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Report

Land Use Planning QRA for the Firlough Windfarm Hydrogen Generation Facility

Prepared for – Mercury Renewables

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EXECUTIVE SUMMARY

Mercury Renewables is submitting a planning application to An Bord Pleanála for the construction and operation of the proposed Firlough Wind Farm and integrated hydrogen production facility (the "Hydrogen Plant"). The Hydrogen Plant will be classed as a lower-tier COMAH site under the COMAH Regulations [1], based upon the expected maximum quantities of hydrogen on site.

Following consultation with the Irish Health and Safety Authority ("HSA"), Mercury Renewables have contracted Risktec to produce a technical Land Use Planning (LUP) style Quantitative Risk Assessment (QRA). The study has been developed in accordance with the inputs, methodology and rulesets outlined in the Irish Health and Safety Authority (HSA) Guidance for technical land use planning advice [2] and the updated guidance for hydrogen installations, intended for addition to Section 3.4 of the guidance [2]. The associated methodology, and hence results presented in this report, are only appropriate for determining offsite risks and should not be used as a basis for determining risks close to the hazard sources.

This document presents the methodology, results and conclusions of the LUP QRA.

The main objectives of the LUP QRA study are to:

- Determine the offsite risks posed by the process hazard scenarios to enable evaluation of the suitability of the proposed location;

- Determine the proposed Consultation Distance (CD) and inner risk zones around the establishment to inform future development projects around the facility;

- Calculate the societal risk levels, if appropriate; and

- Provide recommendations for risk reduction where appropriate measures can be identified.

Consequence Modelling Results

The HSA guidance adopts a risk-based approach to provide advice for the suitability of a facility's location, hence there are no specific criteria associated with the consequence results. Nevertheless, the extent of the hazard consequences from each of the release scenarios have been modelled using the Safeti v8.6 software (which implements Phast consequence modelling software). The results of the modelling are tabulated in Appendix D as follows:

- Distances to LFL and UFL from flammable gas dispersion (showing the flash fire extent);

- Distances to specified thermal radiation levels from jet fires; and

- Distances to specified vapour cloud explosion overpressure levels.

Risk Modelling Results

The individual location-based risk contours for new establishments, not to be exceeded, are as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and

- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

The above forms the primary evaluation criteria on which the acceptability of site location has been assessed.

Individual risk contours corresponding to these criteria, as derived from this study, are presented in the figure overleaf.
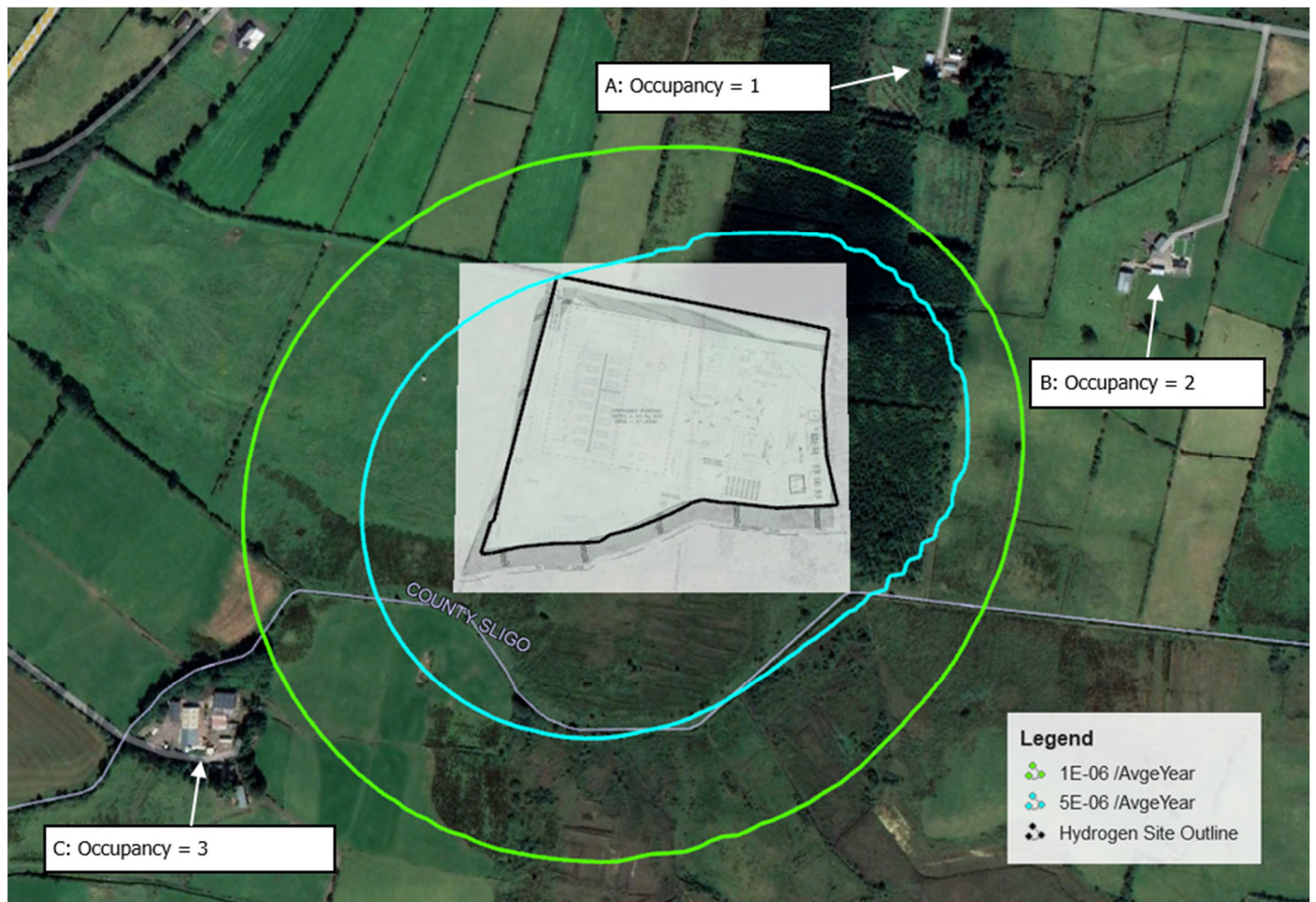
Individual Risk Contours from the Hydrogen Plant (relevant to new establishments)

As can be seen from the above results, there are no occupied areas within the contours. The nearest occupied areas (which are all located outside the 1E-06 /year contour), can be summarised as follows:

- Location A (located 134 m outside the 1E-06 /year contour, to the north): Residential house with one person living in the premises. There is no elevated occupancy (e.g. contractor work) during temporary periods. A maximum occupancy of one can therefore be assigned to this location.

- Location B (located 120 m outside the 1E-06 /year contour, to the east): Premises includes farm shed that houses small number of beef cattle during winter months. The owner of the farm is also resident at the house at premises. Farmer would be considered temporarily onsite / temporary worker as well as one further temporary worker. A maximum occupancy of two can therefore be assigned to this location.

- Location C (located 43 m outside the 1E-06 /year contour, to the south west): Automated milking parlour which has the following occupancy:

  o   One full time worker on site seven days a week;

  o   Milk collection by one person from the farm occurring once every two days; and

  o   Feed delivery by one person occurring every two days.

  A maximum occupancy of three can therefore be assigned to this location, noting that coincident occupancy of the above personnel is an unlikely situation.

The above risk contours have been derived on the basis that the facility is shutdown and isolated within 60 seconds, as per the isolation points outlined in Appendix B. To determine the sensitivity of the contours to this assumption, an alternative case is presented in Appendix E for a theoretical worst case scenario whereby no isolation points are implemented. It can be seen that the worst case contours with no isolation also do not affect the nearest occupied locations.

These results provide evidence that the facility location satisfies the HSA criteria for new establishments.

The addition to the above conclusion, the following conclusions can also be drawn from this analysis:

- The Consultation Distance (CD) is estimated to extend up to a maximum of 390 m from the site boundary. The outer, middle and inner zones are estimated to extend up to a maximum of 360 m, 290 m and 130 m from the site boundary respectively. These contours should be used to inform future development feasibility; and

- Due to the very limited occupancy/populations within the 1E-09 /year contours (CD), societal risks are considered negligible.

In conclusion, the results of the analysis show that the proposed site of the Hydrogen Plant is within the tolerable risk region as per the HSA's TLUP guidance criteria for new establishments. Due to the broadly acceptable results, no recommendations are drawn from the study in relation to the proposed location of the Hydrogen Plant.

The following recommendations have been derived from this study:

- It is recommended that a detailed QRA should be undertaken as the project advances to ensure risk to workers on site is evaluated, but note this is not a requirement at the current stage of development.

- It is recommended that the CD and inner risk zones are updated and finalised as the design progresses.

ISSUE RECORD

Issue	Date	Author Name	Reviewer Name	Approver Name	Revision History
1.0	09-Feb-23	J Wiseman	M Johnson	K Green	Formal issue to client
2.0	17-Feb-23	J Wiseman	M Johnson	K Green	Issue incorporating client comments
3.0	14-June-23	J Wiseman	M Johnson	J Wiseman	Issue incorporating HSA initial comments

DISTRIBUTION

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CONTENTS

TABLES

FIGURES

ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
CD	Consultation Distance
CEDI	Continuous Electro-Deionisation
CIA	UK Chemical Industry Association
COMAH	Control of Major Accident Hazards
cpm	Chances Per Million
ESDV	Emergency Shutdown Valve
EV	Expectation Value
H_2	Hydrogen
HSA	Health and Safety Authority (Irish Regulator)
HV	High Voltage
ISO	International Organization for Standardization
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
LUP	Land Use Planning
LV	Low Voltage
NNF	Not Normally Flowing
QRA	Quantitative Risk Assessment
RO	Reverse Osmosis
RTU	Road Transport Unit
TNO	The Netherlands Organisation (for applied scientific research)
UDM	Unified Dispersion Model
UFL	Upper Flammable Limit
VCE	Vapour Cloud Explosion

1   INTRODUCTION

1.1   Overview

Mercury Renewables is submitting a planning application to An Bord Pleanála for the construction and operation of the proposed Firlough Wind Farm and integrated hydrogen production facility (the "Hydrogen Plant"). The Hydrogen Plant will be classed as a lower-tier COMAH site under the COMAH Regulations [1], based upon the expected maximum quantities of hydrogen on site.

Following consultation with the Irish Health and Safety Authority ("HSA"), Mercury Renewables have contracted Risktec to produce a technical Land Use Planning (LUP) style Quantitative Risk Assessment (QRA).

1.2   Scope and Objectives

The main objectives of the LUP QRA study are to:

- Determine the offsite risks posed by the process hazard scenarios to enable evaluation of the suitability of the proposed location;

- Determine the proposed Consultation Distance (CD) in inner risk zones around the establishment to inform future development projects around the facility;

- Calculate the societal risk levels; and

- Provide recommendations for risk reduction where appropriate measures can be identified.

The study has been developed in accordance with the inputs, methodology and rulesets outlined in the Health and Safety Authority (HSA) guidance on land use planning [2].

The HSA guidance adopts best practice in technical land use planning, and is intended to achieve the principles of consistency, proportionality and transparency as per the European guidelines on land use planning [3]. To fulfil these principles, the methodology is deliberately not as comprehensive as a full QRA and focuses on assessment of off-site risk. The methodology, and hence results presented in this report, are not appropriate for determining risks close to the hazard sources.

2 HYDROGEN PLANT DESCRIPTION

2.1 Site Location

The proposed site of the Hydrogen Plant is approximately 6 km west of the proposed Firlough windfarm, County Sligo as shown in Figure 2-1. The footprint of the proposed site of the Hydrogen Plant is approximately 6.5 hectares.
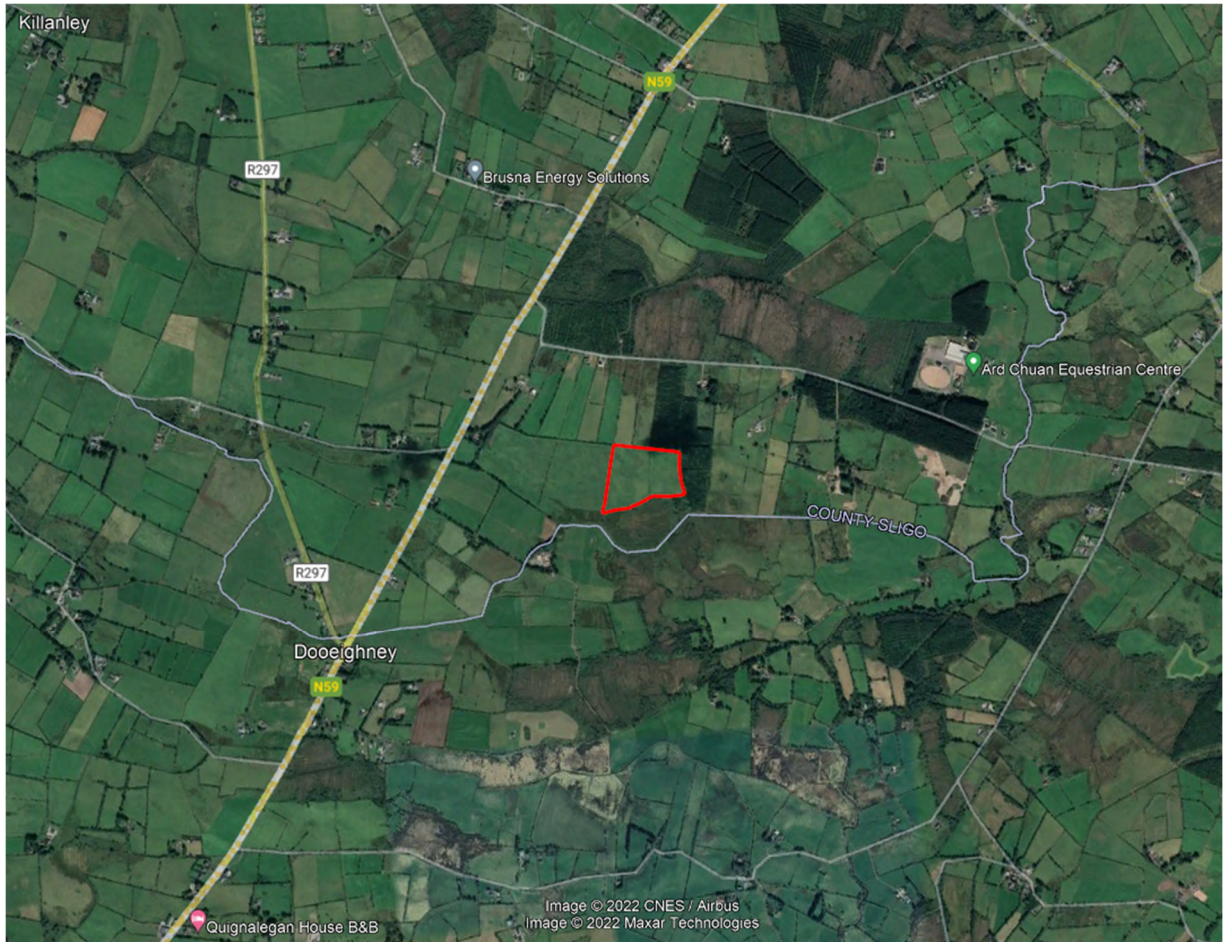
Figure 2-1: Satellite Image Showing Proposed Location of the Hydrogen Plant

2.2 Plant Description

The following sections provide a high-level description of the Hydrogen Plant, key quantities and site layout. It should be noted that all information contained here is based on design stage documents produced as supporting information for the planning application and may change as the project progresses. An overview of the system is provided in Figure 2-2.
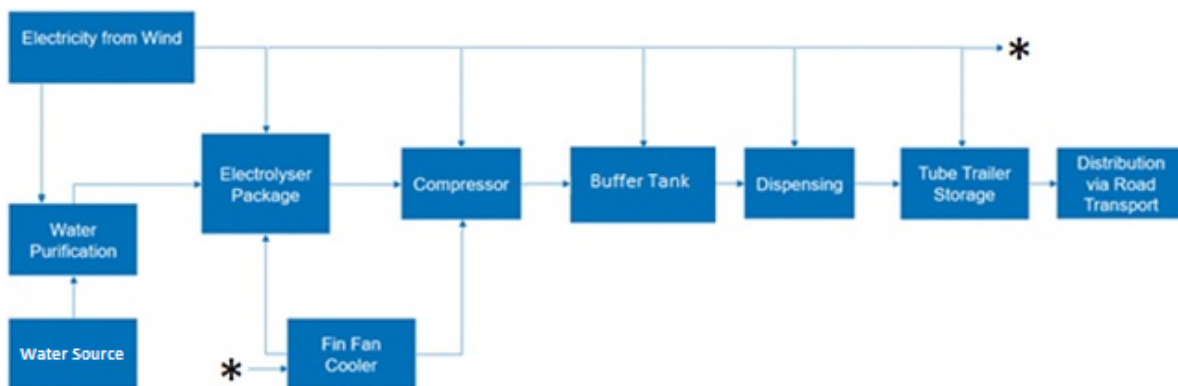
Figure 2-2: Hydrogen Plant High Level Block Diagram

2.2.1   Electricity Supply

A 110kV, 78MW electricity supply, routed via a dedicated power cable from the windfarm substation, will provide power to the Hydrogen Plant for the electrolytic conversion of water to hydrogen for subsequent distribution. The electricity 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.

2.2.2   Water Source

Two onsite water extraction boreholes will provide a source of electrolyte feed water and cooling water. Electrolyte 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 variation.

2.2.3   Water Purification

Water from the borehole will contain minerals and other impurities which, 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 water treatment process includes double pass reverse osmosis (RO) and continuous electro-deionisation (CEDI).

2.2.4   Electrolyser

The electrolyser uses electrical energy to convert the water-based electrolyte to hydrogen and oxygen. The low pressure hydrogen 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.

2.2.5   Oxygen Vent

The oxygen vent routes gaseous by-products from the anode side of the electrolyser, to atmosphere, at a safe location. Sufficient ventilation will be installed into the electrolyser building to prevent accumulation of oxygen.

2.2.6   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 incorporates nine fin fan coolers.

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

2.2.7   HP Compressors

The 2 x 100% compressors (identical in operation) receive hydrogen from the electrolyser and compresses it to a pressure of 500bar for buffering storage. The high-pressure hydrogen will be routed from the output of the compressor to an intermediate buffer vessel for short term storage.

2.2.8   Buffer Tank

The buffer 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 will operate at 500bar, and contain a maximum of 528kg of hydrogen.

2.2.9   Dispensing

Seven road vehicle dispensing units are included in the 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. Hydrogen dispensing stations are designed and will operate in accordance with established safety standards to ensure their safety (such as ISO 16964, ISO 15916 and ISO 1980).

2.2.10 Tube Trailer Storage and Distribution

Compressed hydrogen will be stored onsite and distributed offsite via road tube trailers. Onsite storage is planned for a maximum of 26 x 12m tube trailers, providing a total storage capacity of 31,200kg. The length of time a tube trailer remains onsite will vary depending on market conditions, offtake agreements and offtake purposes. Therefore it is difficult to assess the exact onsite operational storage requirements. However, the quantity of hydrogen stored onsite will be monitored, and if for any reason trailers cannot leave the site, hydrogen production will cease to ensure onsite storage does not exceed 50 tonnes.

2.3 Layout

A plot plan of the Hydrogen Plant is shown in Figure 2-3, with key hydrogen processing and storage locations marked.

Figure 2-3: Plot Plan Showing Hydrogen Processing and Storage Areas

3 METHODOLOGY

The following sections present a summary of the methodology adopted to develop the LUP QRA. The study has been developed in accordance with the HSA guidance [2]. Where necessary, supplementary inputs and assumptions have been developed which are presented in Appendix A of this report.

3.1 Hazard Identification

The initial stage of analysis consists of defining the system as a discrete set of release scenarios. In essence, this activity involves dividing the system into isolatable inventories defined by Emergency Shutdown Valves (ESDVs). Within each isolatable inventory, sub-sections are defined based on variation in location, pressure, temperature and composition. The number of equipment items have been counted within each sub-section and the associated process parameters (pressure, temperature etc.) were selected from review of the available input data.

The output of the above release scenario definition is presented in Appendix B.

Note that modelling has focussed on the hydrogen inventories, since these will pose the most significant offsite hazards. The diesel and glycol inventories at site have not been modelled due to their localised hazard range and low ignition probabilities.

3.2 Consequence Modelling

Consequence modelling has been performed using the Safeti v8.6 software [5], which incorporates Phast; a globally adopted solution for modelling discharge, dispersion, fires and explosions from loss of containment scenarios.

The modelled leak sizes have been based on the recommended scenarios in the HSA guidance [2]. This principally includes catastrophic failures, loss of entire contents over a 10 minute period and small leaks of 10 mm diameter. In addition, loss of containment from Road Transport Units (RTU), storage vessels, loading arms and pipelines within the boundary of the site have been modelled. All release sources are assumed to be at 1 m above ground level, with effect height also at 1 m to represent the most likely impact on personnel.

In alignment with the HSA Guidance [2], gas dispersion modelling has been carried out for two weather conditions, as follows:

- Wind speed 2 m/s and Pasquill stability class 'F'; and
- Wind speed 5 m/s and Pasquill stability class 'D'.

Other meteorological data is presented in Assumption Sheet A03, Appendix A.

The potential hazards arising from loss of containment that have been assessed are based on HSA prescribed requirements and described in further detail in Appendix D.

3.3 Risk Modelling

The Safeti software [5] has been used to calculate the geographic risk profile around the facility. The risk calculation necessitates incorporation of frequency for each release scenario, ignition probability, equipment operating factors, wind direction probability and fatality probability associated with the hazardous effects.

The HSA prescribes both the release event frequency per equipment item, and the end consequence frequencies [2]. These are reproduced in Assumption Sheet A05, Appendix A, along with the ignition probability rulesets to ensure the consequence frequencies align. The release frequency across the Hydrogen Plant has been determined by summing up the number of individual equipment items within each sub-section, and positioning appropriately in the Safeti model as per the site layout.

The seven loading arms and RTUs in the loading bays have conservatively assumed to be in operation 100% of the time. It has been assumed that all twenty-six parking bays in the storage area to the south of site are permanently occupied by fully hydrogen-laden RTUs.

To ensure the total frequency of the consequence outcome (i.e. explosion, jet fire and flash fire) aligns with the HSA recommended consequence frequencies, the ignition probability data as per Assumption Sheet A05 has been incorporated into the Safeti model.

The wind directional probability (windrose), has been derived from data collected by Met Éireann at Knock Airport from 1996 to 2022 [4], and as presented in Assumption Sheet A03, Appendix A.

The fatality probability models, presented in Assumption Sheet A05, Appendix A, were utilised to estimate the probability of fatality from flash fire, thermal radiation and explosion overpressure. The fatality probability models are distinct for personnel located outdoors and indoors, and it has been assumed that people are indoors 90% of the time [2].

3.4 Evaluation Criteria

3.4.1 Consequence Criteria

The HSA guidance adopts a risk-based approach to provide advice for the suitability of facility location, hence there are no specific criteria associated with the consequence results. The consequence modelling results must be combined with the likelihood of each event to obtain a risk value, which can then be compared against criteria, as described in the following sections.

3.4.2 Individual Risk for New Establishments

The risk modelling enables individual location-based risk contours to be drawn on a map of the establishment and the surrounding area. These risk lines represent the average probability per year that a fatality will occur to a person permanently present at a location.

Individual risk is expressed as the risk of fatality per year, usually using scientific notation. Risk per year can also been converted to one fatality every 'X' years by calculating one divided by the risk per year, e.g. 1×10^{-6} fatalities per year is equivalent to 1 fatality every 1,000,000 years. Commonly used formats for these risk values are presented in Table 3-1.

Table 3-1: Scientific Notation

Frequency of fatality (per year)		Chances per million (cpm) years	1 in 'X' years
1×10^{-6}	1E-06	1	1 in a million years
5×10^{-6}	5E-06	5	1 in 200,000 years

In keeping with the longer-term aims for LUP under the Seveso Directive, technical advice in relation to new COMAH establishments is more stringent than that which applies to existing COMAH establishments. The individual location-based risk contours for new establishments, not to be exceeded, are as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and
- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

The above forms to primary evaluation criteria on which the acceptability of site location has been assessed.

3.4.3 Consultation Distance (CD) and Inner Risk Zones

In addition to the criteria for evaluation of new establishments (as per the previous section), it is necessary for new establishments to propose a Consultation Distance (CD) and submit it to the planning authority as part of a planning application.

Within the CD are a number of inner risk zones which are used to inform the acceptability of future developments around the facility. The CD and inner risk zones can be defined as follows:

- 1E-05 /year – risk of fatality for inner zone (Zone 1) boundary;
- 1E-06 /year – risk of fatality for middle zone (Zone 2) boundary;
- 1E-07 /year – risk of fatality for outer zone (Zone 3) boundary; and
- 1E-09 /year – Consultation Distance (CD).

Future proposed developments within the CD will be assigned a category (Level 1 - 4) based on their sensitivity to major hazards. The HSA-defined levels are shown in Figure 3-1, which is an extract from the HSA's LUP guidelines document [2]. Development types are expanded upon in Appendix 2 of the guidelines; Level 2 includes houses, apartments, retirement flats, bungalows, residential caravans and mobile homes.

Figure 3-1: Consultation Distance Categories for Proposed Developments

The HSA LUP guideline document states: "*Broadly, the competent authority's generic technical advice to planning authorities takes the form of 'Advises against' (✕) or 'Does not advise against' (✓)*" as illustrated in Figure 3-2.

Figure 3-2: HSA Advice for Proposed Developments within the Consultation Distance

3.4.4 Societal Risk

Societal risk is a measurement of the potential for accidents from the facility to affect multiple people. To take account of societal risk from the Hydrogen Plant, an estimate of the Expectation Value (EV) is necessary. The EV of a single release scenario is the product of the individual risk (expressed in chances per million) and the potential number of people affected. The EV from an entire facility is the sum of the EV from all release scenarios. The HSA define the following EV criteria [2]:

- The total off-site EV should not exceed the criterion upper limit EV of 10,000;

- Between EVs of 100 and 10,000, it should be demonstrated that all practicable efforts have been made to reduce the risk to a level that is As Low As Reasonably Practicable (ALARP); and

- Above an EV level of 450, an F-N curve will be required (as explained below).

An F-N curve, shows the relationship between the number of likely fatalities (N) and the cumulative frequencies of events likely to cause N fatalities. The F-N criteria as per the HSA guidance [2] is presented in Figure 3-3 below, and can be explained as follows:

- F-N results residing above the red line can be considered unacceptable;

- F-N results between the two lines, operators and potential operators will be required to demonstrate that all reasonable efforts have been made to reduce the risk to a level that is As Low As Reasonably Practicable (ALARP); and

- F-N results below the blue line are considered broadly acceptable.
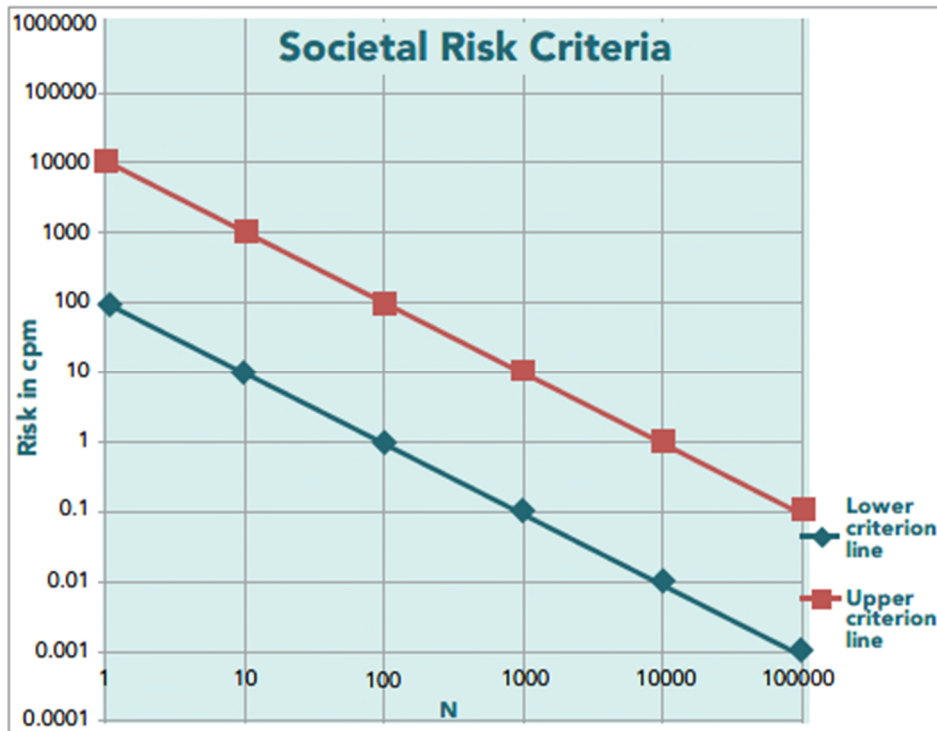
Figure 3-3: F-N Curve Tolerability Criteria (extract from HSA LUP Guidance [2])

4 RESULTS

4.1 Consequence Modelling Results

The extent of the hazard consequences from each of the release scenarios were modelled using the Safeti v8.6 software. The results of the modelling for each type of release are tabulated in Appendix D as follows:

- Distances to the lower flammability limit (LFL) and upper flammability limit (UFL) from flammable gas dispersion (showing the flash fire extent);
- Distances to specified thermal radiation levels from jet fires; and
- Distances to specified vapour cloud explosion overpressure levels.

4.2 Risk Contours for New Establishments

The individual location-based risk contours relevant to new establishments are presented in Figure 4-1 as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and
- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

It can be seen from Figure 4-1 that there are no buildings or outdoor populated areas within the risk contours. The nearest occupied buildings, outside the 1E-06 /year contour as indicated in Figure 4-1, can be summarised as follows:

- Location A (located 134 m outside the 1E-06 /year contour): Residential house with one person living in the premises. There is no elevated occupancy (e.g. contractor work) during temporary periods. A maximum occupancy of one can therefore be assigned to this location.

- Location B (located 120 m outside the 1E-06 /year contour): Premises includes farm shed that houses small number of beef cattle during winter months. The owner of the farm is also resident at the house at premises. Farmer would be considered temporarily onsite / temporary worker as well as one further temporary worker. A maximum occupancy of two can therefore be assigned to this location.

- Location C (located 43 m outside the 1E-06 /year contour): Automated milking parlour which has the following occupancy:

  o One full time worker on site seven days a week;

  o Milk collection by one person from the farm occurring once every two days;

  o Feed delivery by one person occurring every two days

  A maximum occupancy of three can therefore be assigned to this location, noting that coincident occupancy of the above personnel is an unlikely situation.

The results in Figure 4-1 have been derived on the basis that the facility is shutdown and isolated within 60 seconds, as per the isolation points depicted in Appendix B. To assess the sensitivity of the contours to this assumption, an alternative case is presented in Appendix E for a theoretical worst case scenario whereby no isolation is implemented. In this case, the entire facility hydrogen inventory can be released from any release location. It can be seen that the worst case contours with no isolation do not affect the nearest occupied locations.
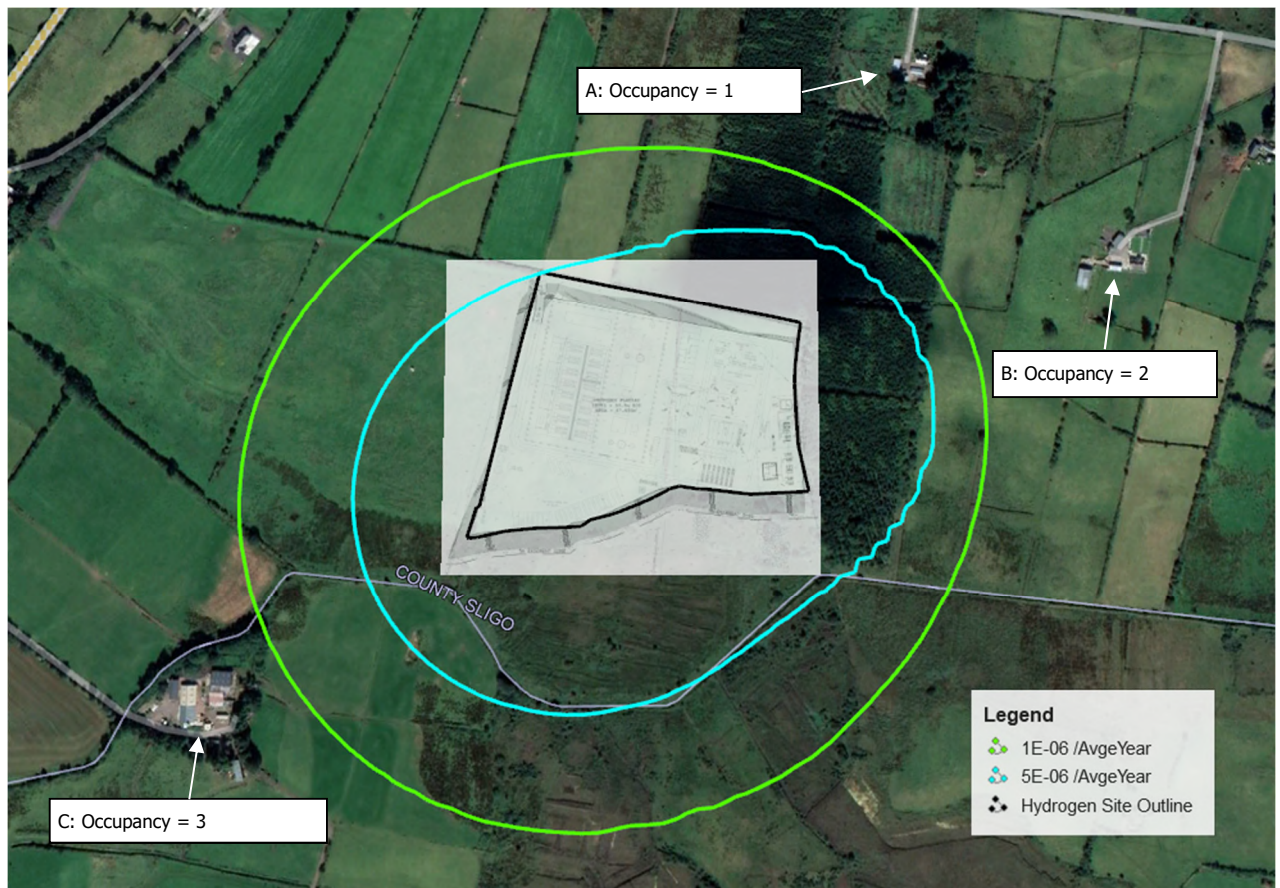
Figure 4-1: Individual Risk Contours from the Hydrogen Plant (relevant to new establishments)

4.3   Consultation Distance (CD) and Inner Risk Zones

The individual location-based risk contours relevant to establishing the CD and inner risk zones are presented in Figure 4-2 as follows:

- 1E-05 /year (10 chances per million (cpm)) – risk of fatality for inner zone (Zone 1) boundary;
- 1E-06 /year (1 cpm) – risk of fatality for middle zone (Zone 2) boundary;
- 1E-07 /year (0.1 cpm) – risk of fatality for outer zone (Zone 3) boundary; and
- 1E-09 /year (0.001 cpm) – Consultation Distance (CD).

The distance to the above levels can be summarised as follows:

- The 1E-05 /year risk contour, or inner zone, is estimated to extend up to a maximum of 130 m from the site boundary;
- The 1E-06 /year risk contour, or middle zone, is estimated to extend up to a maximum of 290 m from the site boundary;
- The 1E-07 /year risk contour, or outer zone, is estimated to extend up to a maximum of 360 m from the site boundary; and
- The 1E-09 /year risk contour, or Consultation Distance, is estimated to extend up to a maximum of 390 m from the site boundary.

The outermost (CD) contour encroaches the three locations as described in Section 4.2, however due to the minimal populations at these locations, the societal risk can considered to be negligible.

Figure 4-2: Consultation Distance and Inner Risk Zones

5   CONCLUSIONS

In support of the planning application for the Hydrogen Plant associated with the proposed Firlough Wind Farm project, this report presents the results of a LUP QRA, based on the inputs, methodology and rulesets prescribed in the HSA Guidance on technical land use planning [2]. This document will be appended to the Firlough Wind Farm and Hydrogen Plant planning application to be submitted to An Bord Pleanála and will also be appended to the Major Accident Prevention Policy to demonstrate the suitability of the proposed site location in terms of process hazard risk posed to the public

The following conclusions can be drawn from the study:

- There are no buildings or outdoor populated areas within the predicted 1E-06 /year individual risk contour. The nearest occupied building is the house to the automated milking parlour, which is 43 m outside of the 1E-06 contour. It can be concluded therefore that the site location is acceptable. To further justify this conclusion, a theoretical worst case scenario with no process isolation points is presented in Appendix E, where it can be seen that the criteria remains satisfied.

- The Consultation Distance (CD) is estimated to extend up to a maximum of 390 m from the site boundary. The outer, middle and inner zones are estimated to extend up to a maximum of 360 m, 290 m and 130 m from the site boundary respectively. These contours should be used to inform future development feasibility; and

- Due to the very limited occupancy/populations within the 1E-09 /year contours (CD), societal risks are considered negligible.

The following recommendations have been derived from this study:

- It is recommended that a detailed QRA should be undertaken as the project advances to ensure risk to workers on site is evaluated, but note this is not a requirement at the current stage of development.

- It is recommended that the CD and inner risk zones are updated and finalised as the design progresses.

6   REFERENCES

1.   Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015 (S.I. No. 209 of 2015)

2.   HSA, Guidance on technical land-use planning advice for planning authorities and COMAH establishment operators.
HSA0512, ISBN 978-1-84496-287-7, February 2023

3.   MAHB (2008). Land Use Planning Guidelines in the Context of Article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC. EC, Brussels

4.   Met Éireann. Irish Meteorological Service Historical Data, Knock Airport, County Mayo.
https://www.met.ie/climate/available-data/historical-data

5.   DNV. Safeti Software.
Version 8.6

6.   Email from Tim Bills of Mercury Renewables to Jonathan Wiseman of Risktec Solutions
Friday, February 3, 2023

APPENDIX A   ASSUMPTIONS REGISTER

The assumptions to be used in the QRA study are provided in the following sections and will be incorporated into the QRA report. Table 6-1 presents the topics that are addressed.

Table 6-1: Assumption Sheets

ID	Topic
A01	Release Scenario Definition
A02	Source Term
A03	Meteorological Data
A04	Consequence Modelling
A05	Event Frequencies
A06	Vulnerability Assessment
A07	Risk Acceptance Criteria

Assumption Sheet ID	A01
Topic/Worksheet:	**Release Scenario Definition**
Data/Rule Set:	

The initial stage of analysis consists of defining the system as a set of release scenarios to be addressed in the study. In essence, this activity involves dividing the system into release inventories defined by Emergency Shutdown Valves (ESDVs). Within each isolatable inventory, the number of equipment items were counted and the associated process parameters (pressure, temperature etc.) were selected from review of the available input data.

The output of the above release scenario definition is presented in Appendix B.

Assumption Sheet ID	A02
Topic/Worksheet:	**Source Term**
Data/Rule Set:	

Release Hole Sizes

The source terms for each release scenario will be input into DNV's consequence modelling software PHAST v8.6 [5], which models the consequences based on standard fluid flow equations for gas flow using the pressure, temperature, material composition and size of release.

The leak sizes modelled will be based on the recommended scenarios in the HSA guidance [2], and will include:

- Equipment item located outdoors or indoors:
  - o Instantaneous failure;
  - o Continuous leak over 10 minutes (total inventory); and
  - o 10 mm pipe leak over 10 minutes;
- Road Transport Unit (RTU):
  - o Instantaneous failure; and
  - o Loss of ensure contents through largest connection.
- Loading hose / arm:
  - o Rupture of loading / unloading arm / hose; and
  - o Leak of loading / unloading arm / hose (10% of loading hose diameter);
- Pipelines within the establishment:
  - o Pipeline rupture; and
  - o Pipeline leak of 0.1D (max 50mm).

Release Location and Orientation

All release sources are assumed to be at 1m above ground level, with effect height also at 1m to represent the most likely impact on personnel. All releases shall be modelled as horizontal un-impinged.

Inventory

The static inventory for each section shall be calculated based on the available documentation and will include estimated pipe lengths and vessel sizes associated with the section. The additional dynamic inventory entering the section pre-isolation shall be determined based on the minimum of either the initial release rate or normal processing flow rate. The time to isolation shall be assumed to be 1 minute.

A sensitivity case shall be assessed assuming no isolation is implemented in the study to understand the effect on the contours.

Assumption Sheet ID	A03
Topic/Worksheet:	**Meteorological Data**
Data/Rule Set:	

Wind Speed and Atmospheric Stability

In alignment with the HSA Guidance, consequence modelling will be carried out for two weather conditions:

- Wind speed 2 m/s and Pasquill stability class 'F'; and
- Wind speed 5 m/s and Pasquill stability class 'D'.

Stability category F represents a temperature inversion, occurring on a clear night, and typically leads to worst-case dispersion distances. F stability class cannot occur with wind speeds above a few metres per second.

Stability category D represents a moderate windy day, with cloud cover, and represents conditions that occur frequently, giving average dispersion distances.

Risk modelling will take into consideration the distribution of wind speeds and directional probability (windrose), derived from data collected by Met Éireann at Knock Airport from 1996 to 2022 [4].
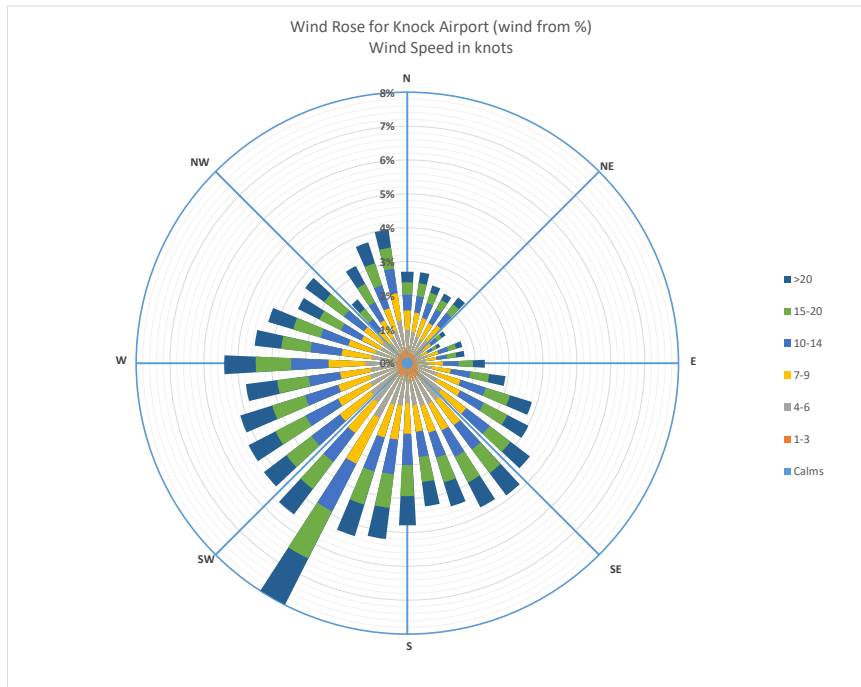
Figure 6-1: Site Specific Wind Rose

	Percentage of time Wind Blows "from" Direction (degrees, North = 0)												
Category	0	30	60	90	120	150	180	210	240	270	300	330	Total
F2	0.66%	0.38%	0.34%	0.31%	0.61%	1.02%	0.82%	0.77%	0.51%	0.49%	0.47%	0.54%	6.93%
D5	5.05%	3.15%	1.90%	3.90%	7.42%	9.79%	10.54%	14.02%	10.94%	11.44%	8.54%	6.19%	92.88%

Meteorological Parameters

In addition to the weather categories, certain meteorological constants are defined as inputs to the consequence modelling, as follows:

- Average ambient atmospheric temperature: 15°C for D5 conditions and 10°C for D5 conditions [1];
- Average relative humidity: 87.9% [4];
- Surface temperature: same as atmospheric; and
- Surface roughness of 100mm (Occasional Large Obstacles).

Assumption Sheet ID	A04
Topic/Worksheet:	**Consequence Modelling**
Data/Rule Set:	

Safeti v8.6 [4] includes a range of validated models for assessment of the physical effects of hazardous releases. The consequence models expected to be used for the QRA are summarised in the following sections.

Flammable Gas Dispersion (Flash Fire)

The Unified Dispersion Model (UDM) shall be used for the flammable gas dispersion modelling in open areas. A dispersion averaging times of 18.75 seconds flammable releases (i.e. the default value in Safeti for flammable averaging time) shall be adopted.

Vapour Cloud Explosion

Overpressures generated by Vapour Cloud Explosions (VCE) shall be assessed using the TNO multi-energy model in the Safeti v8.6 software [4]. The TNO multi-energy model consists of a family of blast curves for peak overpressures to determine positive overpressure and impulse as a function of distance from the explosion source.

Vapour cloud explosions shall be assessed as follows:

- For indoor releases (i.e. within the electrolyser building and compressor house) it shall be assumed that the entire flammable cloud ignites with an explosion source of TNO curve 7 [2]. Dilution of the flammable cloud due to ventilation effects shall not be accounted; and
- For releases outdoors, 40% of the total flammable cloud volume shall be used to define an explosion source with TNO curve 7 equivalent overpressure [2].

Jet Fire

Gaseous jet fires will modelled in Safeti based on the Miller model which is an extension of the Chamberlain and Johnson models specifically for horizontal, vertical and angled low luminosity / non-hydrocarbon jet fires (such as hydrogen jet fires).

Fireball

For near-instantaneous releases, fireballs will be modelled using the default methodology in Safeti (Martinsen Time Varying).

Assumption Sheet ID	A05
Topic/Worksheet:	**Event Frequencies**
Data/Rule Set:	

The HSA specifies event and consequence frequencies [2], which are reproduced in this assumption sheet.

Outdoor fixed installations (e.g. buffer tank):

LOC Scenario	Frequency (/yr)	Consequence	Consequence frequency (/yr)
Instantaneous failure	5×10^{-6}	VCE/Fireball	5×10^{-6}
Continuous leak over 10 minutes (total inventory)*	1×10^{-5}	Jet fire VCE Flash fire	7×10^{-6} 1.2×10^{-6} 1.8×10^{-6}
10mm pipe leak over 10 minutes*	5×10^{-4}	Jet Fire VCE Flash Fire	3.5×10^{-5} 6×10^{-5} 9×10^{-4}

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Immediate ignition probability of 70% with a jet fire.
- Delayed ignition probability of 30%, which splits into a conditional probability of 40% of a VCE and 60% of a flash fire scenario.

Indoor fixed installations (e.g. electrolysers, compressors):

LOC Scenario	Frequency (/yr)	Consequence	Consequence frequency (/yr)
Instantaneous failure	5×10^{-6}	VCE/Fireball	5×10^{-6}
Continuous leak over 10 minutes (total inventory)*	1×10^{-5}	Jet Fire VCE	7×10^{-6} 3×10^{-6}
10mm pipe leak over 10 minutes*	5×10^{-4}	Jet Fire VCE	3.5×10^{-6} 1.5×10^{-4}

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Immediate ignition probability of 70% with a jet fire.
- Delayed ignition probability of 30% with a conditional probability of 100% for VCE.

Road tankers (Number of cylinders per road tanker = N):

LOC Scenario	Frequency (/yr)	Consequence	Consequence frequency (/yr)
Instantaneous failure	$N \times 5 \times 10^{-7}$	VCE/Fireball	$N \times 5 \times 10^{-7}$
Loss of entire contents (complete cylinder array) through largest connection*	$N \times 5 \times 10^{-7}$	Jet Fire Flash Fire VCE	$N \times 2 \times 10^{-7}$ $N \times (1.8 \times 10^{-7})$ $N \times (1.2 \times 10^{-7})$

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Delayed ignition probability of 60% with a VCE probability of 40% for delayed ignition events instead of a flash fire scenario.

It shall be assumed that there are 50 cylinders per road tanker.

It shall be assumed that the RTU parking area to the south of the site has all RTUs present at all times.

Land Use Planning QRA for the Firlough Windfarm Hydrogen Generation Facility
Mercury Renewables

Document No: BLV-04-R-02
Issue: 3.0

Assumption Sheet ID	A05
Topic/Worksheet:	**Event Frequencies**

Road tanker loading bays:

LOC Scenario	Arm Leak Frequency (/hour)	Hose Leak Frequency (/hour)
	Arm	**Hose**
Rupture of loading/unloading arm/hose*	3×10^{-8}	4×10^{-6}
Leak from loading/unloading arm/hose (10% diameter)*	3×10^{-7}	4×10^{-5}

*The consequence frequencies for continuous releases shall be based on the following ignition probability assumptions, as per road tankers [2]:

- Overall ignition probability of 100%;
- Delayed ignition probability of 60% with a VCE probability of 40% for delayed ignition events.

It shall be assumed that each loading bay is occupied with a fully laden RTU at all times. The leak frequency for loading hoses shall be adopted for the study.

Above Ground Pipelines (within the establishment):

Scenario	Frequency m^{-1} yr^{-1}		
	D < 75 mm	**75 ≤ D ≥ 150 mm**	**D>150 mm**
Pipeline rupture*	1×10^{-6}	3×10^{-7}	1×10^{-7}
Pipeline leak of 0.1D (max 50 mm)*	5×10^{-6}	2×10^{-6}	5×10^{-7}

*VCE consequence frequencies for continuous releases shall be based on the following ignition probability assumptions (as per external equipment):

- Overall ignition probability of 100%; and
- Delayed ignition probability of 30% with a VCE probability of 40% for delayed ignition events.

Below Ground Pipelines (within the establishment):

Scenario	Frequency m^{-1} yr^{-1}		
	D < 75 mm	**75 ≤ D ≥ 150 mm**	**D>150 mm**
Pipeline rupture*	1×10^{-7}	3×10^{-8}	1×10^{-8}
Pipeline leak of 0.1D (max 50 mm)*	5×10^{-7}	2×10^{-7}	5×10^{-8}

*VCE consequence frequencies for continuous releases shall be based on the following ignition probability assumptions (as per external equipment):

- Overall ignition probability of 100%; and
- Delayed ignition probability of 30% with a VCE probability of 40% for delayed ignition events.

The diameter of the pipeline (D) is assumed to be 50 mm.

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Assumption Sheet ID	A06
Topic/Worksheet:	**Vulnerability Assessment**
Data/Rule Set:	

The following vulnerability models will be used for fatality estimation. To determine the contribution to risk for both outside and indoor occupancy, it shall be assumed that people are indoors 90% of the time [1].

Explosion Overpressures

Outdoor Vulnerability

The HSA [1] proposes the following vulnerabilities for personnel located outdoors:

- >168 mbar (2.44 psi) overpressure - 1% lethality;
- >365 mbar (5.29 psi) - 10% lethality; and
- >942 mbar (13.66 psi) overpressure - 50% lethality

Indoor Vulnerability

For the indoor personnel, the following correlations [1] will be used:
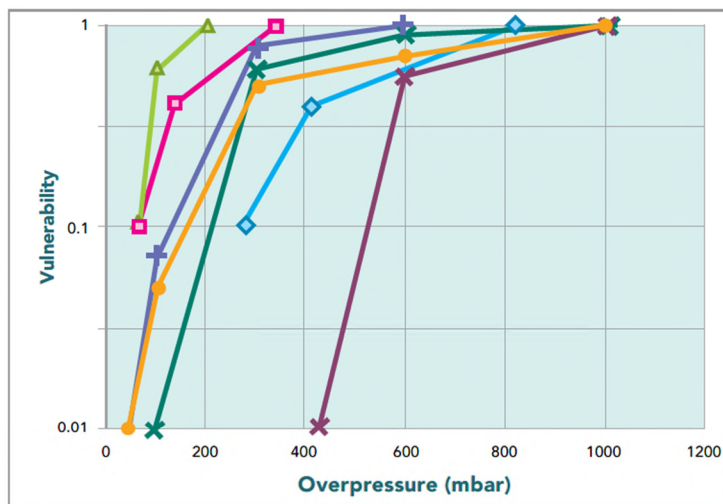
Graph Key:

- CIA 1: Hardened structure building: special construction, no windows
- CIA 2: Typical office block: four story, concrete frame and roof, brick block wall panels
- CIA 3: Typical domestic buildings: two story, brick walls, timber floors
- CIA 4: Portacabin: timber construction, single story
- API B5: Reinforced concrete or reinforced masonry shear wall building
- API B3: Unreinforced masonry bearing wall building
- API B1, B2, B4: Wood frame trailer or shack, steel-frame/metal siding or pre-engineered building, steel or concrete reinforced masonry infill or cladding

NOTE-Building key items 1 - 4 are defined by CIA; items B1 - B5 are defined by API RP 752 (2003) [5, 3].

Category 3 Curve (typical domestic building: two-storey, brick walls, timber floors) will in most circumstances provide a reasonably conservative basis for assessing the risk of fatality to most residential populations, and shall be adopted to assess the risk to the public located indoors. The following indoor vulnerability ruleset shall therefore be adopted for people located indoors (as per the CIA-3 building type in the above graph):

- >50 mbar – 1% lethality;
- >100 mbar – 5% lethality;
- >300 mbar – 50% lethality;
- >600 mbar – 70% lethality; and
- >1000 mbar – 100% lethality.

Building Damage

Assumption Sheet ID	A06
Topic/Worksheet:	**Vulnerability Assessment**

Risks to physical structures will adopt the following overpressure damage values are [1]:

- >10 mbar - glass breakage;
- >35 mbar - light;
- >170 mbar - moderate;
- >350 mbar - severe; and
- >830 mbar - total destruction.

Flash Fires

Outdoor Vulnerability

Personnel located outdoors within the LFL contours are assumed to be fatally injured; those outside are unharmed.

Indoor Vulnerability

Personnel located indoors within the LFL contours are assumed to experience a 10% lethality.

Thermal Radiation

Outdoor Vulnerability

As described in the HSA guidance [1], thermal radiation effects on people outdoors are assessed using the Eisenberg probit with the following thermal radiation effects (assuming an exposure of 60 seconds):

- >8.02 kW/m^2 - 1% lethality;
- >10.9 kW/m^2 - 10% lethality; and
- >15.9 kW/m^2 - 50% lethality.

Indoor Vulnerability

Thermal radiation effects to people indoors are as follows [1]:

- <12.7 kW/m^2 - 0% lethality;
- >15.9 kW/m^2 - 50% lethality; and
- >25.6 kW/m^2 - building catches fire, 100% lethality to occupants.

Property Damage

Thermal radiation effects to property are as follows [1]:

- >37.5 kW/m^2 - sufficient to cause damage to process equipment;
- >25.6 kW/m^2 - minimum heat flux to ignite wood at indefinitely long exposures (non-piloted); and
- >14.7 kW/m^2 - minimum heat flux for piloted ignition of wood, melting of plastic tubing.

Assumption Sheet ID	A07
Topic/Worksheet:	**Risk Acceptance Criteria**
Data/Rule Set:	

Location Specific Individual Risk (LSIR) – new establishment criteria

LSIR is the individual risk for a hypothetical person present at a location for 100% of the time. The LSIR is therefore the sum of the frequency of each hazard event multiplied by the probability of fatality from that event at the location of interest. The QRA uses LSIR to evaluate the tolerability of risk for areas within and around the facility. The HSA guidance [1] states that the individual LSIR contours for new establishments, not to be exceeded, are as follows:

- 1×10^{-6} per year – maximum tolerable risk to a member of the public; and
- 5×10^{-6} per year – maximum tolerable risk to a person at an off-site work location.

The above risk contours that therefore be developed as part of the study to determine whether any areas of public occupancy reside within the contours.

Location Specific Individual Risk (LSIR) – developments within the vicinity

To enable establishment of the protective Consultation Distance (CD) for potential future developments of specific types within the vicinity of the establishment, risk contours down to 1×10^{-9} per year shall also be plotted. Notable LSIR zones are as follows:

- 1×10^{-5} per year – Risk of fatality for inner zone (Zone 1) boundary;
- 1×10^{-6} per year – Risk of fatality for middle zone (Zone 2) boundary;
- 1×10^{-7} per year – Risk of fatality for outer zone (Zone 3) boundary; and
- 1×10^{-9} per year – Consultation Distance.

Societal Risk

To determine the societal risk to the public, offsite areas of public occupancy within the 1×10^{-9} per year shall be identified. The Expectation Value (EV) to these populations shall be determined and assessed in accordance with the following criteria:

- EV greater than 10,000 – intolerable;
- Between EVs of 100 and 10,000 - it should be demonstrated that all practicable efforts have been made to reduce the risk to a level that is as low as reasonably practicable; and
- EV less than 100 – broadly acceptable.

In addition, a F-N curve shall be developed and evaluated in accordance within the following criteria:

Assumption Sheet ID	A07
Topic/Worksheet:	Risk Acceptance Criteria
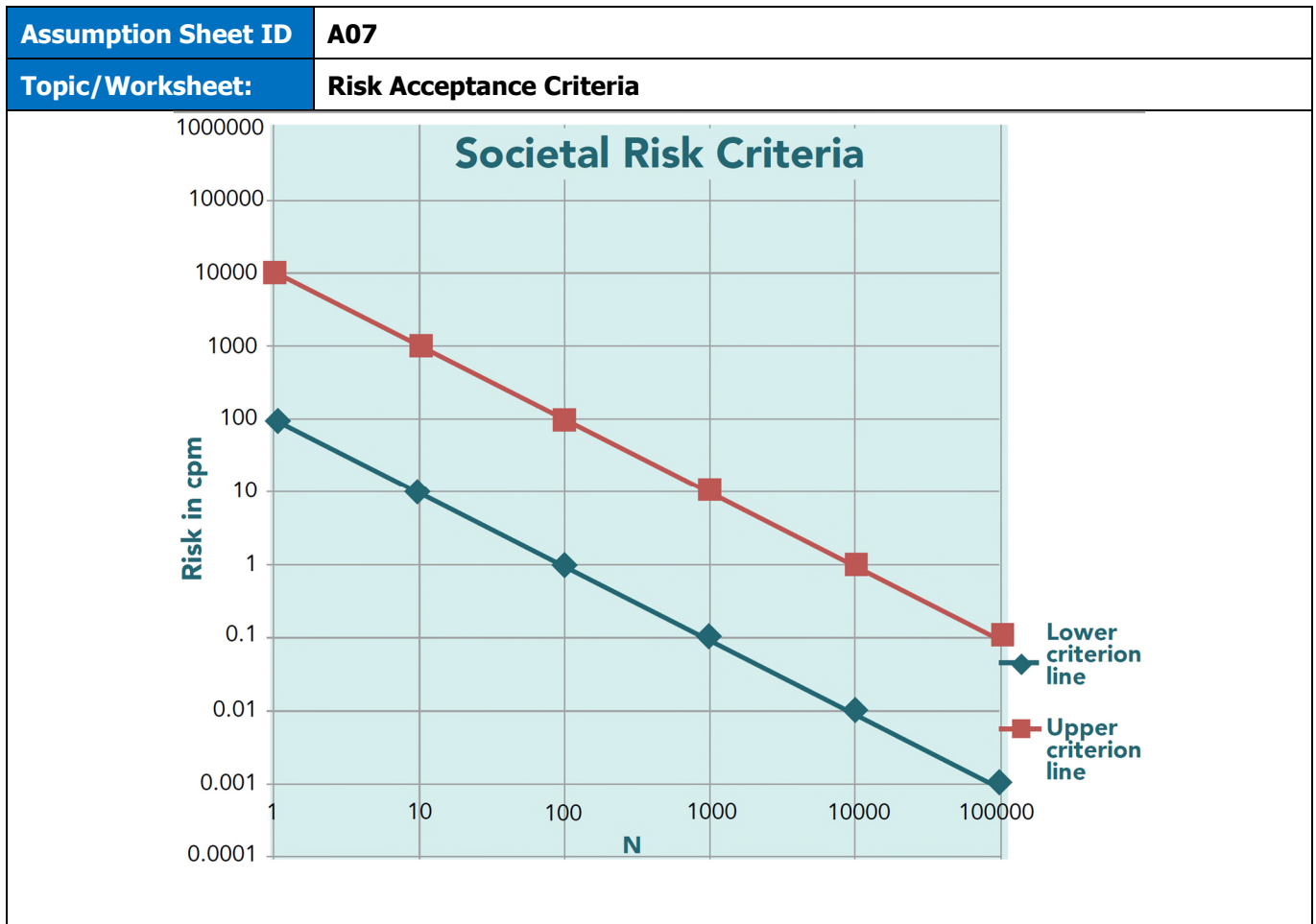
APPENDIX B   RELEASE SCENARIOS

Main Release Scenario Parameters

Release Scenario ID	Release Scenario Description	Modelled Stream Composition	Pressure	Temperature	Flow Rate	Total Inventory	Pipe Diameter	Notes
			(barg)	(°C)	(kg/hr)	(kg)	(mm)	
IS-01	Per Electrolyser Hydrogen Outlet	H_2	0.02	80.0	81.25	1.4	80	1,300 kg/hr peak daily flow rate for the total system. Divided by 16 gives 81.25 kg/hr per electrolyser.
IS-02	H_2/Lye Separator	H_2	0.02	80.0	1300.00	145.7	300	
IS-03	Scrubber	H_2	0.02	80.0	1300.00	145.7	300	
IS-04	Gas Holder	H_2	0.02	25.0	1300.00	145.7	300	
IS-05	Compressor (LP)	H_2	30.0	25.0	1300.00	145.7	80	
IS-06	Deoxidiser	H_2	30.0	25.0	1300.00	145.7	80	
IS-06a	Dryers	H_2	30.0	25.0	1300.00	145.7	80	
IS-07	Compressor (HP)	H_2	30.0	25.0	1300.00	145.7	80	
IS-08	Compressor (A/B)	H_2	500	26	1300.00	23.3	50	
IS-09	H_2 Storage	H_2	500	10	1300.00	551.4	50	
IS-10	Loading Arms and Manifold (1-7)	H_2	380	10	1300.00	24.9	50	It is conservatively assumed that flow into H_2 storage equals flow out.

Release Scenario ID	Release Scenario Description	Modelled Stream Composition	Pressure	Temperature	Flow Rate	Total Inventory	Pipe Diameter	Notes
			(barg)	(°C)	(kg/hr)	(kg)	(mm)	
IS-11	Per Tube Trailer Onsite	H_2	380	10	260.00	1204.3		Flow rate divided by 5, assuming 5 loading bays are in operation (with 1 in standby).
IS-12	Per Tube Trailer Storage	H_2	380	10		1200.0		
PW-13	Cross Site Pipework to H2 Storage	H_2	30.0	25.0	1300.00	21.7	50	

Release Scenario Mark-Up (with Indicative Isolation Valve Location)
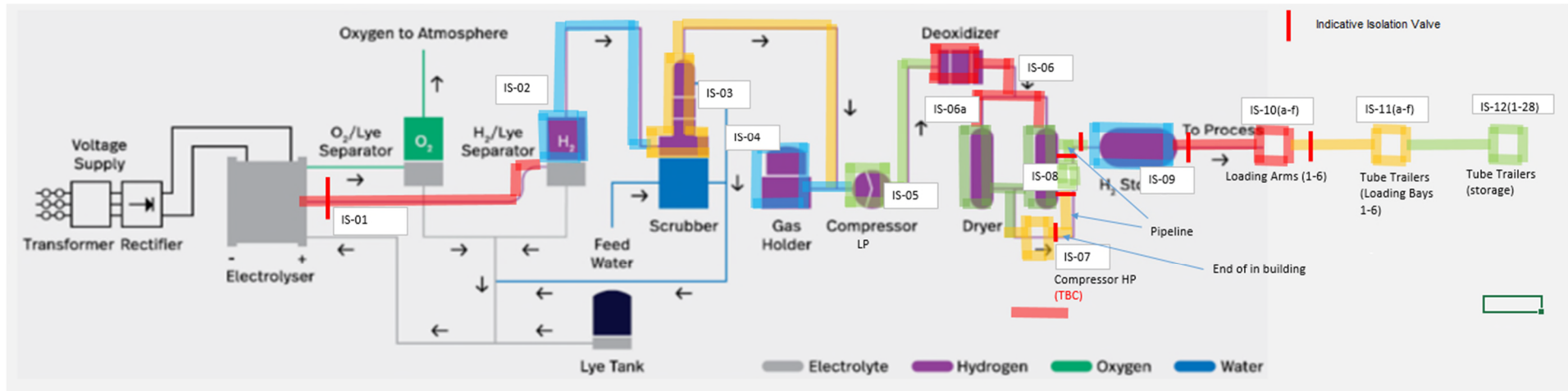
APPENDIX C   RELEASE AND CONSEQUENCE FREQUENCY ASSESSMENT RESULTS

Equipment Releases

Source ID	Release Sources in Safeti	Release Source Description	Equipment Number Per Source	Operating Factor	Equipment Type (as per HSA)	LOC Scenario	Scenario ID	Hole Size (mm)	LOC Frequency (/yr)	Consequence	Scenario Frequency (/yr)
IS-01	16	Per Electrolyser Hydrogen Outlet	1	100%	Indoor fixed installations	Instantaneous failure	IS-01-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-01-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-01-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-01-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-01-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-02	1	H2/Lye Separator	1	100%	Indoor fixed installations	Instantaneous failure	IS-02-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-02-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-02-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-02-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-02-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-03	1	Scrubber	1	100%	Indoor fixed installations	Instantaneous failure	IS-03-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-03-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-03-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-03-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-03-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-04	1	Gas Holder	1	100%	Indoor fixed installations	Instantaneous failure	IS-04-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-04-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-04-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-04-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-04-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-05	1	Compressor (LP)	1	100%	Indoor fixed installations	Instantaneous failure	IS-05-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-05-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-05-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-05-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-05-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-06	1	Deoxidiser	1	100%	Indoor fixed installations	Instantaneous failure	IS-06-IF		5.00E-06	VCE/Fireball	5.00E-06

Source ID	Release Sources in Safeti	Release Source Description	Equipment Number Per Source	Operating Factor	Equipment Type (as per HSA)	LOC Scenario	Scenario ID	Hole Size (mm)	LOC Frequency (/yr)	Consequence	Scenario Frequency (/yr)
						Continuous leak over 10 minutes (total inventory)	IS-06-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-06-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-06-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-06-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-06a	1	Dryers	2	50%	Indoor fixed installations	Instantaneous failure	IS-06a-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-06a-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-06a-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-06a-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-06a-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-07	1	Compressor (HP)	1	100%	Indoor fixed installations	Instantaneous failure	IS-07-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-07-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-07-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-07-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-07-PL	10	5.00E-04	Jet Fire	3.50E-04
IS-08	1	Compressor (A/B)	2	50%	Indoor fixed installations	Instantaneous failure	IS-08-IF		5.00E-06	VCE/Fireball	5.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-08-CL		1.00E-05	VCE	3.00E-06
						Continuous leak over 10 minutes (total inventory)	IS-08-CL		1.00E-05	Jet Fire	7.00E-06
						10mm pipe leak over 10 minutes	IS-08-PL	10	5.00E-04	VCE	1.50E-04
						10mm pipe leak over 10 minutes	IS-08-PL	10	5.00E-04	Jet Fire	3.50E-04

Storage, Tankers and Loading

Source ID	Release Sources in Safeti	Release Source Description	Equipment Number Per Source	Operating Factor	LOC Scenario	Scenario ID	Hole Size (mm)	LOC Frequency (/yr)	Consequence	Scenario Frequency (/yr)	Notes
IS-09	1	H2 Storage	1	100%	Instantaneous failure	IS-09-RTIF		1.80E-05	VCE/Fireball	1.80E-05	
					Loss of entire contents through largest connection	IS-09-RTEC	50	1.80E-05	VCE	4.32E-06	
					Loss of entire contents through largest connection	IS-09-RTEC	50	1.80E-05	Jet Fire	7.20E-06	
					Loss of entire contents through largest connection	IS-09-RTEC	50	1.80E-05	Flash Fire	6.48E-06	
IS-10	1	Loading Arms and Manifold (1-7)	7	100%	Rupture of loading/unloading hose	IS-10-LHR	50	2.45E-01	VCE/Fireball	5.89E-02	7 loading arms, all operational at all times
					Rupture of loading/unloading hose	IS-10-LHR	50	2.45E-01	Jet Fire	9.81E-02	
					Rupture of loading/unloading hose	IS-10-LHR	50	2.45E-01	Flash Fire	8.83E-02	
					Leak from loading/unloading hose (10% diameter)	IS-10-LHL	5	2.45E+00	VCE/Fireball	5.89E-01	
					Leak from loading/unloading arm (10% diameter)	IS-10-LHL	5	2.45E+00	Jet Fire	9.81E-01	
					Leak from loading/unloading hose (10% diameter)	IS-10-LHL	5	2.45E+00	Flash Fire	8.83E-01	
IS-11	7	Per Tube Trailer Onsite	1	100%	Instantaneous failure	IS-11-RTIF		2.50E-05	VCE/Fireball	2.50E-05	7 loading arms, all operational at all times
					Loss of entire contents through largest connection	IS-11-RTEC	50	2.50E-05	VCE	6.00E-06	
					Loss of entire contents through largest connection	IS-11-RTEC	50	2.50E-05	Jet Fire	1.00E-05	
					Loss of entire contents through largest connection	IS-11-RTEC	50	2.50E-05	Flash Fire	9.00E-06	
IS-12	26	Per Tube Trailer Storage	1	100%	Instantaneous failure	IS-12-RTIF		2.50E-05	VCE/Fireball	2.50E-05	All 26 RTUs on site at all times
					Loss of entire contents through largest connection	IS-12-RTEC	50	2.50E-05	VCE	6.00E-06	
					Loss of entire contents through largest connection	IS-12-RTEC	50	2.50E-05	Jet Fire	1.00E-05	
					Loss of entire contents through largest connection	IS-12-RTEC	50	2.50E-05	Flash Fire	9.00E-06	

Pipelines

Release Source Description	Equipment Number Per Source	Operating Factor	Equipment Type (as per HSA)	LOC Scenario	Scenario ID	Hole Size mm	LOC Frequency (/yr/m)	Consequence	Scenario Frequency (/yr)
Cross Site Pipework to H2 Storage	1	100%	Above Ground Pipeline	Pipeline rupture (D < 75mm)	PW-13-PR	50	1.00E-06	VCE/Fireball	1.20E-07
				Pipeline rupture (D < 75mm)	PW-13-PR	50	1.00E-06	Jet Fire	7.00E-07
				Pipeline rupture (D < 75mm)	PW-13-PR	50	1.00E-06	Flash Fire	1.80E-07
				Pipeline leak of 0.1D	PW-13-PL	5	5.00E-06	VCE/Fireball	6.00E-07
				Pipeline leak of 0.1D	PW-13-PL	5	5.00E-06	Jet Fire	3.50E-06
				Pipeline leak of 0.1D	PW-13-PL	5	5.00E-06	Flash Fire	9.00E-07

APPENDIX D TABULATED CONSEQUENCE MODELLING RESULTS

The following potential hazards arising from loss of containment have been assessed:

- Flammable Gas Dispersion / Flash Fire - the extent of the areas covered by concentration of flammable gas to the Lower Flammability Limit (LFL) was calculated to determine the potential flash fire hazard area.

- Jet Fire - the extent of thermal radiation from jet fires arising from immediately ignited continuous releases was determined. Jet fires were modelled based on the Miller model which is an extension of the Chamberlain and Johnson models specifically for horizontal, vertical and angled low luminosity / non-hydrocarbon jet fires (such as hydrogen).

- Fireball - the size of thermal radiation from a fireball following immediately ignited catastrophic ruptures was assessed.*

- Vapour Cloud Explosion (VCE) - the explosions resulting from a delayed ignition of hydrogen were analysed as follows:

  o For indoor releases (i.e. within the electrolyser building and compressor house) it was assumed that the entire flammable cloud ignites with an explosion source of TNO curve 7 [2]. Dilution of the flammable cloud due to ventilation within the building have not been accounted; and

  o For releases outdoors, 40% of the total flammable cloud volume were used to define an explosion source with TNO curve 7 equivalent overpressure [2].

*Note that fireballs have not been assessed in the risk modelling since they are bounded by the explosion hazard.

Flammable Dispersion

Scenario ID	Equipment Description	Release Description	Weather	Distance to LFL (m)	Distance to UFL (m)
IS-01a-IF	Per Electrolyser Hydrogen Outlet	Instantaneous failure	Category 5/D	7.8	0.9
IS-01a-IF	Per Electrolyser Hydrogen Outlet	Instantaneous failure	Category 2/F	3.9	0.9
IS-01a-CL	Per Electrolyser Hydrogen Outlet	Continuous leak over 10 minutes (total inventory)	Category 5/D	1.8	0.1
IS-01a-CL	Per Electrolyser Hydrogen Outlet	Continuous leak over 10 minutes (total inventory)	Category 2/F	1.9	0.1
IS-01a-PL	Per Electrolyser Hydrogen Outlet	10mm pipe leak over 10 minutes	Category 5/D	1.2	0.1
IS-01a-PL	Per Electrolyser Hydrogen Outlet	10mm pipe leak over 10 minutes	Category 2/F	1.4	0.1
IS-02-IF	H2/Lye Separator	Instantaneous failure	Category 5/D	23.2	4.7
IS-02-IF	H2/Lye Separator	Instantaneous failure	Category 2/F	17.9	4.7
IS-02-CL	H2/Lye Separator	Continuous leak over 10 minutes (total inventory)	Category 5/D	9.4	0.4
IS-02-CL	H2/Lye Separator	Continuous leak over 10 minutes (total inventory)	Category 2/F	7.7	0.4
IS-02-PL	H2/Lye Separator	10mm pipe leak over 10 minutes	Category 5/D	1.2	0.1

Scenario ID	Equipment Description	Release Description	Weather	Distance to LFL (m)	Distance to UFL (m)
IS-02-PL	H2/Lye Separator	10mm pipe leak over 10 minutes	Category 2/F	1.4	0.1
IS-03-IF	Scrubber	Instantaneous failure	Category 5/D	23.2	4.7
IS-03-IF	Scrubber	Instantaneous failure	Category 2/F	17.9	4.7
IS-03-CL	Scrubber	Continuous leak over 10 minutes (total inventory)	Category 5/D	9.4	0.4
IS-03-CL	Scrubber	Continuous leak over 10 minutes (total inventory)	Category 2/F	7.7	0.4
IS-03-PL	Scrubber	10mm pipe leak over 10 minutes	Category 5/D	1.2	0.1
IS-03-PL	Scrubber	10mm pipe leak over 10 minutes	Category 2/F	1.4	0.1
IS-04-IF	Gas Holder	Instantaneous failure	Category 5/D	23.6	4.4
IS-04-IF	Gas Holder	Instantaneous failure	Category 2/F	17.7	4.4
IS-04-CL	Gas Holder	Continuous leak over 10 minutes (total inventory)	Category 5/D	9.8	0.4
IS-04-CL	Gas Holder	Continuous leak over 10 minutes (total inventory)	Category 2/F	8.0	0.4
IS-04-PL	Gas Holder	10mm pipe leak over 10 minutes	Category 5/D	1.3	0.1
IS-04-PL	Gas Holder	10mm pipe leak over 10 minutes	Category 2/F	1.5	0.1
IS-05-IF	Compressor (LP)	Instantaneous failure	Category 5/D	25.8	3.1
IS-05-IF	Compressor (LP)	Instantaneous failure	Category 2/F	18.9	3.1
IS-05-CL	Compressor (LP)	Continuous leak over 10 minutes (total inventory)	Category 5/D	14.0	0.5
IS-05-CL	Compressor (LP)	Continuous leak over 10 minutes (total inventory)	Category 2/F	15.7	0.5
IS-05-PL	Compressor (LP)	10mm pipe leak over 10 minutes	Category 5/D	9.1	0.4
IS-05-PL	Compressor (LP)	10mm pipe leak over 10 minutes	Category 2/F	11.1	0.4
IS-06-IF	Deoxidiser	Instantaneous failure	Category 5/D	25.8	3.1
IS-06-IF	Deoxidiser	Instantaneous failure	Category 2/F	18.9	3.1
IS-06-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	Category 5/D	14.0	0.5
IS-06-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	Category 2/F	15.7	0.5
IS-06-PL	Deoxidiser	10mm pipe leak over 10 minutes	Category 5/D	9.1	0.4
IS-06-PL	Deoxidiser	10mm pipe leak over 10 minutes	Category 2/F	11.1	0.4
IS-06a-IF	Deoxidiser	Instantaneous failure	Category 5/D	25.8	3.1
IS-06a-IF	Deoxidiser	Instantaneous failure	Category 2/F	18.9	3.1

Scenario ID	Equipment Description	Release Description	Weather	Distance to LFL (m)	Distance to UFL (m)
IS-06a-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	Category 5/D	14.0	0.5
IS-06a-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	Category 2/F	15.7	0.5
IS-06a-PL	Deoxidiser	10mm pipe leak over 10 minutes	Category 5/D	9.1	0.4
IS-06a-PL	Deoxidiser	10mm pipe leak over 10 minutes	Category 2/F	11.1	0.4
IS-07-IF	Compressor (HP)	Instantaneous failure	Category 5/D	25.8	3.1
IS-07-IF	Compressor (HP)	Instantaneous failure	Category 2/F	18.9	3.1
IS-07-CL	Compressor (HP)	Continuous leak over 10 minutes (total inventory)	Category 5/D	14.0	0.5
IS-07-CL	Compressor (HP)	Continuous leak over 10 minutes (total inventory)	Category 2/F	15.7	0.5
IS-07-PL	Compressor (HP)	10mm pipe leak over 10 minutes	Category 5/D	9.1	0.4
IS-07-PL	Compressor (HP)	10mm pipe leak over 10 minutes	Category 2/F	11.1	0.4
IS-08-IF	Compressor (A/B)	Instantaneous failure	Category 5/D	12.5	1.2
IS-08-IF	Compressor (A/B)	Instantaneous failure	Category 2/F	9.8	1.2
IS-08-CL	Compressor (A/B)	Continuous leak over 10 minutes (total inventory)	Category 5/D	5.0	0.3
IS-08-CL	Compressor (A/B)	Continuous leak over 10 minutes (total inventory)	Category 2/F	5.7	0.3
IS-08-PL	Compressor (A/B)	10mm pipe leak over 10 minutes	Category 5/D	47.3	1.0
IS-08-PL	Compressor (A/B)	10mm pipe leak over 10 minutes	Category 2/F	41.4	1.2
IS-09-RTIF	H2 Storage	Instantaneous failure	Category 5/D	39.1	3.6
IS-09-RTIF	H2 Storage	Instantaneous failure	Category 2/F	30.0	3.6
IS-09-RTEC	H2 Storage	Loss of entire contents through largest connection	Category 5/D	150.4	2.9
IS-09-RTEC	H2 Storage	Loss of entire contents through largest connection	Category 2/F	129.3	3.6
IS-10-LHR	Loading Arms and Manifold (1-6)	Rupture of loading/unloading hose	Category 5/D	93.9	2.2
IS-10-LHR	Loading Arms and Manifold (1-6)	Rupture of loading/unloading hose	Category 2/F	68.6	2.6
IS-10-LHL	Loading Arms and Manifold (1-6)	Leak from loading/unloading hose (10% diameter)	Category 5/D	19.2	0.6
IS-10-LHL	Loading Arms and Manifold (1-6)	Leak from loading/unloading hose (10% diameter)	Category 2/F	20.0	0.6

Scenario ID	Equipment Description	Release Description	Weather	Distance to LFL (m)	Distance to UFL (m)
IS-11(1)-RTEC	Per Tube Trailer Onsite	Loss of entire contents through largest connection	Category 5/D	19.2	0.6
IS-11(1)-RTEC	Per Tube Trailer Onsite	Loss of entire contents through largest connection	Category 2/F	20.0	0.6
IS-11(1)-RTIF	Per Tube Trailer Onsite	Instantaneous failure	Category 5/D	51.6	4.9
IS-11(1)-RTIF	Per Tube Trailer Onsite	Instantaneous failure	Category 2/F	39.7	4.9
IS-12(1)-RTEC	Per Tube Trailer Storage	Loss of entire contents through largest connection	Category 5/D	19.2	0.6
IS-12(1)-RTEC	Per Tube Trailer Storage	Loss of entire contents through largest connection	Category 2/F	20.0	0.6
IS-12(1)-RTIF	Per Tube Trailer Storage	Instantaneous failure	Category 5/D	51.5	4.9
IS-12(1)-RTIF	Per Tube Trailer Storage	Instantaneous failure	Category 2/F	39.6	4.9

Jet Fire

Scenario ID	Equipment Description	Release Description	Jet fire mass rate (kg/s)	Flame length (m)	Distance downwind to intensity level 1 (8.02 kW/m2) (m)	Distance downwind to intensity level 2 (10.9 kW/m2) (m)	Distance downwind to intensity level 3 (12.7 kW/m2) (m)	Distance downwind to intensity level 4 (15.9 kW/m2) (m)	Distance downwind to intensity level 5 (25.6 kW/m2) (m)
IS-01a-CL	Per Electrolyser Hydrogen Outlet	Continuous leak over 10 minutes (total inventory)	0.002	2.5	2.3	2.2	2.1	2.0	1.9
IS-01a-PL	Per Electrolyser Hydrogen Outlet	10mm pipe leak over 10 minutes	0.001	2.2	2.3	2.3	2.3	2.3	n/a
IS-02-CL	H2/Lye Separator	Continuous leak over 10 minutes (total inventory)	0.243	14.6	15.0	13.8	13.2	12.3	10.6
IS-02-PL	H2/Lye Separator	10mm pipe leak over 10 minutes	0.001	2.2	2.3	2.3	2.3	2.3	n/a
IS-03-CL	Scrubber	Continuous leak over 10 minutes (total inventory)	0.243	14.6	15.0	13.8	13.2	12.3	10.6
IS-03-PL	Scrubber	10mm pipe leak over 10 minutes	0.001	2.2	2.3	2.3	2.3	2.3	n/a
IS-04-CL	Gas Holder	Continuous leak over 10 minutes (total inventory)	0.243	14.7	14.8	13.6	12.9	12.1	10.3
IS-04-PL	Gas Holder	10mm pipe leak over 10 minutes	0.001	2.9	2.8	2.8	2.8	2.8	n/a
IS-05-CL	Compressor (LP)	Continuous leak over 10 minutes (total inventory)	0.243	9.3	13.2	12.3	11.9	11.4	10.4
IS-05-PL	Compressor (LP)	10mm pipe leak over 10 minutes	0.130	6.9	9.7	9.0	8.8	8.4	7.7
IS-06-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	0.243	9.3	13.2	12.3	11.9	11.4	10.4
IS-06-PL	Deoxidiser	10mm pipe leak over 10 minutes	0.130	6.9	9.7	9.0	8.8	8.4	7.7
IS-06a-CL	Dryers	Continuous leak over 10 minutes (total inventory)	0.243	9.3	13.2	12.3	11.9	11.4	10.4

Scenario ID	Equipment Description	Release Description	Jet fire mass rate (kg/s)	Flame length (m)	Distance downwind to intensity level 1 (8.02 kW/m2) (m)	Distance downwind to intensity level 2 (10.9 kW/m2) (m)	Distance downwind to intensity level 3 (12.7 kW/m2) (m)	Distance downwind to intensity level 4 (15.9 kW/m2) (m)	Distance downwind to intensity level 5 (25.6 kW/m2) (m)
IS-06a-PL	Dryers	10mm pipe leak over 10 minutes	0.130	6.9	9.7	9.0	8.8	8.4	7.7
IS-07-CL	Compressor (HP)	Continuous leak over 10 minutes (total inventory)	0.243	9.3	13.2	12.3	11.9	11.4	10.4
IS-07-PL	Compressor (HP)	10mm pipe leak over 10 minutes	0.130	6.9	9.7	9.0	8.8	8.4	7.7
IS-08-CL	Compressor (A/B)	Continuous leak over 10 minutes (total inventory)	0.039	3.8	4.8	4.5	4.4	4.3	4.0
IS-08-PL	Compressor (A/B)	10mm pipe leak over 10 minutes	1.925	23.0	31.9	29.7	28.8	27.5	25.3
IS-09-RTEC	H2 Storage	Loss of entire contents through largest connection	49.281	98.8	141.0	130.7	126.1	120.0	108.8
IS-10-LHR	Loading Arms and Manifold (1-6)	Rupture of loading/unloading hose	38.303	88.8	127.1	117.9	113.7	108.2	98.1
IS-10-LHL	Loading Arms and Manifold (1-6)	Leak from loading/unloading hose (10% diameter)	0.383	11.2	15.3	14.3	13.8	13.3	12.2
IS-11(1)-RTEC	Per Tube Trailer Onsite	Loss of entire contents through largest connection	0.383	11.2	15.3	14.3	13.8	13.3	12.2
IS-12(1)-RTEC	Per Tube Trailer Storage	Loss of entire contents through largest connection	0.383	11.2	15.3	14.3	13.8	13.3	12.2

Vapour Cloud Explosion

Scenario ID	Equipment Description	Release Description	Distance downwind to overpressure 1 (0.02068 bar) (m)	Distance downwind to overpressure 2 (0.1379 bar) (m)	Distance downwind to overpressure 3 (0.2068 bar) (m)
IS-01a-IF	Per Electrolyser Hydrogen Outlet	Instantaneous failure	91.6	25.9	21.9
IS-02-IF	H2/Lye Separator	Instantaneous failure	600.1	132.7	104.6
IS-02-CL	H2/Lye Separator	Continuous leak over 10 minutes (total inventory)	79.9	23.6	20.2
IS-03-IF	Scrubber	Instantaneous failure	600.1	132.7	104.6
IS-03-CL	Scrubber	Continuous leak over 10 minutes (total inventory)	79.9	23.6	20.2
IS-04-IF	Gas Holder	Instantaneous failure	600.5	132.8	105.2
IS-04-CL	Gas Holder	Continuous leak over 10 minutes (total inventory)	80.9	23.8	20.3
IS-05-IF	Compressor (LP)	Instantaneous failure	592.0	123.1	96.5
IS-05-CL	Compressor (LP)	Continuous leak over 10 minutes (total inventory)	60.2	19.8	17.3
IS-06-IF	Deoxidiser	Instantaneous failure	592.0	123.1	96.5
IS-06-CL	Deoxidiser	Continuous leak over 10 minutes (total inventory)	60.2	19.8	17.3
IS-06a-IF	Dryers	Instantaneous failure	592.0	123.1	96.5
IS-06a-CL	Dryers	Continuous leak over 10 minutes (total inventory)	60.2	19.8	17.3
IS-07-IF	Compressor (HP)	Instantaneous failure	592.0	123.1	96.5
IS-07-CL	Compressor (HP)	Continuous leak over 10 minutes (total inventory)	60.2	19.8	17.3
IS-08-IF	Compressor (A/B)	Instantaneous failure	301.8	66.7	52.5
IS-08-PL	Compressor (A/B)	10mm pipe leak over 10 minutes	212.1	81.5	73.6
IS-09-RTIF	H2 Storage	Instantaneous failure	707.2	153.6	120.2
IS-09-RTEC	H2 Storage	Loss of entire contents through largest connection	723.4	285.6	261.2

Scenario ID	Equipment Description	Release Description	Distance downwind to overpressure 1 (0.02068 bar) (m)	Distance downwind to overpressure 2 (0.1379 bar) (m)	Distance downwind to overpressure 3 (0.2068 bar) (m)
IS-10-LHR	Loading Arms and Manifold (1-6)	Rupture of loading/unloading hose	313.3	133.4	122.5
IS-10-LHL	Loading Arms and Manifold (1-6)	Leak from loading/unloading hose (10% diameter)	52.6	18.3	16.2
IS-11(1)-RTEC	Per Tube Trailer Onsite	Loss of entire contents through largest connection	58.0	19.3	17.0
IS-11(1)-RTIF	Per Tube Trailer Onsite	Instantaneous failure	908.4	200.5	157.8
IS-12(1)-RTEC	Per Tube Trailer Storage	Loss of entire contents through largest connection	58.0	19.3	17.0
IS-12(1)-RTIF	Per Tube Trailer Storage	Instantaneous failure	907.4	200.2	157.6

APPENDIX E   NEW ESTABLISHMENT CRITERIA - ALTERNATIVE CASE

The following contours present the theoretical worst case contours from the facility, relevant for new establishments, assuming emergency shutdown and isolation is not implemented into the design. This scenario therefore represents the case whereby the entire process inventory can be released from any point in the process. It can be seen from the figure below, that whilst the contours are significantly larger than the base case presented in Section 4.2, the three nearest occupied properties remain unaffected, providing further justification that the new establishment criteria are satisfied.

Individual Risk Contours for New Establishments

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