Base Load Power Hub (BLPH)

ALARP Workshop Report

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

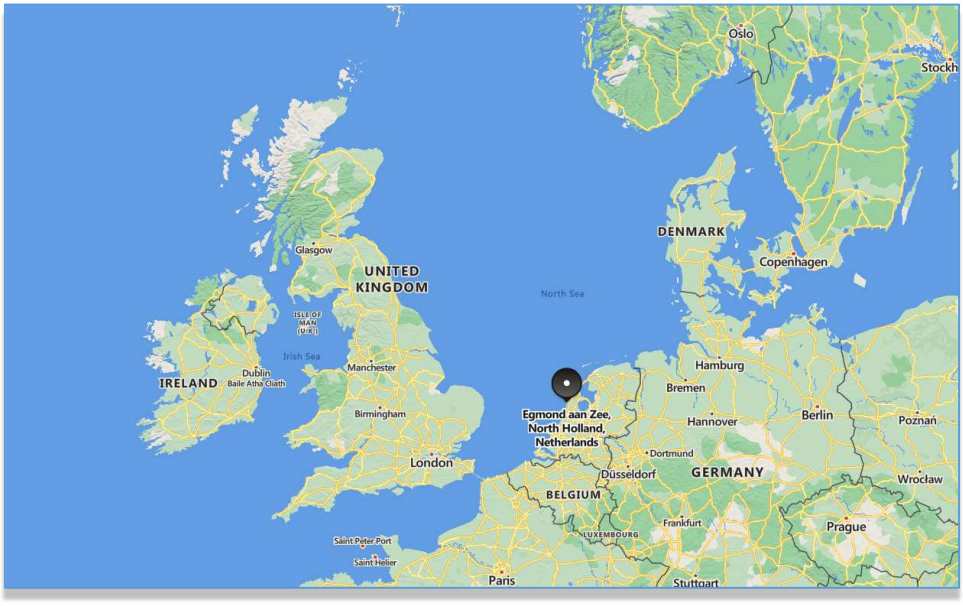


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

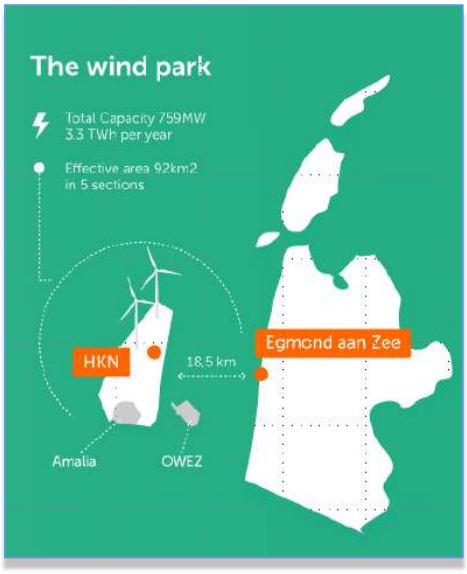


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

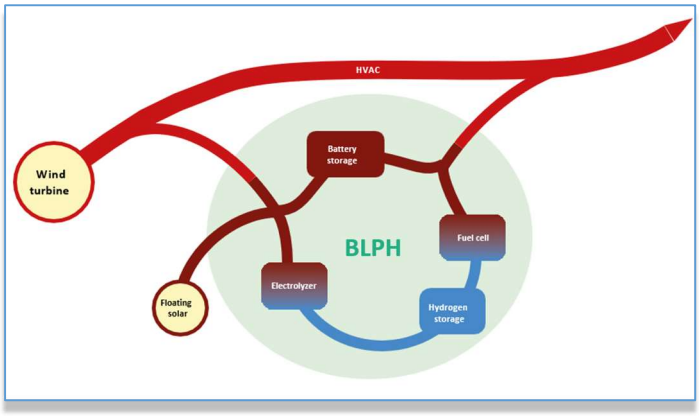


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 EXECUTIVE SUMMARY

This document has the purpose of detailing the results of the ALARP workshop for the new Base Load Power Hub (BLPH), which will be installed in the framework of Hollandse Kust Noord Wind Park Project.

The ALARP workshop was held on December 4th, 2024, at Rosetti Marino's premises in Milan, with a number of technicians remotely connected via Microsoft Teams. The attendance list is reported in Attachment 1.

The objectives of the ALARP workshop were to:

- Review the list of previously selected ALARP items.
- Evaluate the adequacy of in place controls, safeguards, mitigation and recovery measures.
- Identify all possible risk reduction strategies, in addition to those already in place, to bring the risk posed by each item to ALARP.
- Discuss the practicality of the identified additional options, by qualitatively weighing their cost and benefits.
- Issue possible recommendations for further work, design or engineering change to improve the next phases of the project.

During the workshop, the following ALARPitems were assessed:

1. Hydrogen release from single hydrogen storage vessel – during maintenance
2. Hydrogen release from single hydrogen storage vessel leading to escalation
3. BESS thermal runaway
4. Hydrogen release inside electrolyser container
5. Potential for explosion inside electrolyser due to membrane failure
6. Hydrogen release inside fuel cell container
7. Location of hydrogen piping on the lower deck
8. Fire in technical rooms
9. Vent height – operator injuries
10. Possible damage to the platform – transformer location
11. Sequence of hydrogen storage vessels

The following information was recorded for each ALARP item:

- Scenario number
- Major Accident Hazards identified
- Description of scenario
- Qualitative risk assessment
- Safeguards, controls, mitigating and recovery measures
- Proposed additional risk reduction options

- Justification for chosen and rejected options
- Recommendations (if necessary) for the operational phase of the project and responsibility
- Requirements for the Operations HSSE Plan and responsibility

In most cases, the current conditions already demonstrated an ALARP level of risk, either because no additional options were identified at all, or all potential further risk-reduction measures were deemed grossly disproportionate to the benefits achieved. This is because they would require major structural modifications, which are impractical at the current stage of the project. Only item no. 11 was deemed not currently ALARP, and effective options were determined to reduce its risk in a practicable manner. items no. 4 and 5 were not examined as they concern the electrolyser package and are expected to be analyzed in a future dedicated workshop.

The discussion held throughout the workshop was recorded in dedicated worksheets, which are reported in Attachment 2.

In conclusion, a total of 4 recommendations for the operational phase of the project emerged during the workshop, as well as a requirement for the Operations HSSE Plan, as reported in Table 1 and Table 2.

ALARP item no.	Recommendation	By
1	Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
3	Provide technical documentation for the estimation of the hydrogen inventory from BESS exhaust gases due to BESS thermal runaway.	Crosswind
9	Apply controls to restrict access to the impacted area.	Operators
11	Ensure as built documentation, plant signage and HMI reflect the actual status of hydrogen storage vessels V-25001 and D location.	EPC Contractor

Table 1 – Recommendations for the operational phase of the project

ALARP item no.	Requirement for Operations HSSE Plan	By
9	Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization.	Operators

Table 2 – Requirements for Operations HSSE Plan

3 MAIN REFERENCES

[1]	ISO 17776 - Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations
[2]	UK HSE - Guidance on ALARP Decisions in COMAH – UK Health and Safety Executive (UK HSE), SPC/Permissioning/37, 2001
[3]	IEC 61511-3:2016 - Functional safety - Safety instrumented systems for the process industry sector - Part 3: Guidance for the determination of the required safety integrity levels
[4]	API RP 521, Guide for Pressure-Relieving and Depressuring Systems. American Petroleum Institute, Washington DC, 1997.
[5]	123A90-DDL-SAF-RE-30011 – ALARP Terms of Reference
[6]	123A90-DDL-SAF-RE-30019 - Quantified Risk Assessment (QRA) Report
[7]	123A90-DDL-SAF-RE-30020 - Fire and Explosion Risk Analys (FERA) report
[8]	123A90-DDL-SAF-RE-30006 – HAZOP Report
[9]	123A90-DDL-SAF-RE-30009 – HAZID Report
[10]	123A90-DDL-SAF-RE-30021 - Vent Gas Dispersion and Potential Radiation Study
[11]	K559-2254-SE-TEN-001 – Leak Size Analysis
[12]	K559-2254-CWIWP4202201-E99-099 - BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations
[13]	123A90-DDL-SAF-DL-30027 - F&G detectors Layout - lower deck
[14]	123A90-DDL-IN-CE-40002 - Fire & Gas Cause & Effect Matrix
[15]	123A90-DDL-PP-DI-71000 - Isometrics drawing & List
[16]	K559-2254-CWIWP4202202-C99-00 – Megablock Safety Concept
[17]	123A90-DDL-PP-DL-70070 – BLPH – Plot Plan – Lower & Upper Deck
[18]	123A90-DDL-PP-DL-70071 – BLPH – Plot Plan – Below Lower Deck
[19]	123A90-DDL-PP-DL-70072 – BLPH – Plot Plan- Elevation of Looking North & East

Table 3 - Reference Documents

4 DEFINITIONS AND ABBREVIATIONS

4.1 DEFINITIONS

COMPANY or Client (CPY)	Crosswind
EPC CONTRACTOR (CTR)	ROSETTI MARINO S.p.A.
PROJECT	HOLLANDSE KUST NOORD WIND PARK Project
ALARP	Acronym for "As Low As Reasonably Practicable", it represents the concept of "reasonably practicable"; this involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which we expect to see workplace risks controlled.
CONSEQUENCES	The outcome of an event. For the purpose of this project, the outcome is identified in terms of harm to exposed persons and assets.
EVENT	Occurrence or change of a particular set of circumstances.
FERA	Fire and Explosion Risk Assessment. A comprehensive risk evaluation directed to the analysis of the effects of fire and explosion scenarios (due to LOCs of hazardous substance handled in an equipment to be installed during project development) on process equipment, structures and buildings.
FIRE	The outcome of combustion of flammable substance released in the atmosphere as a consequence of a LOC, which can produce effects to exposed people and to process equipment and structure due to thermal radiation.
FREQUENCY	The estimated number of events per defined unit of time (normally refereed to one-year time).
MAJOR ACCIDENT HAZARD	A MAH is defined from at least one of the following categories: • An incident involving an explosion, fire, or release of gas or dangerous substances with a significant potential to cause multiple fatalities. • An incident leading to serious damage to the asset involving, or with a significant potential to cause, multiple fatalities. • Any other incident with a potential to lead to greater than 3 fatalities • Any major environmental incident resulting from incidents referred to in the points above.

OPTION	Any additional risk reduction measure beyond those already in place.
QRA	Quantitative Risk Assessment. For the purpose of this study, a comprehensive risk evaluation focused on the identification of the impact to persons (workers and external population) due to effects of accident scenarios due to LOCs of hazardous substance handled in equipment to be installed during project development.
RECOMMENDATION	Improvements /actions required to reduce the identified risk.
RISK	Combination of frequency and consequence of scenarios. For the purpose of the present project, the risk is evaluated on exposed persons and on project equipment, due to the effects of events caused by LOC of hazardous substances.
SAFEGUARD	Measure, system, or action designed to prevent hazardous events, control risks, or mitigate the consequences of an incident

Table 4 - Definitions

4.2 ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BDV	Blowdown Valve
BESS	Battery Energy Storage System
BLPH	Base Load Power Hub
C&E	Cause and Effect
COMAH	Control of Major Accident Hazards
CPI	Company Provided Item
EPC	Engineering, Procurement and Construction
F&G	Fire and Gas
FEED	Front-End Engineering Design
FERA	Fire and Explosion Risk Assessment
FT	Full Time
HAZOP	Hazard and Operability

HKN	Hollandse Kust Noord
HSSE	Health, Safety, Security and Environment
HT	Half Time
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
LFL	Lower Flammability Limit
LOC	Loss of Containment
MAH	Major Accident Hazard
Occ.	Occurrence
PFP	Passive Fire Protection
PM	Project Manager
PSV	Pressure Safety Valve
PV	Photovoltaic
QRA	Quantitative Risk Assessment
SIMOPS	Simultaneous Operations
VooW	Van Oord Offshore Wind

Table 5 - Abbreviations

5 ALARP DEMONSTRATION WORKSHOP

5.1 ALARP OVERVIEW

The ALARP demonstration is established when all hazards stemming from prior safety studies and workshops are known and understood, particularly Major Accident Hazards. These hazards are then analyzed by reviewing the effectiveness of existing safety measures and exploring potential additional safeguards. The goal is to identify feasible options to further reduce risks while considering their practicality (i.e., by weighing the benefits of these additional measures against the effort, time or cost needed to put them in place). The process ensures that risks are reduced to a level that is ALARP, with clear documentation supporting the decisions made.

The ALARP concept is visually represented by the ALARP triangle, illustrated in Figure 4. At the top of the triangle lies the broadly acceptable region, where risks are low and no further action is necessary. The middle section is the tolerable region, where risks are acceptable only if they have been reduced to a level that is ALARP. Finally, at the base of the triangle is the unacceptable region, where risks are too high to be tolerated under any circumstances and must be reduced.

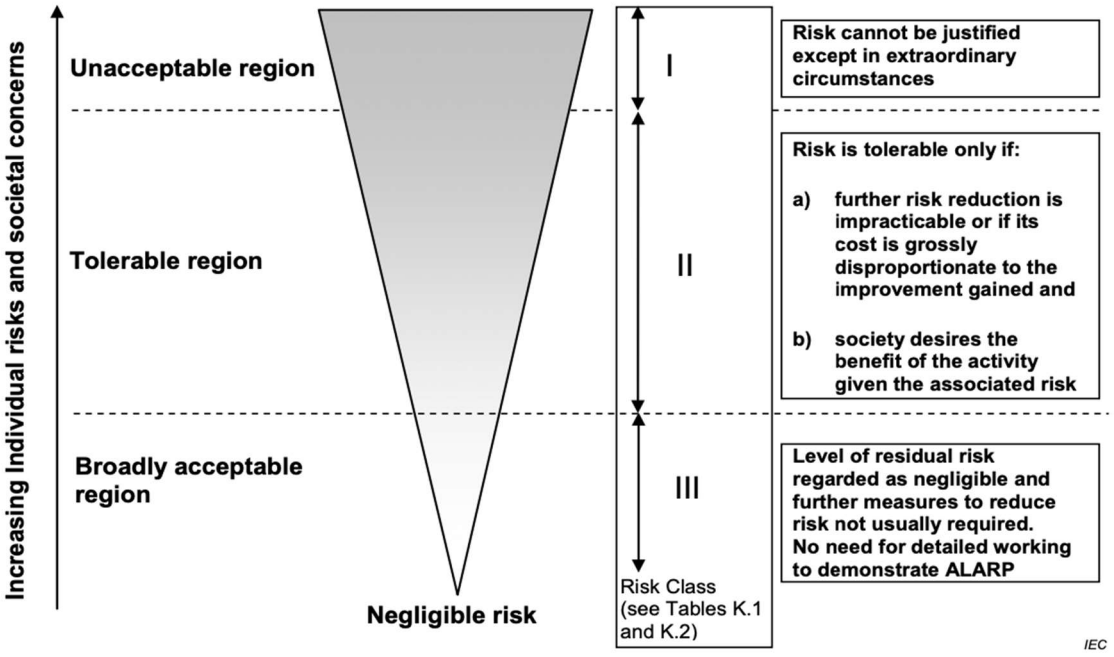


Figure 4 – Representation of the ALARP Triangle [3]

This classification of risk is also reported in Table 6 - Regions of risk [3]Table 6.

Region	Description
Unacceptable region	Risk cannot be justified except in extraordinary circumstances
Tolerable / ALARP region	Risk is tolerable only if: – further risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained, and – society desires the benefit of the activity given the associated risk.
Broadly acceptable region	Level of residual risk regarded as negligible and further measures to reduce risk not usually required. No need for detailed work to demonstrate ALARP

Table 6 - Regions of risk [3]

5.2 SCOPE AND OBJECTIVES

During the workshop all elements in the scope of work of the BLPH platform were considered. The following items were excluded:

- Construction/Commissioning activities, that shall be analyzed during a Constructability workshop/ SIMOPS workshop.
- Decommissioning.

The objectives of the workshop were to:

- Review the list of previously selected ALARP items.
- Evaluate the adequacy of in place controls, safeguards, mitigation and recovery measures.
- Identify all possible risk reduction strategies, in addition to those already in place, to bring the risk associated with each item to ALARP.
- Discuss the practicality of the identified additional options, by qualitatively weighing their cost and benefits.
- Issue possible recommendations for further work, design or engineering change to improve the next phases of the project.

5.3 PROJECT ASSUMPTIONS

The following assumptions were applied during the ALARP demonstration workshop:

- CPIs were included in the discussion based on Company information only.
- The analysis was based on the results of the safety studies present at the moment of the review.
- Major Accident Hazards were related only with what happens inside the parts of the project Scope of Work, meaning that hazards coming from outside, or not reasonably expected and credible, were not part of the workshop.

The following points were applied as well during the ALARP demonstration workshop:

- External factors: temperature, humidity, ducting, smoke, etc. directly influence the performance of the controls systems. Also, if there is power, air, or hydraulic system failure, then control systems cannot work.

5.4 LIST OF ALARP ITEMS

Throughout theworkshop, the following ALARP items were assessed.

No.	Major Accident Hazard
1	Hydrogen release from single hydrogen storage vessel
2	Escalation event of hydrogen from all storage area
3	BESS thermal runaway
4	Hydrogen release inside electrolyser container
5	Potential for explosion inside electrolyser due to membrane failure
6	Hydrogen release inside fuel cell container
7	Location of hydrogen piping on the lower deck
8	Fire in technical rooms
9	Vent height – operator injuries
10	Possible damage to the platform – transformer location
11	Sequence of hydrogen storage vessels

Table 7 – List of Major Accident Hazards

5.5 WORKSHOP EXECUTION

5.5.1 Alarp Team Members

The ALARP session was conducted by a third-party Facilitator, who ensured the correct application of the ALARP methodology.

The ALARP team included all functions involved in the platform design and it was composed, indicatively, by the following figures:

- Facilitator - Consultant for ALARP session
- Scribe - Consultant for ALARP session
- PM representative from Company and Contractor side
- Safety Representatives from Company and Contractor side

- Process and I&C Representatives from Company and Contractor side
- Others on call

5.5.2 Schedule and Venue

The ALARP workshop was held on December 4th, 2024, at Rosetti Marino's premises in Milan, with a number of technicians remotely connected via Microsoft Teams. The attendance list is reported in Attachment 1.

5.5.3 Recording and Reporting

The output of the various review sessions was recorded by the Scribe under the management of the Facilitator, by means of Microsoft Word worksheets, reported in Attachment 2.

The worksheets and the recording process were projected onto a screen during the session, so that the workshop team could view, comment and amend as necessary the generated content as it was produced.

The following information was recorded for each item:

- Scenario number
- Major Accident Hazards identified
- Description of scenario
- Qualitative risk assessment
- Safeguards, controls, mitigating and recovery measures
- Proposed additional risk reduction options
- Justification for chosen and rejected options
- Recommendations (if necessary) for the operational phase of the project and responsibility
- Requirements for the Operations HSSE Plan and responsibility

6 RESULTS

During the workshop, a total of 11 ALARP items were analyzed, and for each of them a discussion was held to identify possible additional risk mitigation measures, if any.

In most cases, the risks associated with the analyzed events were found to be already ALARP, as all the investigated alternative solutions involved effort, time or cost grossly disproportionate to the benefit gained. Otherwise, no additional options were identified at all.

Only one item was deemed not ALARP, and effective options were determined to reduce its risk in a practicable manner.

Two items (i.e., those concerning the electrolyser package) were not examined since they are out of RM's scope and are expected to be analyzed in a future dedicated workshop.

A summary of the discussion about the items evaluated throughout the workshop is reported below.

1. Hydrogen release from single hydrogen storage vessel – during maintenance: this event involves a hydrogen release from a single storage vessel with potential consequences like fire or explosion. Three options were evaluated for this scenario, and the team members eventually considered the current condition ALARP. In particular, the following options were discussed:

   a) As per current design.

   b) Always purge hydrogen inventory with nitrogen prior to personnel boarding and start maintenance activities.

   c) Always minimize hydrogen inventory to 3 barg (minimal operational pressure of the fuel cell, so that no hydrogen is vented) prior to personnel boarding and start maintenance activities.

   Option B was considered grossly disproportionate because it would result in the loss of a considerable amount of hydrogen via the vent and the use of nitrogen to purge the vessels, the cost of both outweighs the potential benefit gained. In addition, purging the vessels with nitrogen would require a significant amount of time to be completed and to reach the required hydrogen purity after the restart, given the presence of nitrogen within the vessels.

   Option C was also excluded since, although being less drastic than the previous one, it still requires lengthy restart operations.

   Therefore, maintaining the current design solution was considered the most practical option, taking into account that several control and mitigation barriers are put in place to reduce the residual risk, as shown in the bow-tie diagrams in Attachment 4.

2. Hydrogen release from single hydrogen storage vessel leading to escalation: this event involves a hydrogen release from a single storage vessel with potential escalation to the adjacent hydrogen storage vessels or to other packages (i.e., fuel cell, electrolyser). Three options were evaluated for this event:

   a) As per current design.

   b) Additional spacing between hydrogen storage vessels.

c) Passive fire protection (PFP) on structural elements around the hydrogen storage vessels.

Option B would entail rethink the design of the whole BLPH, which was considered grossly disproportionate, given the current construction work progress.

Option C was ruled out as well, since the cost to implement passive fireproofing measures was deemed disproportionate to the benefit gained.

In short, in all phases of the project, the potential escalation between:

- hydrogen storage vessels
- other units

have been analysed [6], [7], [11] and deemed ALARP with the current layout.

3. BESS thermal runaway: for the BESS thermal runaway itself, as agreed by the team members, no additional risk reduction options were identified. Regarding the existing safety measures in place, refer to the bow-tie diagram in Attachment 4 and BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations [12].

   However, additional options were evaluated to reduce the risk posed by the venting of the BESS thermal runaway gases below the upper deck, which might lead to the accumulation of flammable substances, the most critical of which is hydrogen, within a congested area, potentially resulting in a fire or explosion. In particular, the following options were discussed:

   a) As per current design.
   b) Route the BESS emergency exhaust ventilation conduit outside the deck to a safe area.
   c) Route the BESS emergency exhaust ventilation conduit through a vent line to the main emergency vent (Q-43004).

   As options B and C were considered grossly disproportionate due to the cost and time needed to implement the new piping given the construction work progress, the team agreed that maintaining the current design was the most practical option. A number of reasons are in support of this:

   - A network of gas detectors is foreseen above the BESS container in the potential hydrogen accumulation area, as indicated in the F&G detectors layout (rev. 02 sh. 1) [13] and F&G C&E Matrix [14].
   - The amount of exhaust gases released by the thermal runaway is very limited.
   - The composition of the gaseous mixture coming out from the exhaust ventilation conduit is below hydrogen LFL. Moreover, from a molecular point of view, hydrogen would stay evenly distributed throughout the mixture and could not spontaneously build up to a hazardous concentration.
   - The area is naturally ventilated.

   Therefore, for this specific scenario, the team members considered the current condition ALARP.

4. Hydrogen release inside electrolyser container: this event was not discussed during the workshop, since the electrolyser specialist was unavailable and a dedicated ALARP workshop is expected to be held for the electrolyser package. Regarding the potential escalation from the electrolyser to the storage vessels, refer to the bow-tie diagram in Attachment 4, and to the FERA [7] and QRA [6] results.
5. Potential for explosion inside electrolyser due to membrane failure: this event was not discussed during the workshop, since the electrolyser specialist was unavailable and a dedicated ALARP workshop is expected to be held for the electrolyser package. Regarding the potential escalation from the electrolyser to the storage vessels, refer to the bow-tie diagram in Attachment 4 and to the HAZOP [8].
6. Hydrogen release inside fuel cell container: for this event, as agreed by the team members, no additional risk reduction options were identified. Therefore, no discussion was held, as the risk associated with this event is deemed already ALARP, as per HAZOP [8] and Megablock safety concept [16]. Regarding the potential escalation from the fuel cell to the storage vessels, refer to the FERA [7] and QRA [6] results.
7. Location of hydrogen piping on the lower deck: this event involves a potential hydrogen release under the plated floor of the upper deck, which might lead to the accumulation of hydrogen within a congested area, potentially resulting in a fire or explosion. It is worth specifying that the piping investigated during the workshop is the one going from the storage vessels to the fuel cell, as the one going from the electrolyser to the storage vessels has been already relocated on the upper deck. The two following options were discussed for this scenario:

    a) As per current design.

    b) Relocate the piping from the storage vessels to the fuel cell above the upper deck floor.

    Option B was excluded, since the only available location of the piping would be above the existing emergency escape route. The relocation of the piping would require a dedicated support structure, which was considered impractical at this stage of the project, due to its high cost and added complexity. Indeed, not only would it increment the total weight of the platform, but it would also be subject to vibrations, increasing the risk of dropped objects in an area that must be free from any obstruction.

    Consequently, the team agreed that maintaining the current design solution is the most practical option, since the frequency of occurrence of a release is estimated to be very low, given that the portion of piping running below the upper deck is entirely welded and no release sources, such as flanges or fittings, are foreseen. The only opening in the section under examination is a removable cap employed only during the commissioning phase for the hydrotest, after which it is seal welded. For further information, refer to FERA [7], QRA [6] and isometric drawing no. 16, line no. 2"-HY-023-01HSS-N [15].

Therefore, the risk posed by a hydrogen release below the plated floor of the upper deck was considered ALARP. Nevertheless, a residual risk still exists, which can be effectively managed through the existing F&G network.

8. Fire in technical rooms: this event was not considered to be a MAH and no bow-tie diagrams have been produced for it. Therefore, as agreed by the team members, no options to reduce the risk were discussed during the workshop.
9. Vent height – operator injuries: this event involves, in case of a simultaneous discharge of all blowdown valves on the storage vessels, a hydrogen release from the vent. This might lead to a jet fire, in case of immediate ignition, or to a flammable gas dispersion, eventually resulting in a flash fire, in case of late ignition. If a jet fire occurs, as stated in the Vent Gas Dispersion and Potential Radiation Study [10], a thermal radiation threshold of 6.31 kW/m^2 can reach areas of the platform where operators might be during maintenance activities. This is because the vent stack is not sufficiently high. As a result, the aforementioned study recommends that the second level of the platform above the storage vessels be prohibited for operators unless total depressurization of the vessels is carried out, which is planned to be done only before maintenance activities on the upper deck (i.e., once a year for a total duration of 8 hours). It is also worth noting that in the FEED phase of the project the boarding of personnel without prior total depressurization of the storage vessels was excluded. This possibility was introduced in the EPC phase and communicated to the Contractor after the vent was already ordered.

   In light of these aspects, the following options were evaluated for this scenario:

   a) As per current design.
   b) Increase vent height.
   c) Staggered depressurization of storage vessels.
   d) Reduce hydrogen storage vessels pressure.

   Option B was considered grossly disproportionate at this stage of the project, due to the time and cost of ordering a new vent and re-considering its support structure.

   Option C was considered not feasible due to the time constraint of the emergency depressurization, according to API 521 [4].

   Option D was ruled out as well, since the pressure that would be required to remove the restriction from the second level of the platform above the storage vessels is as low as 4.5 barg. This, being below the operating pressure of the fuel cell, would cause a significant loss of hydrogen via the vent.

   In conclusion, the team agreed that the risk associated with the current vent configuration is ALARP. Even so, there is still the residual risk of operator exposure to a maximum heat radiation of 8.5 kW/m^2 [10], in case of ignition of the hydrogen vented during an emergency scenario. Hence, a recommendation was issued for the operational phase of the project, to ensure that the relevant controls are applied to restrict access to the impacted area.

10. Possible damage to the platform – transformer location: this event involves the transformer acting as an ignition source for hydrogen, potentially released by the nearby piping. Indeed, although the transformer is turned off during maintenance activities, it is still energized. However, no additional risk reduction options were identified, given that, similarly to item no. 7, the portion of hydrogen piping running close to the transformer is entirely welded. Therefore, as agreed by the team members, the risk associated with this event is deemed already ALARP.
11. Sequence of storage vessels: this event is related to an error in labelling the hydrogen storage vessels, swapping vessel C and D. As a consequence, the vessels are not arranged in alphabetical order but are labelled ABD-CEF instead. This might lead to miscommunication issues (e.g., operator has to perform a maintenance task on vessel C and goes to vessel D instead), potentially resulting in process or maintenance upsets. For this event, two additional options were identified and discussed:
    a) Consider decommissioning vessel D and commissioning vessel C to change the order to ABC-DEF.
    b) Update the project documentation and labelling on the platform to highlight the position of vessels C and D.

    Option A was considered grossly disproportionate at this stage of the project due to the cost and time needed for the re-certification (back to vendor fabrication) of the vessels. Therefore, the team members agreed to adopt option B to reduce the risk to an ALARP level.

All the considerations above are summarized in the worksheets employed during the ALARP workshop, which are reported in Attachment 2.

7 CONCLUSIONS

The outcomes of the ALARP demonstration workshop highlight that for most of the Major Accident Hazards analyzed, the current conditions already demonstrate an ALARP level of risk. This is because all potential additional risk-reduction measures have been deemed grossly disproportionate to the benefits achieved. This outcome is also influenced by the fact that the construction work for the BLPH is already underway, and some of the proposed solutions would require modifications to structures currently being fabricated or already installed (e.g., increasing the height of the vent, or building new support structures to allow a different piping routing), or changes to the arrangement of elements already assembled (e.g., increasing the space between the hydrogen storage vessels). Therefore, such options are impractical at this stage of the project.

Only for item no. 11 was it concluded that additional options can be implemented to bring the risk to an ALARP level. These measures are feasible as they do not involve construction or installation phases but are limited to updates in the project documentation.

In conclusion, the workshop, along with the numerous control and mitigation measures that are currently in place, highlighted four additional recommendations aimed at further reducing residual risks, which are reported in Attachment 3. Two of these recommendations concern the operational phase of the BLPH and involve ensuring that procedures and controls are put in place, while the other two involve updating/providing relevant documentation.

ATTACHMENT 1 – ATTENDANCE LIST

Name	Company	Role	Attendance
Neil Carlo Manning	ICARO	Chairperson	FT presence
Alberto Baldassarri	ICARO	Scribe	FT presence
Claudia Giunchi	ROSETTI MARINO	Project Engineer	FT presence
Edoardo Carminati	ROSETTI MARINO	Technical Safety Engineer	FT presence
Carolina Caracciolo	ROSETTI MARINO	Safety Leader	FT presence
Davide Lo Sterzo	ROSETTI MARINO	Project Engineer Manager	FT presence
Paul Van Rossum	CROSSWIND	Technical Safety Leader	FT presence
Nicolas Le Brun	CROSSWIND	HSE Leader	FT online
Marta Iacopetti	CROSSWIND	Project Engineer	HT online
Hamant Patel	CROSSWIND	Process Leader	FT presence
Paul Williamson	CROSSWIND	I&C Leader	FT presence
Dominik Sznajder	CROSSWIND	Project Manager	FT presence
Stephen Bremmer	CROSSWIND	Engineering Manager	FT presence

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ATTACHMENT 2 – ALARP WORKSHOP WORKSHEETS

This document undergoes an issuance cycle within EDMS Fusionlive". Its distribution is electronically controlled. Once printed shall be considered as "NOT CONTROLLED" copy

1 Hydrogen release from single hydrogen storage vessel – during maintenance

IDENTIFY

Problem Definition

Hydrogen release from single H_2 storage vessel

HSSE Issues and Potential Risk

Loss of Containment of H_2 from the H_2 storage vessels has been identified as an MAH and subjected to Bowtie analysis with following consequences:

- Explosion leading to more than 3 fatalities
- Jet Fire leading to less than 3 fatalities
- Escalation to other packages (fuel cell/electrolyser) – additional asset damage

In case of any maintenance on the H_2 storage vessels themselves requiring containment breaking, a full H_2 removal will be required as per risk assessment.

HSSE Standard and Tolerability Criteria

The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).

Note that the BLPH does not fall under the "mijnbouwwet" and the EU directive https://wetten.overheid.nl/BWBR0014168/2022-01-01

https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0030

as these rules apply for storage below 100 m underground and pipelines.

Note that the BLPH does not fall under the "Besluit risico's zware ongevallen 2015 - https://wetten.overheid.nl/BWBR0036791/2015-07-08", as there will be less than 5 tonne of H_2 (see part 2 of https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:32012L0018).

ASSESS

Options Considered

3 different options have been proposed:

a) As per current design – purge the electrolyser and not operate the fuel cell, keep the H_2 storage vessels pressurized
b) Always purge complete hydrogen inventory with nitrogen prior to personnel boarding and start maintenance activities
c) Always minimize hydrogen inventory to the minimal operational pressure of the fuel cell (3 barg)

Basis for Selection & Uncertainties

UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.

Expert judgement	Decision was taken by the project team.
Risk Based Analysis	Qualitative and Quantitative risk based analysis was part of the decision making.

	Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.
	Justification for Chosen Option
	As the BLPH is normally unmanned the risk to people has been considered ALARP based on the QRA (doc. no. 123A90-DDL-SAF-RE-30019). In combination with process hazard studies (HAZOP/LOPA) [8] and the Bow-Tie in Attachment 4 option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team. The current philosophy is that the H_2 storage vessels will not be emptied and purged while doing maintenance in the vicinity of the H_2 storage vessels. Offshore storage vessels are typically not depressurized for NUIs during maintenance activities.
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
	During the SELECT phase, the ALARP demonstration note considered similar options. The conclusion during the SELECT phase was to purge the whole inventory, as per **option B**, with a recommendation to better analyze this in the next phase. Hence during the DEFINE phase this was done. The conclusion in DEFINE is that it is more hazardous to purge the complete system, specifically the fuel cell system. For the hydrogen inside the storage vessels, completely emptying the storage vessels might lead to other hazards, e.g. air ingress and internal explosion. Also a key issue identified is to get the H_2 back on spec for the fuel cell. It will take many cycles to reach the purity required and hence lots of H_2 need to be sent to the atmosphere prior to restarting the fuel cell. This is a significant cost of the lost hydrogen and cost/time for purging with H_2. **In Option C,** no hydrogen is vented prior to personnel boarding and start of maintenance activities. However, the hydrogen is converted into energy when it is not efficient, hence eliminating the purpose of the hydrogen on the BLPH. So there is a potential for a significant loss of hydrogen which is expensive. Option C will be applied when personnel is required on the elevated deck. When no personnel is required on the elevated deck this option is considered grossly disproportionate as it will not reduce the frequency of a leak.
CONTROL & EVALUATION	Residual HSSE Risk
	Residual risks remain in connection to the presence of H_2 under pressure in the H2 storage vessel but are designed to ALARP as per BowTie in Attachment 4.

Recommendations for Next Project Phase	By
Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators

Requirements for the Operations HSSE-Plan
None

2 Hydrogen release from single hydrogen storage vessel leading to escalation

IDENTIFY

Problem Definition

Hydrogen release from single H_2 storage vessel with potential escalation to the other H_2 storage vessels

HSSE Issues and Potential Risk

Ignited release of H_2 at one H_2 storage vessel leading to escalation to one of the other H2 storage vessels.

A potential scenario for escalation is a flange leak in one of the H_2 storage vessels, leading to a jet fire flame impingement at an adjacent structure.

The risk associated with escalation has been ranked as 3B using the Crosswind Risk assessment matrix (one storage vessel is around €1M, escalation towards 2 storage vessels has been assumed) and is not a major accident.

HSSE Standard and Tolerability Criteria

The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).

Note that the BLPH does not fall under the "mijnbouwwet" and the EU directive
https://wetten.overheid.nl/BWBR0014168/2022-01-01
https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0030
as these rules apply for storage below 100m underground and pipelines.

Note that the BLPH does not fall under the "Besluit risico's zware ongevallen 2015 - https://wetten.overheid.nl/BWBR0036791/2015-07-08", as there will be less than 5 tonne of H_2 (see part 2 of https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:32012L0018).

ASSESS

Options Considered

3 different options have been proposed:

a) As per current design
b) Additional spacing between H2 storage vessels
c) Passive fire protection (PFP) on structural elements around the H_2 storage vessels

Basis for Selection & Uncertainties

UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.

Expert judgement	Decision was taken by the project team.
Risk Based Analysis	Qualitative and Quantitative risk based analysis was part of the decision making.

	Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.
	Justification for Chosen Option
	During the SELECT phase, this concern was initially raised, and a MEMO (416041-40751/MEMO-001) has been created with determined that the distance between the H2 storage vessels was sufficient. In the SELECT ALARP report a recommendation was given: "During the next phase, the basis for the leak size and the related distances between the hydrogen vessels shall be evaluated in more detail." During the DEFINE phase, this recommendation has been closed with the "leak size analysis report" (doc. no. K559-2254-SE-TEN-001) and a FERA (Document No: K559-2254-SE-REP-007). The distance between the H2 storage vessels have been considered ALARP. A key point to note is that the guidance for estimating hydrogen separation distances is geared towards land based hydrogen filling stations and is focused on distances from the entire hydrogen system to an external receptor. During the Execute phase, the FERA (doc. no. 123A90-DDL-SAF-RE-30020) has been updated to the latest design and the risk associated with fire and explosions from the hydrogen storage system is tolerable and ALARP for a 2 year test facility. In combination with process hazard studies (HAZOP/LOPA) [8]and the Bow-Tie in Attachment 4 option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team.
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
	Option B, additional spacing between H2 storage vessels This option requires a larger platform with massive increased CAPEX, which is grossly disproportionate considering the risk for escalation is assesses as tolerable according to FERA (doc. no. 123A90-DDL-SAF-RE-30020), QRA (doc. no. 123A90-DDL-SAF-RE-30019) and leak size analysis (doc. no. K559-2254-SE-TEN-001). Option C – PFP on structural elements around the H2 storage vessels PFP requires an investment of around €80 000 and reduces the fire escalation risk. The potential risk for fire escalation is already below 10^{-4}/yr according to FERA (doc. no. 123A90-DDL-SAF-RE-30020) and leak size analysis (doc. no. K559-2254-SE-TEN-001). The specific directionally has not been taken into account and would reduce the frequency of escalation even further. Normally a Cost Benefit Analysis (CBA) is only performed for MAH. However, for this escalation event, a CBA is performed for PFP. BenefitRR = The statistic value generated in reducing the risk over the period under consideration. BenefitRR [€/year] = (ΔCA + ΔCP + ΔCE) + (ΔCF x FGD)

	• ΔCA = The cost of asset damage avoided over the period under consideration
	  • Assuming PFP would eliminate the fire escalation would lead to a frequency of $<10^{-4}$/yr
	  • Assuming loss of 2 additional storage vessels" with a value of €1M each (€2M total)
	  • ΔCA = €2M * 10^{-4}/yr = €200/yr
	• ΔCP = The cost of production loss avoided over the period under consideration = N/A
	• ΔCE = The cost of environmental damage avoided over the period under consideration = N/A
	• ΔCF = The cost of averting the total fatalities over the period under consideration = N/A
	• FGD = The factor of gross disproportionality in case of fatality = N/A
	CostRR = CAPEX / life time of the project + yearly OPEX = €80 000/2 + 0 = €40 000/yr
	
	CostRR > BenefitRR hence the proposed mitigation is not ALARP and can be discarded.
	
	A key point to note is that the guidance for estimating hydrogen separation distances is geared towards land based hydrogen filling stations and is focused on distances from the entire hydrogen system to an external receptor. The FERA has assumed that the inventory of the 6 H_2 storage vessels are a single unit.
	
	Therefore, adding PFP to structural elements around the H_2 storage vessels is considered grossly disproportionate.

CONTROL & EVALUATION	Residual HSSE Risk
	Residual risks remain in connection to the presence of H_2 under pressure in the H_2 storage vessels but are designed to ALARP as per the BowTie in Attachment 4.
	Recommendations for Next Project Phase — By
	None
	Requirements for the Operations HSSE-Plan
	None

3 BESS thermal runaway

For the BESS thermal runaway itself, as agreed by the team members, no additional risk reduction options were identified. Regarding the existing safety measures in place, refer to the bow-tie in Attachment 4 and BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations (doc. no. K559-2254-CWIWP4202201-E99-099). However, additional options were evaluated to reduce the risk associated with the venting of the BESS thermal runaway gases below the upper deck, which might lead to the accumulation of flammable substances within a congested area.

<table>
<tr><td>IDENTIFY</td><td>Problem Definition</td></tr>
<tr><td></td><td>BESS Thermal Runaway</td></tr>
<tr><td></td><td>HSSE Issues and Potential Risk</td></tr>
<tr><td></td><td>The outlet of the BESS thermal runaway gases from BESS emergency response is on top of the BESS container below the bottom of steel of the upper deck flooring and the primary steel of the upper deck.
Potential accumulation of BESS thermal runaway gases (including hydrogen) below the plated deck.</td></tr>
<tr><td></td><td>HSSE Standard and Tolerability Criteria</td></tr>
<tr><td></td><td>The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).</td></tr>
<tr><td>ASSESS</td><td>Options Considered</td></tr>
<tr><td></td><td>a) As per design, with the presence of gas detectors above the BESS container in the potential hydrogen accumulation area, as indicated in the F&G detectors layout (doc. no. 123A90-DDL-SAF-DL-30027 Rev.02 SH1) and F&G C&E Matrix (doc. no. 123A90-DDL-IN-CE-40002)
b) Route the BESS emergency exhaust ventilation conduit outside the deck to a safe area
c) Route the BESS emergency exhaust ventilation conduit through a vent line to the main emergency vent (Q-43004)</td></tr>
<tr><td></td><td>Basis for Selection & Uncertainties</td></tr>
<tr><td></td><td>UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.

<table><tr><td>Expert judgement</td><td>Decision was taken by the project team.</td></tr><tr><td>Risk Based Analysis</td><td>Qualitative and Quantitative risk based analysis was part of the decision making.</td></tr></table>
Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.</td></tr>
<tr><td></td><td>Justification for Chosen Option</td></tr>
<tr><td></td><td>The BESS thermal runaway scenario is assessed in a Bow-Tie [4]. Any additional barriers from Thermal Runaway mitigations and recommendations (doc. no. K559-2254-CWIWP4202201-E99-099) have been assessed and implemented in the BESS design.</td></tr>
</table>

	The amount of produced gasses by a thermal runaway is limited (doc. no. K559-2254-CWIWP4202201-E99-099) and a limited amount of batteries are affected. Any produced runaway gases from BESS are vented to atmosphere with sufficient dilution to ensure no flammable mixture occurs within the BESS. Once the diluted gasses are exiting the BESS, these gasses cannot de-mix and no flammable mixture can occur outside the BESS. Outside the BESS there is natural ventilation. If the ventilation inside the BESS is not working sufficiently there may be a flammable mixture inside the BESS and subsequently outside the BESS, but this will not be prevented by the installation of ventilation conduit. To be able to detect any elevated hydrogen concentration outside the container, hydrogen detectors are installed under the top deck above the BESS vents. Therefore, option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team.	
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)	
	Both Options B & C require significant engineering changes and cost for implementing new piping. The exhaust ventilation conduit routes the thermal runaway gasses to a safe area, but does not prevent the risk for buildup gasses inside the container if the ventilation is not available. Therefore this is considered grossly disproportionate.	
CONTROL & EVALUATION	Residual HSSE Risk	
	The residual risk remains in the presence of thermal runaway gasses at the top of the BESS below the plated top deck.	
	Recommendations for Next Project Phase	By
	None	
	Requirements for the Operations HSSE-Plan	
	None	

4 Hydrogen release inside eletrolyser container

This ALARP item was not discussed during the workshop. Please refer to Paragraph 6 of this report for further details.

5 Potential for explosion inside electrolyser due to membrane failure

This ALARP item was not discussed during the workshop. Please refer to Paragraph 6 of this report for further details.

6 Hydrogen release inside fuel cell container

This ALARP item was not discussed during the workshop. Please refer to Paragraph 6 of this report for further details.

7 Location of hydrogen piping on the lower deck

IDENTIFY	Problem Definition
	Location of hydrogen piping on the lower deck from the H_2 storage vessels to the fuel cell (the piping from the electrolyser to the H_2 storage vessels has been relocated above the plated floor of the upper deck)
	HSSE Issues and Potential Risk
	A leak from this piping can lead to an explosion or jet fire on the lower deck, which is rated as a non-ATEX zone.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).
ASSESS	Options Considered
	a) As per design b) Relocate the piping from the H_2 storage vessels to the fuel cell above the upper deck floor
	Basis for Selection & Uncertainties
	UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards.
	Expert judgement: Decision was taken by the project team. Risk Based Analysis: Qualitative and Quantitative risk based analysis was part of the decision making. Option Discussion: the team agrees that the risk associated with the current design solution is ALARP
	Justification for Chosen Option
	- The piping from the H_2 storage vessels to the fuel cell will have no flanges or fittings - There is no hazardous area classification around the piping, hence the full lower deck stays a "no hazardous area". - The purity of the H_2 inside this piping is 99.999% hence no corrosion expected. - The outlet to the fuel cell from the H_2 storage vessel is from the top (not from the bottom), so there will be no liquid going to the low point in the piping system - There is a cap installed in the line for the hydrotest, which will be seal welded after commissioning (refer to isometric drawing no. 16, line no. 2"-HY-023-01HSS-N [15]). - The deck above is plated hence no risk of dropped objects Based on the FERA (doc. no. 123A90-DDL-SAF-RE-30020) and QRA (doc. no. 123A90-DDL-SAF-RE-30019) results the risk associated with this piping is small. Additionally, F&G detection is located on the lower deck around the hydrogen piping. Therefore, the risk of the current design (Option A) is considered ALARP by the ALARP workshop team.

	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
	Option B requires re-routing of the hydrogen piping above the emergency escape route on the upper deck. This would increase the complexity of the piping and require dedicated structural support, making the option costly and requires re-engineering.
CONTROL & EVALUATION	Residual HSSE Risk
	Potential hydrogen leak source in the lower deck, which is mitigated by the absence of flanges or fittings, and by the presence of F&G network
	Recommendations for Next Project Phase
	None
	Requirements for the Operations HSSE-Plan
	None

8 Fire in technical rooms

This ALARP item was not discussed during the workshop. Please refer to Paragraph 6 of this report for further details.

9 Vent height – operator injuries

IDENTIFY	**Problem Definition**
	Initially the project philosophy was to depressurize the H_2 storage vessels prior to boarding the BLPH. There was a change in the project philosophy, to keep the H_2 storage vessels pressurized when accessing the BLPH platform. The hydrogen vent was already ordered based on the original non pressurized philosophy. The vent study concluded that the top area of the BLPH exceeds the 6.31 kW/m^2 during an ignited release from the simultaneous discharge of all 7 blowdown valves.
	HSSE Issues and Potential Risk
	Possibility of operator exposure to a maximum heat radiation of 8.5 kW/m^2 in case of ignition of hydrogen vented during emergency scenario.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046). API 521 is used as standard for the vent design. The radiation of 6.31 kW/m^2 (including solar radiation) shall not be reached in location where people presence can be possible. 6.31 kW/m^2 is "the maximum radiant heat intensity in areas where emergency action lasting up to 30 s can be required by personnel without shielding but with appropriate clothing".
ASSESS	**Options Considered**
	a) As per vent study recommendation to have a sterile area on the top of the BLPH b) Increase vent height so that the minimum height of the 6.31 kW/m^2 is above the top of the BLPH c) Staggered depressurization of the storage vessels d) Reduce the pressure to 4.5 barg of the hydrogen storage vessels so that the radiation from the vent is below 6.31 kW/m^2 for the top of the BLPH.
	Basis for Selection & Uncertainties0
	UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards.
	Expert judgement: Decision was taken by the project team. Risk Based Analysis: Qualitative risk based analysis was part of the decision making. Option Discussion: the team agrees that the risk associated with the current design solution is ALARP when the sterile area is implemented.
	Justification for Chosen Option
	Personnel is only required to enter the top of the BLPH for maintenance on the hydrogen storage vessels and related equipment (e.g., valves, instruments, etc.). This is expected to occur once during the 2 years of operation. When the sterile area is implemented, option A is considered ALARP by the ALARP workshop team, because the other options are grossly disproportionate.

	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)	
	- Option B requires a costly design change for building the support structure of the new higher vent and the additional cost of a new vent. Therefore, this is considered grossly disproportionate. - Option C reduces the vent load and subsequently the radiation. However this is not feasible due to the time constraint of the emergency depressurization, according to API 521. Option D The minimum operation pressure of the fuel cell at which the power output is above 600kW is 4 barg. The actual minimum pressure which initiates a shutdown is 3 barg. The pressure of the hydrogen storage vessels so that the radiation from the vent is below 6.31 kW/m^2 for the top of the BLPH is 4.5 barg. As the minimum operation pressure is lower it is required to vent hydrogen for option D, which is considered grossly disproportionate.	
CONTROL & EVALUATION	Residual HSSE Risk	
	The sterile area includes the top area of the BLPH, hence no maintenance can take place when the H2 storage vessels are pressurized. Within the hazard hierarchy, procedures & PPE are least effective. Hence if personnel does not comply to the restriction, there is the possibility of operator exposure to a maximum heat radiation of 8.5 kW/m^2 in case of ignition of hydrogen vented during emergency scenario.	
	Recommendations for Next Project Phase (operational phase)	By
	Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.	EPC contractor
	Requirements for the Operations HSSE-Plan (operational phase)	By
	Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on operator in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.	Operators

10 Possible damage to the platform – transformer location

This ALARP item was not discussed during the workshop. Please refer to Paragraph 6 of this report for further details.

11 Sequence of storage vessels

IDENTIFY	Problem Definition
	Installed sequence of vessels is not as per alphabetic order. The H_2 storage vessel layout is numbered "ABD" for the lower 3 vessels and "CEF" for the top vessels.
	HSSE Issues and Potential Risk
	Human factor error due to miscommunication (e.g., operator has to go to vessel C and goes to vessel D instead), leading to maintenance on the wrong vessel and potential fatalities when incorrect vessel has been depressurized.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).
ASSESS	Options Considered
	a) Consider decommissioning vessel D and commissioning vessel C to change the order to ABC-DEF b) Update the project documentation and labelling on the platform to highlight the position of vessels C and D
	Basis for Selection & Uncertainties
	UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards. Demonstration of ALARP for these types of scenario is by verifying the "appropriate" use of established codes, standards and practices in the design
	Expert judgement: Decision was taken by the project team. Risk Based Analysis: Qualitative risk based analysis was part of the decision making. Option Discussion: the team agrees to select option B.
	Justification for Chosen Option
	Option B is chosen as the benefit gained outweighs the effort, time and cost to implement it.
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
	Option A would need to re-certificate (back to vendor fabrication) the H_2 storage vessels C & D, which is considered grossly disproportionate.
CONTROL & EVALUATION	Residual HSSE Risk
	As per HSSE Issues and Potential Risk
	Recommendations for Next Project Phase
	Ensure as built documentation, plant signage and HMI reflect the actual status of vessels V-25001 and D location. — EPC contractor
	Requirements for the Operations HSSE-Plan
	None

ATTACHMENT 3 – RECOMMENDATIONS

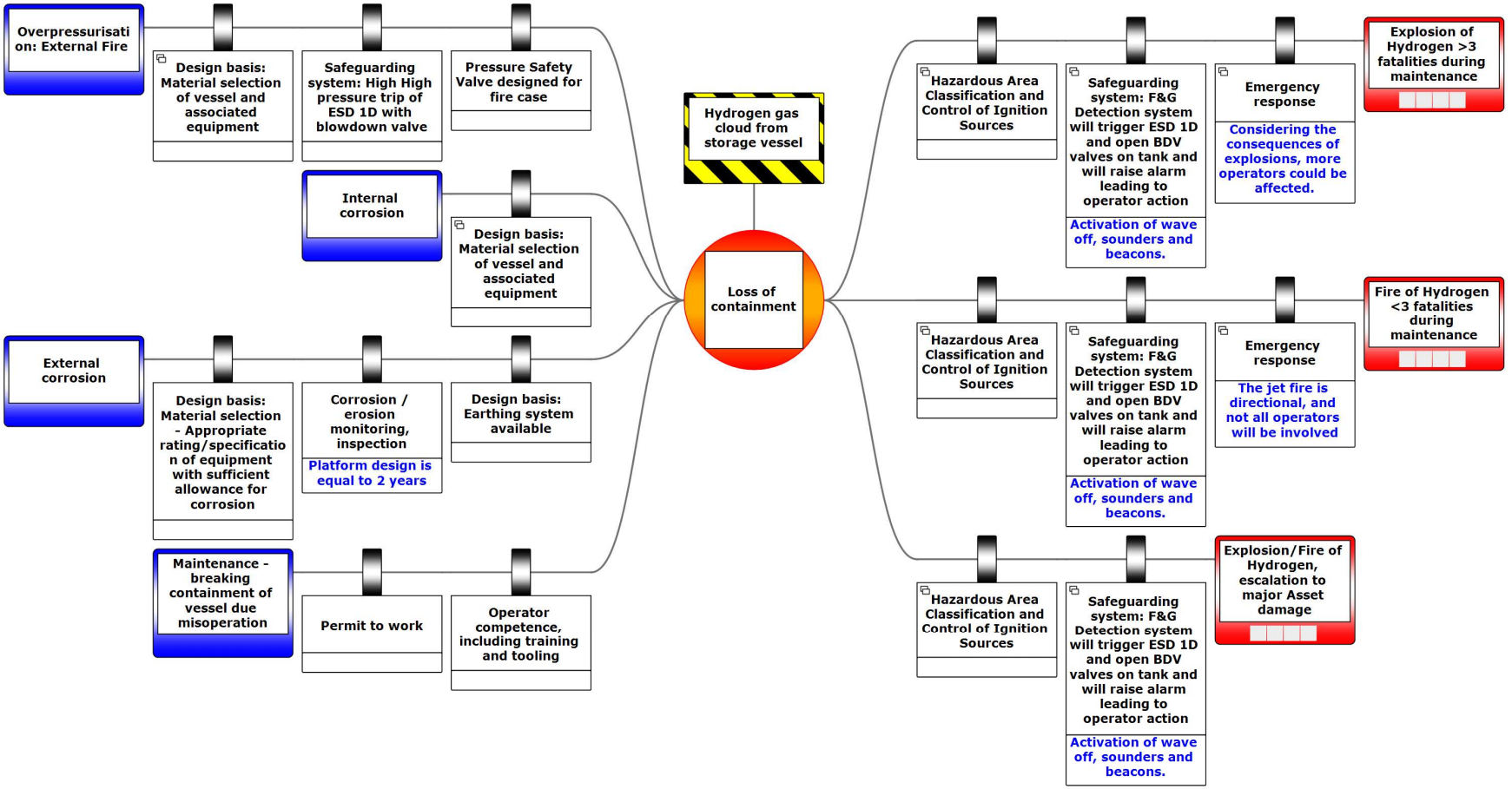
ALARP item no.	Recommendation	By
1	Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
3	Provide technical documentation for the estimation of the hydrogen inventory from BESS exhaust gases due to BESS thermal runaway.	Crosswind
9	Apply controls to restrict access to the impacted area.	Operators
11	Ensure as built documentation, plant signage and HMI reflect the actual status of vessels 25001-C and D location.	EPC Contractor

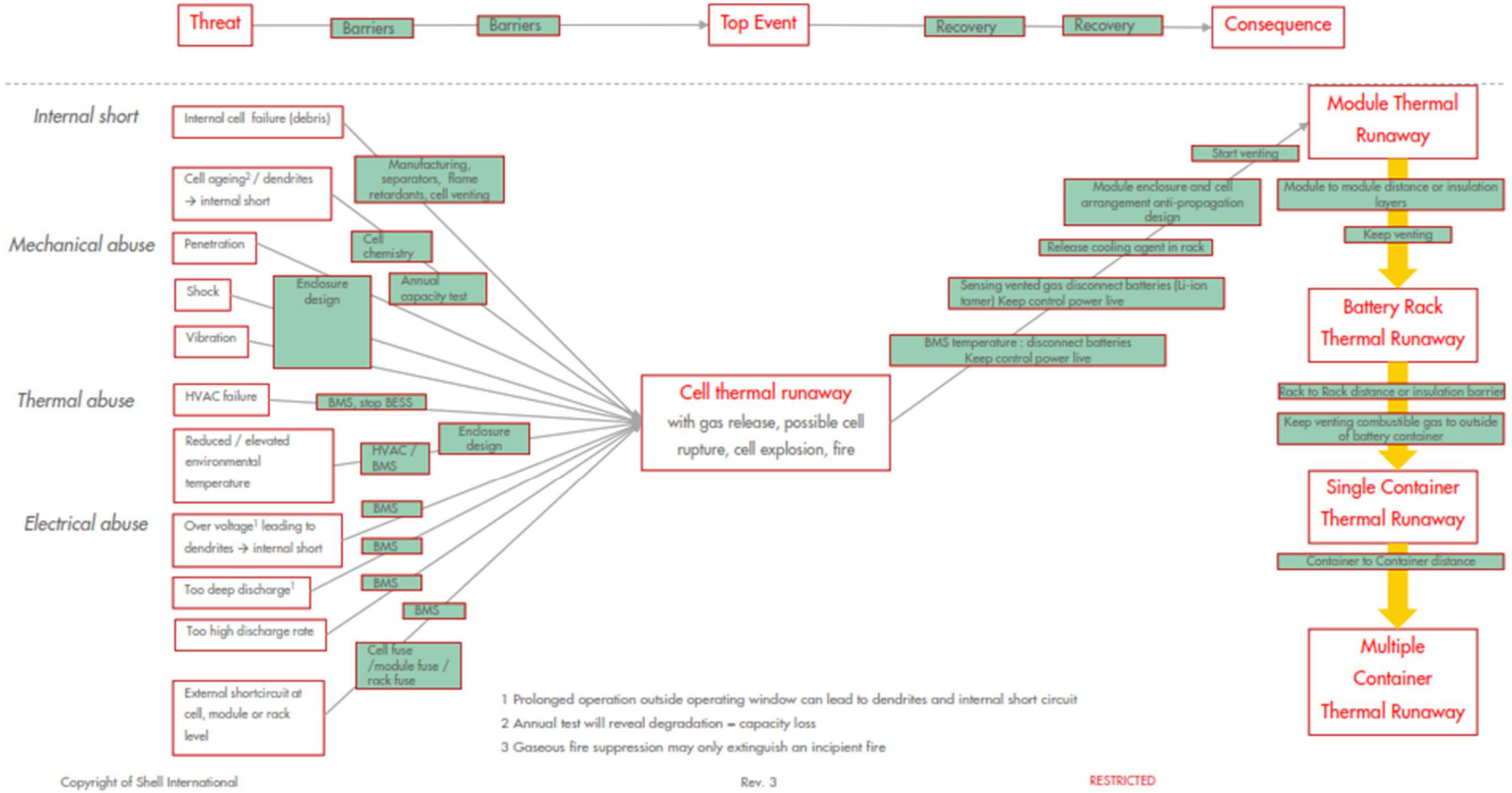
In addition to the actions above, it is required that the following recommendation from the Vent Gas Dispersion and Potential Radiation Study (ref- [10]) be included in the Operations HSSE Plan.

ALARP item no.	Requirement for Operatios HSSE Plan	By
9	Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization.	Operators

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ATTACHMENT 4 – BOW-TIE DIAGRAMS


Overpressurisation: External Fire
Design basis: Material selection of vessel and associated equipment
Safeguarding system: High High pressure trip of ESD 1D with blowdown valve
Pressure Safety Valve designed for fire case
Internal corrosion
Design basis: Material selection of vessel and associated equipment
External corrosion
Design basis: Material selection - Appropriate rating/specification of equipment with sufficient allowance for corrosion
Corrosion / erosion monitoring, inspection
Platform design is equal to 2 years
Design basis: Earthing system available
Maintenance - breaking containment of vessel due misoperation
Permit to work
Operator competence, including training and tooling
Hydrogen gas cloud from storage vessel
Loss of containment
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Emergency response
Considering the consequences of explosions, more operators could be affected.
Explosion of Hydrogen >3 fatalities during maintenance
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Emergency response
The jet fire is directional, and not all operators will be involved
Fire of Hydrogen <3 fatalities during maintenance
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Explosion/Fire of Hydrogen, escalation to major Asset damage


Threat
Barriers
Barriers
Top Event
Recovery
Recovery
Consequence
Internal short
Internal cell failure (debris)
Manufacturing, separators, flame retardants, cell venting
Cell ageing[2] / dendrites → internal short
Mechanical abuse
Penetration
Cell chemistry
Shock
Enclosure design
Annual capacity test
Vibration
Thermal abuse
HVAC failure
BMS, stop BESS
Reduced / elevated environmental temperature
HVAC / BMS
Enclosure design
Electrical abuse
Over voltage[1] leading to dendrites → internal short
BMS
Too deep discharge[1]
BMS
Too high discharge rate
BMS
Cell fuse /module fuse / rack fuse
External shortcircuit at cell, module or rack level
Cell thermal runaway
with gas release, possible cell rupture, cell explosion, fire
Start venting
Module enclosure and cell arrangement anti-propagation design
Release cooling agent in rack
Sensing vented gas disconnect batteries (Li-ion tamer) Keep control power live
BMS temperature : disconnect batteries Keep control power live
Module Thermal Runaway
Module to module distance or insulation layers
Keep venting
Battery Rack Thermal Runaway
Rack to Rack distance or insulation barrier
Keep venting combustible gas to outside of battery container
Single Container Thermal Runaway
Container to Container distance
Multiple Container Thermal Runaway
1 Prolonged operation outside operating window can lead to dendrites and internal short circuit
2 Annual test will reveal degradation = capacity loss
3 Gaseous fire suppression may only extinguish an incipient fire
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