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Economic and Social Council

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

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

Transmitted by the Government of the Netherlands

Annexes to document ECE/TRANS/WP.15/AC.2/2024/31

Annex I

Project MS ANTONIE

Hydrogen fuel system

Table of contents

1. Abbreviations and definitions

1.1 Abbreviations

ESD	Emergency Shut Down
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation Vessels
GA	General arrangement drawings
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
LR	Lloyd's Register
MEGC	Multiple Element Gas Container
PFDs	process flow diagrams
RBC	Risk Based Certification
SoC	State of Charge

1.2 Reference documents

	Number	Name	Revi-sion	Con-cept	Reason
1	3355-CS882-000-001	General Arrangement	4	No	-
2	3355-CS882-000-003	Safety Plan	2	No	-
3	3355-CS882-000-004	Zone Plan	1	Yes	Additional studies ongoing
4	3355-CS882-000-005	Division Area	-	No	-
5	3355-CS882-000-007	Ventilation diagram Foreship	1	Yes	Additional studies ongoing
6	3355-CS882-009	P&ID overall	2	No	-
7	B2001-100-03	MEGC Storage PID	2	No	-
8	S020005	Distribution panel	3	No	-
9	S020004	SRGDG 300 Fuel Cell installation	1	No	-
10	3355-CS882-000-010	Ship Main System	-	No	-
11	BV2100-120	MEGC GA	-	No	-
12	20221012	H2 unloading-loading Method	-	Yes	Additional studies ongoing
13	-	GAP analysis against ES-TRIN 2023	3	No	-
14	-	Risk Assessment Study report, Annex A - HAZID attendance list signed & Annex B - HAZID work-sheet	1	No	-
15	-	Training and education manual	1	Yes	First draft

2. Introduction

The use of a hydrogen system to power the vessel is seen as new/novel. The scope of this document is to inform relevant stakeholders about the principle design, identified risks and corresponding mitigations. The principal purpose and function of the design is: Provision of hydrogen storage and supply to fuel cell system for main electric power for inland waterways, dry cargo vessel “Antonie”.

3. Project/ design description

This project concerns the design, building and outfitting of a hydrogen driven inland waterways dry cargo-container vessel. The main dimensions will be 135x11,45x 3,75 m. The owner, Lenten Scheepvaart has a 10-year contract for transporting salt from Delfzijl to Rotterdam Botlek. Most of the time the vessel will sail the same route. A normal roundtrip will take approximately 5 days.

The vessel is designed with one cargo hold and will be loaded and unloaded in a pre-defined sequence, loading will take place in Delfzijl, unloading in Rotterdam-Botlek. At the present, the owner has a 110x11,45 m dry cargo vessel with which he does the same work as he will be doing with his new vessel (both vessels are named Antonie).
The designing of the vessel was done according ES-TRIN 2023. The vessel will be executed as a double propelled vessel (as required by ES-TRIN) and fitted with two bow thrusters. The vessel is built as a complete double hull vessel which makes the ship “unsinkable” according Class and ES-TRIN regulation.

The vessel will be fitted with hydrogen electrical propulsion. During the design of the vessel the choice was made to situate all hydrogen equipment on the foreship, all crew areas, thus also the wheelhouse are situated on the aft ship.
For determining the correct configuration of the propulsion, the owner monitored his energy use sailing the roundtrip Delfzijl-Rotterdam-Delfzijl. Based on the required data the vessel is designed with one Fuel Cell, three MEGC’s and a battery pack of 1.100kWh. Power/energy needed for the complete vessel (propulsion and hotel load) is generated by a 300 kWh Hydrogen Fuel Cell. The energy generated from the Fuel Cell is stored in a battery pack of 1.100 kWh. This battery pack is also situated on the foreship. The complete vessel (propulsion, bowthruster, all navigation equipment and hotel load) is fed from this battery pack. The battery pack also stores the backup power and peak power of the ship.

The hydrogen needed for running the Fuel Cell is stored in three MEGC which are stored in the hydrogen storage area in open air. While sailing his roundtrip, three other MEGC’s are filled with hydrogen. After finishing the roundtrip, the MEGC’s will be swapped. The MEGC’s will be loaded and unloaded by a crane when the vessel is safely moored alongside a quay (reference is made to H2 unloading-loading method).

The MEGC hold approximately 400 kg hydrogen each, with a pressure of 350 bars. The supply of hydrogen to the Fuel Cell is distributed through a hydrogen distribution panel which is situated in the same area as the MEGC’s.

On the aft ship a (backup) diesel driven, generator is placed. In case of an emergency, failure or additional power request, this generator will supply the necessary additional energy. The vessel will also be able to safely sail on only the diesel generator

Reference documents:

- *General Arrangement (doc. 1)*
- *Zone Plan (doc. 3)*
- *Division Area (doc. 4)*
- *P&ID overall (doc 6)*
- *MEGC Storage PID (doc 7)*
- *Distribution panel (doc. 8)*
- *SRGDG 300 Fuel Cell installation (doc. 9)*
- *Ship Main System (doc. 10)*
- *MEGC GA (doc. 11)*
- *H2 unloading-loading Method (doc.12)*

3.1 GAP analysis

Goal-based requirements need to be satisfied. Where the intention is to deviate from a specific prescriptive requirement then this will be highlighted with a clear description of how the intent of the requirement is to be satisfied.

Reference is made to the GAP analysis against ES-TRIN 2023 (Chapter 30 and Annex 8). The identified deviations will be supported by a supporting study. If during/after the HAZID session other possible deviations will be identified/proposed, these will be supported by supporting study, and will be updated in the PAR document.

Reference documents:

- *GAP analysis against ES-TRIN 2023 (doc.13)*

4. Safety philosophy MS Antonie (CS882)

With reference to general arrangement drawings (GAs) and, where applicable, process flow diagrams (PFDs), describe the basis for safety. For example, the means to identify any malfunction and how persons are protected from harm.

Where appropriate, the basis for safety needs to cover the dependability of essential services; for example, services to maintain propulsion, the failure of which could lead to ship collision and harm to persons.

4.1 Safety of Crew

It is considered that the health of crew may be affected by injuries due to jet fire, pool fire, flash fire, deflagration, detonation, asphyxiation caused by compressed hydrogen leakage. Cryogenic burns and hypothermia are not considered because the hydrogen is stored on board only in gas status.

The risks and hazards of hydrogen explosive atmosphere which may lead to fire and explosion are mitigated as follows:

- On board only compressed hydrogen which being lighter than air can be easily diluted and it is represented by very narrow explosive vapour having no interferences with deck equipment.
- Hydrogen storage containers located in open space provided with natural ventilation enforced by wind during navigation avoiding accumulation of hydrogen cloud in confined space.
- Each cylinders rack (located inside MEGC) provided with high pressure relief system able to discharge safely hydrogen to the atmosphere.
- Each cylinders rack (located inside MEGC) provided with temperature activated pressure relief system able to discharge safely hydrogen to the atmosphere.
- Safety distances of accommodation and crew service spaces from hazardous zones.
- Remote control of fuel cell modules, battery system and hydrogen containment/supply system allowing unattended machinery spaces during normal operation.
- Intrinsically safe fuel cell modules where hydrogen release can be safely detected and diluted with dedicated ventilation.
- Intrinsically safe battery system with very low probability for thermal runaway occurrence.
- Hydrogen rooms only temporary accessed for mobilization of hydrogen storage containers and security patrolling.
- Safety of navigation not impaired by containers located 100 m from wheelhouse.
- Hydrogen supply at very low pressure in the fuel cell room (0,3 bar).
- All hydrogen gas leakages can be safely detected and diluted in the fuel cell space.
- Restricted access to hydrogen storage spaces and fuel cell room only by trained crew with proper PPE.
- Early detection of explosive atmosphere is granted with visible and acoustic alarm at 20% LEL (Lower Explosive Limit) and emergency shutdown at 40% LEL.
- Fire detection system (e.g. flame detectors) leading to alarms and triggering of emergency shut down.

4.2 Safety of the Ship

The functional failures of the hydrogen storage/supply and fuel cell system have no impact on the safe operation of the vessel and all emergency shutdowns initiated by safety system will never lead to loss of propulsion or power on board, hazards and risks which may potentially impact upon the dependability of essential services are also assessed during the risk assessment and they are mitigated as follows:

- E-motors coupled to the shaft lines can be provided with power from auxiliary generator and battery system.
- Ship fitted with 1x auxiliary generator of 602 KW in engine room on the aft ship.
- Auxiliary generator power able to satisfy propulsion and hotel power demand.
- Ship fitted with 1x battery system of 1.100 kW/h.
- When battery runs low 25% an alarm will be activated.
- SoC (state of charge) of battery system controlled for having power redundancy in case of emergency operation (loss of fuel cell room).
- Battery room will be constructed according to existing ES-TRIN requirements.
- Navigation visibility not obstructed by hydrogen storage containers.
- Hydrogen storage containers and fuel cell room protected by double side and double bottom.
- All hydrogen hazards like brittle fracture, ortho-hydrogen to para-hydrogen transition, roll-over, solidification of gases (e.g. oxygen, nitrogen), oxygen enrichment, thermal expansion and contraction are considered not applicable for compressed hydrogen storage system.
- Hydrogen cylinders designed and tested according to international recognized standard taking into account hydrogen embrittlement and high temperature hydrogen attack.
- All piping including connections, couplings, seals, gaskets, welds, valves designed and tested according to international recognized standard for hydrogen application in order to minimise leakage occurrence.

4.3 Safety for Surroundings

Basic idea is similar as item 1, make sure people stay (far) away from the hydrogen area. Establish where it is safe to moor the vessel and where the it is better not to moor. Notify vessels surroundings (by sign) that the vessel is sailing on hydrogen. Safety and security zones assessment will be established on the basis of a worst leakage scenario foreseen for 3 possible conditions:

- Sudden release of hydrogen through vent mast during navigation;
- Sudden release of hydrogen through vent mast during stay at port;
- Hydrogen leakage during containers mobilisation.

4.4 Safety during loading/off-loading hydrogen storage containers

Safe means for disconnecting the containers and connecting the full containers. Only certified personnel is allowed to swap the containers. Area to be foreseen where uncertified persons are not allowed to enter. Only the minimum number of persons who need to be in this area, whereas they are involved in swapping the hydrogen storage container, are allowed to enter the area. Swapping to be executed in dedicated area.

4.5 Total quantity of Hydrogen

Three full MEGCs on board will have a total of 1200 kg hydrogen. If a fourth MEGC to be loaded on bord a total quantity of hydrogen will be 1600 kg. When MEGCs are “empty” there will still be a small quantity of hydrogen will still be present.

4.6 Safety of the cargo.

To keep ADN goods safe the ADN goods may not be located in a part of the Cargo hold that can be affected by the hydrogen installation. ADN goods could in the event of an accident with the hydrogen installation be affected if they are located to close to the MEGC area (location where hydrogen storage containers are placed).

Accidents that may occur are leakages (worst case full born pipe rupture), vent off due to overpressure in the hydrogen cylinders (PV-valves venting of) and vent off due to fire in the area of the Hydrogen installation (TPRD's venting off). Worst case scenario of the three above mentioned is the case of TPRD's venting off (established during Hazid and additional studies).
To prevent above accidents from happening and/or affecting the ADN goods, various mitigating measures have been applied:

- Steel bulkhead between Cargo hold and MEGC area.
- Steel bulkhead on the aft side of the MEGC's creating a second barrier to the cargo hold.
- Sprinkler installation in MEGC area to prevent overheating of the cylinders, thus preventing TPRD's tripping.
- Flooding possibility of MEGC area, preventing fire within foreship area's (bow thruster rooms, battery room, electrical room and fuel cell room) affecting the MEGS's an thus preventing vent off.
- Manual firefighting possibilities with the on board firefighting pump and the hoses and nozzles connected to this.

To keep the cargo safe, worst case scenario TPRD's venting of and igniting of the hydrogen causing heat radiation was calculated by RINA (Consequence assessment of H2 release plume and heat radiation Doc. No. P0035587-H1 Rev. 2 – July 2023).
Based on these calculations a safety distance from AND goods to the MEGC area is established. AND goods have to be kept out of the, by heat radiation affected, dangerous zone. Safe zone is considered as a maximum heat radiation of 1.6 kW/m^2. Practically this means no AND containers to be stored in position 1, 2, 3 and 4.
In added drawing, "3355-000-AND Safety Distance", safe distance is shown.
Also added the RINA report mentioned above.

4.7 Main Risks

Table 1, Hydrogen release to atmosphere - initiating hazardous events requiring additional consideration

Initiating hazardous events	
Pressure related	Sloshing
	Liquid to dag expansion
	Loss of vacuum
Leakage related	Viscosity, diffusion and buoyancy

Ignition sources

Table 2, Hydrogen ignition sources

Ignition sources		
Electrical	**Mechanical**	**Thermal**
Static discharge	Mechanical impact	Open flames
Electrical arc	Friction, galling, fretting (e.g. ship contact)	Hot surfaces
Charge accumulation and discharge	Metal fracture	Welding
Short circuits, sparks and arcs	Tensile rupture	Exhaust from thermal IC engine
Static electricity – two phase flow	Mechanical vibration	Explosive charges
Lighting / charged atmosphere		High velocity jet heating
Electrical charge generated by equipment operation		Shock waves created by a rupture
		Fragments from burst disc or vessel

Fire

- Fire passive protection with A60 insulation
- Sprinkler for cooling down the hydrogen storage containers
- Firefighting systems (flooding by water and Novec)
- Emergency Shut down of H2 supply system and fuel cell modules
- Power supply from auxiliary generator (switch over)
- No ignition source

Explosion

- Detection of H2 20% LEL is warning 40% LEL is Emergency Shut Down (ESD)
- Ventilation with dilution rate according to IEC 60079-10
- Simple room geometry avoiding the presence of hydrogen pockets
- ESD of H2 supply system and fuel cell modules
- EX proof equipment selected according to hazardous zones classification
- Temperature class of equipment suitable for the ignition temperature of hydrogen
- Suitable earthing of equipment and piping for avoiding electrostatic charge
- Explosion hatches
- EX equipment no sparks no static electricity
- Temperature limits for equipment
- No “pockets” where hydrogen can accumulate

Grounding/Collision

- Double side and double bottom to protect hydrogen storage containers
- Fuel cell and battery system fixed on the ship structure
- Hydrogen containers secured considering acceleration forces from collision
- All hydrogen equipment located behind collision bulkhead
- Hydrogen storage containers protected by structural bulkhead from cargo shifting

Leakage

- Proper design of piping according to international recognised standard
- Hydrogen storage and fuel cell rooms not subject to high level vibration
- Only hydrogen leakage in gas status which can be easily diluted
- Shutting down H2 systems
- Changing to Diesel generator

Annex II

Project MS ANTONIE

Hydrogen fuel system
Risk Assessment (RBC – 2)
Risk Assessment Report

Rev.	Description	Prepared by	Controlled by	Date
01	First revision of the document	BB(TOP)	PB (Concordia Damen)	09-01-2023

Table of contents

1. Abbreviations and definitions

1.1 Abbreviations

ALARP	As Low as reasonably practicable
ATEX	Atmospheres Explosibles
D&S Statement	Design and Safety Statement
ESD	Electro Statical Discharge
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation Vessels
FMECA	Failure mode effect & criticality analysis
GAs	General arrangement drawings
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
IGF Code	Code of safety for ships using gases or other low-flashpoint fuels
IMO	International Maritime Organisation
LR	Lloyd's Register
MEGC	Multiple Element Gas Container
MoM	Minutes of Meeting
PFDs	process flow diagrams
PLC	Programmable Logic Controller
RBC	Risk Based Certification
SoC	State of Charge
ToR	Terms of Reference
TSO	Technical Support Office

1.2 Definitions

1.3 Reference documents

[1] **LR** – Guidance notes for Fuel System Risk Assessments, Hazard Identification – Hydrogen and Ammonia (May 2021)

[2] **ShipRight** design and construction Risk Based Certification (RBC), September 2021

[3] **CESNI** - Draft requirements for hydrogen storage (CESNI/PT/FC (22) 24, 29th July 2022)

[4] **CESNI** - European Standard laying down Technical Requirements for Inland Navigation Vessels (ES-TRIN) (Edition 2021/1) & (Edition 2023/1)

[5] **LR** – Rules and regulations for the classification of ships using gasses or other low-flashpoint fuels (July 2022)

[6] **LR** – Draft Rules Fuel Cell Power Installations 2021

[7] **Concordia Damen** - Design & Safety Statement MS Antonie Project

[8] **Concordia Damen** – RBC-2 Risk Assessment Terms of Reference

2. Introduction

This document is prepared based on RBC-2 process step of the **ShipRight** Design and Construction Risk Based Certification (RBC), September 2021 [2]. The output of RBC-2 is a written Terms of Reference (this document) and a Risk Assessment Study Report prepared by the Submitter and submitted to LR for appraisal.

This document is a sequel to the Terms of Reference for Risk Assessment (RBC-2) [8], which will describe the outcome of the HAZID sessions

3. HAZID Worksheet results

3.1 Summary

Prior to the HAZID it

In preparation of the HAIZD (RBC1 & RBC-2) two important changes were made to improve the safety of design. Originally the aim was 4 storage containers, but in during RBC-1 it was decided to use only 3 storage containers. Also initially it was considered to place a hatchcover over the storage containers, but due to safety concerns it was decided not to.

The outcomes of the HAZID sessions were positive and no further significant changes to design have been identified.

3.2 HAZID results

The attendance list of the HAZID sessions can be found in Annex A. An additional 3rd HAZID session has been held online to finalise certain points of discussion. Annex A also contains a list with signatures which implies that the participants who signed this list agree with the HAZID sheet as shown in Annex B from 05.01.2023.

The populated HAZID worksheet can be found in Annex B together with a signed sheet

3.3 Conclusion

All combinations of activities (nodes), identified risks and the corresponding control measures have been found acceptable by the HAZID team. However the team felt the need to further investigate the residual risks. These residual risks come forth from nodes 2, 4 and 6. The supporting studies are listed below in chapter 4.

4. Supporting studies

To support certain decision making and to see if during the operational status certain additional measures must be taken, the HAZID team has mutually agreed to perform a number of supporting studies. Additional studies to be performed are:

- Heat radiation calculations (Node 2);
- Plume development with 9 m/s wind from forward direction (Node 2);
- Storage container HAZOP (Node 2);
- Fuel cell room – leak and ventilation modelling (CFD modelling on the most likely leakages in the fuel cell room) (Node 4);
- Battery room – battery safety system FMEA (Node 6).

5. Revised plan of completion RBC process

Table below represent a revised plan of completion for the RBC process.

Table 1, Revised plan of completion RBC process MS Antonie

	Output	Estimated finish date	Additional information
RBC-1 D&S Statement	- D&S Statement report rev.01	Start of October 2022 / Before the end of November 2022.	Completed
RBC-2 Risk Assessment	- Terms of Reference (ToR) - Risk Assessment Study Report	A pre-HAZID is planned for end September / begin October 2022. Terms of Reference (ToR) will be prepared before mid November 2022. HAZID session to be held in November of 2022 (17th of November & 01 December 2022) Risk Assessment Study Report prepared before second week of January 2023.	ToR completed Risk Assessment Study Report completed
RBC-3 Supporting studies	- Terms of Reference (ToR) - Supporting Study Report	Estimated finish date ToR (if needed multiple)end of January 2023. February 2023 estimated finish date supporting study/studies.	If any deviations from the rules and regulations will be considered, the deviation will be supported by an additional study. If actions documented in Risk Assessment Study report require supporting studies these will be done during this RBC step. Prior undertaking a study a ToR to be prepared and agreed with LR.
RBC-4 Final design assessment	- Terms of Reference (ToR) - Final Design Assessment Study Report	Estimated finish date ToR February 2023. Final Design Assessment Study session to be held in May of 2023. Estimated finish date report June 2023.	Study of completed design.
RBC-5 Construction and in service assessments	- Terms of Reference (ToR) - Procedures for installation and commissioning	Estimated finish date ToR June 2023. Estimated finish date procedures June 2023.	RBC-5a: Construction, Installation and Commissioning Assessment.
	- Terms of Reference (ToR) - In-service documentation	Estimated finish date ToR June 2023. Estimated finish date documentation June 2023.	RBC-5b: Development of in-Service Documentation

6. Annexes overview

- **Annex A: HAZID attendance list & signatures**
- **Annex B: HAZID worksheet**

Annex B: HAZID Worksheet

	Overview													
	#.1	#.2	#.3	#.4	#.5	#.6	#.7	#.8	#.9	#.10	#.11	#.12	#.13	#.14
Node 1. Loading & connecting of hydrogen units onboard	2B	3A	1B	1B	2B	2A	2B	2A	0	0	0	0	0	0
	2B	3A	1B	1B	2B	2A	2B	2A	0	0	0	0	0	0
Node 2. Hydrogen storage containers	3B	2A	2B	1B	2A	2B	2A	1B	1A	1A	1A	2A	1A	1A
	3B	2A	2B	1B	2A	2B	2A	1B	1A	1A	1A	2A	1A	1A
Node 3. Piping & valves etc. related the storage panel	2A	2A	1A	1A	2A	3A	1A	1A	1A	0	0	0	0	0
	2A	2A	1A	1A	2A	3A	1A	1A	1A	0	0	0	0	0
Node 4. Fuel cell room + ventilation	2A	2A	1A	1A	2A	0	0	0	0	0	0	0	0	0
	2A	2A	1A	1A	2A	0	0	0	0	0	0	0	0	0
Node 5. Auxiliary systems supporting hydrogen storage area	1A	1A	2A	2A	3A	0	0	0	0	0	0	0	0	0
	1A	1A	2A	2A	3A	0	0	0	0	0	0	0	0	0
Node 6. Battery pack – battery room	1A	1A	1A	0	0	0	0	0	0	0	0	0	0	0
	1A	1A	1A	0	0	0	0	0	0	0	0	0	0	0
Node 7. Electrical motor - propulsion	1A	1A	0	0	0	0	0	0	0	0	0	0	0	0
	1A	1A	0	0	0	0	0	0	0	0	0	0	0	0
Node 8. Safe Access & maintenance (general)	1A	1A	1A	1A	0	0	0	0	0	0	0	0	0	0
	1A	1A	1A	1A	0	0	0	0	0	0	0	0	0	0

Node 1. Loading & connecting of hydrogen units onboard																
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
1.1		Loading MEGC on board of vessel	Leakage	- Damage to containers while lifting / installing	- Fire - Explosion	- Lifting plan (including an instruction to place the container back on the quay side for inspection in case of unforseen situation / significant damage to the container) - Visual pressure monitoring in the MEGC - RAMS - Competent lifitng supervisor and crane operator - ADR drop test including tanks and valves - MEGC container according to European standard	2	B	2B		2	B	2B			
			Damage to MEGC container	- Damage to containers while lifting / installing	- Loss of structural integrity of container	- Lifting plan (including an instruction to place the container back / keep the container on the quay side for inspection in case of unforseen situation / significant damage to the container) - RAMS - Competent lifitng supervisor and crane operator - ADR drop test including tanks and valves - MEGC container according to European standard	3	A	3A	Containers will not be lifted over each other. To be included in the operational procedure	3	A	3A			
			Damage to the vessel	- Impact to vessel structure during lifting/placement	- Loss of structural integrity of vessel	- Lifting plan - RAMS - Competent lifitng supervisor and crane operator - Assessment of shipframing and any additional strengthening by third party before sailing	1	B	1B		1	B	1B			
			Injury to personnel	- Impact with container while lifting and loading on board	- Severe / fatal injury (B)	- Lifting plan - RAMS - Competent lifting supervisor and crane operator - Proper PPE	1	B	1B		1	B	1B			
1.2		Connecting H2 units	Leakage	- Incorrect connecting/damaged quick connect/hose assembly	- Fire - Explosion - Loss of hydrogen	- Pressure test - RAMS - Visual pressure monitoring on the ship system - Only competent personnel (through instruction or training) allowed to connect - Only necesarry & competent personnel in the area - Swapping to be executed only in dedicated area - Quick connects (couplings) part of the vessel planned maintenance system and will be inspected at safe intervals. - All containers are identical - no adapters required - Two independent actions required for connecting / disconnecting the hose - Maximum pressure 1-2 bar at the connecting / disconnecting area - Pneumatic valve remains closed during the process (normally closed)	2	B	2B	- Visual indication for entering the area (green - < 2 bars Red > above two bars)	2	B	2B			
			Injury to personnel	- Contact with H2 while connecting	- Severe / fatal injury(B)	- Only competent personnel (through instruction or training) allowed to connect - RAMS + toolbox - Only necesarry & competent personnel in the area - Swapping to be executed only in dedicated area - Propper PPE - Maximum pressure 1-2 bar at the connecting / disconnecting area	2	A	2A	- Visual indication for entering the area (green - < 2 bars Red > above two bars)	2	A	2A			
		Disconnecting H2 units	Leakage	- Incorrect disconnecting/damaged quick connect/hose assembly	- Fire - Explosion - Loss of hydrogen	- Pressure test - RAMS - Visual pressure monitoring on the ship system - Only competent personnel (through instruction or training) allowed to connect - Only necesarry & competent personnel in the area - Swapping to be executed only in dedicated area - Quick connects (couplings) part of the vessel planned maintenance system and will be inspected at safe intervals. - All containers are identical - no adapters required - Two independent actions required for connecting / disconnecting the hose - Maximum pressure 1-2 bar at the connecting / disconnecting area - Pneumatic valve is closed during the process (normally closed)	2	B	2B	- Visual indication for entering the area (green - < 2 bars Red > above two bars)	2	B	2B			
			Injury to personnel	- Contact with H2 while disconnecting	- Severe / fatal injury (B)	- Only competent personnel (through instruction or training) allowed to connect - RAMS + toolbox - only necesarry & competent personnel in the area - Swapping to be executed only in dedicated area - Propper PPE - Maximum pressure 1-2 bar at the connecting / disconnecting area	2	A	2A	- Visual indication for entering the area (green - < 2 bars Red > above two bars)	2	A	2A			

Node 2. Hydrogen storage containers																
ID	**Unit**	**Item/Activity**	**Hazard**	**Cause**	**Possible Consequences**	**Existing Safeguard & Barriers**	**Original risk screen**			**Additional/ alternative action(s)**	**New risk screen**			**Action by**	**Implemented by (dd-mm-20yy)**	**Priority**
							L	**C**	**R**		**L**	**C**	**R**			
2.1		Storage of MEGC containers on board during voyage	Leakage	- Losening connections due to vibrations, wrong maintenance etc.	- Fire - Explosion - Loss of hydrogen	- Gas detection system in the panel - Planned Maintenance System (PMS) - Pressure monitoring system on the high pressure side - CCTV system in the radar dome to oversee the H2 storage area	3	B	3B	An excess flow valve is required on the MEGC that closes itself if there is a larger flow than the maximal consumption	3	B	3B			
			Leakage	Failure of Valve HBV07, TPRD01 or HPSV01	- Loss of a MEGC - Fire	- Valves are certified by a third party classification to ensure they are suitable for the purpose they are used for - Valves are pressure tested	2	A	2A	Ensure compliance with all applicable marine regulations taking the dynamic forces on a vessel into consideration	2	A	2A			
			Increase of pressure	- Increase of ambient temperature	- Fire - Explosion - Sudden release of H2 after activating the PRV	- Gas detection system in the panel - Pressure monitoring system - Remote monitoring of system valves - One pressure relieve valve per container - TPRD Temperature relieve valves - Tank type 4 - able to withstand all environmental conditions	2	B	2B	Additional studies to be performed: - Heat radiation calculations - Plume development with 9 m/s wind from forward direction	2	B	2B			
			Failure of container lashing	- Ships motion - Corrosion failure	- Damage to MEGC container - Loss of structural integrity container and/or ship - Fire - Explosion - Loss of hydrogen	- Regular checks remotely / physically - Vessel to avoid heavy weather / movements - Lashing done by twist locks - calculations	1	B	1B		1	B	1B			
			Fire in the surrounding area	- Cargo on fire due to external sources / type of cargo - fire from (electrical room / Battery room / bowthruster room / fuel cell room)	- Damage to MEGC container - container and/or ship - Fire - Explosion - Loss of hydrogen	- No dangerous cargo in the vicinity of the storage area (forward 40' container or 2 x 20'cotainers without dangerous cargo) - Fire detection installed in electrical / battery / bowthruster / fuel cell room) - after fire detection is activated, fire fighting equipment is activated manually. - SW pump connection to cool / flood surrounding area's - multiple connections on PS and SB to connect fire hoses	2	A	2A	Fixed water spray with an actuator operated from the bridge (redundant power supply and redundant pumps)	2	A	2A			
			Blockages of the ventpipes	- Dust / debris / water accumulation	-Overpressurization leading to containment failure	Vents provided with water trap in the MEGC	2	B	2B		2	B	2B			
			Collision from the side	- Collision / allision	-Damage to MEGC containers / Loss of containment - Fire	- containers are located 2 meter from the ship side - Restricted area without presence of crew	2	A	2A		2	A	2A			
			Air ingress into the system	No H2 pressure in the system	Formation of explosive mixture	- check valves on the venting lines - pressure monitoring system - minimum pressure in the system before change-over is 30 bars.	1	B	1B		1	B	1B			
			Lighting strike against MEGC containers	Source of ignition at vent pipe	- Fire	- Mast with antenna is the heighest point on the vessel - Bulkheads before and after the storage area are positioned higher -Earthing points on containers	1	A	1A		1	A	1A			
			Static electricity	gas flow causing static electricity	- Fire / source of ignition	-Earthing point on containers	1	A	1A		1	A	1A			
			Contamination of H2 system	- Dust / debris / water accumulation	- Flow failure	- Dust caps over the connectors	1	A	1A		1	A	1A			
			High Diffusivity	- Hydrogen gas leakage	- Loss of fuel (H2)	- Gas tight sealings - Hydostatic pressure testing with water (strenght testing) - pressure testing protocol carried out N2. - in design minimum amount pipe connections are included - MEGC stored on open deck - maintenance plan available with regular intervals for re-inspection of safety valves & connections, fittings.	2	A	2A		2	A	2A			
			Pressures in cylinders drop below 30 bar(g)	- Stoppage of H2 flow to fuel cell	- Loss of power / propulsion	- automated change over procedure - Visual indication on bridge for levels within container	1	A	1A		1	A	1A			
			Vibration	cracks in pipework / damage to containers	- Loss of fuel (H2)	- in design minimum amount pipe connections are included - MEGC stored on open deck - maintenance plan available with regular intervals for re-inspection of safety valves & connections, fittings. - MEGC containers stored in low vibration area	1	A	1A		1	A	1A			

Node 3. Piping & valves etc. related the storage panel																
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
3.1		Panel and Piping between fuel cell room & H2 storage area	Leakage	- Ships motion / vibration - adverse weather extreme low temperatures; - Failure of connection joints - Structural damage during connection	- Fire - Explosion - Loss of hydrogen	- Gas detection system in the panel - Pressure monitoring system - Fire and smoke detection - natural ventilation - low pressure area - butt welded piping, SS 316-P material, full penetration welding 100% NDT radiographic including pressure testing - ignition sources are minimized - no rotating machines	2	A	2A		2	A	2A			
			Structural failure of piping	- Ships motion - Vibrations - Impact while loading / unloading container	- Fire - Explosion - Loss of hydrogen	- Gas detection system in the panel - Pressure monitoring system - Fire and smoke detection - natural ventilation - low pressure area - butt welded piping, SS 316-L material, full penetration welding 100% NDT radiographic including pressure testing - Ignition sources are minimized - no rotating machines - lift plan available - system will be de-pressurized when loading and un-loading the container - Piping will be protected against direct impact	2	A	2A		2	A	2A			
			Contamination of H2 system	- Dust / debris / water accumulation	- Flow failure	- Dust caps over the connectors - prescription on quality of hydrogen / ISO14687-2 Grade >-2.5 - Filter F901	1	A	1A		1	A	1A			
			Formation of Ice or Water blocking PSVs, exhausts	- Dust / debris / water accumulation	-Overpressurization leading to containment failure	- Pressure monitoring system switching off in case of high back pressure in the fuel cell - vent masts to be designed to not allow for water ingress	1	A	1A		1	A	1A			
			Permeability	- Brittle fracture due to H2 permeability	- Leakage / Loss of H2	- LRQE certified piping system (B-31.3 standard - 3.1 certificates) - -DPT (dye Penetrant Test) for all weld joints - Leak test (bubble method by submersing the pipe section) -SS 316-L material	2	A	2A		2	A	2A			
			Static Electricity	-Gas flow causing static electricity	- Fire / source of ignition	-Earthing point on containers - Earthing point on the panel - Anti-static overal, Anti-static shoes (PPE's) ant-static tooling	3	A	3A		3	A	3A			
			Lighting strike	Source of ignition at vent pipe	- Fire	- Mast with antenna is the heighest point on the vessel - Bulkheads before and after the storage area are positioned higher -Earthing points on containers	1	A	1A		1	A	1A			
			Very High Pressure Equipment	- Containment failure	- Loss of H2	- Pressure monitoring system switching off in case of high back pressure in the fuel cell by activating the Block and bleed - vent masts - possible to vent off the overpressure	1	A	1A		1	A	1A			
3.2		Panel	XV901 does not operate (Electrical HP line)	mal-function	unable to disconnect the quick couping QC901	vent-off through the the intermediate vent mast (through XV 904 / XV907)	1	A	1A		1	A	1A			

Node 4. Fuel cell room + ventilation																		
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
4.1		Fuel cell room during operation	Leakage	- Ships motion - Failure of connection joints - Structural damage during connection	- Fire - Explosion - Loss of hydrogen	- Gas detection system - Pressure monitoring system - Ventilation system - ESD philosophy - Safe to enter light before intering the room	2	A	2A	Additional study: safety study with CFD modelling of the most likely leakages in the fuel cell room in combination with ventilation increase from 15 to 30 airchanges.	2	A	2A			
			Failure of ventilation system	- Mechanical or system failure	- Built up of hydrogen in the fuel cell room leading to fire / explosion	- redundant ventilation system - Gas detection system - ESD philosopy - Fire detection - Safety system operated seperately from the operation system. - Safe to enter light before entering the room	2	A	2A		2	A	2A			
			Asphyxiation hazard to personnel (B)	- Lack of oxygen - Leakage	- Built up of hydrogen in the fuel cell room	- Personal gas meters - Gas detection system - Safe to enter light of entering the room	1	A	1A	Additional study: safety study with CFD modelling of the most likely leakages in the fuel cell room in combination with ventilation increase from 15 to 30 airchanges.	1	A	1A			
			High ambient temperatures	- External heat sources - No cooling	- Fire - Explosion - Loss of hydrogen	- Temperature monitored in the room maximum temepratures set	1	A	1A		1	A	1A			
			Hydrogen leakage to cooling water circuit	- Internal failure of fuel cell stack	Build up of hydrogen in the cooling water system	- Demi water tank is vented off - Bad cell alarm through stack monitoring will identify a leakage water will enter the hydrogen area instead of hydrogen entering the cooling water circuit	2	A	2A		2	A	2A			

Node 5. Auxiliary systems supporting hydrogen storage area																	
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
5.1		Gas detection system	System failure	- Instrumental error - System error - Loss of power	- Undetected leakages leading to fire/ explosion	- Alarm system to indicate failure (set points set in the AMS) - Power back up - Regular maintenance and callibration of the system by certified personnel - On board personnel to be trained in detecting failure	1	A	1A		1	A	1A			
5.2		Pressure monitoring system	System failure	- Instrumental error - System error - Loss of power	- Undetected leakages leading to fire/ explosion	- Alarm system to indicate failure (set points set in the AMS) - Power back up - Regular maintenance and callibration of the system by certified personnel - On board personnel to be trained in detecting failure	1	A	1A		1	A	1A			
5.3		H2 control system for flow	System failure	- Instrumental error - System error - Loss of power	- System failure leading to loss of power / propulsion - Over pressure of system	- Alarm system to indicate failure (set points set in the AMS) - Diesel generator as power back up - Regular maintenance and callibration of the system by certified personnel - On board personnel to be trained in detecting failure	2	A	2A		2	A	2A			
5.4		leakage	- Asphyxiation hazard to personnel (B)	- Failure of piping / small un-identified leakage	- Harm to health	- Personal gas meters - Gas detection system	2	A	2A		2	A	2A			
5.5		compressed air system	System failure	- Instrumental error - System error - Loss of power	- Unable to operate the Block & Bleed or other safety critical pneumatic valves	- Buffer system (Pressure vessels) to allow for pressure to operate the B&B valve - Use nitrogen as a back-up (8 bars)	3	A	3A		3	A	3A			

Node 6. Battery pack – battery room																
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
6.1		Storage of batteries	Release hydrogen	- Leaking batteries - Defective battery - Mechanical damage to battery	- Fire - Explosion	- Ventilation system - Gas detection system	1	A	1A	Additional study to be carried out: FMEA for the battery room	1	A	1A			
			Fire (spontaneous)	- Li metal fire due to short connection or mechanical damage	- Class D metal fire	- Fire fighting system (ficed/portable) for class D fire - **iron - phosphate battery**	1	A	1A		1	A	1A			
			Leakage of chemical from the battery	-Heat / mechanical damage / manufacturing defect	-Chemical burns (A) - Fire	-Maintenance free batteries -Regular physical checks	1	A	1A		1	A	1A			

Node 7. Electrical motor - propulsion																	
ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
7.1		Navigation	Loss of power / propulsion	- Failure of fuel cell system	- Fire - Grounding - Collision - Injury to personnel (B)	- Battery pack back up for essential systems (redundancy 1) - Diesel generator back up to charge the battery pack (redudancy 2)	1	A	1A		1	A	1A			
				- Failure of electrical propulsion motor	- Fire - Grounding - Collision - Injury to personnel (B)	- Regular maintenance and monitoring - Two seperately independent propulsion trains (PS & SB side) - Double bowthruster system (redundant)	1	A	1A		1	A	1A			

Node 8. Safe Access & maintenance (general)

ID	Unit	Item/Activity	Hazard	Cause	Possible Consequences	Existing Safeguard & Barriers	Original risk screen			Additional/ alternative action(s)	New risk screen			Action by	Implemented by (dd-mm-20yy)	Priority
							L	C	R		L	C	R			
8.1		Personnel access to fuel cell room/ battery room	Contact with hydrogen	- Leakages in the system	- Injury to personnel (A)	- PTW system - Propper PPE - Fixed gas detection system - Personal gas meaters	1	A	1A		1	A	1A			
			Asphyxiation hazard to personnel	- Leakages in the system	- Fatal / severe injury (B)	- PTW system - Propper PPE - Fixed gas detection system - Personal gas meaters - Ventilation system	1	A	1A		1	A	1A			
8.2		Maintenance of fuel cell system	System malfunction	- Incorrect operation by personnel	- Loss of propolsion which can lead to grounding, collision etc.	- Only compotent personnel to carry out maintenance - Standard operation and maintenance procedures - PTW - Propper PPE - Fixed gas detection system - Personal gas meaters - safe to enter access light	1	A	1A		1	A	1A			
			Loss of power (black-out)	- Probable system shut down during maintenance	- Loss of propolsion which can lead to grounding, collision etc.	- Back up diesel generator - Standard operation and maintenance procedures - Only compotent personnel to carry out maintenance - Essential maintenance to be carried out while vessel in port - safe to enter access light	1	A	1A		1	A	1A			

Annex III

summit engineering

WEVA

Work plan

Loading and unloading hydrogen containers on MV Antonie

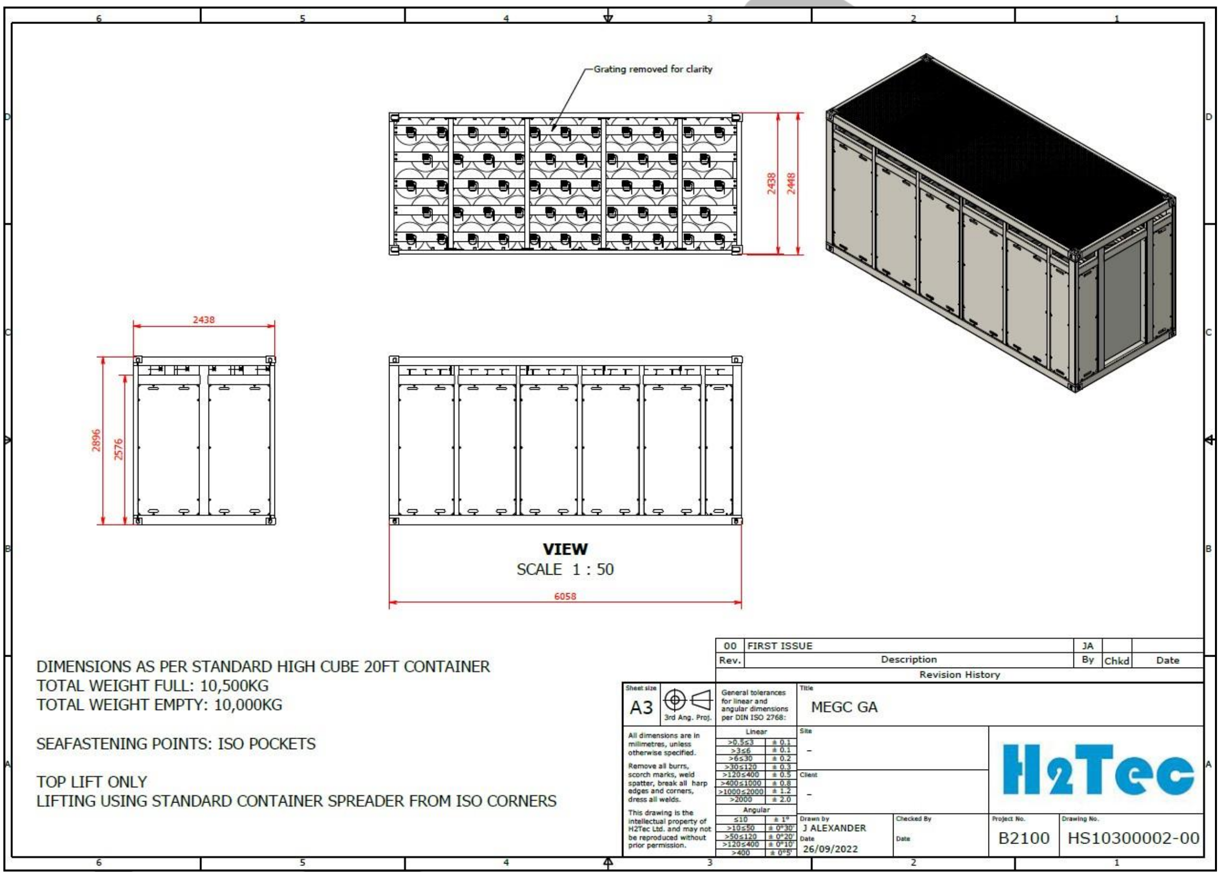
Date	12-10-2022
Status	Draft
Revision	
Document reference	

Introduction

The new salt ship MS Antonie will be emission-free and will be used for the NPRC salt shuttle for Nouryon between Delfzijl and Rotterdam. This ship will run on hydrogen by applying fuel cell electric propulsion. The hydrogen that will be used as fuel for this ship will be put on board in the form of containers.

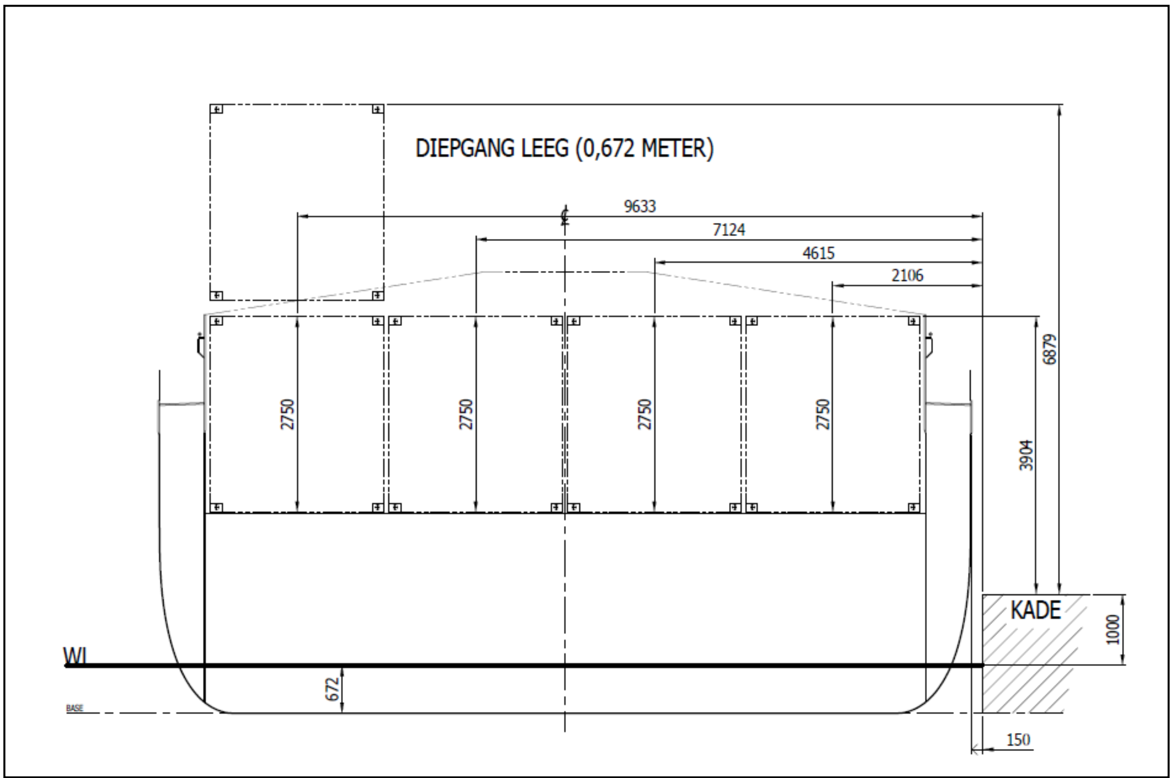
Hydrogen containers

The hydrogen containers have the dimensions of a 20ft standard High Cube container weighing (filled) 10,500 kg. The containers have ISO pockets on the four corners. Plastic bottles are mounted inside the containers, containing the hydrogen under high pressure in gaseous form. Pictured below for information.



Loading and unloading

Loading and unloading of the containers will take place in Farmsum/Delfzijl. The H2 containers will be placed (3 or) 4 wide, transversely in a sunken space on the ship just aft of the foreship.



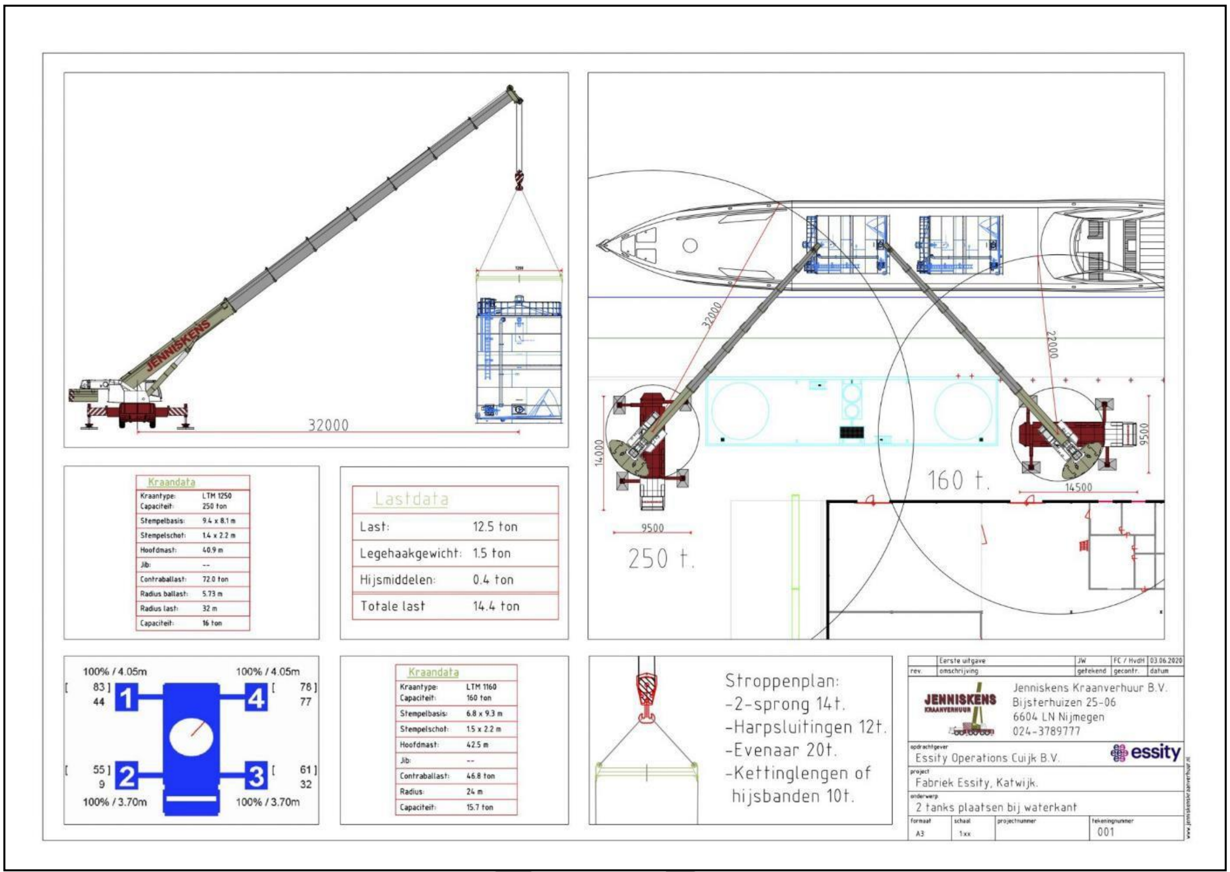
A mobile crane will be used to load and unload the containers, which will take the empty containers off board and replace them for full containers that will be loaded/unloaded by truck and trailer.

The location for loading and unloading has not yet been determined but a jetty/berth where the vessel can be moored will be used.

The crane company will draw up a lifting plan based on the available data to lift the 'load' move safely. The minimum data required for this:

- Location (subsoil, surroundings, obstacles)
- Weight, centre of gravity, dimensions and other characteristics of the load
- Information about the starting position and end position of the load (vessel and truck/trailer) and the associated characteristics and distances

Below is an example of a lifting plan:



Roadmap:

1. Mobilise crane and set up crane according to lifting plan
2. Set up truck with trailer to receive empty container
3. Unlocking empty container on board
4. Connecting empty container to crane spreader beam
5. Lifting empty container and placing on available trailer
6. Loosening spreader beam
7. Locking 4 x ISO twistlocks
8. Departing truck with empty container
9. Setting up truck and trailer with full H2 container
10. Unlocking 4 ISO twistlocks
11. Docking full container to crane spreader beam
12. Lifting full container and placing it on board
13. Received full container on board
14. Disconnecting spreader beam
15. Locking container

This sequence repeats until all containers are unloaded and loaded. Then the crane company will demobilise.

Trailers can be used for 2 x 20 ft containers. Then the discharge and supply truck/trailer is the same.

Annex IV

Training & education manual proposal

Concordia Damen - Antonie

Why set up a "training and education manual" for your organisation?
Setting up and managing a training and education manual for your own organisation is an important part of maintaining insight into the competences of all employees.

The knowledge level and the risks are mapped out in advance for each position with associated tasks, on the basis of which courses, training and education are selected and offered to the employees. This allows you to achieve a certain level within the organisation, limit your risks and retain your skills and competences.

What are the learning objectives of a training?
Learning objectives are determined in advance and shared with the candidates, which gives insight into what they will learn during the training and what is expected after completing a training. This can then also be tested.

How can you achieve the best results for your organisation:
The best results for an organization can be achieved by training employees as well as possible, transferring knowledge, retaining knowledge and empowering employees by offering them the appropriate course, training or education.

Theory:
Learning theory from textbooks. This mainly tests the independence of a candidate. As a follow-up, a practical day is usually scheduled to look at the knowledge gained and whether someone has the right skills.

Classroom training:
By training employees in class, the teaching material is discussed together and any questions can be asked directly to a trainer. In addition, assignments are scheduled during a classroom training that require employees to work together (in groups). This ensures a good connection between employees at various levels.

E-learning:
An emerging way of learning is the E-learning variant. This digital way of learning is an easy way to transfer knowledge. The benefits include:

- digitally available, it can be followed on a PC, laptop or PC;
- (usually) available in multiple languages;
- to be followed when it suits the candidate, not always tied to a time slot;
- digitally and therefore can be followed anywhere in the world;
- by means of linking an exam, results can be made transparent and treated.

Practical assignments:
Alternating theory / E-learning and classroom training ensures variety and interaction with the candidate. By adding interactive elements in an E-learning and by performing practice-oriented assignments, the lesson material is better absorbed and certain scenarios are also better recognised.

This is also called “blended learning” where all ways of knowledge transfer are covered.

Set-up of the training with regard to the Hydrogen system onboard vessel ‘Antonie’

Activity	E-learning	E-learing with exam	Practical assignment
General knowledge about hydrogen & FiFi / Emergency response systems onboard	X		
Loading and unloading MEGC Containers		X	
Connecting & disconnecting the MEGC containers		X	
Entering the Battery room – general		X	X
Entering the Fuel cell room		X	X
Performing maintenance - General		X	
Main risks & corresponding mitigations identified onboard the ‘Antonie’		X	
Emergency scenario’s (fire, blow-off, gas detection)	X		X
Emergency Escape Room and emergency zones onboard			