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Report

Firlough Windfarm Hydrogen Plant Hazard Log Report

Prepared for – Black and Veatch

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EXECUTIVE SUMMARY

Mercury Renewables (Mercury) is submitting a planning application to local authorities for a hydrogen generation plant, to be designed by Black and Veatch (BV), connected to the proposed, Mercury operated, Firlough Windfarm project located in Co. Mayo, Ireland. BV have requested Risktec to undertake a Preliminary Hazard Analysis (PHA) and generate a Hazard Log, based on the current design. This report describes the PHA activity and presents the Hazard Log.

Risktec followed a systematic approach to assess the design details presented in this report to create a draft PHA. The draft PHA was subjected to a panel of technical experts from BV and Mercury in a workshop setting using online means. The workshop generated a set of changes to the draft PHA which were recorded and refined into the project hazard log presented in this report.

Limitations on this assessment are detailed in section 1.4. They are related to design maturity, which meant that the compressor, water purifier and buffer tank system components have not been subject to this assessment process and this should be carried out when designs are mature. In addition, the overall level of maturity in the design meant assigning risk parameters of severity and likelihood was not possible at this stage and should also be carried out when design maturity increases.

This report provides:

1) A set of actions, Table 3, which are required to be carried out by the project team in order to continue this PHA and complete the safety requirements in Table 4.
2) A set of Safety Requirements, Table 4 intended to influence the design of the system hardware in order to reduce risk.
3) A set of actions, Table 5, which are intended to influence the through life safety management, but which do not necessarily influence the design of the system hardware.

ISSUE RECORD

Issue	Date	Author Name	Reviewer Name	Approver Name	Revision History
1.0	10-Feb-22	Nick Taylor	Ed Thomas	David Rees	Formal Issue
2.0	9th Dec 22	Nick Taylor	Ed Thomas	G Dixon	Update following client comments.

DISTRIBUTION

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ABBREVIATIONS

Abbreviation	Description	Abbreviation	Description
BV	Black and Veatch	PEM	Proton Exchange Membrane
CEDI	Continuous Electrodeioisation	PHA	Preliminary Hazard Assessment
HAZID	Hazard Identification	RAM	Risk Assessment Matrix

1 INTRODUCTION

1.1 Overview

Mercury Renewables (Mercury) is submitting a planning application to local authorities for a hydrogen generation plant, to be designed by Black and Veatch (BV), connected to the proposed, Mercury operated, Firlough Windfarm project located in Co. Mayo, Ireland. BV have requested Risktec to undertake a Preliminary Hazard Analysis (PHA) and generate a Hazard Log, based on the current design. This report describes the PHA activity and presents the Hazard Log.

1.2 Objectives and Scope

The objective of this work is to form the basis for demonstration of management of safety as part of the planning application.

The scope of the work includes the hydrogen generation systems and ancillaries only. The assessment considers the planned operation of the facility including:

1) Interactions between equipment,
2) Persons with intentional interactions with the equipment (maintainers, operators, etc.), and
3) Persons with no intentional interactions with it (site neighbours, trespassers, etc.).

1.3 Assumptions

The following assumptions were identified in the workshop:

Table 1 Assumptions

Assumption ID	Assumption
ASS1	A power transformer is included in the electrical design of the system in the scope of this assessment.
ASS2	The location of the hydrogen plant is far enough away from general population for noise issues from neighbours to be unlikely. Mercury are undertaking a separate noise assessment.

1.4 Limitations

In addition to the assumptions in Table 1, the limitations described in this section should be noted. It is assumed these limitations will be removed as the design matures.

The first limitation on the assessment is that the compressor technology has not been selected and so this stage of the PHA was not conducted to the same level as for stages where technology selection was more firm. However, it is known that a diaphragm or reciprocating compressor are the options under consideration. Robust options selection for compressor technology is beyond the scope of this work. However, examples of each technology have been found in industry, [4], [5], and any option selection work would require more detailed information on the parameters of the compression stage. Therefore, further work would be required from both BV and Risktec in order to determine the safest compression technology for this application.

The second limitation on the assessment is that the Water Purification technology has not been selected and so this stage of the PHA was not conducted to the same level as for stages where technology selection was more firm. However, it is known that reverse osmosis and Continuous Electrodeionisation (CEDI) technologies are under consideration. Robust options selection for water purification technology is beyond the scope of this work. However, an example of both technologies being used in the production of high purity water has been identified, [6] as well as examples of the technologies being used in isolation, [7], [8]. On the basis of these industrial examples, it is assumed that options selection for the water purification would require more detailed information on the parameters of the purification stage and require further work from BV and Risktec in order to determine the safest water purification technology for this application.

The third limitation on the assessment is that it was not possible to identify hazards arising from the buffer tank or storage nodes. This is due to the current maturity of the design. In order to identify hazards associated with these nodes, further work would be required from Black and Veatch, in order to provide a design to subject to the systematic process followed in this work.

This issue of the report is provided to reflect the updated layout of the system design. On the basis that the inputs, process and outputs remain the same as for the previous layout, it is considered that the results of this assessment remain valid for the revised system design.

1.5 System Description

In order to complete the PHA and to provide detail that will aid in the understanding of the PHA, the following sections provide a description of the system operation, key quantities and site layout. It should be noted that all information contained here is based on early design stage documents and may change as the project progresses.

1.5.1 System Operation

1.5.1.1 Electricity supply

An 110kV, 78MW electric supply, routed via a dedicated power cable from the windfarm substation will provide energy to the facility for the electrolytic conversion of water into:

- hydrogen for distribution, and
- waste oxygen for venting.

The electrical supply will be routed to site via a dedicated high voltage (HV) and low voltage (LV) switchboard and stepdown transformer located to the east of site. The site equipment will be housed in a building. The electricity supply and hydrogen plant componentry are shown in Figure 1.

1.5.1.2 Water Source

Two onsite boreholes and rainwater harvesting will provide a source of electrolyte feed water and cooling water. Raw water will be routed to a water purification plant; cooling water will only be required during top up of systems and will be mixed with glycol to provide a coolant solution capable of handling the generated heat and environmental temperature variations.

1.5.1.3 Water Purification

Water from the borehole will contain minerals and other impurities that, if allowed to enter the electrolyser, may present a hazard to equipment. As such all feed water will be routed via a water purification plant. The specification of the purification plant is to be defined, but is expected to be reverse osmosis with ultrafilter and electrodeionisation.

1.5.1.4 Electrolyser

The electrolyser uses electrical energy to convert the water-based electrolyte to hydrogen and oxygen. The current design conservatively assumes an Alkaline Electrolyser as it has the largest footprint and is more commercially mature. The low pressure hydrogen produced will be routed to the multistage compressor for compression to suitable pressure for storage or distribution. The produced oxygen will be vented to atmosphere via the oxygen vent.

The block diagram in Figure 1Figure 1 shows a single electrolyser, but an option exists, as presented in Figure 6, for 16 electrolysers in total. For the purpose of the preliminary hazard analysis (PHA), a single electrolyser 'stage' has been considered.

1.5.1.5 Oxygen Vent

The oxygen vent routes gaseous by-products from the anode side of the electrolyser, to atmosphere at a safe location. Initial assessment considered a credible worst-case pipe diameter of 200-300mm.The actual vent size will be determined during detailed design.

1.5.1.6 Fin Fan Cooling

Splitting of water to hydrogen and oxygen requires a large amount of energy, which results in a significant amount of waste heat. To ensure optimal and safe running of the alkaline electrolyser, the excess heat will be managed via a liquid to air exchange system designed around a bank of fin fan coolers. These will be located away from the main process area.

The electrolyser elements will be housed within a water jacket, or similar direct contact exchange system, with a pumped coolant system carrying waste heat to the remote fin fans. The design currently incorporates 9 fin fan coolers of length 16.87 meters, width 5.57 metres and height of 7.5 meters.

The fin fan coolers will also provide a heat exchange for the hydrogen compressor package cooling loop, which is separate to the electrolyser cooling system but is expected to include a similar cooling design.

1.5.1.7 Compressor

The compressor receives hydrogen from the electrolyser and compresses it to a pressure of up to 500bar for storage and distribution. The type of compressor is yet to be confirmed. The high pressure hydrogen will be routed from the output of the compressor to an intermediate "buffer" vessel for short term storage.

1.5.1.8 Buffer Tank

The buffer vessel "tank" is located between the hydrogen compressor package and the road vehicle dispensing units to provide a consistent supply of hydrogen that is not reliant on the output of the electrolyser. The buffer tank is expected to operate at 500bar, and contain a maximum of 528kg of hydrogen.

1.5.1.9 Dispensing

Multiple Road vehicle dispensing units have been included in the current design. The dispensing units consist of a number of gas control devices, a gas receiver and hose work to dispense hydrogen to road approved tube trailers. Specific details of the dispensing system are not yet available but are expected to follow standard good practice for road tanker loading bays.

1.5.1.10 Tube Trailer Storage

Compressed hydrogen is stored onsite and distributed offsite via road tube trailers. Maximum onsite storage is currently 26 x 12m tube trailers, plus potential for one full trailer in each of the 7 filling bays, providing a total storage capacity of 39,600kg + 528kg buffer for a total of 40,128kg. However, it is planned that tube trailers will only be onsite for short periods of time following loading before being dispatched to client facilities.

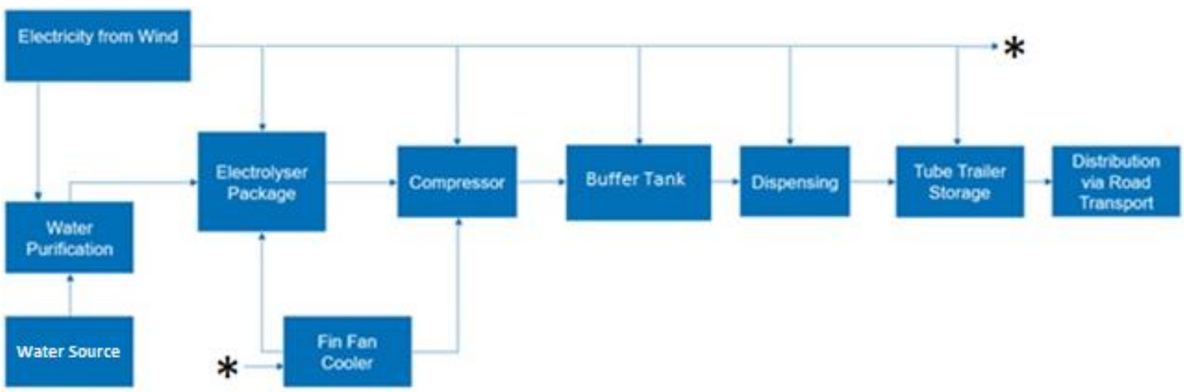
In order to remain within the threshold for consideration as a 'Lower Tier' COMAH site, Mercury shall calculate the total onsite quantity of H_2 at any given time.

Furthermore, Mercury shall limit the total onsite quantity of H_2 to be beneath the lower tier COMAH threshold for H_2.

1.5.1.11 Distribution

Distribution is by road, using Carriage of Dangerous Goods (ADR) approved tube trailers.

Figure 1 Hydrogen Plant High Level Block Diagram



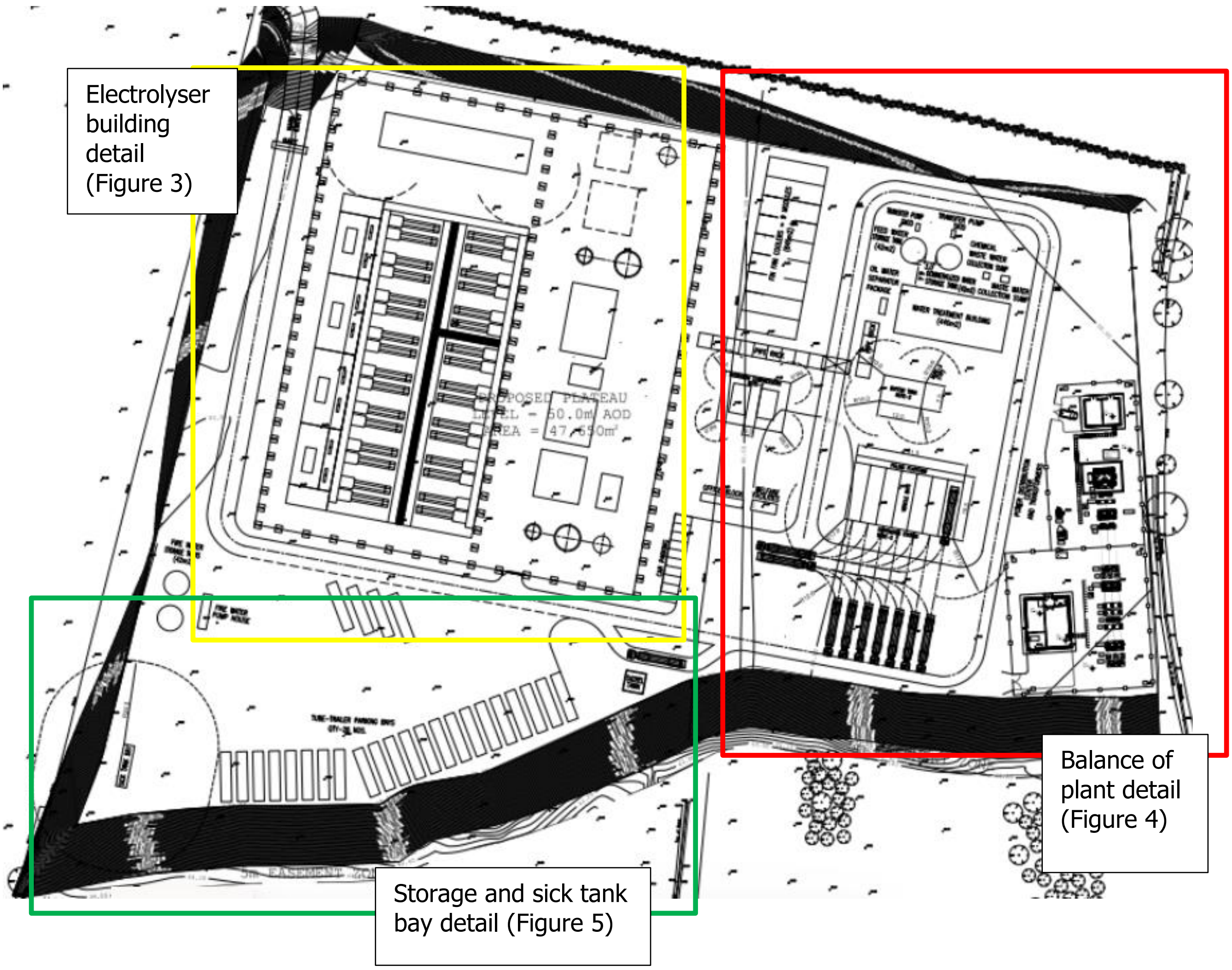
1.6 Key Project Detail

Table 2 Key Project Details

Aspect	Detail
Size of footprint	< 6.5 hectares
Annual quantity of raw water required	65021 m^3/year
Quality of water required	The electrolyser manufacturer has defined approx. requirements of a conductivity level of < 5 micro Siemens/cm and a resistivity level of > 10MΩ/cm.
Annual H_2 Production	4567 Tonnes
Max daily H_2 Production	31.2 Tonnes
Onsite hydrogen storage (Buffer Tank Capacity + Total Tube Trailer Capacity)*	Buffer Tank Capacity (0.528 Tonnes) + Total Tube Trailer Capacity, incl. filling stations (39.6 Tonnes) = 40.1 Tonnes
Transportation from site, i.e. number of vehicles per day	26 x 12m tube trailers
Working pressure	500Bar

1.7 Layout

Figure 2 Hydrogen Plant Plan*



*Note the original analysis was carried out on an earlier version of the plant layout, however the layout shown here is similar and so the findings in this report remain valid.

Figure 3 Electrolyser Building Detail

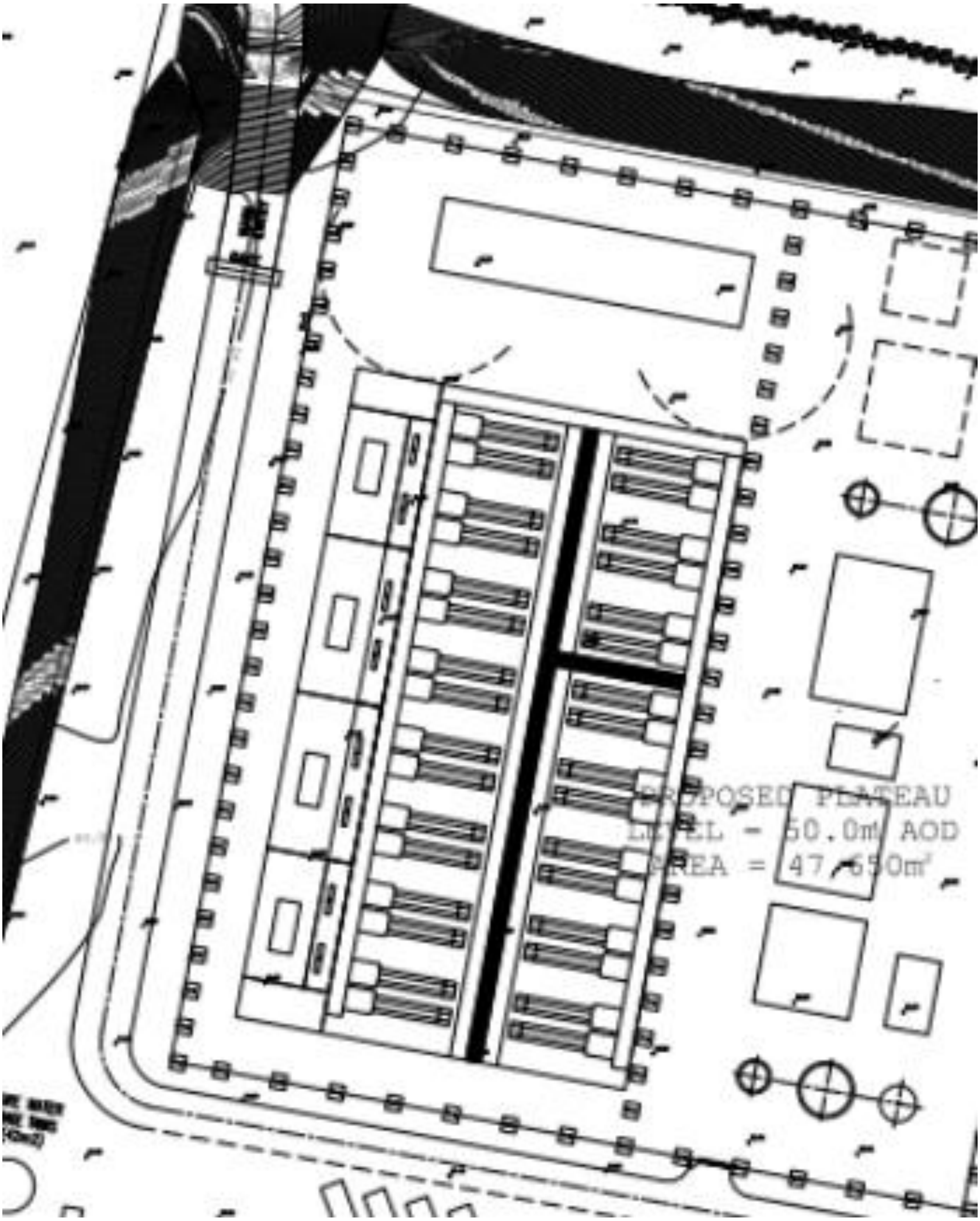


Figure 4 Balance of Plant Detail

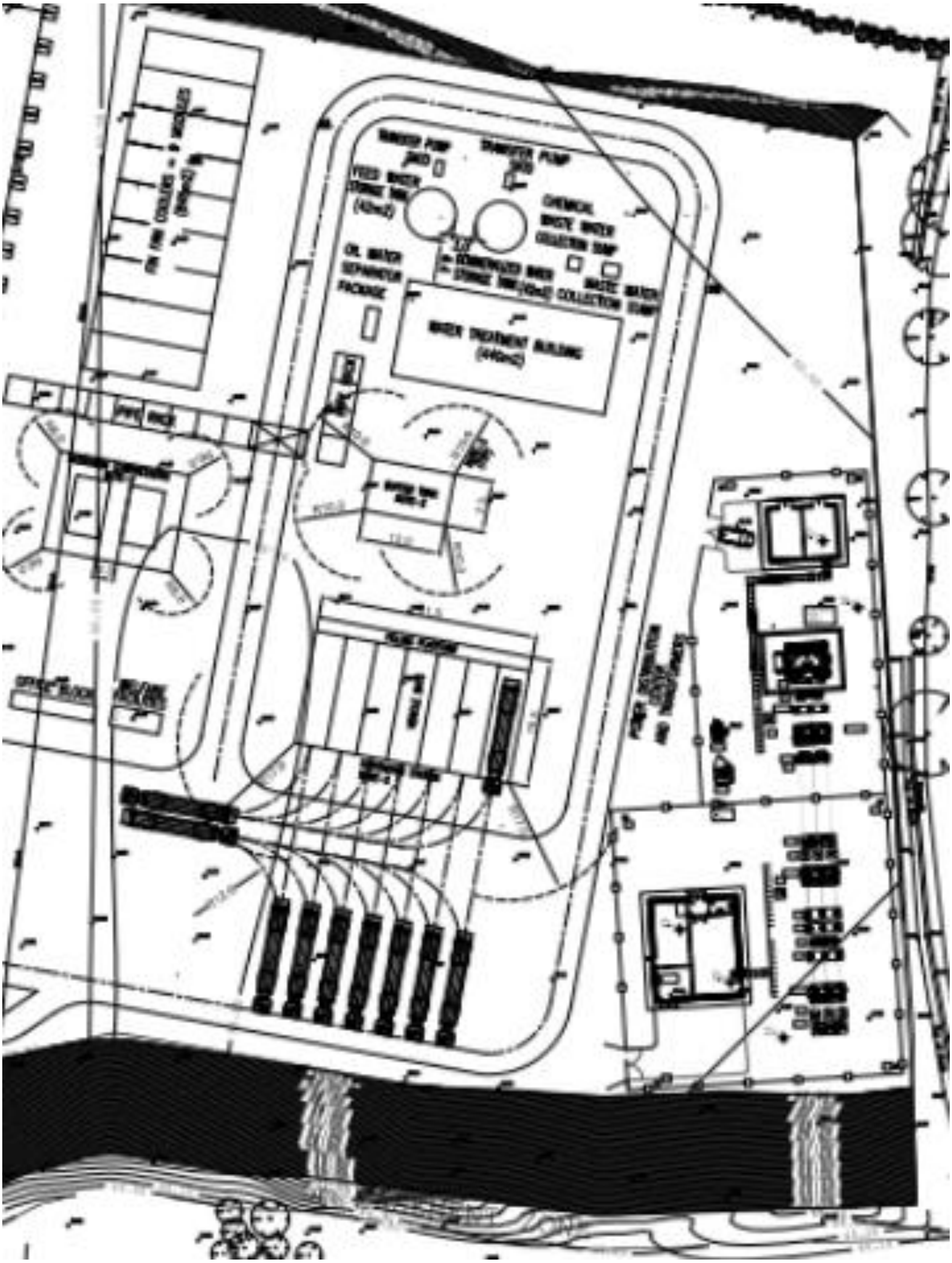


Figure 5 Storage and sick tank bay detail

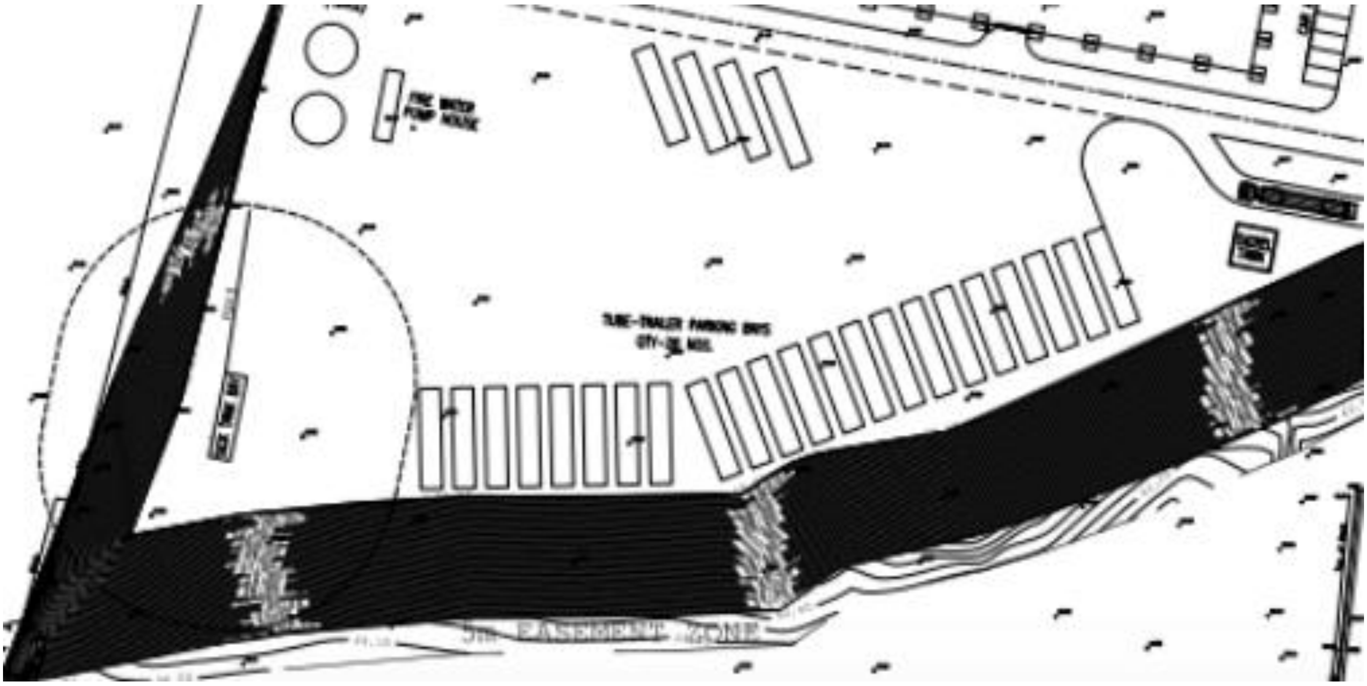
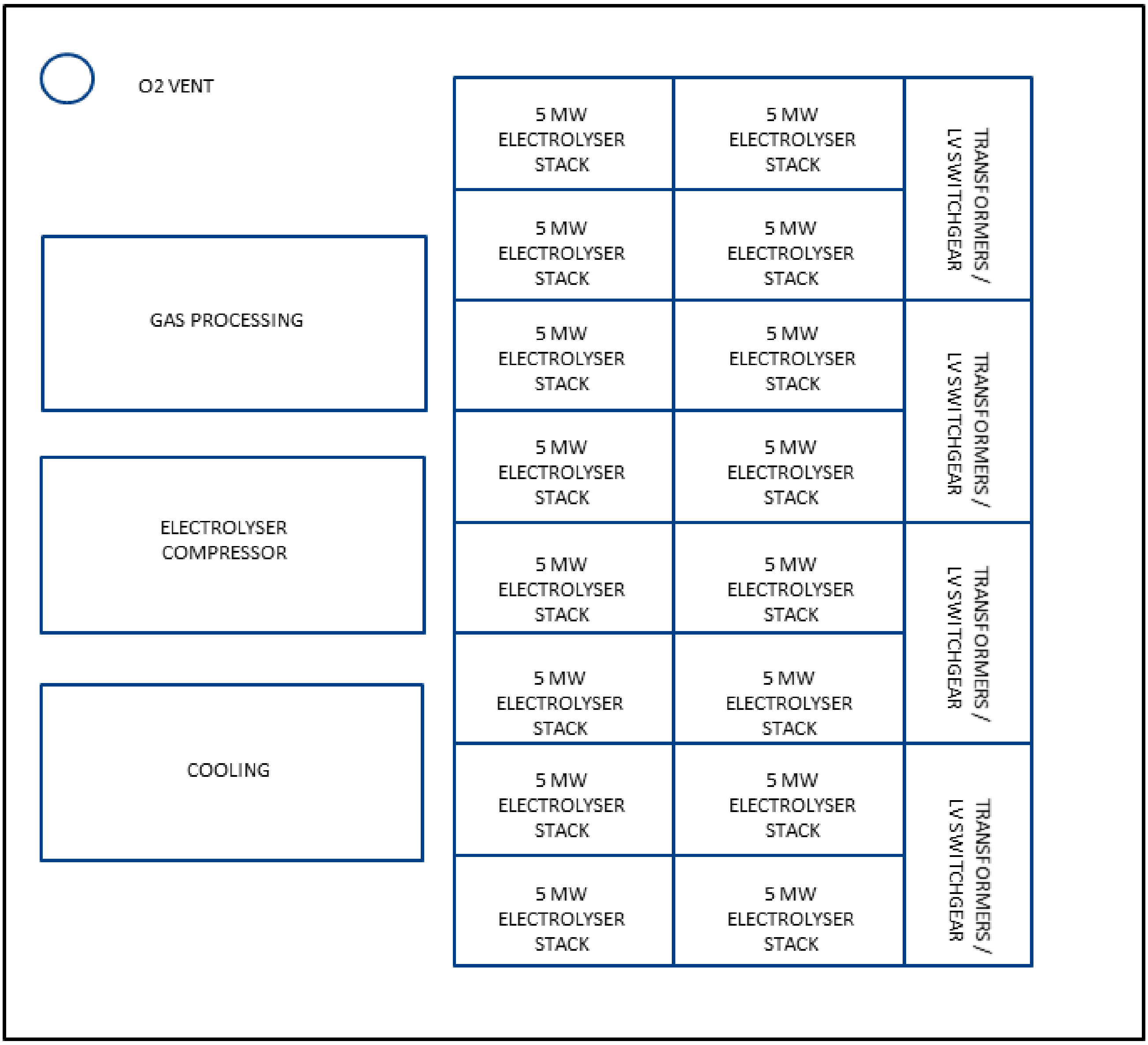


Figure 6 Electrolyser Concept Layout



2 METHODOLOGY

2.1 Hazard Identification

This PHA study has been carried out as an initial desktop exercise to develop a draft based on information provided followed by a review by technical experts from B&V in a workshop. The methodology is presented in the following sections.

The desktop PHA has been carried out following guidance presented in ISO 12100 [2]. Specifically the keywords provided have been used to develop a bespoke set of guidewords for the hazard review presented in Appendix C. The guidewords were used as an "aide memoire" for the PHA, rather than being a tick list exercise, i.e. if other hazards were identified they were included during the process.

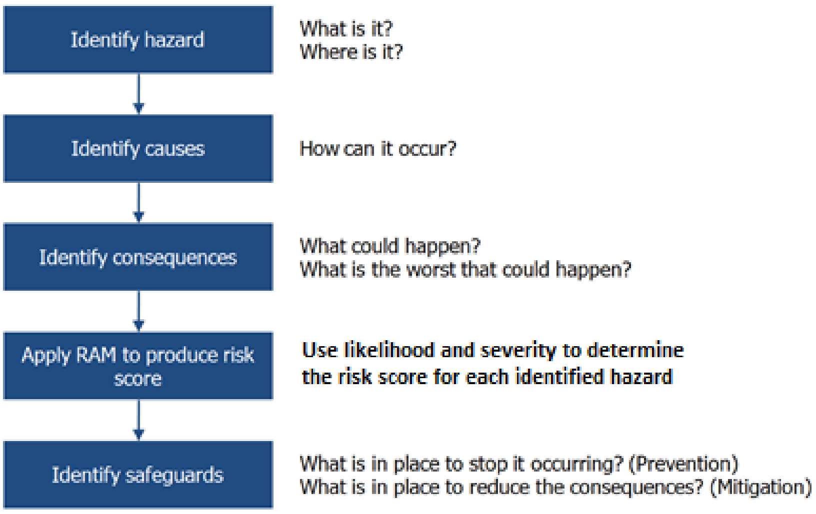
The systems described in Section 1.3 divided into the following nodes, each of which were subject to systematic desktop analysis by considering the keywords against the description of the node (including node ID):

- Electricity supply (node ES) from windfarm up to the connection to the electrolyser;
- Borehole (node BH) up to the connection to the water purifier;
- Water purification (node WP) up to the connection to the electrolyser;
- Electrolyser (node ET) up to the connection to the compressor;
- Oxygen vent (node OV) including the connection to the electrolyser;
- Fin fan cooling (node FFC) up to the connections to the electrolyser and the compressor;
- Compressor (node CMP) up to the connection to the storage facility;
- Buffer tank (node BFT) which smooths out the supply of hydrogen to the dispenser;
- Dispenser (node DSP) which provides some level of isolation between compressor and trailer connection;
- Storage (node STR) including the physical location of the tube trailers; and
- Distribution (node DTR) including the actions of the vehicle drivers whilst on site.

Each identified hazard was assessed in terms of causes and consequences, however due to design immaturity, it was agreed that insufficient design detail was available for the assignment of severity and likelihood values, thus prioritisation of hazards for further assessment has not been completed.

Notwithstanding the assignment severity and likelihood, the methodology for the review is summarised in Figure 7 below.

Figure 7 Workshop Method Overview



The output from the desktop PHA and workshop has been refined to provide the PHA worksheet [3] for final review by BV. The PHA worksheets have been used to develop the Hazard Log presented in Appendix B and summarised in Section 3.

2.2 Workshop

A workshop was carried out on the following dates with representatives from Key stakeholders including BV, Mercury, and haulage providers. Attendance records are provided in Appendix A :

- Tuesday 15th February 2022 14:00 to 17:00 GMT

  Tuesday 1st March 2022 14:00 to 17:00 GMT. Both sessions were held virtually using MS Teams.

the workshop was supported by an independent facilitator and scribe provided by Risktec Solutions Ltd.

3 RESULTS

3.1 Hazards

The desktop PHA and workshop identified a list of hazards related to the systems within the facility. The workshop results [3] are presented in the Hazard Log, provided in Appendix B.

The Hazard log contains 62 hazards, across all nodes identified. The Hazard log provides suggested safety requirements, which are listed in Table 4. Each safety requirement should be included in the requirements specification of the overall system.

3.2 Actions

During the PHA a number of actions have been identified, which are to be prioritised and resolved by BV as part of the work planning and design process. Table 3 provides actions for additional work required in order to assess specific hazards. Table 4 provides safety requirements to ensure risk is managed by design. Table 5 provides a set of actions to be carried out to manage risk by means other than by design.

The Hazard ID refers to the node and the numbered hazard identified at that node, for example WS3 is the 3rd hazard identified when considering the Whole Site, node WS.

Table 3 Actions Required to Identify Safety Requirements

Hazard ID	Hazard	Action ID	Action Text
BH3	Radon gas	ACT6	Borehole survey workpackage to be included as part of planning application.
WP1	Heavy metals within the water course	ACT8	Identification of heavy metals within watercourse to be included in borehole surveys.
OV2	Material incompatibility in the Oxygen vent line	ACT14, ACT15	HAZOP to be conducted on the selected design. Identify design basis for material compatibility in the oxygen vent line.
WS1	External fire source	ACT20	Fire risk from external sources to be assessed as part of layout design.
WS3	Rare weather event	ACT21	Weather issues e.g. wind loading and temperature change to be included in design requirements.
WS4	Security breach	ACT22	Security assessment to be included in overall workpackage planning.
N/A	N/A	ACT23	Future risk assessment activities should use the risk parameters presented in Appendix D when design maturity allows.

3.3 Safety Requirements

During the workshop, the design intent for hazard mitigation was, where known, captured, for each hazard, and formalised in the safety requirements presented in Table 4, below. Each safety requirement has a unique identifier in the format SRn and a reference to the ID of the hazard, which generated the requirement:

Table 4 Safety Requirements and Source Hazard

Safety Requirement ID	Safety Requirement Text	Source Hazard ID
SR1	The system shall use standard Switchgear and transformer design with relevant specific safeguards to be defined during detailed design of electrical supply.	ES1, ES2

Safety Requirement ID	Safety Requirement Text	Source Hazard ID
SR2	The earthing and bonding system shall follow industry standards for this type of application.	ES3, DTR1
SR3	Hydrogen compound layout design shall consider measures to prevent a transformer explosion from having detrimental impact on the switchgear.	ES2
SR4	Cable routing shall be designed to minimise the potential for insulation degredation.	ES4
SR5	Access to the hydrogen compound shall be limited to those with specific competencies.	ES5
SR6	Conductive surfaces shall be bonded to provide a conductive path to earth in accordance with suitable standards.	ES5
SR7	Signage and employee education shall include potential risk to people with electrical implants e.g. pacemakers.	ES6
SR8	The offsite substation shall include measures to segregate the hydrogen plant supply from other electrical systems.	ES5
SR9	Ergonomic principles shall be considered during control system design.	ES7
SR10	Transformer shall be placed above existing ground level.	ES8
SR11	Lightning strike protection systems shall be installed.	ES8
SR12	The control system shall ensure safe recovery from dead busbars.	ES9
SR13	Isolation scheme shall include off site electrical supply isolation measures.	ES10
SR14	Borehole design shall use proven design of borehole to prevent borehole collapse.	BH1
SR15	Electrolysers shall be fitted with safety systems to shut down hydrogen production on loss of vital parameters, e.g. temperature, water level or water quality etc.	BH2, ET1, ET3
SR16	Water source design shall ensure a continuous supply of water in the event that a single bore hole becomes unusable e.g due to running dry, total collapse or pipe blockage.	BH4
SR17	Firewater system design shall be developed during detailed design.	BH2
SR18	The system shall include the ability to shut down the electrolyser in more than one location.	ET1
SR19	Control system logic shall shutdown electrical feed on detection of any out of operating envelope event.	ET1

Safety Requirement ID	Safety Requirement Text	Source Hazard ID
SR20	Noise mapping to be conducted as part of detailed design.	FFC4
SR21	The safety system shall shutdown the electrolyser on detection of over voltage.	ET2
SR22	Mechanical segregation shall be provided between compressor and electrolyser to eliminate transfer of vibration.	ET4
SR23	The gas path design shall include measures to ensure the concentration of oxygen in the hydrogen path is less than less than 25% of the lower explosive limit of hydrogen.	ET5, ET6, ET10, OV5
SR24	Control system shall take executive action, e.g. electrical isolation or purge on detection of gases out of specification .	ET6
SR25	The electrolyser package shall be designed to enable the purging of the hydrogen system prior to maintenance of systems.	ET7
SR26	Electrolyser package shall include safety mechanisms and 'safe by design' materials specifications.	ET9
SR27	The electrolyser package shall include measures to shutoff the hydrogen supply on detection of a hydrogen leak.	ET8, ET11
SR28	Alkaline additive transport and handling shall be included as part of operations manual.	ET12
SR29	COSHH management shall be implemented as part of operations and maintenance of the site.	ET13
SR30	Oxygen vent shall be designed by electrolyser supplier to take account of suitable routing within the building.	OV1
SR31	Oxygen sizing calculations shall be conducted by electrolyser package supplier.	OV1
SR32	Mitigation of the effects of backpressure in oxygen vent line shall be included in the electrolyser package design.	OV1
SR33	The presence of pure oxygen shall be included in the overall claim for compliance to ATEX requirements.	OV4
SR34	The electrolyser building gas detection system shall include oxygen level detection.	OV5
SR35	Hydrogen detection shall be installed in the oxygen vent pipe.	OV5
SR36	The gas path design shall include measures to ensure the concentration of oxygen in the hydrogen path is less than 25% of the lower explosive limit of hydrogen	OV5
SR37	The fin fan cooler shall be installed away from other plant.	FFC1
SR38	Effects of vibration to be mitigated by fin fan cooler supplier.	FFC1

Safety Requirement ID	Safety Requirement Text	Source Hazard ID
SR39	The fin fan cooler control system shall have a minimum operating temperature.	FFC2
SR40	The fin fan cooler system shall maintain temperature within safe limits in the event of loss of a single Fin fan cooler.	FFC3
SR41	The hydrogen plant shall be forced to a safe state on detection of a high fin fan cooler temperature.	FFC3
SR42	The fin fan cooler shall be designed for the worst credible scenario, e.g 'hot day' scenario.	FFC3
SR43	Operations and maintenance package shall ensure vibration arising from plant degradation is detected and managed.	FFC5
SR44	The effects of human contact with coolant shall be mitigated by the design of the operations and maintenance processes.	FFC6
SR45	Control system monitoring shall shutdown hydrogen production in advance of low or high temperature scenario.	FFC8
SR46	ATEX shall be considered during detailed design to allow equipment specification to be identified.	CMP1, CMP2, CMP3, CMP4, CMP5
SR47	The filling process control system shall include measures for pressure regulation and delta pressure monitoring across the dispensing hose.	DSP1
SR48	The filling process control system shall include redundancy to ensure no single failure can lead to the overpressure of a tube trailer.	DSP1
SR49	All road going tube trailers shall be compliant with TPED-EN17339.	DSP2
SR50	The filling system shall include measures to prevent high pressure hydrogen release due to tube trailer leaving the filling location whilst a filling hose is attached.	DSP3
SR51	Filling hoses shall be robust to their environment and foreseeable mechanical damage.	DSP4
SR52	The filling area shall include measures to ensure the tube trailer and attached vehicles cannot drive into the dispenser.	DSP5
SR53	The filling system shall mitigate the severity of 'mechanical shock'.	DSP6
SR54	Dispensing of hydrogen shall be inhibited unless earth continuity is confirmed.	DSP7
SR55	Overall site design shall include provision for lighting of the filling locations and driving routes.	DTR3
SR56	Hydrogen distribution infrastructure shall include weather protection for areas where drivers of hydrogen distribution vehicles would be required to carry out their tasks.	DTR4

Safety Requirement ID	Safety Requirement Text	Source Hazard ID
SR57	Cold surfaces will be insulated or designed out to prevent inadvertent exposure to personnel.	DTR2
SR58	The selected system design shall incorporate requirements arising from human factors assessment.	OV3, FFC7
SR59	Fin fan cooler device shall be a CE marked COTS item, and will need to be installed and operated in accordance with its designed limits and environment.	FFC1
SR60	Ensure the coolant is specified to avoid freezing due to environmental conditions.	FFC2
SR61	Fin fan cooler shall shutdown on detection of vibration beyond operating threshold.	FFC5
SR62	Mechanical segregation shall be provided between compressor and electrolyser to eliminate transfer of vibration.	CMP6

Table 5 Actions and Source Hazard ID

Action ID	Action Text	Source Hazard
ACT1	Competence for access to be defined as part of the overall planning operations and maintenance planning process.	ES5
ACT2	Confirm if the energy in the installation breaches the threshold for people with pacemakers.	ES6
ACT3	Lightning assessment recommended.	ES8
ACT4	Review, in discussion with other operators of similar windfarms the best practice method for ensuring continuous power supply in case of interruption, e.g. UPS.	ES9
ACT5	Undertake Hazardous Area Classification and Assessment to define safe locations for electrical systems.	ES10
ACT6	Borehole survey workpackage to be included as part of planning application.	BH1, BH3
ACT7	System safety design activities should be integrated into the design work as part of the overall workpackage planning process.	BH2
ACT8	Identification of heavy metals within watercourse to be included in borehole surveys.	WP1
ACT9	The electrolyser supplier selection procedure should ask the candidates to demonstrate how electrolyser package risks are managed, and the scope of their supply should be defined to interfaces to safety systems within the electrolyser building.	ET1
ACT10	If following a phased introduction of electrolysers, then hazards associated with interactions between units is to be considered as part of the design process.	ET1
ACT11	Include 'cause and effect diagrams' within vendors deliverables package.	ET2
ACT12	Confirm temperature of hydrogen coming out of the electrolyser.	ET3
ACT13	Safe Systems of Work required to be developed and used on the site, for example to limit exposure of people to electrolyte.	ET12
ACT14	HAZOP to be conducted on the selected design.	OV2
ACT15	Identify design basis for material compatibility in the oxygen vent line.	OV2
ACT16	Inspection and maintenance training to include signage and necessary precautions around the oxygen vent line.	OV3
ACT17	Ensure oxygen handling standards are included in the overall requirements suite.	OV4
ACT18	Determine operating temperature range. Ambient temperature may not be a concern but the need for temperature control should be considered.	FFC2
ACT19	Decommissioning HAZID to be included in the lifecycle workpackage planning.	DSP7

Action ID	Action Text	Source Hazard
ACT20	Fire risk from external sources to be assessed as part of layout design.	WS1
ACT21	Weather issues e.g. wind loading and temperature change to be included in design requirements.	WS3
ACT22	Security assessment to be included in overall workpackage planning.	WS4
ACT23	Future risk assessment activities should use the risk parameters presented in Appendix D when design maturity allows.	N/A

4 CONCLUSION

A PHA has been undertaken on the hydrogen system planned to be installed at the Firlough Windfarm based on the information and details available at this time. The PHA remains incomplete due to design maturity of the Compressor, Buffer Tank, Water Purifier and Hydrogen Storage. Additional PHA work will be required once the designs for these components are sufficiently mature. In addition, the overall level of maturity in the design meant assigning risk parameters of severity and likelihood was not possible and should be carried out during later stages of the design.

The PHA work carried out to date has enabled the generation of a Hazard Log. The Hazard Log presents the potential sources of harm arising from the current system design and suggests 62 safety requirements for reduction of risk associated with the listed hazards. the assessment identified 23 actions which should be used to support activities during the design phase of the facility. The further PHA for the components previously identified will generate further hazards and therefore safety requirements and actions.

The Hazard Log should be treated as a living document throughout the project lifecycle. The hazard log present provides a start to this process based on information available at the time of development. Further assessment will be required as designs mature and additional, more detailed hazard identification and management activities are undertaken. The Hazard Log should act as a repository for this information and will support the planning process at this stage.

5 REFERENCES

Ref	Title
1.	Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) (Text with EEA relevance)
2.	ISO 12100, S*afety of machinery — General principles for design — Risk assessment and risk reduction 2010*
3.	BLV-03-R-01 PHA Worksheet, Issue 1, Author: Nick Taylor, Principal Consultant, Risktec Solutions Ltd.
4.	Accessed 5/5/22: https://www.elliott-turbo.com/Files/Admin/Articles/compression-options-hydrogen-report-may-%28reduced%29.pdf?msclkid=1c8855e9ae9711eca5d8da95c399fb50
5.	Accessed 5/5/22: https://www.sollant.com/diaphragm-compressor/#:~:text=Brief%20Introduction%20of%20Diaphragm%20Compressor%20The%20diaphragm%20compressor,pipelines%2C%20an%20electronic%20control%20system%2C%20and%20some%20accessories.?msclkid=b146db9cae9711ec9b6e575e0af6d162
6.	Accessed 5/5/22: https://www.veoliawatertechnologies.co.uk/products/ionpro-lx?utm_medium=ppc&utm_source=adwords&utm_term=reverse%20osmosis&utm_campaign=Campaign++-+IonPro+Awareness+Campaign&hsa_src=g&hsa_kw=reverse%20osmosis&hsa_mt=p&hsa_acc=5205785480&hsa_grp=97441552046&hsa_ad=423782979010&hsa_cam=9563837885&hsa_tgt=kwd-10254191&hsa_net=adwords&hsa_ver=3&gclid=CjwKCAjwuYWSBhByEiwAKd_n_nqW2cNdV7-X04hVOiJAxTx46sSHnCGGAwPqnDPNj8-S8nzmqQSfxhoCkr8QAvD_BwE
7.	Accessed 5/5/22: https://www.evoqua.com/en-GB/evoqua/products--services/electrochemical-products/continuous-electrodeionization-cedi-products/?variationCode=Continuous-Electrodeionization-CEDI-Products_1
8.	Accessed 5/5/22: https://www.industrialwaterequipment.co.uk/products/reverse-osmosis/?gclid=CjwKCAjwuYWSBhByEiwAKd_n_lh-Rljj19q5a7a61DM5Ndqzl5oBG1RkKt7scIfEFpXXXImu6KC4fhoCdkIQAvD_BwE

Appendix A WORKSHOP ATTENDEE REPORTS (MS TEAMS)

APPENDIX A.1 WORKSHOP 1

Total Number of Participants	13					
Meeting Title	Firlough Windfarm Hydrogen Plant Preliminary Hazard Identification confirmatory workshop					
Meeting Start Time	2/15/2022, 1:53:31 PM					
Meeting End Time	2/15/2022, 5:03:09 PM					
Meeting Id	09182bfd-7fee-459d-9e0d-a6f72ee3fed9					
Full Name	Join Time	Leave Time	Duration	Email	Role	Participant ID (UPN)
Nick Taylor	2/15/2022, 1:53:31 PM	2/15/2022, 5:03:09 PM	3h 9m	Nick.Taylor@risktec.tuv.com	Organizer	TAYLORNI@tuv.group
David Rees	2/15/2022, 1:59:35 PM	2/15/2022, 5:03:05 PM	3h 3m	David.Rees@risktec.tuv.com	Presenter	reesda@tuv.group
Cait O'Reilly	2/15/2022, 1:59:59 PM	2/15/2022, 3:46:49 PM	1h 46m	coreilly@jodireland.onmicrosoft.com	Attendee	coreilly@jodireland.onmicrosoft.com
Cait O'Reilly	2/15/2022, 3:51:13 PM	2/15/2022, 5:03:02 PM	1h 11m	coreilly@jodireland.onmicrosoft.com	Attendee	coreilly@jodireland.onmicrosoft.com
Tim Bills	2/15/2022, 2:00:07 PM	2/15/2022, 2:04:59 PM	4m 51s	TBills@mercuryrenewables.ie	Attendee	TBills@mercuryrenewables.ie
Bloor, Leanne	2/15/2022, 2:00:10 PM	2/15/2022, 5:03:05 PM	3h 2m	BloorL@bv.com	Attendee	BloorL@bv.com
Doerflinger, Andrew M. (Denver)	2/15/2022, 2:00:35 PM	2/15/2022, 5:03:06 PM	3h 2m	DoerflingerAM@bv.com	Attendee	DoerflingerAM@bv.com
Stevenson, Ben	2/15/2022, 2:00:36 PM	2/15/2022, 5:03:05 PM	3h 2m	StevensonB@bv.com	Attendee	StevensonB@bv.com
Sean Molloy	2/15/2022, 2:00:44 PM	2/15/2022, 3:46:36 PM	1h 45m	smolloy@jodireland.onmicrosoft.com	Presenter	smolloy@jodireland.onmicrosoft.com
Sean Molloy	2/15/2022, 3:51:02 PM	2/15/2022, 4:28:51 PM	37m 48s	smolloy@jodireland.onmicrosoft.com	Presenter	smolloy@jodireland.onmicrosoft.com
Cristiani, Jonathan M.	2/15/2022, 2:00:47 PM	2/15/2022, 5:03:05 PM	3h 2m	CristianiJM@bv.com	Attendee	CristianiJM@bv.com
Pearson, Geraint	2/15/2022, 2:01:13 PM	2/15/2022, 5:03:04 PM	3h 1m	PearsonG@bv.com	Attendee	PearsonG@bv.com
Mosher, Jonathan R.	2/15/2022, 2:01:24 PM	2/15/2022, 3:30:40 PM	1h 29m	MosherJR@bv.com	Attendee	MosherJR@bv.com
Mosher, Jonathan R.	2/15/2022, 4:13:56 PM	2/15/2022, 5:03:06 PM	49m 10s	MosherJR@bv.com	Attendee	MosherJR@bv.com
Paul Preston	2/15/2022, 2:02:39 PM	2/15/2022, 5:03:03 PM	3h	ppreston@reynoldslogistics.com	Attendee	ppreston@reynoldslogistics.com
John Duffy (Guest)	2/15/2022, 2:03:12 PM	2/15/2022, 5:03:05 PM	2h 59m		Attendee	

APPENDIX A.2 WORKSHOP 2

Total Number of Participants	13					
Meeting Title	Firlough Windfarm Hydrogen Plant Preliminary Hazard Identification confirmatory workshop 2					
Meeting Start Time	3/1/2022, 1:58:39 PM					
Meeting End Time	3/1/2022, 5:10:08 PM					
Meeting Id	7ed0a3ef-9650-4177-8438-59a5aa9de629					
Full Name	Join Time	Leave Time	Duration	Email	Role	Participant ID (UPN)
Nick Taylor	3/1/2022, 1:58:39 PM	3/1/2022, 5:10:08 PM	3h 11m	Nick.Taylor@risktec.tuv.com	Organizer	TAYLORNI@tuv.group
David Rees	3/1/2022, 2:00:04 PM	3/1/2022, 5:10:03 PM	3h 9m	David.Rees@risktec.tuv.com	Presenter	reesda@tuv.group
Ruairi Geary	3/1/2022, 2:00:52 PM	3/1/2022, 2:40:36 PM	39m 44s	Ruairi.Geary@TLI.ie	Attendee	ruairi.geary@tli.ie
Doerflinger, Andrew M.	3/1/2022, 2:00:52 PM	3/1/2022, 5:10:05 PM	3h 9m	DoerflingerAM@bv.com	Attendee	DoerflingerAM@bv.com
Stevenson, Ben	3/1/2022, 2:00:52 PM	3/1/2022, 5:10:04 PM	3h 9m	StevensonB@bv.com	Attendee	StevensonB@bv.com
Cait O'Reilly	3/1/2022, 2:00:52 PM	3/1/2022, 3:56:39 PM	1h 55m	coreilly@jodireland.onmicrosoft.com	Attendee	coreilly@jodireland.onmicrosoft.com
Cait O'Reilly	3/1/2022, 4:10:00 PM	3/1/2022, 5:10:03 PM	1h	coreilly@jodireland.onmicrosoft.com	Attendee	coreilly@jodireland.onmicrosoft.com
Sean Molloy	3/1/2022, 2:00:52 PM	3/1/2022, 3:56:23 PM	1h 55m	smolloy@jodireland.onmicrosoft.com	Presenter	smolloy@jodireland.onmicrosoft.com
Sean Molloy	3/1/2022, 4:09:54 PM	3/1/2022, 5:10:01 PM	1h	smolloy@jodireland.onmicrosoft.com	Presenter	smolloy@jodireland.onmicrosoft.com
Cristiani, Jonathan M.	3/1/2022, 2:01:08 PM	3/1/2022, 3:14:11 PM	1h 13m	CristianiJM@bv.com	Attendee	CristianiJM@bv.com
Cristiani, Jonathan M.	3/1/2022, 4:31:37 PM	3/1/2022, 5:10:05 PM	38m 27s	CristianiJM@bv.com	Attendee	CristianiJM@bv.com
Mosher, Jonathan R.	3/1/2022, 2:01:19 PM	3/1/2022, 5:00:53 PM	2h 59m	MosherJR@bv.com	Attendee	MosherJR@bv.com
Bloor, Leanne	3/1/2022, 2:01:23 PM	3/1/2022, 5:10:03 PM	3h 8m	BloorL@bv.com	Attendee	BloorL@bv.com
John Duffy (Guest)	3/1/2022, 2:02:44 PM	3/1/2022, 5:10:02 PM	3h 7m		Attendee	
Tim Bills	3/1/2022, 2:07:29 PM	3/1/2022, 5:10:05 PM	3h 2m	TBills@mercuryrenewables.ie	Attendee	TBills@mercuryrenewables.ie
Paul Preston	3/1/2022, 2:13:09 PM	3/1/2022, 2:20:06 PM	6m 56s	ppreston@reynoldslogistics.com	Attendee	ppreston@reynoldslogistics.com
Paul Preston	3/1/2022, 2:25:43 PM	3/1/2022, 5:10:04 PM	2h 44m	ppreston@reynoldslogistics.com	Attendee	ppreston@reynoldslogistics.com

Appendix B HAZARD LOG

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
ES1	Electricity Supply	Electrical Hazards	Arcing between HV cables	PHA Worksheet	Undetected HV cable insulation degredation	Electrocution Fire Projection of molten particles	The system shall use standard Switchgear and transformer design with relevant specific safeguards to be defined during detailed design of electrical supply.	N/A	N/A
ES2	Electricity Supply	Electrical Hazards	Arcing from the transformer	PHA Worksheet	Assuming transformer on hydrogen site. 'transformer failure	Electrocution Fire Projection of molten particles Transformer explosion leading to plant damage	The system shall use standard Switchgear and transformer design with relevant specific safeguards to be defined during detailed design of electrical supply. Hydrogen compound layout design shall consider measures to prevent a transformer explosion from having detrimental impact on the switchgear.	N/A	N/A
ES3	Electricity Supply	Electrical Hazards	Electromagnetic phenomena	PHA Worksheet	Loss of earth bonds	Hazardous induced voltage in conducting materials, e.g. fence or rebar.	The earthing and bonding system shall follow industry standards for this type of application.	N/A	N/A
ES4	Electricity Supply	Electrical Hazards	Short circuit between HV cables	PHA Worksheet	Undetected HV cable insulation degredation	Electrocution Fire Projection of molten particles	Cable routing shall be designed to minimise the potential for insulation degredation.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
ES5	Electricity Supply	Electrical Hazards	Parts which have become live under fault conditions;	PHA Worksheet	Loss of earth bonds	Electrocution Fire Projection of molten particles	Access to the hydrogen compound shall be limited to those with specific competencies. Conductive surfaces shall be bonded to provide a conductive path to earth in accordance with suitable standards. The offsite substation shall include measures to segregate the hydrogen plant supply from other electrical systems.	Competence for access to be defined as part of the overall planning operations and maintenance planning process.	N/A
ES6	Electricity Supply	Radiation Hazards	Exposure to HV Electromagnetic Radiation	PHA Worksheet	HV AC Electrical current present, where people may work.	Pacemaker malfunction	Signage and employee education shall include potential risk to people with electrical implants e.g. pacemakers.	Confirm if the energy in the installation breaches the threshold for people with pacemakers.	N/A
ES7	Electricity Supply	Ergonomic Hazards	Hard to reach or illogical control layout.	PHA Worksheet	Misoperation of equipment Loss of maintenance coverage due to difficult tasks	Fire Electrocution	Ergonomic principles shall be considered during control system design.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
ES8	Electricity Supply	Hazards associated with the environment in which the machine is used	Lightning strike	PHA Worksheet	Weather conditions conducive to lightning strike	Electrocution	Transformer shall be placed above existing ground level. Lightning strike protection systems shall be installed.	Lightning assessment recommended.	N/A
ES9	Electricity Supply	Combination of hazards	Startup from deadbus leads to unprotected electrical connection	PHA Worksheet	Loss of power from wind farm supply	Potential for unsafe startup	The control system shall ensure safe recovery from dead busbars.	Review, in discussion with other operators of similar windfarms the best practice method for ensuring continuous power supply in case of interruption, e.g. UPS.	N/A
ES10	Electricity Supply	Combination of hazards	Unable to isolate the electrical supply during emergency conditions	PHA Worksheet	Inability to electrically isolate the hydrogen plant	Electricity supplied during unsafe condition, normally requiring isolation	Isolation scheme shall include off site electrical supply isolation measures.	Undertake Hazardous Area Classification and Assessment to define safe locations for electrical systems.	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
BH1	Borehole	Mechanical Hazards	Collapse of Borehole	PHA Worksheet	Integrity of surrounding substrate	Loss of Water supply	Potentially looking at 2 borehole locations. Borehole design shall use proven design of borehole to prevent borehole collapse.	Borehole survey workpackage to be included as part of planning application.	N/A
BH2	Borehole	Mechanical Hazards	Water pump failure	PHA Worksheet	Blockage and burn out Random internal failure	Loss of Water supply	Electrolysers shall be fitted with safety systems to shut down hydrogen production on loss of vital parameters, e.g. temperature, water level or water quality etc. Firewater system design shall be developed during detailed design.	System safety design activities should be integrated into the design work as part of the overall workpackage planning process.	N/A
BH3	Borehole	Material / substance Hazards	Radon gas	PHA Worksheet	Undetected harmful, substances e.g. Radon materials in ground	Exposure to harmful substances	None	Include borehole survey workpackage as part of planning application.	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
BH4	Borehole	Hazards associated with the environment in which the machine is used	Loss of borehole supply	PHA Worksheet	Borehole runs dry	Over temperature	Water source design shall ensure a continuous supply of water in the event that a single bore hole becomes unusable e.g due to running dry, total collapse or pipe blockage.	N/A	Changes in design since the hazard workshop have included rainwater harvesting and underground water storage to accomodate c. 1-4 months water consumption
WP1	Water Purification	Combination of hazards	Heavy metals within the water course	PHA Worksheet	Undetected heavy metals in the water course	People or plant exposed to heavy metals.	None	Identification of heavy metals within watercourse to be included in borehole surveys.	N/A
ET1	Electrolyser	Electrical Hazards	Excessive current applied to electrolyser	PHA Worksheet	Membrane or diaphragm damage	Achieve stoichiometric ratio in electrolyser	Electrolysers shall be fitted with safety systems to shut down hydrogen production on loss of vital parameters, e.g. water level or water quality etc. Excessive current is unlikely to result in excessive hydrogen production. The system shall include the ability to shut down the electrolyser in more than one location.	The electrolyser supplier selection procedure should ask the candidates to demonstrate how electrolyser package risks are managed, and the scope of their supply should be defined to	Unlikely for an electrolyser to have internal failure leading to a hydrogen ignition Likely to be a phased introduction of electrolyser capacity.

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
							Control system logic shall shutdown electrical feed on detection of any out of operating envelope event.	interfaces to safety systems within the electrolyser building. If following a phased introduction of electrolysers, then hazards associated with interactions between units is to be considered as part of the design process. Include 'cause and effect diagrams' within vendors deliverables package.	
ET2	Electrolyser	Electrical Hazards	High voltage in the presence of water	PHA Worksheet	Pipework Failure Electrolyser failure	Arcing, leading to equipment damage and creation of ignition source. Livening of cooling water system	The safety system shall shutdown the electrolyser on detection of over voltage.		Similar to row immediately above.

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
ET3	Electrolyser	Thermal Hazards	Overheating	PHA Worksheet	Membrane damage Loss/blocked coolant	Hydrogen ignition and high energy debris.	Electrolysers shall be fitted with safety systems to shut down hydrogen production on loss of vital parameters, e.g. temperature etc.	Confirm temperature of hydrogen coming out of the electrolyser.	Unlikely to reach auto ignition temperatures of hydrogen.
ET4	Electrolyser	Vibration Hazards	Induced resonance	PHA Worksheet	Compressor vibration reaches electrolyser	Hydrogen leakage Fire/Explosion	Mechanical segregation shall be provided between compressor and electrolyser to eliminate transfer of vibration.	No compressor type specified. Yet.	
ET5	Electrolyser	Material / substance Hazards	Hydrogen concentration into Oxygen	PHA Worksheet	Membrane damage	Achieve stoichiometric ratio in electrolyser	The electrolyser package shall include gas analysis within the gas stream to ensure gases in the outlet path remain within specification during production.	N/A	N/A
ET6	Electrolyser	Material / substance Hazards	Oxygen Concentration into Hydrogen	PHA Worksheet	Membrane damage	Achieve stoichiometric ratio in electrolyser	Control system shall take executive action, e.g. electrical isolation or purge on detection of gases out of specification . The gas path design shall include measures to ensure the concentration of oxygen in the hydrogen path is less than less than 25% of the lower explosive limit of hydrogen.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
ET7	Electrolyser	Material / substance Hazards	Residual hydrogen in electrolyser	PHA Worksheet	Incorrect maintenance	Hydrogen leakage Fire/Explosion	The electrolyser package shall be designed to enable the purging of the hydrogen system prior to maintenance of systems.	N/A	N/A
ET8	Electrolyser	Material / substance Hazards	Undetected hydrogen leak	PHA Worksheet	Loss of hydrogen detection	Hydrogen leakage Fire/Explosion	The electrolyser package shall include measures to shutoff the hydrogen supply on detection of a hydrogen leak.	N/A	N/A
ET9	Electrolyser	Material / substance Hazards	Alkaline leakage	PHA Worksheet	Electrolyser internal failure Piping failure	Corrosion of plant	Electrolyser package shall include safety mechanisms and 'safe by design' materials specifications.	N/A	N/A
ET10	Electrolyser	Material / substance Hazards	Oxygen/Hydrogen mixture in pipework	PHA Worksheet	Electrolyser internal failure	Hydrogen leakage Fire/Explosion	The gas path design shall include measures to ensure the concentration of oxygen in the hydrogen path is less than 25% of the lower explosive limit of hydrogen.	N/A	N/A
ET11	Electrolyser	Material / substance Hazards	Undetected hydrogen accumulation	PHA Worksheet	Loss of hydrogen detection	Hydrogen leakage Fire/Explosion	The electrolyser package shall include measures to shutoff the hydrogen supply on detection of a hydrogen leak.	N/A	N/A
ET12	Electrolyser	Ergonomic Hazards	Alkaline leakage	PHA Worksheet	Electrolyser internal failure Piping failure	Skin damage if contacted by people.	Alkaline additive transport and handling shall be included as part of operations manual. Preventing the use of wrong alkaline to be considered during operational design.	Safe Systems of Work required to be developed and used on the site, for example to limit exposure of	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
								people to electrolyte.	
ET13	Electrolyser	Combination of hazards	Chemical storage within hydrogen compound	PHA Worksheet	Chemical incompatibility	Explosion risk	COSHH management shall be implemented as part of operations and maintenance of the site.	N/A	N/A
OV1	Oxygen Vent	Electrical Hazards	Inability to vent oxygen	PHA Worksheet	Loss of power supply to the site Foreign object in oxygen vent line oxygen vent line pipework damage	Excess oxygen pressure in electrolyser leading to rupture and Hydrogen release	Oxygen vent shall be designed by electrolyser supplier to take account of suitable routing within the building. Oxygen sizing calculations shall be conducted by electrolyser package supplier. Mitigation of the effects of backpressure in oxygen vent line shall be included in the electrolyser package design.	N/A	N/A
OV2	Oxygen Vent	Material / substance Hazards	Material incompatibility in the oxygen vent line	PHA Worksheet	Unidentified material compatibility	Loss of integrity of oxygen vent line	None	HAZOP to be conducted on the selected design. Identify design basis for material compatibility in	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
								the oxygen vent line.	
OV3	Oxygen Vent	Ergonomic Hazards	Working at height	PHA Worksheet	Vent location requires maintenance to be carried out at height	Lost time injury Fatality	The selected system design shall incorporate requirements arising from human factors assessment.	Inspection and maintenance training to include signage and necessary precautions around the oxygen vent line.	N/A
OV4	Oxygen Vent	Hazards associated with the environment in which the machine is used	Released oxygen	PHA Worksheet	Incorrect hadling of oxygen	Explosion risk	The presence of pure oxygen shall be included in the overall claim for compliance to ATEX requirements.	Ensure oxygen handling standards are included in the overall requirements suite.	N/A
OV5	Oxygen Vent	Combination of hazards	Undetected hydrogen emission	PHA Worksheet	Electrolyser internal failure	Hydrogen leakage Fire/Explosion	The electrolyser building gas detection system shall include oxygen level detection. Hydrogen detection shall be installed in the oxygen vent pipe.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
							The gas path design shall include measures to ensure the concentration of oxygen in the hydrogen path is less than 25% of the lower explosive limit of hydrogen.		
FFC1	Fin Fan Cooling	Mechanical Hazards	High energy debris	PHA Worksheet	Cooling fan blade failure	Injury to maintainer	Fin fan cooler device shall be a CE marked COTS item, and will need to be installed and operated in accordance with its designed limits and environment. The fin fan cooler shall be installed away from other plant. Effects of vibration to be mitigated by fin fan cooler supplier.	N/A	Multiple cooling systems will be at the site. Coolant systems using the Fin fan cooler will be defined during detailed design. Primarily, the Fin fan cooler will be included to cool the electrolyser. 310rpm fan speed. Tip speed 55m/s. Forced draft configuration. Tip diameter 3.4m. Liquid medium separates Fin fan

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
									cooler from hazardous materials.
FFC2	Fin Fan Cooling	Thermal Hazards	System under temperature	PHA Worksheet	Coolant freezes due to environmental conditions	Sub optimal performance	The fin fan cooler control system shall have a minimum operating temperature. Ensure the coolant is specified to avoid freezing due to environmental conditions.	Determine operating temperature range. Ambient temperature may not be a concern but the need for temperature control should be considered.	N/A
FFC3	Fin Fan Cooling	Thermal Hazards	System Over temperature	PHA Worksheet	Internal blockage in cooler	Potential ignition sources	The fin fan cooler system shall maintain temperature within safe limits in the event of loss of a single Fin fan cooler.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
							The hydrogen plant shall be forced to a safe state on detection of a high fin fan cooler temperature. The fin fan cooler shall be designed for the worst credible scenario, e.g 'hot day' scenario.		
FFC4	Fin Fan Cooling	Noise Hazards	Repetitious noise emissions	PHA Worksheet	Moving parts	Neighbour annoyance Worker hearing damage	Low RPM Fin fan cooler is expected to be a low noise emitter.	Noise mapping to be conducted as part of detailed design.	Assumed to be far enough away from general population for noise to be a problem for neighbours.
FFC5	Fin Fan Cooling	Vibration Hazards	Forced air prime mover achieves resonant frequency	PHA Worksheet	Unbalanced rotating parts Failed mounting	Neighbour annoyance Worker hearing damage	Operations and maintenance package shall ensure vibration arising from plant degradation is detected and managed. Fin fan cooler shall shutdown on detection of vibration beyond operating threshold.	N/A	N/A
FFC6	Fin Fan Cooling	Material / substance Hazards	Leaked Coolant	PHA Worksheet	Material deterioration	Skin irritation.	The effects of human contact with coolant shall be mitigated by the design of the operations and maintenance processes.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
FFC7	Fin Fan Cooling	Ergonomic Hazards	Maintenance access	PHA Worksheet	Serviceable items having poor access	Limb injury to maintainer	The selected system design shall incorporate requirements arising from human factors assessment.	N/A	N/A
FFC8	Fin Fan Cooling	Hazards associated with the environment in which the machine is used	Ambient temperature	PHA Worksheet	Ambient temperature too great for cooler capacity	Equipment failure leading to hydrogen release.	Control system monitoring shall shutdown hydrogen production in advance of low or high temperature scenario.	N/A	N/A
CMP1	Compressor	Mechanical Hazards	Pressure Release Valve Lift	PHA Worksheet	Random component failure	Hydrogen leakage Fire/Explosion	ATEX shall be considered during detailed design to allow equipment specification to be identified.	N/A	N/A
CMP2	Compressor	Electrical Hazards	Ignition source	PHA Worksheet	Electrical component in hydrogen leak path	Hydrogen leakage Fire/Explosion	ATEX shall be considered during detailed design to allow equipment specification to be identified.	N/A	N/A
CMP3	Compressor	Thermal Hazards	Excessive surface temperature	PHA Worksheet	Undetected process error	Hydrogen leakage Fire/Explosion	ATEX shall be considered during detailed design to allow equipment specification to be identified.	N/A	N/A
CMP4	Compressor	Noise Hazards	Hi speed hydrogen leak	PHA Worksheet	Equipment failure below detection threshold	Hydrogen leakage Fire/Explosion	ATEX shall be considered during detailed design to allow equipment specification to be identified.	N/A	N/A
CMP5	Compressor	Noise Hazards	Unbalanced rotating parts	PHA Worksheet	Internal machinery error	Hydrogen leakage Fire/Explosion	ATEX shall be considered during detailed design to allow equipment specification to be identified.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
CMP6	Compressor	Vibration Hazards	Resonance in pipework	PHA Worksheet	Mounting failure	Pipe fracture leading to high pressure hydrogen release Hydrogen leakage Fire/Explosion	Mechanical segregation shall be provided between compressor and electrolyser to eliminate transfer of vibration	N/A	N/A
DSP1	Dispenser	Mechanical Hazards	Overpressure of a tube trailer leading to rupture	PHA Worksheet	HYDROGEN pressure in excess of tube trailer design max pressure	Hydrogen leakage Fire/Explosion	The filling process control system shall include measures for pressure regulation and delta pressure monitoring across the dispensing hose. The filling process control system shall include redundancy to ensure no single failure can lead to the overpressure of a tube trailer.		Balance fill design. Dispenser will include a buffer tank. In this case, the 'buffer' will be a cascade type of arrangement made up of a number of different bottles. This will feed all the trailer stations. Output pressure of the compressor and buffer system to be approx. 500Bar.

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
DSP2	Dispenser	Mechanical Hazards	Overpressure of a tube trailer leading to natural diffusion of hydrogen in pipework.	PHA Worksheet	Material incompatibility for high pressure hydrogen systems.	Hydrogen leakage Fire/Explosion	All road going tube trailers shall be compliant with TPED-EN17339.	N/A	N/A
DSP3	Dispenser	Mechanical Hazards	Trailer driven away while filling	PHA Worksheet	Driver drives away during fill process	High pressure release of hydrogen.	The filling system shall include measures to prevent high pressure hydrogen release due to tube trailer leaving the filling location whilst a filling hose is attached.	N/A	N/A
DSP4	Dispenser	Mechanical Hazards	Hose degradation	PHA Worksheet	Filling hose subject to effects of abrasion	Hydrogen leakage Fire/Explosion	Filling hoses shall be robust to their environment and foreseeable mechanical damage.	N/A	N/A
DSP5	Dispenser	Mechanical Hazards	Vehicle collision with dispensing equipment.	PHA Worksheet	Driver drives or reverses into the dispenser equipment.	Hydrogen leakage Fire/Explosion	The filling area shall include measures to ensure the tube trailer and attached vehicles cannot drive into the dispenser.	N/A	N/A
DSP6	Dispenser	Mechanical Hazards	Mechanical shock in Hydrogen transfer line	PHA Worksheet	Rapid change in hydrogen pressure	Fatigue of high pressure components	The filling system shall mitigate the severity of 'mechanical shock'.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
DSP7	Dispenser	Electrical Hazards	Static discharge in the presence of hydrogen	PHA Worksheet	Operator error leading to improper grounding.	Hydrogen ignition.	Dispensing of hydrogen shall be inhibited unless earth continuity is confirmed.	Decommissioning HAZID to be included in the lifecycle workpackage planning.	Earth continuity to be included in the dispensing system. Dispenser units to be bought from reputable supplier who can supply full hazard analysis with the dispenser system.
DTR1	Distribution	Electrical Hazards	Electrostatic phenomena	PHA Worksheet	Static discharge during connection/disconnection of tube trailer	Hydrogen leakage Fire/Explosion	The earthing and bonding system shall follow industry standards for this type of application.	N/A	Potential for the use of a staged area away from site to limit use of small roads by unfamiliar drivers.
DTR2	Distribution	Thermal Hazards	Cold surfaces	PHA Worksheet	Pressure change in pipework	Limb injury to maintainer by cold burns	Cold surfaces will be insulated or designed out to prevent inadvertent exposure to personnel.	N/A	N/A
DTR3	Distribution	Ergonomic Hazards	Unsafe HGV operations	PHA Worksheet	Insufficient lighting	Hydrogen ignition	Overall site design shall include provision for lighting of the filling locations and driving routes.	N/A	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
DTR4	Distribution	Hazards associated with the environment in which the machine is used	Unsafe HGV operations	PHA Worksheet	Poor visibility due to weather Poor road surface due to weather	Hydrogen leakage Fire/Explosion	Hydrogen distribution infrastructure shall include weather protection for areas where drivers of hydrogen distribution vehicles would be required to carry out their tasks.	N/A	N/A
WS1	Whole site	External Influences	External fire source	PHA Worksheet	Forest or Peat fire	Fire and Explosion	N/A	Fire risk from external sources to be assessed as part of layout design.	N/A
WS2	Whole site	External Influences	External high energy debris	PHA Worksheet	Wind Turbine Blade Throw	Fire and Explosion	N/A	Blade throw assessment to be conducted on the windfarm in order to show that the hydrogen plant is not in a blade strike zone.	Location of the hydrogen plant has now moved to a place 6-7km away from the windfarm, and on this basis, this issue is removed.
WS3	Whole site	External Influences	Rare weather event	PHA Worksheet	Increasing storm strength/frequency.	Fire and Explosion	N/A	Weather issues e.g. wind loading and temperature change to be included in design requirements.	N/A
WS4	Whole site	External Influences	Security breach	PHA Worksheet	Sabotage	Fire and Explosion	N/A	Security assessment to	N/A

Hazard ID	Node	Type or group of hazard	Hazard	Source	Cause	Consequence	Safeguards	Actions	Comments
								be included in overall workpackage planning.	

Appendix C HAZID GUIDEWORDS

No.	Type or Group	Examples of Hazards	
		Origin[a]	Potential Consequences[b]
1	Mechanical Hazards	– acceleration, deceleration; – angular parts; – approach of a moving element to a fixed part; – cutting parts; – elastic elements; – falling objects; – gravity; – height from the ground; – high pressure; – instability; – kinetic energy; – machinery mobility; – moving elements; – rotating elements; – rough, slippery surface; – sharp edges; – stored energy; – vacuum.	– being run over; – being thrown; – crushing; – cutting or severing; – drawing-in or trapping; – entanglement; – friction or abrasion; – impact; – injection; – shearing; – slipping, tripping and falling; – stabbing or puncture; – suffocation.
2	Electrical Hazards	– arc; – electromagnetic phenomena; – electrostatic phenomena; – live parts; – not enough distance to live parts under high voltage; – overload; – parts which have become live under fault conditions; – short-circuit; – thermal radiation.	– burn; – chemical effects; – effects on medical implants; – electrocution; – falling, being thrown; – fire; – projection of molten particles; – shock.
3	Thermal Hazards	– explosion; – flame; – objects or materials with a high or low temperature; – radiation from heat sources.	– burn; – dehydration; – discomfort; – frostbite; – injuries by the radiation of heat sources; – scald.

No.	Type or Group	Examples of Hazards	
		Origin[a]	Potential Consequences[b]
4	Noise Hazards	– cavitation phenomena; – exhausting system; – gas leaking at high speed; – manufacturing process (stamping, cutting, etc.); – moving parts; – scraping surfaces; – unbalanced rotating parts; – whistling pneumatics; – worn parts.	– discomfort; – loss of awareness; – loss of balance; – permanent hearing loss; – stress; – tinnitus; – tiredness; – any other (for example, mechanical, electrical) as a consequence of an interference with speech communication or with acoustic signals.
5	Vibration Hazards	– cavitation phenomena; – misalignment of moving parts; – mobile equipment; – scraping surfaces; – unbalanced rotating parts; – vibrating equipment; – worn parts.	– discomfort; – low-back morbidity; – neurological disorder; – osteo-articular disorder; – trauma of the spine; – vascular disorder.
6	Radiation Hazards	– ionizing radiation source; – low frequency electromagnetic radiation; – optical radiation (infrared, visible and ultraviolet), including laser; – radio frequency electromagnetic radiation.	– burn; – damage to eyes and skin; – effects on reproductive capability; – mutation; – headache, insomnia, etc.
7	Material / substance Hazards	– aerosol; – biological and microbiological (viral or bacterial) agent; – combustible; – dust; – explosive; – fibre; – flammable; – fluid; – fume; – gas; – mist; – oxidizer.	– breathing difficulties, suffocation; – cancer; – corrosion; – effects on reproductive capability; – explosion; – fire; – infection; – mutation; – poisoning; – sensitization.

No.	Type or Group	Examples of Hazards	
		Origin[a]	Potential Consequences[b]
8	Ergonomic Hazards	– access; – design or location of indicators and visual displays units; – design, location or identification of control devices; – effort; – flicker, dazzling, shadow, stroboscopic effect; – local lighting; – mental overload/underload; – posture; – repetitive activity; – visibility.	– discomfort; – fatigue; – musculoskeletal disorder; – stress; – any other (for example, mechanical, electrical) as a consequence of a human error.
9	Hazards associated with the environment in which the machine is used	– dust and fog; – electromagnetic disturbance; – lightning; – moisture; – pollution; – snow; – temperature; – water; – wind; – lack of oxygen.	– burn; – slight disease; – slipping, falling; – suffocation; – any other as a consequence of the effect caused by the sources of the hazards on the machine or parts
10	Combination of hazards	– for example, repetitive activity + effort + high environmental temperature	– for example, dehydration, loss of awareness, heat stroke
-	[a] A single origin of a hazard can have several potential consequences. [b] For each type of hazard or group of hazards, some potential consequences can be related to several origins of hazard.		

Appendix D SUGGESTED RISK ASSESSMENT MATRIX

The following risk assessment matrix is suggested for future work:

APPENDIX D.1 RISK ASSESSMENT MATRIX

The following tables will be used to determine the level of risk presented by the identified hazards.

Figure 8 Risk Assessment Matrix

HRN	Risk	color code	PLr
0-5	Negligible		NR
6-50	Low		A
51-80	Medium		B
81-130	High		C
131-500	Very High		D
Over 500	Unacceptable		E

Where:

HRN = Hazard Rating Number = LO* x FE* x DPH* x NP*

PLr=Performance Level required for safety circuits-Level A, Level B, etc.

NR= None Required

- See Table 6, Table 7, Table 8 and Table 9

Table 6 LO – Liklihood of Occurrence

LO (Likelihood of Occurrence)		
0.033	Almost impossible	Only in extreme circumstances
1	Highly unlikely	Though conceivable
1.5	Unlikely	But could occur
2	Possible	But unusual
5	Even chance	Could happen
8	Probable	Not surprising
10	Likely	To be expected
15	Certain	No doubt

Table 7 DPH - Degreee of Possible Harm

DPH (Degree of Possible Harm)	
0.1	Scratch or bruise
0.5	Laceration or mild ill-effect
2	Break of minor bone or minor illness (temporary)
4	Break of major bone or major illness (temporary)
6	Loss of one limb, eye, hearing (permanent)
10	Loss of two limbs or eyes (permanent)
15	Fatality

Table 8 FE - Frequency of Exposure

FE (Frequency of Exposure)	
0.5	Annually
1	Monthly
1.5	Weekly
2.5	Daily
4	Hourly
5	Constantly

Table 9 NP - Number of Persons at Risk

NP (Number of Persons at risk)	
1	1-2 persons
2	3-7 persons
4	8-15 persons
8	16-50 persons
12	50+ persons

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