onto the hydrogen containers. Given that this risk would most likely be associated with cargo operations, the HAZID team conservatively assumed there to be 2 persons on deck and 2 persons on the quayside that would all be directly affected. The HAZID team further selected a conservative likelihood based on typical crane failure rates and considered for the actual likelihood and consequence to be lower if the recommendations regarding the forward cargo hold bulkhead cell guides, prohibition of lifting operations over the hydrogen containers and reduced personnel numbers when loading/unloading cargo bay 1 would be implemented effectively.

The second highest “C3-L3” risk ranking (1 identified) was associated with a dropped filled hydrogen container whilst swapping the hydrogen containers. Noting that at least the crane operator needs to be in the vicinity as a minimum, the HAZID team considered the risk mitigated as low as reasonably practicable (ALARP).

In total 7 risks were assigned a “C3-L2” ranking. These risks (3 identified) were associated with the potential for hydrogen containers falling overboard due to frontal and side collisions by 3rd party vessels and bridge allisions. In addition, they were associated with high- and low-pressure leaks originating from bridge allision resulting in cylinder punctures (1 identified) and various leak scenarios of the hydrogen pipework and components (2 identified). In all the aforementioned scenarios the HAZID team assumed 1 person to be present at the bow. The 7th “C3-L2” risk was associated with an overpressurization event during nitrogen purging, which the HAZID team agreed could fairly easily be ‘engineered out’, by fixing the pressure regulating valves between the nitrogen inlets and the system’s pipework.

The “C2-L4” risk ranking (1 identified) was associated with an adjacent / external fire case that could lead to activation of the hydrogen cylinders’ TPRDs. Noting that there would be time to respond and assess the situation prior to commencing firefighting operations, as well as the hydrogen cylinders being Type 4, the HAZID team considered it not credible for fatalities to occur. Given that it was likely that only one person would be involved in the manual firefighting activity, a conservative major injury consequence was selected by the HAZID team.

3.3 HAZID recommendations (condensed list)

During the workshop the HAZID team made 43 recommendations, see **Appendix 2** for the full list. As many of the recommendations were already being implemented or were referred to detailed documentation and supporting evidence, a condensed list was generated. The condensed list in **Table 4** contains all the recommendations associated with medium risks, as well as any high priority actionable items.

RR	Recommendation	Place(s) used	Responsibility	Comments
Medium	4. To assess the likelihood of personnel being present in the bow area at the time of a ship collision, review the frequency, duration and staffing requirements for routine engine room and hydrogen system inspection rounds.	Consequences: 1.3.1.1		No comments received
Medium	5. To reduce the likelihood of bridge allisions, the crew and cargo planning office should assume the top of the 2nd hydrogen container as the minimum air draft of the vessel in their route and cargo planning. Where this would lead to conflict, special consideration could be given for tides and the actual presence of the 2nd hydrogen container tier on that particular voyage.	Consequences: 1.3.2.1, 1.3.2.2		**LR Class 20/01/2023:** Vessel is foreseen to have a " bridge-scout system", set to protect the top of the H2 cartridges
Medium	7. To reduce the likelihood of dropped objects on the hydrogen containers, no cargo or provision lifting operations should be conducted over the hydrogen containers.	Consequences: 1.9.1.1		No comments received
Low	8. To understand the dimensions of the effect zones and set reliable safety distances, perform dispersion and explosion analyses for the worst credible loss of containment scenarios, including the catastrophic failure of one and multiple hydrogen cylinders.	Consequences: 1.9.1.1, 4.1.1.1		No comments received
Medium	9. To reduce the consequence of dropped objects on the hydrogen containers, minimise the persons on deck and on the quayside when loading/unloading container cargo bay 1.	Consequences: 1.9.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Medium	10. To reduce the likelihood of an external fire impacting the hydrogen containers, include a suitable boundary cooling system for the hydrogen containers that can be activated remotely, in line with the forthcoming ESTRIN guidelines for hydrogen storage.	Consequences: 1.12.1.1		No comments received
Medium	14. To further reduce the likelihood of ignited hydrogen leakages, no reefer containers to be carried in the first cargo bay, with their connectors to be situated on the side of the vessel, away from the hydrogen installation.	Consequences: 2.1.1.1		No comments received
Medium	15. To further reduce the likelihood of an undetected hydrogen release, include hydrogen detectors in the design, which are situated directly above the GHUs and associated pipework.	Consequences: 2.1.1.1		No comments received
Medium	16. To reduce the risk of overpressurization during nitrogen purging as a result of human error, include fixed Pressure Reduction Valves in between the nitrogen connection points and the system's pipework.	Consequences: 2.2.1.1		No comments received
Low	20. To ensure that the fuel cell modules can be safely removed for maintenance purposes without the risk of hydrogen leakages towards the fuel cell room, the double-block-and-bleed arrangements to be updated such that they prevent hydrogen flow towards the removed and/or deactivated fuel cells.	Consequences: 2.10.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	22. To reduce the likelihood of hydrogen leakages during maintenance activities on the GHUs or fuel cells, the ship's operating procedures to require the hydrogen containers to be fully disconnected and the system bled prior to any maintenance work being carried out. There is no merit in removing the containers themselves, given that they can be carried onboard as ADN cargo. To prevent inadvertent reconnection of the hydrogen supply prior the maintenance work being completed, consider options for tagging-out the air-supply unit to the hydrogen containers, such that the cylinder valves cannot be opened, as well as tagging-out the hydrogen inlet connections.	Consequences: 2.10.1.1, 3.9.1.1		No comments received
Low	37. To reduce the consequence of a dropped hydrogen container, only permit the crane operator to be present in the safety zone during loading and unloading of the hydrogen containers. The hydrogen containers should only be connected upon completion of the container swap operation.	Consequences: 4.2.1.1, 4.5.1.1		No comments received

Table 4: Results - HAZID recommendations (condensed list)

4. Discussion[3]

The participation in the HAZID workshop discussions by all attendees was good and the atmosphere collaborative. This allowed for issues to be openly discussed with viewpoints and concerns freely aired. All participants understood the status of the design well and worked hard to derive practicable recommendations to be included in the detailed design. It is duly noted that equivalently safe or safer alternatives to the recommendations can be considered for approval.

The onus of monitoring and actioning the HAZID recommendations lays with the designers of the system. Keeping a dedicated action log of all recommendations is considered best practice and will often greatly assist the approval process. The log should show how the recommendation objectives will be met and include sound justification for the methods used. If any methods or solutions have been discounted in the design process, these should be noted in the log with the associated reasoning.

In general, the risks identified in the HAZID workshop fell in-line with expectation and can, to some extent, be reasonably assumed part of normal hydrogen operations. The two highest risks were associated with dropped containers from cranes, either onto the hydrogen containers or the hydrogen container themselves. Effectively, for these highest risks there is no significant difference between the hydrogen containers being used onboard to those being transported as ADN cargo.

Although the design was not finalised at the time of the HAZID workshop, it is not foreseen that the implementation of the HAZID recommendations would pose a problem for the designers and builders of the system. From a risk perspective, the designers have already implemented the principles of inherently safer design and minimalization. It is duly noted that the HAZID team considered the current locations and arrangement of the hydrogen systems *(storage, GHU and fuel cells)*, as far away as possible from the accommodation, the best possible option with consideration to alternatives and design aspects.. In addition, the multiple layers of mechanical and automated control system protection are in-line with industry best practice.

Overall, the risks identified in the HAZID workshop can be considered well understood by all involved and mitigated as low as reasonably practicable.

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5. References

[1] LR – *ShipRight Design and Construction – Risk Based Certification (RBC)* – September 2021

[2] LR – *Terms of Reference – Hydrogen fuel cell and hybrid propulsion* - Version 1 – 2211-0055 – 04 January 2022

[3] IMO – *Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments* – IMO Publications and Documents - Circulars - Maritime Safety Committee - MSC.1/Circular.1455 - 24 June 2013

[4] British Standards Publication - *Risk Management – Principles and Guidelines* - BS ISO 31000: 2018 - 2018

[5] British Standards Publication - *Risk Management – Risk Assessment Techniques* - BS ISO 31010: 2019 – 2019

Appendix 1 HAZID Worksheet

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
1. Hydrogen storage system	What if the ship encountered heavy weather / seas? What accelerations could the system experience?	1. High waves, wind gusts	1. High roll motions on containers with the potential for the 2nd tier hydrogen container to fall overboard or against the adjacent hydrogen container stack. The port 2nd tier hydrogen container could impact the vent lines on its way down.	C1	1. Containers stacked in guidance structures	Pc	L1	Low	1. Guides initially designed to limit horizontal movement of the hydrogen containers	1. To understand the credibility of a 2nd tier hydrogen container falling overboard or onto the adjacent hydrogen container stack, investigate the maximum credible weather induced, vessel roll angles and compare these against the vessel's stability calculations. Additional information could potentially be gathered from design criteria for twistlocks and ADR regulations. Alternatively, interviews with experienced captains could be conducted.
					2. Top container is guided for bottom 40cm. Requires 67° (y-axis) and 80° (x-axis) static angle of heel before centre of gravity is above the top of the guides	Pc			2. By design, no twist locks are being used, for this allows reduction in number of persons involved in the loading/unloading operation, as well as the probability of human error	
					3. Main valves on the hydrogen cylinders are fail-to-close	Cr			3. Not expected to see high accelerations on inland vessels due to adverse weather conditions. Highest heel angles normally generated by manoeuvring	
					4. With high waves / adverse weather conditions the forward area is an unattended space	Pc			4. Based on the HAZID team's experience, the loss of containers due to weather induced vessel roll motions not seen in inland industry	
					5. Full automatic hydrogen system shutdown if a hydrogen container would be lost.	Cr			5. In case a 2nd tier container would topple out of the guidance structure, all hydrogen container connections would be ripped off and all valves subsequently closed due to loss of actuating air pressure.	
					6. Shock and angle sensors on the containers would provide warning. Data is logged and transferred to the system	Dm			6. Uncertain whether hydrogen container will float	
					7. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
			2. High vibrations resulting from bow slamming loads that could impact the hydrogen container integrity, with the potential for high pressure leaks	C1	1. Hydrogen container is designed for road transport	Other	L1	Low	1. There are currently no machinery design criteria for accelerations in the inland waterway regulations	2. To understand the risks associated with high vibration loads on the hydrogen container, make a comparison of marine vibrations against the design acceleration requirements for road transport. If this comparison shows that road design acceleration requirements are larger,
					2. Main valves on the hydrogen cylinders are fail-to-close	Cr			2. For wheelhouse accelerations LR advises to use 0.5g.	
					3. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in	Mr			3. For deck mounted LNG tanks on seagoing vessels LR, has advised 2g	

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					case of full bore rupture / inadvertent opening of downstream pipework				longitudinal, 2g transverse, 1g vertical	no further investigation would be required.
					4. Shock and angle sensors on the containers would provide warning. Data is logged and transferred to the system	Dm			4. The hydrogen containers have substantial mass and will consequently be harder to excite than, for example, structure mounted pipework	
					5. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
		2. Lightning storm	1. Electric charge on hydrogen container	C1	1. Earth connections	Pi	L1	Low	1. Simultaneous hydrogen leakage and lightning strike considered to be double jeopardy	
					2. Steel frame of container deflects lightning into the hull	Pi				
					3. The composite carbon fibre structure is a poor conductor	Pi				
					4. With high waves / adverse weather conditions the forward area is an unattended space	Pc				
					5. Main valves on the hydrogen cylinders are fail-to-close	Cr				
					6. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
	What if there was a flooding event / exposure to salt laden environment / green water / icing / snow?	1. Standing waves resulting in, potentially salt laden, spray	1. Potential for increased level of corrosion	C1	1. The hydrogen container's steel structure is galvanised	Other	L1	Low		
					2. The hydrogen cylinders are composite carbon fibre structure	Other				
					3. All piping and connectors are manufactured from stainless steel	Other				
			2. Potential for flooding the high and low pressure vent lines	C1	1. Water drain provided in vent line with regular drainage part of the standard operating procedure	Other	L1	Low	1. Draining frequency based on best practice. Optimum frequency to be established during first year of operation.	3. To reduce the likelihood of water ingress into and icing of the high-pressure vent line, place a plastic vent cap on the top of the vent line.
					2. The vent lines are angled upwards	Other			2. For the high pressure vent line a plastic cap is being considered.	

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					3. A high pressure vent scenario would expel all water from the high pressure vent line	Other			3. The low pressure vent line cannot be capped due to frequent venting of the fuel cells	
					4. The vent pipes are directed overboard and not in way of pathways	Pc			4. No non-return valves can be placed on vent lines by regulations	
									5. In case of water flow down to fuel cells this would cause an operational issue, rather than a safety issue. Due to fuel cell operating parameters going outside their limits, i.e. back pressure, the fuel cell is assumed to perform a controlled shut down.	
			3. Potential for icing of vent line	C1	1. High temperature coming out of the low pressure vent line	Other	L1	Low	1. No trace heating system currently foreseen on any safety critical systems	3. To reduce the likelihood of water ingress into and icing of the high-pressure vent line, place a plastic vent cap on the top of the vent line.
					2. Blocked low pressure vent line would result in high back pressure on fuel cell leading to shutdown prior to start-up	Other				
					3. Due to the high pressure incase of a high pressure venting scenario, substantial loads would be exerted on the ice plug.	Other				
	What if the ship was involved in a collision / allision event?	1. Collision by third party vessel	1. High acceleration loads on the hydrogen container in case of head-on collision, with the potential for high pressure leaks	C3	1. Shock and angle sensors on the containers would provide warning. Data is logged and transferred to the system	Dm	L2	Medium	1. Immediate shutdown of hydrogen could in itself pose a risk. It is reasonable to expect a increased load requirement for the bilge pumps	4. To assess the likelihood of personnel being present in the bow area at the time of a ship collision, review the frequency, duration and staffing requirements for routine engine room and hydrogen system inspection rounds.
					2. Main valves on the hydrogen cylinders are fail-to-close	Cr			2. Due to natural constraints, most river collisions will be bow-on and stern-on	
					3. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr			3. Vessel will operate part of its time in seagoing ports, like Rotterdam. Therefore a collision with seagoing vessels would be credible.	
					4. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc			4. For the risk ranking, the HAZID team assumed one daily routine inspection by two persons	
									5. Risk ranking based on the likelihood of a ship collision and someone being present at the bow area. The likelihood may be conservative if routine inspection is of short duration.	
			2. High angle of heel due to asymmetric flooding of hull with the potential for the	C1	1. Containers stacked in guidance structures	Pc	L1	Low	1. There is no practical limit on the heel angle for operating the hydrogen system	

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
			2nd tier hydrogen container to fall overboard or against the adjacent hydrogen container stack. The port 2nd tier hydrogen container could impact the vent lines on its way down.		2. The forward engine room is the full width of the vessel. Consequently, if this section of the vessel is hit it will be difficult to achieve high angles of heel, which require strong asymmetry in the flooded condition.	Pc			2. Fuel cells running might provide power continuity in case of diesel shutdown. Marinized diesel engines typically cut-out at static heel angles above 22.5 degrees.	
					3. Top container is guided for bottom 40cm. Requires 67° (y-axis) and 80° (x-axis) static angle of heel before centre of gravity is above the top of the guides	Pc				
					4. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				
					5. Main valves on the hydrogen cylinders are fail-to-close	Cr				
					6. Full automatic hydrogen system shutdown if a hydrogen container would be lost.	Cr				
					7. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
			3. Side impact by striking 3rd party vessel with the potential for the 2nd tier hydrogen container to fall overboard or against the adjacent hydrogen container stack. The port 2nd tier hydrogen container could impact the vent lines on its way down.	C3	1. More than 1.7m spacing between side shell and containers	Pr	L2	Medium	1. On balance the HAZID team considered it potentially beneficial for the container guides to be weaker, such that the hydrogen containers would be pushed away / overboard, rather than being crushed by the impacting vessel due to the hydrogen containers being strongly held in position by the container guides. Arguably this would reduce the risk of a total loss of all hydrogen cylinders simultaneously to one or potentially two cylinders being punctured if they would fall overboard. This breakaway feature	
					2. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr				
					3. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					4. Main valves on the hydrogen cylinders are fail-to-close	Cr			could be accomplished by shear bolts, either at the bottom of the guides, or higher up.	
					5. Full automatic hydrogen system shutdown if a hydrogen container would be lost.	Cr				
					6. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
		2. Allision with low bridge	1. Potential for hydrogen container to be lost overboard or crushed underneath bridge	C3	1. Quick couplings will release in case the container falls off	Mr	L2	Medium	1. Risk ranking based on 2 hydrogen containers per stack	5. To reduce the likelihood of bridge allisions, the crew and cargo planning office should assume the top of the 2nd hydrogen container as the minimum air draft of the vessel in their route and cargo planning. Where this would lead to conflict, special consideration could be given for tides and the actual presence of the 2nd hydrogen container tier on that particular voyage.
					2. Vessel will have a bridge guard system	Pr			2. For most of the sailing time a barge will be coupled in front on which containers can be stacked higher than the hydrogen containers	
					3. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr			3. Contargo responsible for load planning	
					4. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc			4. Various drop tests are performed on the hydrogen container, with one being a drop from 2.2m height flat on a flat surface, another being angled onto a flat surface.	
					5. Main valves on the hydrogen cylinders are fail-to-close	Cr				
					6. Full automatic hydrogen system shutdown if a hydrogen container would be lost.	Cr				
					7. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
			2. Potential for puncturing the hydrogen cylinders	C3	1. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc	L2	Medium	1. Risk ranking brought in-line with previous point: "Potential for hydrogen container to be lost overboard or crushed underneath bridge" for consistency purposes. The effect, one or multiple punctured cylinders, is the same. With the proximity of the funnel, it is reasonable to assume ignition in both cases. The original ranking was C1-L2.	5. To reduce the likelihood of bridge allisions, the crew and cargo planning office should assume the top of the 2nd hydrogen container as the minimum air draft of the vessel in their route and cargo planning. Where this would lead to conflict, special consideration could be given for tides and the actual presence of the 2nd hydrogen container tier on that particular voyage.
					2. The stainless steel hexagon plates on either end of the cylinders offer protection against forward impacts	Pr				
			3. Potential for damage to vent lines	C1	1. The vent lines are lower than the top of the container guides	Other	L2	Low	1. Damage to the vent line would not directly cause harm, it would require a leakage in addition and persons presence	
	What if the ship was involved in a grounding event?	1. Navigational error	1. Potential for high angle of heel if grounded on a bank, with the potential for the 2nd tier hydrogen container to fall overboard or against the adjacent hydrogen container stack. The port 2nd tier hydrogen container could impact the vent lines on its way down.	C3	1. In terms of continued operation, there is no impact of high angle of heel on the hydrogen cylinders or the fuel cells	Other	L1	Low	1. Consequence brought in-line with previous point: "Potential for hydrogen container to be lost overboard or crushed underneath bridge" for consistency purposes. The effect, one or multiple punctured cylinders, is the same. With the proximity of the funnel, it is reasonable to assume ignition in both cases. The original ranking was C1-L1	
					2. Top container is guided for bottom 40cm. Requires 67° (y-axis) and 80° (x-axis) static angle of heel before centre of gravity is above the top of the guides	Pc			2. The likelihood is set to remote, for it requires the following three events simultaneously: grounding, vessel in a section of the river with steep enough banks to achieve a 30 degrees angle of heel and a person to be present at the forward end at time of grounding	
					3. Shock and angle sensors on the containers would provide warning. Data is logged and transferred to the system	Dm				
					4. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
			2. Potential impact on the cooling water circuits for the fuel cells	C1	1. During a grounding event there is no direct high power demand for propulsion	Other	L1	Low		
					2. The increase in cooling water temperature is a gradual process.	Other				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					Therefore it is reasonable to assume that there will be time for the hydrogen systems to be safely shutdown if the situation requires it					
					3. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
	What if cell guides were not sufficient?	1. Incorrect scantlings used for the expected loads	1. Potential for hydrogen container overboard		1. See "Hydrogen storage system - What if the ship encountered heavy weather / seas? What accelerations could the system experience? and What if the ship was involved in a collision / allision event?" nodes				1. No additional risks identified. Hence no risk ranking	
	What if there if there were high vibrations / impact damage to the systems?	1. Engine vibrations, thruster vibrations	1. Potential for small leaks developing due to piping and couplings becoming lose	C2	1. Flexible hose couplings between container and vessel	Pr	L2	Low	1. No vibration damping installed under containers or fuel cell cabinets	6. To fully understand the impact vibrations could have on the safe operation of the fuel cells, request the vibration limits from the fuel cell manufacturer (Ballard) and compare these against the typical vibration levels created by generators and bow thrusters.
					2. All pipework is to be completely welded up to the fuel cells, where there is a double walled flanged connection	Pr			2. No vibration limits imposed by the fuel cells manufacturer	
					3. All pipework will be mounted in resilient clamps	Pr			3. Technical tight connection accounts for vibrations. German standard to be forwarded to Class for review	
					4. Resilient mounting of generators	Pr			4. If barge is attached, the most forward bow thruster will be used for manoeuvring purposes	
					5. All connections are on the open deck, allowing for small leakages to disperse swiftly	Vr			5. Information to Class needs to be updated	
					6. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr			6. No hydrogen fire detection is planned in way of the hydrogen containers and the gas handling units. Tests are currently conducted on the detectable leakage size by the automated control system	
					7. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown	Dm				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if there was an issue with materials selection, manufacturing or damage mechanisms corrosion, erosion?	1. Improper materials used	1. Potential for leakage, ruptures, component failures		1. Everything is properly earthed. Not only for corrosion, but also for safety aspects	Pr			1. Due to the level of protection in the existing design, the HAZID team considered this not a credible safety risk. Hence no risk ranking.	
					2. The hydrogen container's structure is galvanised steel based on international container standards	Other				
					3. The hydrogen cylinders are Type 4 carbon wound vessels with plastic liner, for weight consideration and low permeation	Pr				
					4. The hexagon plates on either end of the type 4 cylinders are stainless steel or Aluminium ALSI05	Other				
					5. Stainless steel 316L for pipework, suitable for hydrogen	Other				
					6. Valve blocks on cylinders are also stainless steel to prevent salt water corrosion	Other				
					7. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown	Dm				
					8. All materials used in the installation will be subjected to independent Class review	Other				
	What if there was a mooring/articulation line snap-back?	1. Mooring line snapback	1. Potential for impact on the hydrogen container		1. Steel lines used for coupling, which are short and deployed next to horizontal	Pr			1. The protective netting on the sides and top of the hydrogen containers will not provide mechanical protection	
					2. Mooring lines will be polymer and will not be laid at such a steep angle that snapback could impact the cylinders	Pr			2. The HAZID team considered it not a credible scenario that a mooring / coupling line could snapback and impact the hydrogen containers due to the high line angles required for this scenario. Hence no risk ranking	
					3. Front of cylinders are protected by the hexagon plates	Pr				
					4. The hydrogen containers are located at the top of the forward deckhouse, which is about 2.5 metres above the mooring deck	Pr				
	What if there was a object dropped onto the container?	1. Dropped objects from cargo or supply cranes	1. Impact on hydrogen containers, with potential for full release of inventory	C4	1. There is no ship-to-ship (transloading) foreseen between sea going vessel and the Rhenus Mannheim. Therefore it is unlikely required to have containers moved over the hydrogen containers	Pr	L3	Medium	1. Terminals and operator are licensed to ship dangerous good containers. Hydrogen likely to be loaded on these existing terminals	7. To reduce the likelihood of dropped objects on the hydrogen containers, no cargo or provision lifting operations should be conducted over the hydrogen containers.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					2. The container will be certified as an ISO container suitable for the transport of dangerous goods under the ADN regulation	Other			2. Gensets to be changed about every 5 to 10 years	8. To understand the dimensions of the effect zones and set reliable safety distances, perform dispersion and explosion analyses for the worst credible loss of containment scenarios, including the catastrophic failure of one and multiple hydrogen cylinders.
					3. The vessel will be ADN certified and therefore permitted to carry the sealed hydrogen containers as normal dangerous good cargo containers.	Other			3. During cargo operations there will be about 2 persons on deck and 2 persons on the quay side. Although no cargo operations will take place over the hydrogen containers, due to their proximity to the cargo hold, the HAZID team conservatively selected a C4 consequence.	9. To reduce the consequence of dropped objects on the hydrogen containers, minimise the persons on deck and on the quayside when loading/unloading container cargo bay 1.
					4. Replacement of generators cannot take place with hydrogen containers on board.	Pr			4. The implementation of the recommendation to keep personnel away from bay 1 during loading/unloading, as well as the introduction of cell guides on the forward cargo bulkhead would arguably reduce both the consequence as well as the likelihood.	
					5. The conventional marine diesel oil bunkering station will be in the vicinity of the hydrogen installation, but situated on the main deck. Marine diesel oil bunkering will be done with standard IWW flexible hoses that can be carried on board	Pr				
					6. Lubrication oil is bunkered flexible hoses that can be carried on board	Pr				
					7. UREA is bunkered with flexible hoses that can be carried on board	Pr				
	What if there was a hydrogen leak on the hydrogen storage lines, valves, cylinders?	1. Dropped object on lines, coupling failures, valve external failures	1. High pressure hydrogen release	C3	1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr	L2	Medium	1. Risk ranking based on the conservative assumption that a person could be present around the hydrogen storage containers (hence consequence C3). A comparatively lower likelihood than dropped objects from cranes was selected due to the much smaller target area.	
					2. The hexagon plates on either end of the type 4 cylinders are stainless steel or Aluminium ALSI05	Pr				
					3. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if the blowdown system operated spuriously?	1. Failure of TPRD	1. High-pressure venting through vent mast	C1	1. TPRD are certified for up to 50,000 loading cycles depending on the storage condition. The exact number of cycles will be confirmed and included in the maintenance planning	Pr	L4	Low	1. Likelihood based on Pressure Safety Valve (PSV) statistics (3.55E-02/year Oreda 2002) because of lack of data (new data) and the probability of someone being present in way of the vent mast (30 minutes/day). Note likelihood updated based on above calculation. The original risk ranking was C1-L3	
					2. The vent system is designed for the simultaneous activation of all TPRDs on the hydrogen container, including ignited releases.	Vr				
					3. There are no other valves available for voluntary venting	Pr				
					4. Access to the filling connection will be mechanically hindered by the presence of a metal plate fixed to the container guide structure	Pc				
	What if there was an external / adjacent fire event / heat source?	1. Engine room fire, fuel cell fire, cargo fire, funnel fire, bunkering fire	1. Potential for TPRD activation with container liners cooling down and release through the vent mast. In worst case scenario, the situation could escalate leading to a hydrogen release through the cylinder walls in case of a very intense and long lasting fire.	C2	1. The vent system is designed for the simultaneous activation of all TPRDs on the hydrogen container, including ignited releases.	Vr	L4	Medium	1. Design of the fuel cell room not fully completed. Balance need to be found between open deck condition and access control	10. To reduce the likelihood of an external fire impacting the hydrogen containers, include a suitable boundary cooling system for the hydrogen containers that can be activated remotely, in line with the forthcoming ES-TRIN guidelines for hydrogen storage.
					2. The hydrogen containers are subjected to a bonfire test whilst under pressure. These tests showcase that a fire directly underneath the hydrogen cylinder would not lead to an explosion event	Pc			2. Review how directional nozzles can assist in fire cases impacting the hydrogen system	
					3. The forward engine room has a Class Approved fire suppression system that can be activated remotely and has A60 boundaries	Pr			3. New H2 storage guidelines ES-TRIN require sprinkler/boundary cooling system	
					4. The generator exhausts in the starboard funnel are fitted with spark arresters	Pi			4. The generator exhausts are insulated inside the forward engine room and pass through a weather tight opening directly into the open funnel structure.	
					5. The hydrogen containers are in range of the onboard fire hydrants, which will be located adjacent to fuel cell room	Ef			5. Consensus of the room is that the escape of persons is not hindered	
					6. Due to the available detection and alarms, as well as the fixed fire fighting system in the forward engine room and its A60 boundaries, it can reasonably be assumed that there will be	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					sufficient time to escape before the situation escalates 7. In case of manual firefighting, it will likely be only one person involved	 Pc				
	What if there was a hydrogen fire?	1. Ignited leakages, spurious TPRD activation	1. Potential for personal injury (burns) and escalation leading to TPRD activation	C2	1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework 2. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown 3. Hydrogen containers are on open deck 4. Escape routes on both side of vessel around superstructure 5. There is time to escape before the situation escalates 6. Hydrogen cylinders fitted with two TPRDs 7. The vent system is designed for the simultaneous activation of all TPRDs on the hydrogen container, including ignited releases.	Mr Dm Vr Other Pc Pc Vr	L2	Low	1. Consensus of the HAZID team is that the escape of persons is not hindered in the current design 2. Lifebuoy location not yet determined 3. Due to the automated leakage detection and excess flow valves fitted in each hydrogen cylinder, a large undetected leakage that could lead to a sizeable fire is not considered a credible scenario. The vent mast, in case of spurious TPRD activation, is designed for an ignited release scenario. Note: no risk ranking selected in HAZID. Risk ranking based on burns and the above note on leakage detection and excess flow prevention	
	What if there was an issue with any Safety Critical Equipment (SCE) on the hydrogen containers?	1. Equipment failure	1. Potential for high pressure hydrogen release via vent mast	C1	1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework 2. The vent system is designed for the simultaneous activation of all TPRDs on the hydrogen container, including ignited releases. 3. Control and monitoring system software design based on ISO26262:2 (Road vehicles - Functional Safety) standard 4. Multiple layers of protection (valves and sensors) 5. All safety critical equipment is mechanical (TPRD, excess flow valves)	Mr Vr Dm Pc Pc	L3	Low	1. Class to investigate whether ISO26262 can be accepted 2. Block diagram of control system is not yet available 3. System is designed to be safe with mechanical systems. No software driven safety functions	11. To ensure that the control and monitoring system for the hydrogen system can be approved by Class, Lloyd's Register Class to investigate whether the use of the ISO 26262 Road vehicles Functional Safety standard can be accepted for the software design and architecture.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if maintenance needs to be completed? Safe Isolation, venting, purging & inerting / return to service.	1. Work on cylinder valves and piping	1. Potential for high pressure hydrogen release		1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr			1. Not considered a safety risk onboard the vessel. If any component of the hydrogen container would fail, the hydrogen cylinders would be closed and the container lifted off the vessel. Hence no risk ranking	
					2. Manual stop valves on cylinder that would allow for slow cylinder bleeding prior to work commencing on cylinders themselves (i.e. no potential for stored energy)	Pc				
					3. Each tank has a manual valve	Pr				
					4. All maintenance on the hydrogen containers is done away from the vessel in a dedicated facility onshore by trained and certified personnel	Pc				
	What if the vessel sinks?	1. Collisions, allision, ground contact	1. Vessel sinking with the potential to submerge the hydrogen system	C3	1. There are no concerns for water ingress into the hydrogen system	Other	L1	Low	1. Combined likelihood of sinking and subsequent collision by 3rd party vessel. The HAZID team assumed it reasonable that vessels in the vicinity would be alerted of the casualty by means of maritime communications and traffic control	
					2. Unlimited holding time for the hydrogen cylinders	Pr			2. The HAZID team conservatively selected a similar consequence to an ordinary collision.	
					3. The hydrogen system will be shut down and the hydrogen cylinders automatically closed	Pr				
					4. Hydrogen is not pollutant to the environment	Other				
					5. Once the hoses are disconnected by the salvage company, the hydrogen containers could be lifted off directly (i.e. no twistlocks).	Other				
	What if safety could be enhanced through the movement / addition of components?	1. Design choices	1. Potential for missed opportunities for a more inherently safer design		1. Burst pressure of hydrogen cylinders is 1250 bar	Pr			1. The HAZID team's consensus is that, based on all available design parameters, the hydrogen containers are in the best possible location from a risk perspective	
					2. Horizontal tank orientation reduces the risk of items falling on the associated pipework. The cylinders are considered the strongest part in the design	Pr				
					3. The hydrogen containers are situated on open deck and as far as possible away from the accommodation and navigational bride	Vr				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					4. The hydrogen container location on top of the forward engine room roof is favourable from a venting perspective when compared to alternative locations at or below decks	Vr				
					5. The hydrogen container locations permits for a clear segregation with cargo operations	Pc				
	What if there was an issue with change / configuration management?	1. Change of hydrogen container supplier	1. New type of container onboard		1. Having a large industrial supplier of hydrogen might be beneficial from a risk perspective, as they would do the hydrogen container integrity monitoring part, instead of the ship's crew. It is reasonable to assume that a large industrial supplier would have a dedicated and suitably qualified team.	Other			1. In the current situation, Rhenus will own the hydrogen containers and they are assigned to the vessel. I.e. they're a "mobile" part of the vessel.	12. To prepare for future industrial suppliers of hydrogen containers, equivalent safety levels to be required for 3rd party hydrogen containers to be used on board, including but not limited to fully compatible connectors without the need for adapters.
					2. Each container will have an identifier code	Other			2. In the future an industrial gas supplier might be able to supply the hydrogen containers. 3. The change of hydrogen container supplier is not part of the current certification. Hence no risk ranking	13. To prepare for future industrial suppliers of hydrogen containers, Lloyd's Register Class to investigate the routes for acceptance, including but not limited to the requirements for future inspections of these 3rd party hydrogen containers.
2. Gas Handling Unit (GHU), connections and vent mast	What if there was a H2 leak on the hydrogen container connections, GHU, connecting pipework or vent masts?	1. Leakages of hoses, couplings, filters, valves, pressure transducers, cargo impact, dropped objects	1. Potential for low pressure releases with the potential for hydrogen fire	C3	1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr	L2	Medium	1. See node "Hydrogen storage system - What if there was a hydrogen leak on the hydrogen storage lines, valves, cylinders?" for high pressure hydrogen releases	14. To further reduce the likelihood of ignited hydrogen leakages, no reefer containers to be carried in the first cargo bay, with their connectors to be situated on the side of the vessel, away from the hydrogen installation.
					2. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown	Dm				15. To further reduce the likelihood of an undetected hydrogen release, include hydrogen detectors in the design, which are situated directly above the GHUs and associated pipework.
					3. GHU excess flow valve is inside the valve block. Even if this would suffer a full bore failure, it needs to disperse through the valve block casing, which is solid steel.	Mr				
					4. All components of the GHU are integrated in one single solid steel block	Mr				
					5. Train certification used for the GHU block, which poses high demands on vibration	Pr				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					6. Location of GHU selected to reduce length of high pressure pipelines	Mr				
					7. No electrical equipment in area around GHU	Pi				
					8. Control and monitoring system software design based on ISO26262:2 (Road vehicles - Functional Safety) standard	Dm				
					9. Normally not an attended space, apart from routine engine room inspection rounds	Pc				
					10. Persons attending the area to wear personal hydrogen detector	Dm				
	What if there was a failure during nitrogen purging?	1. Human error resulting in full 300 barg N2 release into the system via connection A	1. Potential for overpressurization to fuel cells and pipework that could lead to flying debris	C3	1. Pressure reduction valve on N2 bottle	Pc	L2	Medium	1. There is a potential for the Pressure Reduction Valve (PRV) on the N2 bottle to be forgotten	16. To reduce the risk of overpressurization during nitrogen purging as a result of human error, include fixed Pressure Reduction Valves in between the nitrogen connection points and the system's pipework.
					2. Pressure safety valve between nitrogen purge point and fuel cell	Pc			2. Likelihood is based on frequency of fuel cell maintenance and persons forgetting the PRV on the N2 bottle (existing design)	
					3. Pressure reduction valve between nitrogen purge and fuel cell	Pc				
					4. Ballard accepts the use of nitrogen purging towards the fuel cell	Other				
					5. 2 persons involved in the purging operation	Other				
					6. Nitrogen purging only performed when the fuel cell is taken off the vessel (intended interval is once per 5 years). There is no nitrogen carried onboard	Pr				
			2. Backflow through the hydrogen filters		1. None return valve	Other			1. Not considered a safety risk. Hence no risk ranking	
	What if there was a failure during pressure testing?	1. Incorrect connections made, faulty welds, inadvertent operation of 2nd PRV	1. Potential for flying debris	C3	1. No direct access to 1st Pressure Reduction Valve	Pc	L1	Low		17. To reduce the likelihood of inadvertent overpressurization, include the pressure ratings of all pipework and components on the P&ID.
					2. Both Pressure Reduction Valves are of a fixed spring design	Pc				
					3. The handwheel on the 2nd Pressure Reduction Valve will be taken off, such that it can only be manipulated with tools	Pc				
					4. All pipework and components after the 1st Pressure Reduction Valve, which is set to 22 barg, to be of at least PN40 rating.	Pr				
					5. Fully automated leak detection tests on sections of and the complete system before starting	Dm				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					the hydrogen system and after controlled shutdown					
					6. Normally not an attended space, apart from routine engine room inspection rounds	Pc				
	What if there was a failure of a Pressure Safety Valve?	1. Mechanical failure prevents Pressure Safety Valve from opening	1. Potential for overpressurization of the downstream equipment and pipework with the potential for flying debris	C3	1. Two-stage pressure reduction by design making the supplied pressure to the fuel cells very stable	Pc	L1	Low	1. Low likelihood due to double jeopardy: It requires both the Pressure Safety Valve and the upstream Pressure Reduction Valve to fail for achieve overpressurization of the downstream components and pipework	
					2. All pipework and components after the 1st Pressure Reduction Valve, which is set to 22 barg, to be of at least PN40 rating.	Pr				
					3. Control and monitoring system software design based on ISO26262:2 (Road vehicles - Functional Safety) standard	Dm				
					4. The (inadvertent) opening of a pressure safety valve is a scenario accounted for in the design.	Vr				
	What if there was back pressure from the vent mast?	1. Failure of upstream 22 barg PSV	1. Potential for back pressure on downstream 8 barg PSV		1. Back pressure calculations performed for the sizing of the vent mast. These will be submitted to Class for independent review and approval	Vr			1. Not considered a credible scenario, hence no risk ranking.	
					2. All pipework and components after the 1st Pressure Reduction Valve, which is set to 22 barg, to be of at least PN40 rating.	Pr				
	What if there was a (partial) blockage of the filters or valves?	1. H2 contamination, dust, debris	1. Potential for too low hydrogen supply to fuel cells		1. Control and monitoring system software design based on ISO26262:2 (Road vehicles - Functional Safety) standard	Dm			1. Operational issue, rather than safety issue. Hence no risk ranking.	
					2. Multiple pressure sensors surrounding the filters	Dm				
					3. Fuel cell will automatically shutdown on low pressure	Dm				
	What if there was a failure in the double walled piping?	1. Internal cracks, welding errors, accelerated corrosion	1. Potential for hydrogen leakage via ventilation outlet	C1	1. Double wall pipeline is ventilated by the fuel cell	Vr	L1	Low	1. Hydrogen leakage towards the forward engine room would require a double failure, i.e. both pipewalls need to fail.	18. To fully understand the potential for hydrogen release following a failure in the double walled piping, confirm with the fuel cell manufacturer (Ballard) that the double walled pipeline is ventilated by the fuel cell.
					2. Double wall pipeline is fully welded up to the double walled flanged coupling with the fuel cell.	Pr				19. In case the double walled piping is not ventilated by the fuel cell, inert the annular space with nitrogen and monitor its pressure, with a pressure deviation leading to automatic alarm and controlled shutdown of the hydrogen system.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if there was a failure in the control & monitoring system?	1. Equipment failure	1. Potential for low pressure hydrogen release via ventmast	C1	1. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr	L3	Low	1. Class to investigate whether ISO26262 can be accepted	11. To ensure that the control and monitoring system for the hydrogen system can be approved by Class, Lloyd's Register Class to investigate whether the use of the ISO 26262 Road vehicles Functional Safety standard can be accepted for the software design and architecture.
					2. The vent system is designed for the simultaneous activation of all TPRDs on the hydrogen container, including ignited releases.	Vr			2. Block diagram of control system is not yet available	
					3. Control and monitoring system software design based on ISO26262:2 (Road vehicles - Functional Safety) standard	Dm			3. System is designed to be safe with mechanical systems. No software driven safety functions	
					4. Multiple layers of protection (valves and sensors)	Pc				
					5. All safety critical equipment is mechanical (TPRD, excess flow valves)	Pc				
	What if there was a failure in an auxiliary system (power, instrument air, ventilation of double walled pipe)?	1. Human error, mechanical failure of equipment	1. Failure to supply power, air or ventilation		1. Fail-to-close cylinder valves (i.e. due to loss of instrument air)	Cr			1. Due to the system design, not considered a credible safety risk. Hence no risk ranking	
					2. Fail-to-close solenoid valves (i.e. due to loss of power)	Cr				
					3. Safe start procedure	Other				
					4. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown	Dm				
					5. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
	What if maintenance needs to be completed on the GHU's and associated pipework?	1. Filter replacement of GHU, PSV valve checks	1. Potential for hydrogen leakage due to opening of equipment	C1	1. Double block and bleed arrangement (to be reviewed for correct working)	Pr	L4	Low	1. GHU and safety valves need to be periodically calibrated away from the vessel. If this is not done within the timeframe of the certification, it would expire. This should be included in the planned maintenance schedule of the vessel.	20. To ensure that the fuel cell modules can be safely removed for maintenance purposes without the risk of hydrogen leakages towards the fuel cell room, the double-block-and-bleed arrangements to be updated such that they prevent hydrogen flow towards the removed and/or deactivated fuel cells.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					2. Hydrogen containers are not maintained on the vessel	Pc		🟩	2. For the current double-block-and-bleed arrangements to function properly, the post GHU cross-over, which also includes nitrogen connection A, needs to be removed.	21. To ensure the risk assessments and Class review cover the potential future installation of up to 4 fuel cell modules (800 kW in total), update the P&ID to include the maximum installed configuration.
					3. Risk comes from the residual gas inside the lines, which is minimal	Mr				22. To reduce the likelihood of hydrogen leakages during maintenance activities on the GHUs or fuel cells, the ship's operating procedures to require the hydrogen containers to be fully disconnected and the system bled prior to any maintenance work being carried out. There is no merit in removing the containers themselves, given that they can be carried onboard as ADN cargo. To prevent inadvertent reconnection of the hydrogen supply prior the maintenance work being completed, consider options for tagging-out the air-supply unit to the hydrogen containers, such that the cylinder valves cannot be opened, as well as tagging-out the hydrogen inlet connections.
										23. To reduce the likelihood of the certification of the GHU and Safety Valves expiring, include their periodic calibration in the planned maintenance schedule of the vessel.
	What if safety could be enhanced through the movement / addition of components?	1. Design choices and current status of design	1. Potential for missed opportunities for a more inherently safer design						1. The recommendations provided by the HAZID team are to further reduce risks discussed elsewhere. Hence no risk ranking	24. To permit for swift emergency shutdown of the hydrogen system upon visual fault observations add strategically placed emergency stop buttons along the route taken for the routine forward engine room inspection rounds.
										25. To further reduce the likelihood of cargo impact and dropped objects on the hydrogen containers, the GHUs and their associated pipework, add container guides on the forward cargo hold bulkhead, which are the same height or higher than the hydrogen container guides. The recommended container guides can double as support for the bridge structure under which the GHU's are mounted.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if there was an issue with change / configuration management?	1. None	1. None						1. No scenarios identified that could pose a credible safety risk. Systems designed for the vessel's lifetime, with like-for-like component swap foreseen in case of component failure.	
3. Fuel cells	What if there was a leak event?	1. Leaking coupling, flanges, connections	1. Potential for hydrogen accumulation in fuel cell module and room with the potential for fire	C1	1. Double walled piping up to the Fuel Cell Space, which is inside the fuel cell module	Pc	L4	Low	1. The fuel cell room is to be considered a machinery space, according to article 2.3.9.2 of ES-TRIN	26. To understand the likelihood of an undetected hydrogen release towards the fuel cell room, clarify with the fuel cell manufacturer (Ballard) whether the fuel cell module is monitored by a hydrogen leak detection system inside the cabinet.
					2. Internal area around the fuel cell stacks is classed as a non-hazardous zone	Vt			2. The current IWW regulations include a provisions for only having a single escape route from a machinery space on the condition that the space is below a certain footprint. It is understood that the full cell room will be well below the limit.	27. To understand the likelihood and consequence of an internal hydrogen leak inside the fuel cell module, request from the fuel cell manufacturer (Ballard) the maximum hydrogen concentration inside the process air outlet following any foreseeable purge scenario and compare this against hydrogen's Lower Explosive Limit (LEL) to confirm that the process air outlet can indeed be single walled.
					3. Fuel cell outlet is designed to handle hydrogen quantities, for the fuel stacks frequently purge	Vr			3. In the current regulations, only the outside faces need to be open for over 30% for the space to be classed as open deck. This might be possible but would need to be confirmed	28. To correctly dimension the fixed firefighting system in the fuel cell room, establish the total combustible energy inside room that could be ignited following a hydrogen leak and fire.
					4. The fuel cell room is open to air space, significantly reducing the likelihood of accumulation	Pc			4. If an open deck classification of the fuel cell room cannot be achieved, the fuel cell room should be considered an enclosed space in the design with the fire protection selected accordingly. A safety argument will be required for using a sprinkler based firefighting system. It is duly noted that a gas based firefighting system will not work if there are non-closeable ventilation openings, which is part of the hydrogen safety concept of the design. It is further noted that there is a ventilation requirement for enclosed machinery spaces.	29. To reduce the consequence of a hydrogen leak and fire inside the fuel cell room, add fixed fire detection sensors in the fuel cell room that are interlocked with the hydrogen supply, resulting in an automatic hydrogen supply shutdown upon fire detection.
					5. The fuel cell room is normally not attended. No maintenance activities are foreseen inside the	Pc			5. Review if shutter has fusible link and whether this needs to be there. ES-TRIN doesn't want the fusible links	30. Noting that the fuel cell room will be considered a machinery space according to ES-TRIN, provide a safety justification for only having a single

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					space due to limited footprint and access.			🟩	6. The HAZID team considered the likelihood to be conservative, but assumed it due to the lack of statistics proving otherwise	escape route from the fuel cell room that is based on the planned footprint and access requirements.
	What if there was an external / adjacent fire event / heat source?	1. Engine room fire, cargo fire, funnel fire, hydrogen container fire	1. Potential for ignited hydrogen releases		1. A60 boundaries between the fuel cell room and forward engine room	Pc			1. Discussions during the previous prompt warrant a design update and correct space classification for the fuel cell room. Therefore, the risk ranking has been parked	
					2. Funnel on fuel cell room side is not used for hot engine exhausts but for fuel cell air intake and open ventilation (current design) of the fuel cell room	Pi				
					3. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
					4. No human intervention required if any of the fuel cell parameters goes beyond scope. Automatic controlled shutdown will follow	Pc				
	What if there was a failure in an auxiliary system (power, air, heating / cooling system, ventilation)?	1. Human error, mechanical failure of equipment	1. Potential for fan failure inside the fuel cell module when hydrogen is present	C1	1. The fuel cells used onboard will be Marine Type Approved	Pc	L1	Low	1. The fuel cell does not have means to detect poor (dust, salt) inlet air quality. Poor quality air would impact the fuel cell's power output, but not its safety	
					2. Fail safe design with interlock to the hydrogen container supply valves and the GHUs	Pc				
					3. Backup 24V power supply provided to the fuel cells modules for redundant ventilation purposes	Pc				
					4. Redundant ventilation fans inside fuel cell module	Pc				
					5. The increase in cooling water temperature is a gradual process. Therefore it is reasonable to assume that there will be time for the hydrogen systems to be safely shutdown if the situation requires it	Pc				
					6. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells			🟩		
	What if there was cross-over of hydrogen into the cooling water systems?	1. Internal leakages of heat exchangers	1. Potential for hydrogen accumulation in the cooling water expansion tanks.		1. Parked until clarification is received. If indeed double jeopardy, C1-L1 rating	Other			1. If the fuel cell uses internal cooling circuits that interface with the ship's supplied hot and cold cooling water circuits, it would require a double jeopardy to get hydrogen accumulation in the ship's cooling water expansion tanks.	31. To understand the likelihood of hydrogen crossover into the ship's supplied high and low temperature cooling water circuits, confirm with the fuel cell manufacturer (Ballard) whether the high and low temperature heat exchangers are in direct contact with hydrogen or whether they interface with internal cooling circuits. If there would be a potential for direct hydrogen crossover, the ship's cooling water expansion tanks should be fitted with hydrogen detectors.
					2. The ship supplies high and low temperature cooling water circuits are of a closed loop design. Even if there would be hydrogen including, there arguably won't be sufficient oxygen to react.	Pc				
	What if the systems were affected by the environment?	1. Ambient temperature, condensation, humidity, salt-laden air	1. Potential for internal damage to fuel cells		1. Air filtration supplies pre-heated salt free air to fuel cell	Other			1. Environmental conditions considered an operational concern, rather than an safety concern.	32. To correctly design the fuel cell air supply system and the auxiliary systems servicing the fuel cell room, confirm with the fuel cell manufacturer (Ballard) the operational limitations in terms of environmental conditions.
					2. Fuel cell has own filtration in addition to the filtered air supply	Other				
					3. Operational limits set on external temperatures for fuel cell, due to potential of freezing and condensation risks	Other				
					4. Internal dehumidification process for the fuel cell, that permits it being stored at temperatures down to minus 40dC	Pc				
					5. Maximum permitted operational outside temperature for the fuel cell is 45dC	Other				
					6. Snow, rain and icing impact the reason for using a semi-enclosed space to house the fuel cell modules.	Pc				
					7. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
					1. Perforated roller shutter	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if there was gas accumulation in the systems. Are the hazardous areas identified and suitably managed?	1. Incomplete identification of hazardous areas	1. Potential for insufficient vent arrangements and ventilation that could lead to an accumulation of leaked hydrogen gas		2. Open decorative funnel design on the port side permitting upward flow through the fuel cell room, preventing accumulation of hydrogen underneath the roof of the fuel cell room	Pc			1. Based on an in depth discussion the HAZID team agreed that all potential hazardous areas were fully identified	
					3. Fuel cell modules are considered non-hazardous zones.	Pc				
					4. The fuel cell spaces inside the fuel cell modules are considered non-hazardous zones.	Pc				
	What if there were high vibrations	1. Engine vibrations, thruster vibrations	1. Potential for internal hydrogen leakages due to cracks or loose couplings, potential for fire due to loose electrical connection, potential for loss of cooling water due to hose rupture, etc.		1. The fuel cells used onboard will be Marine Type Approved	Pc			1. High vibrations resulting from propulsion/generator engines and thruster operation were considered by the HAZID team as part of Marine Type Approval for the fuel cells, as these are not unique to this vessel. Hence no risk ranking	6. To fully understand the impact vibrations could have on the safe operation of the fuel cells, request the vibration limits from the fuel cell manufacturer (Ballard) and compare these against the typical vibration levels created by generators and bow thrusters.
					2. Fuel cells are mounted directly on the deck	Other			2. This information should be available to LR from Ballard, which includes vibration tests. The availability needs to be confirmed	
					3. Resilient mounting of generators	Pr				
					4. All pipework will be mounted in resilient clamps	Pr				
	What if there is an issue during start-up / transient conditions?	1. Load increases, variation in supply pressure	1. Potential to trip fuel cells		1. Integrated onboard power management system	Other			1. In the opinion of the HAZID team, the integration of the fuel cell with the onboard power distribution is no different than that of conventionally fuelled generators or batteries. All power supplies have their own ramp time, which need to be set accordingly in the power management system	33. To fully understand the fuel cell's response to Emergency Shut Down (ESD) activation, clarify with the fuel cell manufacturer (Ballard) the sequence following ESD and how this impacts the fuel cell's power output.
					2. Two-stage pressure reduction by design making the supplied pressure to the fuel cells very stable	Pc			2. Not considered a safety issue. Hence no risk ranking	
					3. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc				
	What if maintenance needs to be completed on the fuel	1. Human error	1. Potential for hydrogen release into the fuel cell room	C1	1. Pipework of removed fuel cell will be blanked, permitting parallel fuel cell to be used	Pr	L4	Low	1. Space surrounding the fuel cells is too limited to reasonably conduct any maintenance	22. To reduce the likelihood of hydrogen leakages during maintenance activities on the GHUs or

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	cells and their internal pipework?				2. Excess flow valve in each GHU that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr		🟩	activities. Therefore the current design solution is to lift out the entire fuel module, such that maintenance and revision can take place under controlled conditions on shore	fuel cells, the ship's operating procedures to require the hydrogen containers to be fully disconnected and the system bled prior to any maintenance work being carried out. There is no merit in removing the containers themselves, given that they can be carried onboard as ADN cargo. To prevent inadvertent reconnection of the hydrogen supply prior the maintenance work being completed, consider options for tagging-out the air-supply unit to the hydrogen containers, such that the cylinder valves cannot be opened, as well as tagging-out the hydrogen inlet connections.
					3. Control system	Dm				
					4. Fuel cell space normally not occupied	Pc				
					5. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr				
	What if safety could be enhanced through the movement / addition of components?	1. Design choices and current status of design	1. Potential for missed opportunities for a more inherently safer design		1. Furthest point from accommodation and wheelhouse	Pc			1. The HAZID team's consensus is that, based on all available design parameters, the hydrogen fuel cells are in the best possible location from a risk perspective	
					2. The fuel cell room is normally not an occupied space	Pc				
					3. Shortest possible pipeline connections from GHUs and hydrogen containers	Mr				
	What if there was an issue with change / configuration management?	1. Change of fuel cell supplier	1. Issues with compatibility, other dimensions, other power rates		1. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft each and the hydrogen powered fuel cells	Pc			1. Considered an operation issue. Ship can run without fuel cell and an incompatible fuel cell cannot be commissioned. Hence no risk ranking	
									2. If other manufacturer's fuel cell is also Marine Type Approved and matches the safety criteria set in this HAZID, there should be no additional safety issues with using fuel cells from other manufacturers	
4. Hydrogen container swapping	How will Hazardous Areas, Safety Zones, Security Zones be managed?	1. Insufficient access control to safety zone when swapping hydrogen containers	1. Potential for unauthorised persons, not involved in the swapping operation, accessing the safety zone	C2	1. Terminals and operator are licensed to ship dangerous good containers.	Other	L2	Low	1. Container terminal access is in general managed, but not fully watertight. I.e. persons could potentially walk around.	8. To understand the dimensions of the effect zones and set reliable safety distances, perform dispersion and explosion analyses for the worst credible loss of containment scenarios, including the catastrophic failure of one and multiple hydrogen cylinders.
					2. Existing access control measures in container terminals due to continuous lifting operations	Pc			2. Terminals and operator are licensed to ship dangerous good containers. Hydrogen likely to be loaded on these existing terminals	34. To correctly dimension and set the safety zone for hydrogen container swap operation, base the safety zone's dimensions on the dispersion and explosion analyses, accounting for one laden container dropping out of the crane and bursting all cylinders (worst case scenario)

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
									3. The selected likelihood is based on a 3rd party vessel being present within effect zone, which the HAZID team considered likely less than 1% of time. For the unloading and loading of the hydrogen containers 1 hour was assumed in the likelihood	35. To reduce the consequence of unauthorized access into the safety zone during hydrogen container swapping, the lifting operation should be immediately but safely stopped and the access issue resolved before continuing with the hydrogen container swap operation. 36. To understand the impact that the introduction of a safety zone will have on the container terminal's operation and thereby understand the potential constraints and limitations, request feedback from Contargo on the operating procedures for existing container terminals the vessel intends to attend.
	What if there is differential movement between ship and quay side?	1. Insufficient mooring lines and planning, exceeding of permitted wind conditions, passing traffic	1. Differential motion of vessel and container crane, with the potential for hydrogen cylinders contacting the container guides, vent pipes and hydrogen lines	C3	1. Hydrogen container guides	Pc	L1	Low	1. In the opinion of the HAZID team the risk of differential movement of the ship and quay side is no different as for normal container handling operational, which also have limits imposed 2. The HAZID teams selected the same consequence as for a dropped container but with the lowest likelihood, for it requires a double failure (differential movement and crane operator not correcting in time) for the consequence to be realised.	25. To further reduce the likelihood of cargo impact and dropped objects on the hydrogen containers, the GHUs and their associated pipework, add container guides on the forward cargo hold bulkhead, which are the same height or higher than the hydrogen container guides. The recommended container guides can double as support for the bridge structure under which the GHU's are mounted. 37. To reduce the consequence of a dropped hydrogen container, only permit the crane operator to be present in the safety zone during loading and unloading of the hydrogen containers. The hydrogen containers should only be connected upon completion of the container swap operation.
	What if disconnection has not been completed correctly?	1. Human error	1. See " Hydrogen storage system - What if there was a hydrogen leak on the hydrogen storage lines, valves, cylinders?" node	C1	1. Resulting released volume extremely low due to quick coupling and the cylinder valves closing as soon as the air supply pressure drops 2. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework 3. Crane operator will be away from area of leakage	Mr Mr Pc	L4	Low		
				C1	1. Hydrogen container guides	Pr	L4	Low		

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	What if the hydrogen container contact objects on deck during loading / offloading?	1. Wind gusts, human error, failure of lifting appliances	1. Potential for hydrogen container to contact cargo containers, radar mast and hot exhausts in starboard funnel		2. Radar mast is light aluminum structure	Pr			1. Power plan intention for running on batteries in harbour. However, it can not be excluded that generators are running	
					3. Crane operator will be away from area of leakage	Pc				
					4. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				
	What if the hydrogen container was dropped during loading / offloading?	1. Human error, failure of lifting appliances	1. Hydrogen container dropped from height onto uneven surface	C3	1. All lifting appliances to be certified and operated by suitably qualified and trained personnel	Pr	L3	Medium		37. To reduce the consequence of a dropped hydrogen container, only permit the crane operator to be present in the safety zone during loading and unloading of the hydrogen containers. The hydrogen containers should only be connected upon completion of the container swap operation.
					2. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr				
					3. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				
	What if there was electro-static discharge?	1. Weather conditions	1. Potential for lightning strike that could lead to damage of hydrogen container	C1	1. Visual inspections part of the bunkering process	Dm	L1	Low	1. Simultaneous hydrogen leakage and lightning strike considered to be double jeopardy	38. To reduce the risks associated with electrostatic discharge, the hydrogen container connections are not to be made, apart from the earth connection, when a lightning storm is forecaster or ongoing during the hydrogen container swap.
					2. Weather forecast	Pc				39. To reduce the likelihood of undetected damage to the hydrogen container following a lightning storm, the vessel's operational procedures to include an additional inspection round after the vessel has sailed through a lightning storm.
					3. Automated start-up checks and diagnostics of controller inside the hydrogen container	Dm				
					4. The composite carbon fibre structure of the hydrogen cylinders is a poor conductor	Pc				
					5. The vessel has a hybrid propulsion system combining 4 diesel generators situated inside the forward engine room, 2 redundant battery packages situated in the aft engine room, 2 redundant electric propulsion motors driving a propeller shaft	Pc				

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
					each and the hydrogen powered fuel cells					
	What if connections are not made correctly?	1. Human error	1. No supply of hydrogen possible / potential for small leakage	C1	1. All three connections need to be made properly for the hydrogen delivery valves on the cylinders to open	Pr	L4	Low	1. Debris or damage to connector seals can indeed lead to a hydrogen leakage, which could potentially be audible, but should be picked-up by the automated leak detection tests	
					2. No data connection = No check on valves = Not opening	Pr				
					3. No process air = No pressure to actuate pneumatic valves to open position	Pr				
					4. No hydrogen connection = no hydrogen supply	Pr				
					5. Leak free quick connection coupling used	Mr				
					6. Fully automated leak detection tests on sections of and the complete system before starting the hydrogen system and after controlled shutdown	Dm				
					7. Only one person to attend the installation upon the system detecting a leakage	Pc				
	What if simultaneous operations (SIMOPS) are taking place?	1. Fuel, add blue, urea bunkering at same forward location at deck level	1. Potential for persons in safety zone, potential for adjacent fire		1. All liquid bunkering conducted via hoses (no lifting)	Pc			1. The term Simultaneous Operations (SIMOPS) is generally understood to refer to maritime operations (like cargo handling) that occur simultaneously with the bunkering operation. Although the hydrogen container swap is arguably not a bunkering operation from a technical point of view, in terms of the risk profile and the recognition within the maritime community of elevated risks associated with SIMOPS it can be seen as such. The HAZID team assumed that SIMOPS refers to the swapping of hydrogen containers whilst simultaneously carrying out other maritime operations, like cargo handling.	
					2. No other persons on deck or quay side during container swap	Pc			2. See "Hydrogen container swapping - How will Hazardous Areas, Safety Zones, Security Zones be managed?" node 3. See "Hydrogen storage system - What if there was an external / adjacent fire event / heat source?" node	

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
									4. No additional risk scenarios identified. Hence no risk ranking	
5. Human factors / General risks	General Safety / Are there any additional hazards to persons (manual handling / lifting operations / confined spaces / exposure to high pressures during purging, venting, asphyxiating, hot surfaces)	1. There could be "snapback" from flexible hose housing when connecting and disconnecting the hydrogen container	1. Potential for personal injury	C2			L3	Low		40. To reduce the risk of snapback associated with the (de)coupling under pressure of the hydrogen container, add a safeguard chain and eyelet to the design of the hydrogen container and connecting hoses.
		2. Vertical ladder used to access the hydrogen container deck	1. Potential for fall from height		1. Access only required when coupling the hydrogen containers	Pc			1. The design will follow national / international standards for added fall protection, as well as ES-TRIN guidelines. Hence no risk ranking	
					2. National / International requirements to be followed	Other				
					3. Handrails to extend above the hydrogen container deck to allow for easy transition from ladder to deck	Pc				
	Human Elements / Are there any issues with the understanding / operational of the system including alarms and suitable actions / responses to them? Or unintended operation? Training Requirements / Drills	1. Inadvertent operations, control systems left in manual mode	1. Potential for delayed or incorrect response.		1. No manual mode on the hydrogen control system	Pc			1. The recommendations provided by the HAZID team are to further reduce risks discussed elsewhere. Hence no risk ranking	41. To reduce the risk of inadvertent continued operation of the hydrogen system, include in the ship's operational procedures and training clear guidance on the reasonably foreseeable emergency situations that are unrelated to the hydrogen system, under which the hydrogen system is permitted to continue operating and under which conditions a controlled shutdown should immediately be initiated.
					2. In case of emergency situations not related to the hydrogen, the hydrogen system will be permitted to continue running, with manual deactivation if situation escalates. The fuel cell power could assist the vessel reaching save haven	Other				42. To reduce the risk of extinguishing a hydrogen fire before the source is isolated provide clear indication, close to the fire control panel on the navigational bridge, on when to manually activate the boundary cooling system for the hydrogen containers. For power continuity purposes, manual activation of the boundary cooling system should not automatically lead to a full shutdown of the hydrogen system.
					3. No alarms foreseen in the hydrogen system that would require direct intervention from the captain or watchkeeper	Other				43. To reduce the likelihood of a delayed response to a fire adjacent to the hydrogen containers, interlock the boundary cooling system activation with the activation of the forward engine room and fuel cell room fire alarms.

Node	What If Questions	Causes	Consequences	C	Safeguards	Type	L	RR	Remarks	Recommendations
	LSA, Escape, Evacuation and Rescue	1. No additional risks identified to those discussed above	1. None							
	Unauthorised access	1. Vessel moored with no persons in attendance on the navigational bridge	1. Potential for unauthorised access to hydrogen system, i.e. due to curiosity, industrial action, criminal intent or terrorism		1. Container terminals run access control due to lifting operations	Pc			1. Given that the highest risk is associated with the hydrogen storage, rather than the fuel cell, it is considered acceptable to keep the hydrogen system running when berthed with no-one in attendance on the navigational bridge	
					2. No human intervention required if any of the fuel cell parameters goes beyond scope. Automatic controlled shutdown will follow.	Pc			2. It is understood that the control and mitigation of criminal and terrorism activities are the prerogative of the State. In the HAZID teams opinion, all reasonable precautions have been taken to minimise the consequence of inadvertent system operations with suitable mechanical safeguards in place.	
					3. No manual mode on the hydrogen control system	Pc				
					4. The hydrogen containers are subjected to a bonfire test whilst under pressure. These tests showcase that a fire directly underneath the hydrogen cylinder would not lead to an explosion event	Pc				
					5. The hydrogen cylinders are subjected to ballistic tests whilst under the operation pressure of 500 barg. Even when penetrated by a large caliber round, this doesn't lead to an explosion event.	Pc				
					6. Excess flow valves in each hydrogen cylinder (1.3 gram/second) that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr				
					7. Excess flow valve in each GHU that would close in case of full bore rupture / inadvertent opening of downstream pipework	Mr				
					8. All three connections need to be made properly for the hydrogen delivery valves on the cylinders to open	Pr				

Appendix 2 HAZID recommendations (full list)

The complete list of HAZID recommendations is given below.

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	1. To understand the credibility of a 2nd tier hydrogen container falling overboard or onto the adjacent hydrogen container stack, investigate the maximum credible weather induced, vessel roll angles and compare these against the vessel's stability calculations. Additional information could potentially be gathered from design criteria for twistlocks and ADR regulations. Alternatively, interviews with experienced captains could be conducted.	Consequences: 1.1.1.1		No comments received
Low	2. To understand the risks associated with high vibration loads on the hydrogen container, make a comparison of marine vibrations against the design acceleration requirements for road transport. If this comparison shows that road design acceleration requirements are larger, no further investigation would be required.	Consequences: 1.1.1.2		No comments received
Low	3. To reduce the likelihood of water ingress into and icing of the high-pressure vent line, place a plastic vent cap on the top of the vent line.	Consequences: 1.2.1.2, 1.2.1.3		No comments received
Medium	4. To assess the likelihood of personnel being present in the bow area at the time of a ship collision, review the frequency, duration and staffing requirements for routine engine room and hydrogen system inspection rounds.	Consequences: 1.3.1.1		No comments received
Medium	5. To reduce the likelihood of bridge allisions, the crew and cargo planning office should assume the top of the 2nd hydrogen container as the minimum air draft of the vessel in their route and cargo planning. Where this would lead to conflict, special consideration could be given for	Consequences: 1.3.2.1, 1.3.2.2		LR Class 20/01/2023: Vessel is foreseen to have a " bridge-scout system", set to protect the top of the H2 cartridges

RR	Recommendation	Place(s) used	Responsibility	Comments
	tides and the actual presence of the 2nd hydrogen container tier on that particular voyage.			
Low	6. To fully understand the impact vibrations could have on the safe operation of the fuel cells, request the vibration limits from the fuel cell manufacturer (Ballard) and compare these against the typical vibration levels created by generators and bow thrusters.	Consequences: 1.6.1.1, 3.7.1.1		No comments received
Medium	7. To reduce the likelihood of dropped objects on the hydrogen containers, no cargo or provision lifting operations should be conducted over the hydrogen containers.	Consequences: 1.9.1.1		No comments received
Low	8. To understand the dimensions of the effect zones and set reliable safety distances, perform dispersion and explosion analyses for the worst credible loss of containment scenarios, including the catastrophic failure of one and multiple hydrogen cylinders.	Consequences: 1.9.1.1, 4.1.1.1		No comments received
Medium	9. To reduce the consequence of dropped objects on the hydrogen containers, minimise the persons on deck and on the quayside when loading/unloading container cargo bay 1.	Consequences: 1.9.1.1		No comments received
Medium	10. To reduce the likelihood of an external fire impacting the hydrogen containers, include a suitable boundary cooling system for the hydrogen containers that can be activated remotely, in line with the forthcoming ESTRIN guidelines for hydrogen storage.	Consequences: 1.12.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	11. To ensure that the control and monitoring system for the hydrogen system can be approved by Class, Lloyd's Register Class to investigate whether the use of the ISO 26262 Road vehicles Functional Safety standard can be accepted for the software design and architecture.	Consequences: 1.14.1.1, 2.8.1.1		No comments received
	12. To prepare for future industrial suppliers of hydrogen containers, equivalent safety levels to be required for 3rd party hydrogen containers to be used on board, including but not limited to fully compatible connectors without the need for adapters.	Consequences: 1.18.1.1		No comments received
	13. To prepare for future industrial suppliers of hydrogen containers, Lloyd's Register Class to investigate the routes for acceptance, including but not limited to the requirements for future inspections of these 3rd party hydrogen containers.	Consequences: 1.18.1.1		No comments received
Medium	14. To further reduce the likelihood of ignited hydrogen leakages, no reefer containers to be carried in the first cargo bay, with their connectors to be situated on the side of the vessel, away from the hydrogen installation.	Consequences: 2.1.1.1		No comments received
Medium	15. To further reduce the likelihood of an undetected hydrogen release, include hydrogen detectors in the design, which are situated directly above the GHUs and associated pipework.	Consequences: 2.1.1.1		No comments received
Medium	16. To reduce the risk of overpressurization during nitrogen purging as a result of human error, include fixed Pressure Reduction Valves in between the nitrogen connection points and the system's pipework.	Consequences: 2.2.1.1		No comments received
Low	17. To reduce the likelihood of inadvertent overpressurization, include the pressure ratings of all pipework and components on the P&ID.	Consequences: 2.3.1.1		**LR TID 19/01/2023:** Submit the matrix for the equipment / component design details to LR. These should include:

RR	Recommendation	Place(s) used	Responsibility	Comments
				- Design Temperatures, Pressures, MAWPs, Working Temperatures / Pressures, Material Specifications, Design and Certification Standards, Design Life.
Low	18. To fully understand the potential for hydrogen release following a failure in the double walled piping, confirm with the fuel cell manufacturer (Ballard) that the double walled pipeline is ventilated by the fuel cell.	Consequences: 2.7.1.1		No comments received
Low	19. In case the double walled piping is not ventilated by the fuel cell, inert the annular space with nitrogen and monitor its pressure, with a pressure deviation leading to automatic alarm and controlled shutdown of the hydrogen system.	Consequences: 2.7.1.1		No comments received
Low	20. To ensure that the fuel cell modules can be safely removed for maintenance purposes without the risk of hydrogen leakages towards the fuel cell room, the double-block-and-bleed arrangements to be updated such that they prevent hydrogen flow towards the removed and/or deactivated fuel cells.	Consequences: 2.10.1.1		No comments received
Low	21. To ensure the risk assessments and Class review cover the potential future installation of up to 4 fuel cell modules (800 kW in total), update the P&ID to include the maximum installed configuration.	Consequences: 2.10.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	22. To reduce the likelihood of hydrogen leakages during maintenance activities on the GHUs or fuel cells, the ship's operating procedures to require the hydrogen containers to be fully disconnected and the system bled prior to any maintenance work being carried out. There is no merit in removing the containers themselves, given that they can be carried onboard as ADN cargo. To prevent inadvertent reconnection of the hydrogen supply prior the maintenance work being completed, consider options for tagging-out the air-supply unit to the hydrogen containers, such that the cylinder valves cannot be opened, as well as tagging-out the hydrogen inlet connections.	Consequences: 2.10.1.1, 3.9.1.1		No comments received
Low	23. To reduce the likelihood of the certification of the GHU and Safety Valves expiring, include their periodic calibration in the planned maintenance schedule of the vessel.	Consequences: 2.10.1.1		**LR TID 19/01/2023:** The RBC-5 document should consider the in-service inspection of the GHUs and PSVs.
	24. To permit for swift emergency shutdown of the hydrogen system upon visual fault observations add strategically placed emergency stop buttons along the route taken for the routine forward engine room inspection rounds.	Consequences: 2.11.1.1		No comments received
Low	25. To further reduce the likelihood of cargo impact and dropped objects on the hydrogen containers, the GHUs and their associated pipework, add container guides on the forward cargo hold bulkhead, which are the same height or higher than the hydrogen container guides. The recommended container guides can double as support for the bridge structure under which the GHU's are mounted.	Consequences: 2.11.1.1, 4.2.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	26. To understand the likelihood of an undetected hydrogen release towards the fuel cell room, clarify with the fuel cell manufacturer (Ballard) whether the fuel cell module is monitored by a hydrogen leak detection system inside the cabinet.	Consequences: 3.1.1.1		No comments received
Low	27. To understand the likelihood and consequence of an internal hydrogen leak inside the fuel cell module, request from the fuel cell manufacturer (Ballard) the maximum hydrogen concentration inside the process air outlet following any foreseeable purge scenario and compare this against hydrogen's Lower Explosive Limit (LEL) to confirm that the process air outlet can indeed be single walled.	Consequences: 3.1.1.1		No comments received
Low	28. To correctly dimension the fixed firefighting system in the fuel cell room, establish the total combustible energy inside room that could be ignited following a hydrogen leak and fire.	Consequences: 3.1.1.1		No comments received
Low	29. To reduce the consequence of a hydrogen leak and fire inside the fuel cell room, add fixed fire detection sensors in the fuel cell room that are interlocked with the hydrogen supply, resulting in an automatic hydrogen supply shutdown upon fire detection.	Consequences: 3.1.1.1		No comments received
Low	30. Noting that the fuel cell room will be considered a machinery space according to ESTRIN, provide a safety justification for only having a single escape route from the fuel cell room that is based on the planned footprint and access requirements.	Consequences: 3.1.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
	31. To understand the likelihood of hydrogen crossover into the ship's supplied high and low temperature cooling water circuits, confirm with the fuel cell manufacturer (Ballard) whether the high and low temperature heat exchangers are in direct contact with hydrogen or whether they interface with internal cooling circuits. If there would be a potential for direct hydrogen crossover, the ship's cooling water expansion tanks should be fitted with hydrogen detectors.	Consequences: 3.4.1.1		No comments received
	32. To correctly design the fuel cell air supply system and the auxiliary systems servicing the fuel cell room, confirm with the fuel cell manufacturer (Ballard) the operational limitations in terms of environmental conditions.	Consequences: 3.5.1.1		No comments received
	33. To fully understand the fuel cell's response to Emergency Shut Down (ESD) activation, clarify with the fuel cell manufacturer (Ballard) the sequence following ESD and how this impacts the fuel cell's power output.	Consequences: 3.8.1.1		No comments received
Low	34. To correctly dimension and set the safety zone for hydrogen container swap operation, base the safety zone's dimensions on the dispersion and explosion analyses, accounting for one laden container dropping out of the crane and bursting all cylinders (worst case scenario)	Consequences: 4.1.1.1		No comments received
Low	35. To reduce the consequence of unauthorized access into the safety zone during hydrogen container swapping, the lifting operation should be immediately but safely stopped and the access issue resolved before continuing with the hydrogen container swap operation.	Consequences: 4.1.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
Low	36. To understand the impact that the introduction of a safety zone will have on the container terminal's operation and thereby understand the potential constraints and limitations, request feedback from Contargo on the operating procedures for existing container terminals the vessel intends to attend.	Consequences: 4.1.1.1		No comments received
Low	37. To reduce the consequence of a dropped hydrogen container, only permit the crane operator to be present in the safety zone during loading and unloading of the hydrogen containers. The hydrogen containers should only be connected upon completion of the container swap operation.	Consequences: 4.2.1.1, 4.5.1.1		No comments received
Low	38. To reduce the risks associated with electrostatic discharge, the hydrogen container connections are not to be made, apart from the earth connection, when a lightning storm is forecaster or ongoing during the hydrogen container swap.	Consequences: 4.6.1.1		No comments received
Low	39. To reduce the likelihood of undetected damage to the hydrogen container following a lightning storm, the vessel's operational procedures to include an additional inspection round after the vessel has sailed through a lightning storm.	Consequences: 4.6.1.1		No comments received
Low	40. To reduce the risk of snapback associated with the (de)coupling under pressure of the hydrogen container, add a safeguard chain and eyelet to the design of the hydrogen container and connecting hoses.	Consequences: 5.1.1.1		No comments received

RR	Recommendation	Place(s) used	Responsibility	Comments
	41. To reduce the risk of inadvertent continued operation of the hydrogen system, include in the ship's operational procedures and training clear guidance on the reasonably foreseeable emergency situations that are unrelated to the hydrogen system, under which the hydrogen system is permitted to continue operating and under which conditions a controlled shutdown should immediately be initiated.	Consequences: 5.2.1.1		No comments received
	42. To reduce the risk of extinguishing a hydrogen fire before the source is isolated provide clear indication, close to the fire control panel on the navigational bridge, on when to manually activate the boundary cooling system for the hydrogen containers. For power continuity purposes, manual activation of the boundary cooling system should not automatically lead to a full shutdown of the hydrogen system.	Consequences: 5.2.1.1		No comments received
	43. To reduce the likelihood of a delayed response to a fire adjacent to the hydrogen containers, interlock the boundary cooling system activation with the activation of the forward engine room and fuel cell room fire alarms.	Consequences: 5.2.1.1		No comments received

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Annex III

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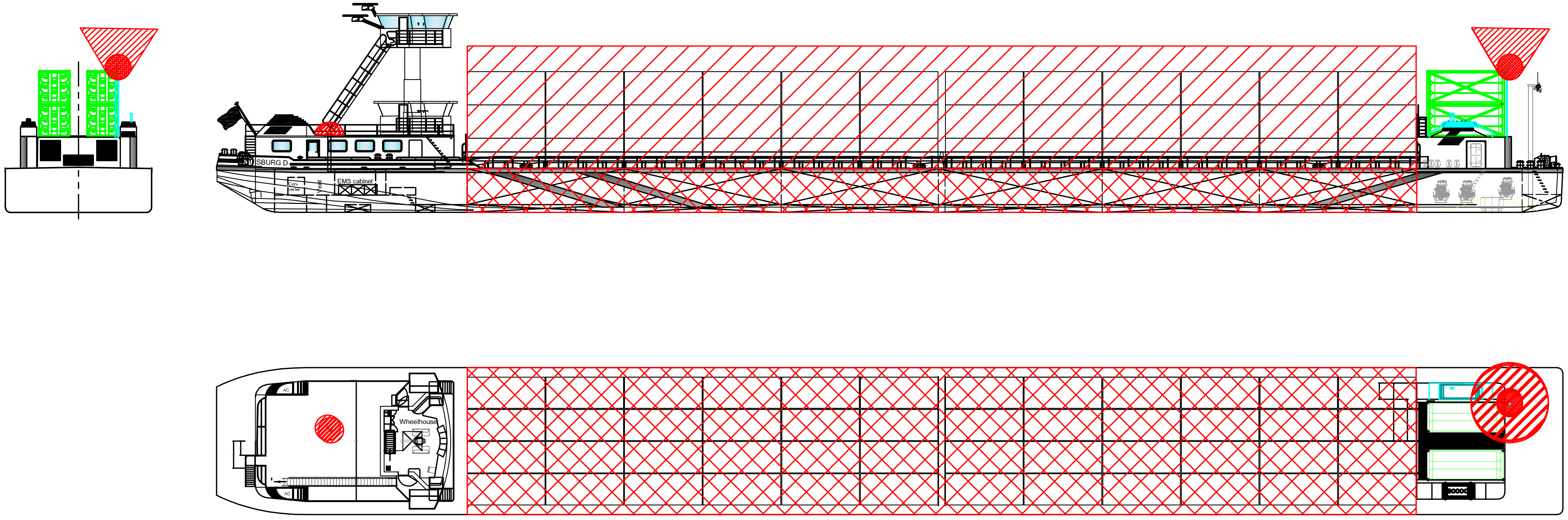

Zone 0:
Bereich, in dem explosionsfähige Atmosphäre als Gemisch aus Luft und brennbaren Gasen, Dämpfen oder Nebeln ständig, über lange Zeiträume oder häufig vorhanden ist.

Zone 1:
Bereich, in dem sich bei Normalbetrieb gelegentlich eine explosionsfähige Atmosphäre als Gemisch aus Luft und brennbaren Gasen, Dämpfen oder Nebeln bilden kann.

Zone 2:
Bereich, in dem bei Normalbetrieb eine explosionsfähige Atmosphäre als Gemisch aus Luft und brennbaren Gasen, Dämpfen oder Nebeln normalerweise nicht oder aber nur kurzzeitig auftritt


Vorsicht
Druckgasbehälter

REV	CHANGES	DATE	GEZ
02	ATEX zone added In the cargo hold	05.10.2023	RP
01	Exhaust modified	03.05.2023	RP
00	Customers Drawing	09.09.2022	RP

APPROVED –
CHECKED –
DRAWED RP
DATE: 09.09.2022

Explosion protection zone plan ship
B-22-05-08 Den Breejen, Rhenus H2-Schubschiff

FORMAT
A3

ARGO ANLEG
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Sheet 1 of 1

Annex IV

Rhenus Mannheim H_2 System - Tanktainer (H2 Storage Container) swapping procedure

Requirements:

1. Crew is instructed in the operation
2. Reachstacker/container spreader/crane system is on site and is permitted to transport the 16 t Tanktainer
3. Good weather conditions
4. Ship is safely moored ashore
5. Vessel properly earthed at the shoreside

Disconnection of H_2-Tanktainer

1. Switching off the fuel cell
2. Starting of the electrical disconnection procedure at the H_2 systems PLC out of the wheelhouse
3. Visual inspection on damages
4. Closing of the manual Tanktainer main valve
5. Disconnecting of the pneumatic lines
6. Securing of working air supply line at the desired space to prevent damages due crane operations
7. Disconnecting of H_2 line (due to a dedicated dry quick coupling connection no H2 will be released)
8. Securing of flexible H_2 line at the desired space to prevent damages due crane operations
9. Disconnecting of H_2 vent lines
10. Securing of flexible H_2 vent lines at the desired space to prevent damages due crane operations
11. Disconnection of the data cable
12. Securing of Data cable at the desired space to prevent damages due crane operations
13. Disconnection of the earthing connector (Vessel - Tanktainer)
14. Securing of earthing cable at the desired space to prevent damages due crane operations
15. Open Tanktainer Safety Locking mechanism
16. Leaving the fore deck area for a safe crane operations

Swapping of H_2-Tanktainer

1. Filled Tanktainer were delivered to the dangerous goods area of the terminal
2. Visual inspection of the delivered Tanktainer on shore before lifting
3. Communication between vessel-crane operator to ensure a proper disconnection from the vessel and the crew to be outside the dangerous area before the lifting operation can start
4. Lifting of empty Tanktainers off the vessel and transferring them into the dangerous goods area
5. Lifting of filled Tanktainers from the dangerous goods area to the dedicated Tanktainer positions
6. Communication between vessel-crane operator to confirm a completed lifting operation

Connection of H_2-Tanktainer

1. Securing the Tanktainers on board
2. Optical inspection of all connectors on pollution or damage
3. Connecting of the earthing cable (vessel – Tanktainer)
4. Connection of the data cable
5. Connection of H_2- vent lines
6. Connection of H_2 line
7. Connection of working air supply line
8. Optical inspection of all connectors to ensure a proper connection
9. Opening of the manual Tanktainer main valve
10. Leaving the fore deck area for a safe electrical start-up procedure
11. Starting of the connection/start-up procedure at the H_2 systems PLC out of the wheelhouse
12. Checking the measurements and status report on the data logger /controller

Annex V

Rhenus Mannheim H_2 System – Training concept

General

The training concept is designed to enable a shipmaster and persons familiar with hydrogen systems (e.g. workplace safety employee, safety exercise instructors, inspectors) to become expert knowledge persons, who can carry out:

- Periodically schooling of the crew
- Schooling for new crew members
- Schooling for external technicians

Handout documentation will also be provided for this purpose.

The training course for the expert knowledge of a hydrogen system includes

- a theoretical training and
- a practical training.

The course is successfully completed when the final examination is passed. The final examination consists of a theoretical and a practical part. The training provider issues a certificate of successful completion of the training course.
The theoretical part of the examination is passed if the examinee has answered at least 80 percent of the examination questions correctly.
The practical part of the examination is passed if the examinee has successfully passed the practical examination for obtaining the Union Certificate of Competency for H_2.

The practical part of the examination shall be taken on board the GMS RHENUS MANNHEIM or wholly or partly on a shore installation which meets the technical requirements of the hydrogen system of the GMS RHENUS MANNHEIM.

Trainings are conducted by Argo-Anleg GmbH, the manufacturer and supplier of the H_2 system.

A training course held by an accredited school does not seem to make sense, since such a system is not currently common in the shipping industry and no technical standard is yet available to put together a universally valid training based on it.
We envision that training would be provided to become an expert on a hydrogen system. This could be a shipmaster, a specialist for work safety or external persons who maintain or repair hydrogen systems. These trained experts are qualified to instruct crew members or other persons.
Handout documentation is also provided for this purpose.

Training as an expert for a hydrogen system

- Theoretical education (8 h)
    - General information regarding the special properties of hydrogen (knowledge of definition, composition, safety data sheet, physical properties, environmental properties, storage temperature, flash point, explosion limits, pressure properties).
    - General information on relevant legislation and standards (RheinSchPV, technical regulations)
    - General information on relevant health and safety regulations (use of personal protective equipment, safety documentation, operating instructions, safety equipment, behavior in case of emergencies or accidents).
    - Knowledge of the provisions of the special approval of the hydrogen system (operation of the system, labeling, safety plans, safety tasks, fire safety regulations, detection of faults, maintenance intervals and monitoring of the system, malfunctions, and alarms, changing Tanktainers, ventilation system, behavior in the event of an accident)

- Practical education (16 h)
    - Guide for portable H 2-Detector
    - Handling H2 detector handheld, leakage detection
    - Commissioning and shutdown of the plant
    - Maintenance of the equipment (air filter, self-test, visual inspections)
    - replacement of Tanktainers and connection procedures (mooring of the vehicle, activities of the crew, removal of the crew)
    - Restart and reset of the system
    - Standard troubleshooting
    - Advanced troubleshooting
    - Briefing of technicians and other visitors on board
    - Briefing and instruction of the crew