QUANTITATIVE RISK ASSESSMENT FOR THE EUROA HYDROGEN DOMESTIC PROJECT - GLADSTONE HYDROGEN PRODUCTION FACILITY

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Quantitative Risk Assessment for the Euroa Hydrogen Domestic Project - Gladstone Hydrogen Production Facility

Acknowledgment

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Disclaimer

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EXECUTIVE SUMMARY

Introduction

Vena Energy Australia (VENA) are proposing the Euroa H_2 Domestic Project at a designated site in Aldoga in the Gladstone region.

The Euroa H_2 Domestic Project is an integrated hydrogen electrolysis, hydrogen compression, storage and domestic distribution facility located approximately 18 kilometres west of the Gladstone CBD.

The project seeks to create an integrated hydrogen production and supply chain solution that will cater to the domestic and international markets.

UGL has commissioned Planager Pty Ltd (Planager) to prepare a Quantitative Risk Assessment (QRA) including determining the risk profile associated with the Euroa H_2 Domestic Project, as related to hazards and risks associated with hydrogen.

This QRA is prepared at the FEED-stage of the Euroa H_2 Domestic Project.

Overview of the risk assessment methodology

Hazards and risks are assessed in compliance with international methodology for such studies, including as specified in the ISO 31000:2009 - *Risk management - Principles and guidelines.* The study is conducted using a combined qualitative and quantitative approach to consequences and risks using internationally recognised consequence and risk modelling software tools and likelihood databases developed for the type of facility being assessed.

In this study software models Effects® and Riskcurves® (by Gexcon, previously developed by Dutch Government TNO) are used, and the methodology employed follow that in TNO's *Yellow* and *Purple* Books which are internationally recognised for such studies.

Hydrogen incident categorisation, failure rates and probabilities are based on the Hydrogen Risk Assessment Models (HyRAM) database.

Scope and aim

The aim of the FEED-stage QRA is to identify and assess the risk associated with high-consequence, low-probability events, so called *Major Incidents* (MIs), and ensure that these are in line with current criteria for land use planning in use in Queensland.

The study focuses on the acute effects of fires and explosions that could result in injury and fatality in case of a loss of containment or major event at the proposed facility.

The purpose of the FEED-stage QRA is to demonstrate that the proposed Euroa H_2 Domestic Project development is designed and sited, so far as reasonably practicable, to ensure:

- Human health and safety, and the built environment are protected from off-site risks resulting from physical or chemical hazards.

The FEED-stage QRA can be used to support internal and external stakeholder consultation, including with QLD Governmental Agencies as required.

Results and conclusions

This FEED stage QRA has found that the levels of hazards and risks from the Euroa H_2 Domestic Project can be managed within general Performance Outcomes defined in SDAP21, provided suitable fire and overpressure protection is implemented at the southwestern and southeastern boundaries of the site.

The individual fatality risk footprint of 50×10^{-6}/yr, associated with the Euroa H_2 Domestic Project, is fully contained within the site boundary.

The safety, efficiency and stability of the Euroa H_2 Domestic Project can be achieved through the use of high-level safety systems including automatic detection and protective measures and a regular preventative maintenance program.

The performance outcome of the project development against PO1 to PO5 is summarised in the table below, with detailed findings from consequence and risk assessments provided in the body of the report.

Table E1: Euroa H_2 Domestic Project Performance Outcomes PO1 to PO5 compliance

<table>
<tr><th rowspan="2">Land use</th><th colspan="2">Performance outcomes</th><th rowspan="2">Euroa H_2 Domestic Project compliance</th></tr>
<tr><th>Dangerous dose</th><th>Risk assessment</th></tr>
<tr><td>Vulnerable land use or land zoned for a vulnerable land use (childcare centre; community care centre; educational establishment; health care service; hospital; retirement facility)</td><td rowspan="3"><u>PO1, PO2 and PO3:</u>
The hazardous chemical facility does not create a dangerous dose to human health
<u>with dangerous dose defined as follows:</u>
For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m^2 and/or 7 kPa.</td><td rowspan="3">Not applicable</td><td rowspan="3">The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any vulnerable, sensitive of commercial land use or land zoned for vulnerable, sensitive of commercial activity.</td></tr>
<tr><td>Sensitive land use or land zoned for a sensitive land use (community residence; dual occupancy; dwelling house; educational establishment; multiple dwelling; relocatable home park; residential care facility; rooming accommodation; short-term accommodation; tourist park)</td></tr>
<tr><td>Commercial or community activity land use or land zoned for a commercial or community activity land use (shopping centre; shop; office; major sport, recreation and entertainment facility; market; showroom; tourist attraction; entertainment facility; place of worship; community use; theatre)</td></tr>
</table>

Land use	Performance outcomes		Euroa H_2 Domestic Project compliance
	Dangerous dose	Risk assessment	
Open space land use or land zoned for an open space land use (Outdoor sport and recreation; park; environment facility; rural industry)	PO4: The hazardous chemical facility does not create a dangerous dose to human health with dangerous dose defined as follows: For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m^2 and/or 7 kPa	Where the dangerous dose cannot be eliminated, the individual fatality risk criteria of 10 x 10^{-6}/year and the societal risk criteria in Figure 21.1 of SDAP21	The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any open space land use or land zoned for open space activity.
Industrial land use or land zoned for an industrial land use (an extractive industry; a high impact industry; a low impact industry; a marine industry; a medium impact industry; a research and technology industry; a service industry; a special industry; a warehouse)	PO5: The hazardous chemical facility does not create a dangerous dose to the built environment with dangerous dose defined as follows: Exposure to heat and/or overpressure from a fire or explosion: 12.6 kW/m^2 and/or 14 kPa	The hazardous chemical facility does not create an individual fatality risk level of 50 x 10^{-6}/year	The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any industrial land use or land zoned for industrial activity, with the exception of a worst-case release at the: • Compression inlet, dispensers and tube trailer loading impacting the southwestern boundary of the site • Storage Management Package to hydrogen storage interunit pipework and hydrogen storage impacting the southeastern boundary of the site. This will be addressed with the implementation of earth berms at the southwestern and southeastern boundary of the site (see recommendation 1). The individual fatality risk level of 50 x 10^{-6}/year for the Euroa H_2 Domestic Project development does not extend into any off-site industrial land use or land zoned for industrial activity.

The individual fatality risk contour, associated with the Euroa H_2 Domestic Project development, is presented in Figure E1 below. The 50 x 10^{-6} per year fatality risk contour is contained within the project site, demonstrating compliance with Performance outcome PO5.

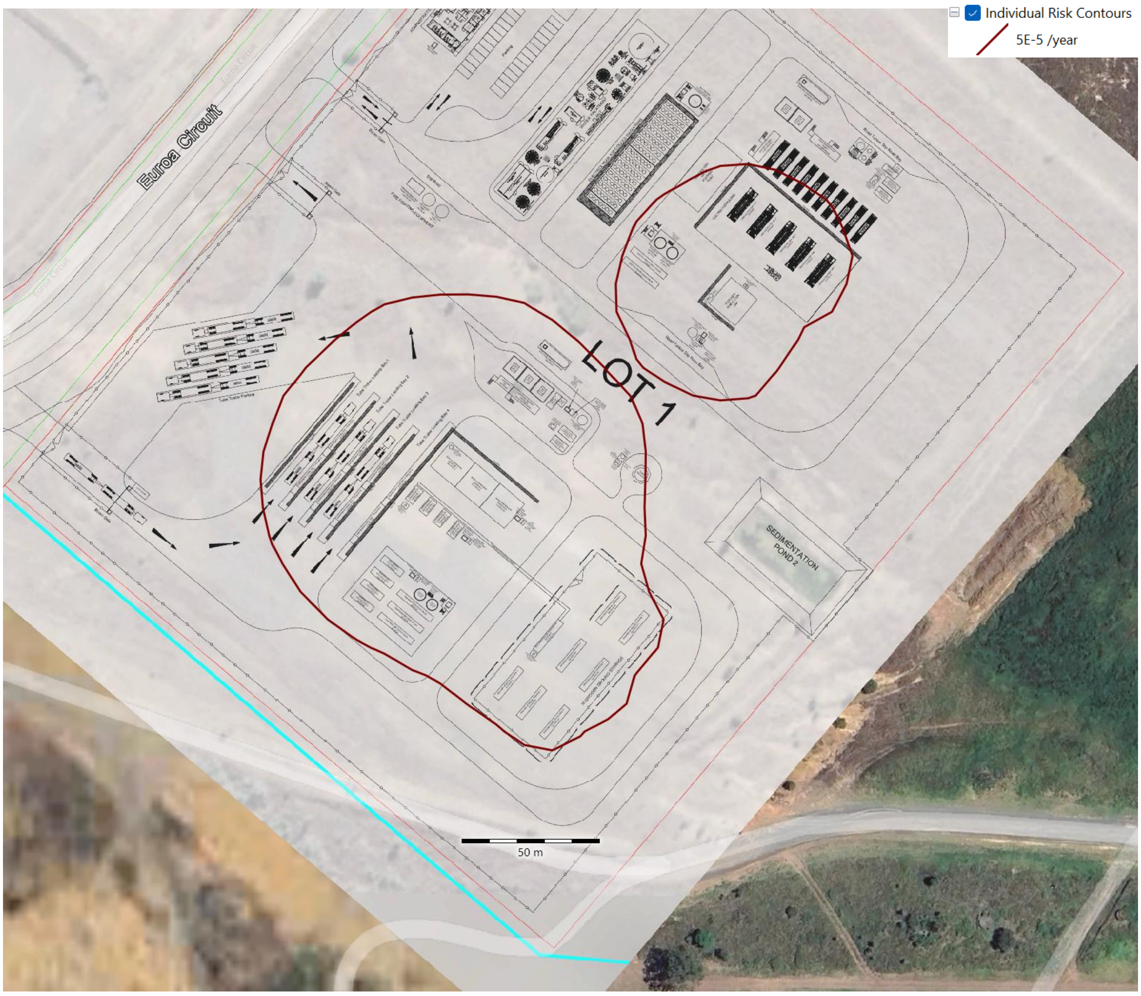

Figure E1: Individual risk contour for PO5, of 50 x 10^{-6} per year, for Euroa H_2 Domestic Project

Recommendations

It is recommended that the following safety considerations be included into the design process:

Recommendation 1: Review the requirements for fire and overpressure protection (e.g. implementation of earth berm) at the southwestern boundary and southeastern boundary of the site. Should an earth berm be installed, ensure a sizing review is completed during detailed design (consider use of CFD modelling when determining the design criteria).

Recommendation 2: Review the design of the safety instrumented systems during the detailed design phase using a Layer Of Protection Analysis (LOPA) methodology to ensure the required

SIL rating is achieved (inc. meeting the SIL requirements e.g. probability of failure on demand of the safety instrumented function).

Recommendation 3: This quantitative risk assessment has been developed using the design assumptions for risk reduction at the FEED stage. Key assumptions include:

- Automatic closure of isolation valves on process upset detection within system (e.g. due to a rupture or major leak causing a major loss of pressure)
- Automatic closure of isolation valves on gas (LEL) detection, gas leak detection and/or fire detection
- Double dissimilar non-return valves are provided in the process to prevent backflow of hydrogen in the event of isolation failure (provided as a minimum at the main compression, dispensing compression and hydrogen storage)
- Automatic blowdown valves are provided to relieve the gas inventory between isolatable sections to the flare header.

Other key assumptions are detailed in Appendix 1.

The quantitative risk assessment should be reviewed and risk reduction measures verified as part of the detailed design

GLOSSARY

BOM	Bureau Of Meteorology
CBD	Central Business District
CFD	Computational Fluid Dynamics
DA	Development Application
DCS	Distributed Control System
ESD	Emergency Shut-Down
FEED	Front End Engineering Design
F0.5	Pasquil stability condition "F" (stable wind weather) with 0.5 metres per second wind
HAZOP	Hazard and Operability Study
HMI	Human Machine Interfaces
HyRAM	Hydrogen Risk Assessment Models
LFL	Lower Flammabilty Limit
LOC	Loss Of Containment
LOPA	Layers Of Protection Analysis
MI	Major Incident
PFD	Probability of Failure on Demand
PO	Performance Outcome
QRA	Quantitative Risk Assessment
SDAP	State Development Assessment Provision
SFAIRP	So Far As Is Reasonably Practicable
SIL	Safety Integrity Level
TNO	Netherlands Organisation for Applied Scientific Research
UFL	Upper Flammability Limit
UPS	Uninterrupted Power Supply
VCE	Vapour Cloud Explosion
WHS	Work Health and Safety

Planager
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REPORT

1 INTRODUCTION

1.1 BACKGROUND

Vena Energy Australia (VENA) are proposing the Euroa H_2 Domestic Project at a designated site in Aldoga in the Gladstone region.

The Euroa H_2 Domestic Project is an integrated hydrogen electrolysis, hydrogen compression, storage and domestic distribution facility located approximately 18 kilometres west of the Gladstone CBD.

The project seeks to create an integrated hydrogen production and supply chain solution that will cater to the domestic and international markets.

UGL has commissioned Planager Pty Ltd (Planager) to prepare a Quantitative Risk Assessment (QRA) including determining the risk profile associated with the Euroa H_2 Domestic Project, as related to hazards and risks associated with hydrogen.

This QRA is prepared at the FEED-stage of the Euroa H_2 Domestic Project.

1.2 SCOPE AND AIM OF THE STUDY

This QRA is carried out at the FEED-stage of the facility.

The aim of the FEED-stage QRA is to identify and assess the risk associated with high-consequence, low-probability events, so called *Major Incidents* (MIs), and ensure that these are in line with current criteria for land use planning in use in Queensland.

The study focuses on the acute effects of fires and explosions that could result in injury and fatality in case of a loss or major event at the proposed facility (usually associated with a loss of containment (LOC) event).

The scope includes all plant and equipment where hydrogen is generated and produced, handled and stored, as these will have major hazard implications to the site.

1.3 PURPOSE STATEMENT

The purpose of the FEED-stage QRA is to demonstrate that the proposed Euroa H_2 Domestic Project development is designed and sited, so far as reasonably practicable, to ensure:

- Human health and safety, and the built environment are protected from on-site risks resulting from physical or chemical hazards;

The above statement consists of point one of the *Purpose statement* in State Code 21 Ref 2 (*SDAP21*) for hazardous chemical facilities[1]. Offsite hazard scenarios at existing hazardous chemical facilities and natural hazards are outside of the scope of this QRA.

1.4 METHODOLOGY AND REPORT STRUCTURE

The methodology for the risk assessments is well established in Australia. The Hazard Analysis has been carried as per the ISO 31000:2009 - *Risk management - Principles and Guidelines*Ref 1.

It aligns with the methodology for Hazard Analysis in SDAP21 including as described in the guidance Planning guideline for *State code 21: Hazardous chemical* facilities Ref 2.

An overview of the ISO 31000 methodology is depicted in Figure 1-1 and described below.

[1] From SDAP21: *A hazardous chemical facility (HCF) means the use of premises for a facility at which a prescribed hazardous chemical is present or likely to be present in a quantity that exceeds 10 per cent of the chemical's threshold quantity under schedule 15 of the Work Health and Safety Regulation 2011.* For hydrogen (UN number 1049) the threshold is 50 tonnes and 10% of the threshold is 5 tonnes.

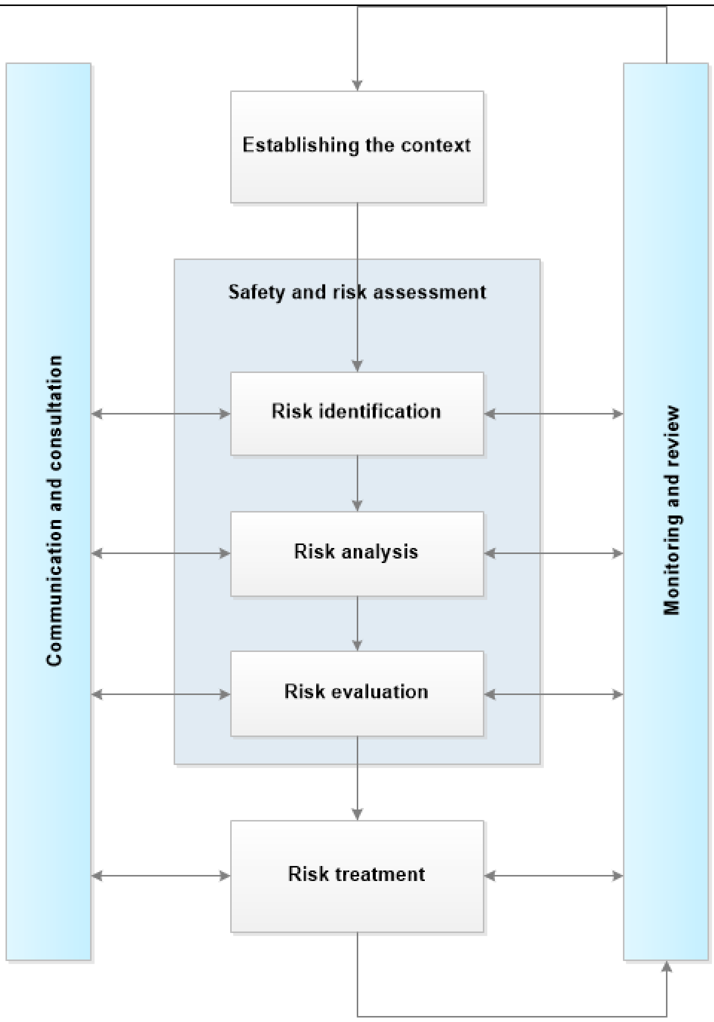


Figure 1-1: General risk management framework

The study is conducted using a combined qualitative and quantitative approach to consequences and risks using internationally recognised consequence and risk modelling software tools and likelihood databases developed for the type of facility being assessed, as follows:

- The *Context* for the study is described in Sections 1.4 to 1.7 and Section 2.
- The *Risk identification* is described in Section 3. The process for this Project involved desktop assessment carried out by Planager, considering available information against known loss of containment, fire and explosion incidents that have occurred generally in industry and as available in databases. Further hazard identification studies would need to be undertaken as part of the design process, including evaluation of layouts to minimise risk of confinement or congestion of hydrogen gas and incident propagation and detailed Hazard and Operability (HAZOP) studies.
- *Risk analysis* conducted for this assessment is a combination of qualitative and quantitative assessment. In accordance with SDAP21[Ref 2] the risk analysis consists of (1) an assessment of the off-site *dangerous dose to human safety and the built environment* (Section 4) and (2) an analysis of the risk levels to human safety (Section 5).

The software tool developed by the Dutch Government TNO (the Netherlands Organisation for Applied Scientific Research) and commercialised by Gexcon®, entitled Effects® are used for all assessment of the dangerous doses. The software tool allows for calculations of dispersion, jet and pool fire, vapour cloud explosions and flash fires associated with releases of hazardous material to atmosphere. It is developed based on the TNO "Yellow Book[Ref 3].

To characterise the range of leaks that may occur from the different equipment items typically presented within this type of facility, a set of representative hole sizes are defined and used in the consequence calculations, as defined in the database documented in the Hydrogen Risk Assessment Models (HyRAM [Ref 4]) database.

Following assessment of incident consequence, events may need to be carried forward for frequency analysis and risk assessment as per the methodology for Hazard Analysis in SDAP21. The software tool entitled Riskcurves® (TNO / Gexcon®) was used to calculate risk levels in this study.

- *Risk evaluation* consists of evaluating the performance of the Euroa H_2 Domestic Project against the performance outcomes (PO1 to PO5) in SDAP21[Ref 2]. The risk evaluation for this study is presented in Section 6.
- *Monitoring and review*: This is the first quantitative risk assessment conducted for the Euroa H_2 Domestic Project and is based on FEED-stage design information. As the Project design progresses, the assessment should be reviewed to ensure the performance outcomes are adhered to. Further, risk to people onsite and offsite would need to be critically evaluated and demonstrated to adhere to So Far As Reasonably Practicable (SFARP) principles.
- *Communication and consultation*: Stakeholder engagement is required as part of the Euroa H_2 Domestic Project development.

1.5 Risk and Criteria

1.5.1 Performance outcomes for off-site impact at neighbouring land use

The performance outcomes (POs) associated with siting of potentially hazardous facilities in relation to surrounding land use are summarised in the table below, as sourced from SDAP21[Ref 2].

Table 1: Performance outcomes for off-site outcomes at neighbouring land use (SDAP21)

Land use	Performance outcomes	
	Consequence screening	Maximum fatality risk level
Vulnerable land use or land zoned for a vulnerable land use (childcare centre; community care centre; educational establishment; health care service; hospital; retirement facility)	PO1, PO2 and PO3: The **hazardous chemical facility** does not create a	

	Performance outcomes		
Land use	Consequence screening	Maximum fatality risk level	
Sensitive land use or land zoned for a sensitive land use (community residence; dual occupancy; dwelling house; educational establishment; multiple dwelling; relocatable home park; residential care facility; rooming accommodation; short-term accommodation; tourist park)	**dangerous dose** to human health <u>with dangerous dose defined as follows:</u> For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m^2 and/or 7 kPa.		
Commercial or community activity land use or land zoned for a commercial or community activity land use (shopping centre; shop; office; major sport, recreation and entertainment facility; market; showroom; tourist attraction; entertainment facility; place of worship; community use; theatre)			
Open space land use or land zoned for an open space land use (outdoor sport and recreation; park; environment facility; rural industry)	<u>PO4:</u> The **hazardous chemical facility** does not create a **dangerous dose to human health** <u>with dangerous dose defined as follows:</u> For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m^2 and/or 7 kPa	OR, if not achievable	An individual fatality risk level of 10×10^{-6}/year AND Societal risk from figure 21.1 in SDAP21
Industrial land use or land zoned for an industrial land use (an extractive industry; a high impact industry; a low impact industry; a marine industry; a medium impact industry; a research and technology industry; a service industry; a special industry; a warehouse)	<u>PO5:</u> The hazardous chemical facility does not create a **dangerous dose to the built environment** <u>with dangerous dose defined as follows:</u> Exposure to heat and/or overpressure from a fire or explosion: 12.6 kW/m^2 and/or 14 kPa	AND	An individual fatality risk level of 50×10^{-6}/year

1.6 Safety Management

Quantitative risk assessments can only be a valid tool for assisting in the overall assessment of a site if the facility being examined is or will be subject to appropriate management control of hazards.

Without such control, the assumptions inherent to quantitative techniques become invalid in two general areas. First, the identification of hazards is based on experience in similar installations and on engineering judgement - without proper management control of safety issues, the range and impact of potential hazards becomes unpredictable. Second, the frequency at which incidents of any type may occur cannot be adequately estimated using historical data.

Safety management systems allow the risk from potentially hazardous installations to be minimised by a combination of hard controls and soft controls. It is essential to ensure that the reliability of the systems and procedures used to assure the safe operation of the facility are of the highest standards.

This study assumes that an effective Safety Management System will be implemented at the Euroa H_2 Domestic Project site.

1.7 Major assumptions

The FEED-stage QRA is conducted with a number of major assumptions as listed below. These assumptions consist of essential safety requirements which are not individually listed:

- Plant will be under competent management and the control room will be staffed 24/7.
- Plant will be operated and maintained in accordance with good practice by experienced, competent, and qualified workers.
- Plant will be inspected and maintained in good working order:
  - all items will be included in a maintenance system with specific routines and frequencies nominated.
  - plant and equipment, including critical control functions such as control loops, will be tested regularly and maintained in good working order.
  - faulty controls will be replaced.
- Plant will be operated at or below design rates and process conditions.
- Changes to plant will be investigated using robust Management of Change process.

These tasks will be integrated within the Safety Management System.

2 DESCRIPTION OF THE PROJECT

2.1 DESCRIPTION OF PLANT AND OPERATION AT FEED

The Project location, as known at the FEED-stage, is shown in Figure 2-1. A FEED-stage block flow diagram with major process components shown is shown in Figure 2-2.

The project's main infrastructure systems are:

- *Hydrogen Production System:* Hydrogen production system, including an electrolysis plant.
- The hydrogen production system includes 50 MW hydrogen gas electrolysis facility including water purification, de-oxidation, dehydration, and hydrogen gas compression, storage and dispensing components.
- *Hydrogen Storage and Compression:* The hydrogen gas will be compressed and stored on site to allow continuous supply of hydrogen gas to tube trailers with intermittent operation of the electrolysers.
- *Hydrogen Distribution:* Four (4) hydrogen tube trailer loading bays are provided to facilitate distribution of compressed gas into tube trailers.

The proposed site is located approximately 18km west of the Gladstone CBD in the Aldoga locality within the Gladstone region.

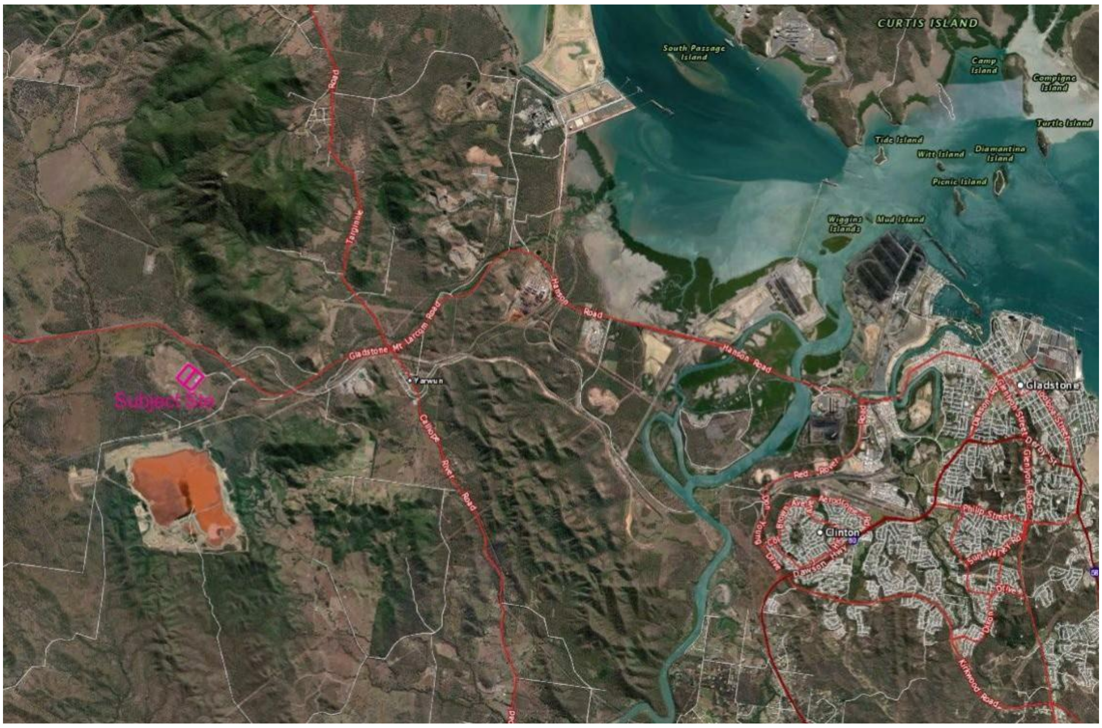
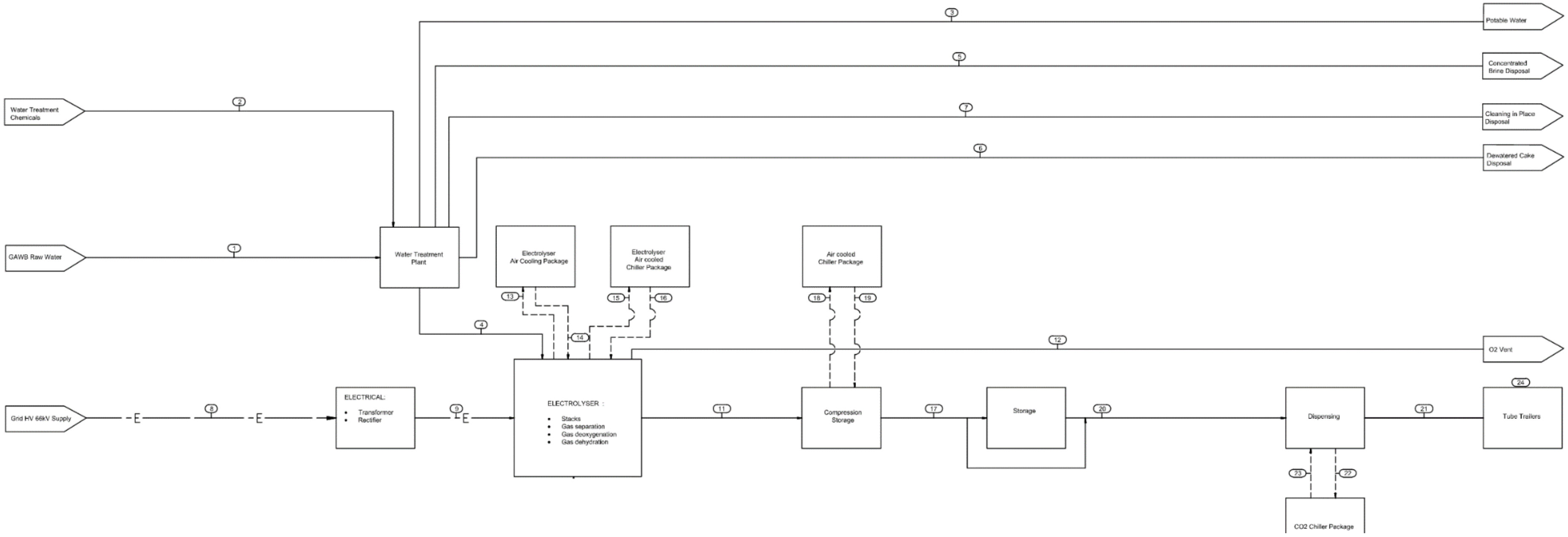


Figure 2-1: Site Location

Figure 2-2: FEED block flow diagram



2.2 Land Use

The proposed location is within an area which has been zoned for industrial use. As this stage there are some non-developed areas adjacent to the site but none are zoned as per the definition of open space in SDAP21.

2.3 Significant Design Assumptions and Parameters

All data used in the present QRA is for a plant operating 100% of the time and with all pipes, vessels and tanks pressurised and full to capacity 100% of the time, with the exception of intermittent operations which have been considered at 100% of their design capacity.

Major design assumptions and parameters for the hydrogen plant and equipment for the Euroa H_2 Domestic Project are detailed in Table 2 and Table 3, with the isolatable areas shown in Figure 2-3.

Table 2: Major design assumptions

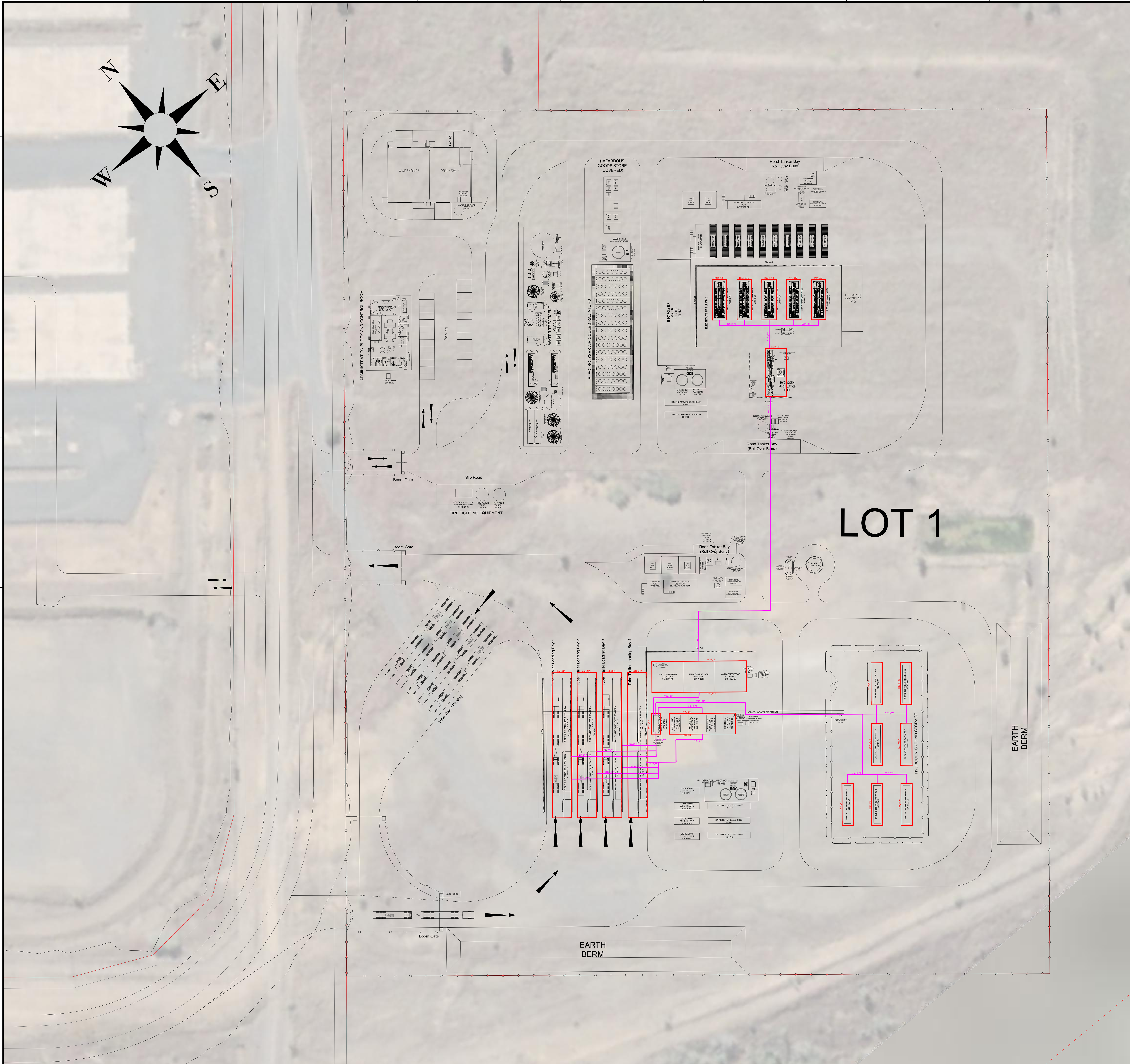
Item	Detail
Materials assessed in the QRA	Hydrogen – major hazard potential
Other hazards	Electricity (including transmission line and connection point infrastructure) WHS type hazards (work at heights, confined space, pressure equipment, moving machinery, rotating machinery etc.). These hazards are outside of the scope of this QRA
Pipe, vessels and storage material	Preliminary details in FEED design
Isolation System(s)	Full remote control of automatic isolation valves from control room and via key trips (to be defined in detailed design)
Control Measures	Hydrogen awareness programs, Standard Operating Procedures and competency training. Site patrols / tours, signage, maintenance inspections and preventative maintenance programs, in line with manufacture recommendations. These systems will be implemented on the site.

Table 3: Major design parameters (per individual unit)

Isolatable section code	Isolatable section, title and colour coding (refer to PRELIMINARY HAZARD ASSESSMENT ISOLATABLE SECTIONS)	Outside Diameter (mm)	Pressure (bar g)	Temp (°C)	Length of pipe (m)	Approx. volume of isolatable section (m^3)	Pipe location (Above / Under ground)
ISOL1A_ELS	Electrolyser Skid (2" pipe) – High Pressure side	50.8	40	75	39.5	2.65	AG
ISOL1B_ELS	Electrolyser Skid (3" pipe) – High Pressure side	76.2	40	75	39.5	2.65	AG

Isolatable section code	Isolatable section, title and colour coding (refer to PRELIMINARY HAZARD ASSESSMENT ISOLATABLE SECTIONS)	Outside Diameter (mm)	Pressure (bar g)	Temp (°C)	Length of pipe (m)	Approx. volume of isolatable section (m^3)	Pipe location (Above / Under ground)
ISOL1C_ELS	Electrolyser Skid (2" pipe) – Low Pressure side	50.8	5	75	25	2.79	AG
ISOL1D_ELS	Electrolyser Skid (3/4" pipe)	19.05	40	75	21	2.65	AG
ISOL1E_ELS	Electrolyser Ultrapure Water side (3" pipe)	76.2	40	75	55	2.65	AG
ISOL1-2_PIP	Electrolyser to purification interunit pipework	76.2	40	75	62	0.28	UG
ISOL2_GSP	Gas Purifier	76.2	40	15	150	4.00	AG
ISOL2-3_PIP	Purification to compression interunit pipework	76.2	40	15	165	0.75	UG
ISOL3_CPI	Compression inlet	76.2	40	15	18	0.31	AG
ISOL4_CPO	Compression outlet	25.4	450	15	5	0.31	AG
ISOL4-5_PIP	Compression to storage management interunit pipework	25.4	450	15	90	0.05	AG
ISOL5_SMP	Storage management Package	25.4	450	15	20	0.01	AG
ISOL5-6_PIP	Storage management to dispensing compression interunit pipework	25.4	450	15	78	0.04	AG
ISOL6_DCI	Dispensing compression inlet	25.4	450	15	7	0.15	AG
ISOL7_DCO	Dispensing compression outlet	25.4	650	15	8	0.15	AG
ISOL7-8_PIP	Dispensing compression to dispensing bay interunit pipework	25.4	650	15	105	0.05	AG
ISOL8_DIS	Dispensers	25.4	650	-30	7.2	0.004	AG
ISOL5-9_PIP	Storage management to storage pipework	25.4	450	15	91	0.05	AG
ISOL9_STO	Storage	25.4	400	25	20	42.8	AG
ISOL10_TUB	Tube trailer inc. loading hose	25.4	517	-30	10	19.4	AG

Figure 2-3: PRELIMINARY HAZARD ASSESSMENT ISOLATABLE SECTIONS, 17695-SITE-GA-1005-01



LEGEND

Isolatable Section-
- **Identifier** — ISOL1_ELS-1
- **Equipment**
- **Pipe**

Lot boundary

Fence

Isolatable Section ID	Description	Pressure (Bar_g)	Temperature (°C)	H_2 Volume (m^3)
Isolatable Equipment				
ISOL1_ELS-1	Electrolyser Skid 1 (10MW)			
ISOL1A_ELS-1	Electrolyser Skid (2") - HP	40	75	2.65
ISOL1B_ELS-1	Electrolyser Skid (3") - HP	40	75	2.65
ISOL1C_ELS-1	Electrolyser Skid (2") - LP	5	75	2.79
ISOL1D_ELS-1	Electrolyser Skid (3/4")	40	75	2.16
ISOL1E)_ELS-1	Electrolyser UPW side (3")	40	75	2.65
ISOL1_ELS-2	Electrolyser Skid 2 (10MW)	Refer Electrolyser Skid 1		
ISOL1_ELS-3	Electrolyser Skid 3 (10MW)	Refer Electrolyser Skid 1		
ISOL1_ELS-4	Electrolyser Skid 4 (10MW)	Refer Electrolyser Skid 1		
ISOL1_ELS-5	Electrolyser Skid 1 (10MW)	Refer Electrolyser Skid 1		
ISOL2_GSP	Hydrogen Purification Unit	40	15	3.70
ISOL3_CPI	Main Compressors inlet	40	15	0.62
ISOL4_CPO	Main Compressors outlet	450	15	
ISOL5_SMP	Ground Storage Management Package	450	15	N/A
ISOL6_DCI	Dispensing Compressors Inlet	450	65	0.269
ISOL7_DCO	Dispensing Compressors Outlet	650	15	
ISOL8_DIS-1	Hydrogen Dispensing 1	650	-30	0.0036
ISOL8_DIS-2	Hydrogen Dispensing 2	650	-30	0.0036
ISOL8_DIS-3	Hydrogen Dispensing 3	650	-30	0.0036
ISOL8_DIS-4	Hydrogen Dispensing 4	650	-30	0.0036
ISOL9_STO-1	Ground Storage 1	400	65	42.8
ISOL9_STO-2	Ground Storage 2	400	65	42.8
ISOL9_STO-3	Ground Storage 3	400	65	42.8
ISOL9_STO-4	Ground Storage 4	400	65	42.8
ISOL9_STO-5	Ground Storage 5	400	65	42.8
ISOL9_STO-6	Ground Storage 6	400	65	42.8
ISOL9_STO-7	Ground Storage 7	400	65	42.8
Isolatable Pipes				
ISOL1-2_PIP	Electrolyser Skids to Hydrogen Purification Unit	40	75	0.28
ISOL2-3_PIP	Hydrogen Purification Unit to Main Compressors	40	15	0.75
ISOL4-5_PIP	Main Compressors to Ground Storage Management	450	15	0.05
ISOL5-6_PIP	Ground Storage Management to Dispensing Compressors	450	15	0.04
ISOL5-8_PIP	Ground Storage Management to Dispensing Note 3	450	15	0.05
ISOL7-8_PIP	Dispensing compressors to dispensing	650	15	0.05
ISOL5-9_PIP	Ground storage Management to Ground storage	450	15	0.05

Notes
1. Isolatable Pipe routing is diagrammatic showing Isaolatable pipes between equipment
2. Isolatable sections are further detailed in the PHA report and Control Narrative(17695-CONT-SPC-1001)
3. Not considered in QRA modeling ISOL7-8 represents worst case operating scenario

0 30 60 Meters

REV	AMENDMENT DETAILS	DESIGN	CHK'D	DRAWN	CHK'D	APP'D	DATE
D	ISSUED FOR MILESTONE 3	BW	IM	BW	SHB	SHB	09/05/2025
C	REVISED	BW	IM	BW	IM	SHB	05/05/2025
B	REVISED	BW	IM	BW	IM	SHB	30/04/2025
A	ISSUED FOR REVIEW	BW	IM	BW	SHB		04/04/25

VENA ENERGY AUSTRALIA

UGL
A MEMBER OF THE CIMIC GROUP CIMIC
ABN 96 096 365 972
40 Miller Street
North Sydney NSW 2060
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DESIGNED BW | CHECKED IM | DRAWN BW | CHECKED SHB | APPROVED SHB

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A1 NTS

VENA ENERGY HYDROGEN PROJECT
HYDROGEN PRODUCTION PLANT
STAGE 1: FEED STUDY 50MW ELECTROLYZER
PRELIMINARY HAZARD ASSESSMENT
ISOLATABLE SECTIONS

CLIENT	UGL DRAWING No	SHEET	REV
VENA ENERGY	17695-SITE-GA-1005-01	01	D

CONFIRM SCALE 100mm ON A1 ORIGINAL

2.4 OPERATING PARAMETERS

2.4.1 Operating hours

The Euroa H_2 Domestic Project site would operate continuously with on-site personnel 24 hour per day 365 days per year.

2.4.2 Operational Workforce

The site operation would be managed by a Site Manager and would consist of multiple teams which would include Plant shift operators, Maintenance staff, Engineering staff and Administrative Support staff. Plant shift operations would typically be led by the Operations Team leader who would be responsible for site operations in the absence of the Site Manager.

Staffing levels and shift team composition would be determined based on benchmarking and good operating practice.

2.5 FACILITY SAFEGUARDING SYSTEMS

2.5.1 Plant control

A Central Control Room would be used to control and monitor the facility via various Human Machine Interfaces (HMI). It would be continuously staffed by trained and competent operators (24/7).

A Distributed Control System (DCS) would be installed on site to manage the control systems of plant and processes. The DCS would control process alarms and shut-down, fire and gas detection and alarms, and Emergency Shutdown functions. Critical control functions would operate independently of each other and the Central Control Room.

Critical control functions would operate on battery backup so that, in the event of a total power failure, operators are enabled to shut down the plant in a completely controlled and safe manner. After a set duration, the plant would fail automatically in a safe manner if the main power supply is not restored.

2.5.2 Power supply

Mains power to the facility would be supplied to the site, e.g. via a Substation. IA stand-by generator is be installed to provide backup power for the emergency systems; and an Uninterrupted Power Supply (UPS) will provide backup power to critical control functions, the Control Room, egress lighting, and security.

2.5.3 Venting and flaring operations

It is assumed that hydrogen gas venting would be included in the Euroa H_2 Domestic Project, with hydrogen gas vented to the flare header. Hydrogen venting is expected to be undertaken under the following circumstances:

- Compressor unit blowdown (via blowdown valves on individual compressor units)
- During plant start-ups and shut-down, and plant commissioning
- Emergency blowdown following emergency shut-down (ESD) at each isolatable section
- Plant and vessel overpressure relief

2.5.4 Fire prevention and protection

Fire detection, gas (LEL) detection, and gas leak detection systems

Fire detection, gas (LEL) detection and gas leak detection systems would be installed, capable of providing indication of the existence of fire or flammable gas, and the means to initiate appropriate executive actions. Gas leak detection would be installed on all above ground hydrogen piping.

A process upset detection from pressure transmitters (e.g. due to a rupture or major leak causing a major loss of pressure) would also be installed.

The detection system(s) would receive signals from detection equipment located around the facility providing alarms to the operators via the control room HMI.

Automatic shutdowns of electrical equipment (motors and valves) within a zoned area would be included, as defined during the detailed design phase.

Fire protection systems

Fighting a fire involving hydrogen involves first and foremost isolation of the source (usually by closing valves on either side of the leak). Isolation is achieved at each isolatable section through the following:

- Automatic closure of isolation valves on process upset detection within system (e.g. due to a rupture or major leak causing a major loss of pressure)
- Automatic closure of isolation valves on gas (LEL) detection, gas leak detection or fire detection
- Double dissimilar non-return valves are provided in the process to prevent backflow of hydrogen in the event of isolation failure (provided as a minimum at the main compression, dispensing compression and hydrogen storage)

In addition, automatic blowdown valves are provided to relieve the gas inventory between the isolatable section to the flare header.

Fire walls are provided at the electrolyser building, hydrogen purification unit, main compression area and in between each tube trailer loading bay.

The main purpose of a firewater system in the event of a fire is to cool adjacent structures and plant to prevent propagation of the event to other parts of the facility.

The need for cooling or fire water would be assessed during the detailed design phase.

2.5.5 Emergency management

An Emergency Response Plan would be prepared for the Project in collaboration with emergency services. The Emergency Response Plan and procedures would include measures to evacuate the workforce and, if required, adjacent industrial facilities. The Emergency Response Plan would include a communication strategy which would address the need to communicate with other parties, e.g. neighbouring facilities in the vicinity of the site in the event of an emergency.

The appropriate government agencies would be consulted to provide input to the Emergency Response Plan.

2.5.6 Security management

A Security Plan would be developed for the site. The Security Plan would include responses to actual security events and threats.

The plan would be prepared in consultation with the appropriate government agencies.

3 HAZARD IDENTIFICATION AND FAILURE MODES

3.1 HAZARDOUS MATERIALS

3.1.1 Inventories

Refer to Section 2.3 Table 3 for the inventory of hydrogen in each isolatable section.

3.1.2 Properties of hydrogen

A summary of physical properties and hazards associated with hydrogen produced, and handled in the Project are listed in Table 4 below.

Table 4: Summary of physical properties and materials hazards (hydrogen)

Topic	Description
Appearance	Hydrogen gas is colourless, odourless, and non-toxic gas which is highly buoyant and much lighter than air.
Physical properties	With molecular weight 2 g/mol hydrogen is the lightest element at ambient temperatures, with a relative density at STP of approx. 0.089 compared to 1.225 of air. Upon release the gas tends to quickly rise into the atmosphere provided the gas is not released into an obstructed or contained environment. This property is taken into account as part of the project design to minimise risks associated with hydrogen, where all plant and equipment where hydrogen is stored or transported at significant volumes and pressures would be located outdoors, allowing for safe dispersion of the gas in an accidental release. If a pressure vessel or pipeline of hydrogen starts leaking, hydrogen gas would be pushed out by the high operating pressures resulting in significant release rates.
Hazard	Hydrogen is a low flash-point fuel, and flammability and explosion risk are usually the major concern. Compared to methane (a major constituent of natural gas), which is a well-known and used gas in Australia (as it is often used as fuel for households), hydrogen has a 15-20 times lower minimum ignition energy than methane. The lower and upper flammability limits of hydrogen are 4% and 75% in air (by volume) at a temperature of 25°C, which is 6-7 times wider flammable range than methane, and up to 6-7 times higher burning velocity than methane with associated higher explosion pressures. The flame temperature of hydrogen jet-fires are reported to be higher than for methane. Hydrogen flames are invisible in daylight, which may represent an additional hazard to people. Hydrogen flames are, on the other hand, generally reported to be directed upwards due to the high buoyancy of the gas and to give significantly less radiation than natural gas flames, thus if direct flame exposure

Topic	Description
	is prevented, the hazards from flame radiation should be less compared to natural gas. A sudden release from a rupture of a pressurised storage vessel may give rise to a fire ball or rapid flash fire. Hydrogen may cause embrittlement in equipment used for its storage and transport, due to its small size which allows hydrogen molecules to permeate through materials to a greater extent compared with other gases. Hydrogen may combine with carbon in carbon-steel to form methane pockets, potentially weakening the materials – this is prevented through material selection. The high pressure associated with the pressurised hydrogen can cause pressure hazards, typically to on-site personnel during maintenance activities.

3.2 Detailed consideration of all hazards

Several variables must be addressed in developing an assessment of a release and its general dispersion, including potential for ignition sources. The factors determine the possible outcomes of an uncontrolled release, whether it:

- Disperses without any flammable effect
- Burns as a jet or flash fire or as a fireball or explodes as a vapour cloud explosion.

The hazards identified with potential to cause loss of containment associated with hydrogen can be broadly categorised as:

- Internal and process related hazards
- External hazards, including natural hazards and intentional acts (outside of the scope of this QRA).

Heat radiation and explosion overpressures associated with an ignited releases from a plant or equipment have the potential to escalate to other plant and facilities.

Flame impingement, heat radiation or explosion overpressure exceeding safe design limits (defined as 23kW/m^2 and 14 kPa(g) in several NSW planning documents[2]) impacting on vessels or pipes can result in failure with consequences more serious than those of the initiating event. Such potential would be considered in plant layouts and pressure relief considerations during the detailed design process of the Project and is not included in the scope of this QRA.

[2] NSW Department of Planning Hazardous Industry Planning Advisory Paper Number 4, HIPAP6, 2011

4 DANGEROUS DOSE TO HUMAN HEALTH AND THE BUILT ENVIRONMENT

The SDAP21[Ref 2] requires assessment of the *dangerous dose to human health* and to the *built environment* (refer to Section 1.5) as part of the demonstration of compliance with Performance outcome criteria PO1 to PO5.

To this effect, worst case scenarios have been evaluated, assuming that built-in safety provisions fail and consequently, maximum release rates occur.

The probability that the incidents will develop to this magnitude is not taken into account in the analysis of this part of the assessment (refer to Section 5).

4.1 INTRODUCTION AND THEORIES

Consequence analysis includes evaluation of the gas outflow rates and dispersion, thermal radiation and explosion overpressures in case of ignition, and the effects of radiation and overpressure on people and property.

The software modelling software tool Effects® (by TNO, commercialised by Gexcon®) is used to model release behaviour for compressed gas and liquids from tanks, vessels and pipelines. Effects® incorporates the consequence models described in the *Yellow Book*[Ref 3]. The tool is used to model release conditions and outflow rates, gas dispersion, heat radiation and explosion overpressures.

Effects® and the Yellow Book models have world-wide recognition as consequence assessment tools and have been used for several decades for decision support for infrastructure design and licencing, including for hydrogen infrastructure. The version of Effects® used in this study (v.12.4) has been updated for use in hydrogen assessment.

4.1.1 Hole sizes and release rate

An appropriate release rate equation is selected based on the release situation and initial state of the material. Riskcurves® and Effects® software products model release behaviour for compressed gas or liquid from vessels, pipelines, or total vessel rupture. Input data includes the type of release, location of release with respect to vessel geometry, pipe lengths and initial conditions of the fluid before release.

Representative hole sizes are set for each release case, in line with the methodology in the HyRAM[Ref 4] for hydrogen plant and equipment (refer to Appendix 1 assumption no. 5).

The release rate is assumed to remain constant until isolation can be achieved – this is a conservative approach as in reality there would be pressure reduction and hence a reduction in leak rate.

4.1.2 Duration

The duration of a leak would depend on the hardware systems available to isolate the source of the leak, the nature of the leak itself and the training, procedures, and management practices at the facility.

While in some cases it may be argued that a leak can easily be isolated within one minute, the same leak under different circumstances may take 10 minutes to isolate.

Under worst case conditions, for example where there are large quantities of materials between two isolating valves, the release may last even longer. In such cases, the release pressure and hence the release rate would decrease with time. The approach used in this study for the identified failure scenarios is to assume the release continues until the inventory has been released, or when steady-state dispersion has been established.

4.1.3 Dispersion of gas

The processes of release and subsequent distribution of a gas is strongly dependent on its thermodynamic state during storage. Pressurized hydrogen gas forms a free jet or would be flash-released if there was a failure of the storage vessel or pipeline.

In either case, parameters of concern are the expansion of a gas or vapor cloud, the height that it could attain, the time until it becomes sufficiently diluted below the flammability limits, and the total quantity of gas in the cloud.

The atmospheric dispersion model is used to model dispersion behaviour of gas and vapours. The software tool can predict when the dispersed gas becomes neutral through incorporation of air and switches model automatically.

Dispersion is affected by the atmospheric conditions at the time of the release, including surface roughness, wind speed and weather stability, with the local wind weather conditions used in the modelling[3].

The worst case steady-state distance to a given concentration is used to describe the distance to hazardous endpoints (see Table 5 and Table 6).

[3] Meteorological data from Aldoga (Gladstone Region), located approximately 2km north-west of the site was used (refer to Appendix 1, assumption no. 2)

4.1.4 Heat radiation calculation

- *Jet fire:* High-pressure gas release generates a high momentum jet or spray with a high discharge velocity. The jet results in a high degree of mixing of the gas with air and can burn with very high intensity and emit large amounts of heat to the surrounding environment. Jet fires generally continue to burn for as long as the supply of flammable material is sustained and can therefore last for a long time.

  Heat radiation effects are calculated based on flame surface emissive power which is dependent on the quantity of material, its heat of combustion, flame dimensions and the fraction of heat radiated.

  The view factor method is used to determine heat radiation, taking into account the distance from the flame to the target, the flame dimensions and the orientation angle between the flame and the target.

  The flame dimensions for each wind weather category are calculated in Effects® and Riskcurves® and incorporated into the risk assessment together with their respective probability of occurrence.

  The Chamberlain® model is used for jet fire modelling. This model shows acceptable correlations with hydrogen fires. Jet fires are conservatively assessed as 100% horizontal and 0% vertical (unless obstructed by a firewall, in which case the jet flame is assumed to be directed vertically).

- *Flash fire:* If a flammable gas is mixed with air before it is ignited, large amounts of combustible material can be burned in a short time resulting in a flash fire or a vapour cloud explosion. The combustion would mainly take place where the substance is present in a flammable concentration (i.e. at concentrations above the LFL), but due to the temperature rise during combustion, the air in the flame would expand and may push the unburned flammable cloud outwards to approximately double size if ignition occurs in the centre of the flammable cloud (Ref 5). For edge ignition, this effect is significantly lower since the expansion only partially enters the flammable cloud.

  If the flammable cloud is in an area with a high equipment density, or, as in the case of highly reactive hydrogen gas, combustion reactions in the flammable cloud would accelerate and thus also the pressure build-up, transitioning into a deflagration.

  The consequences of a deflagration would typically be represented by larger distances to end point values than those for a pure flash fire. Hence, in this QRA, flash fires have been ignored and instead assessed as deflagrations, as discussed in Section 4.1.5. This is in line with current recommendations for hazard and risk assessments involving hydrogen[Ref 5, 6].

  As per standard methodology in hazard and risk assessment, the risk of injury or fatality is calculated without taking into account any chance of escape from the incident.

  The end point values relevant to SDAP21 [Ref 2] for heat radiation is presented in bold in Table 5.

Table 5: End point values and effects of heat radiation

Radiant Heat Level (kW/m²)	*Dangerous dose* as per SDAP21	Effect (results of exposure depends on exposure duration)
1.2	Not included	Received from the sun at noon in summer
2.1	Not included	Minimum to cause pain after 1 minute
4.7	**To human safety**	**Will cause pain in 15-20 seconds and injury after 30 seconds' exposure**
12.6	**To the built environment**	**Significant chance of fatality for extended exposure. High chance of injury**
23	Not included	Likely fatality for extended exposure and chance of fatality for instantaneous (short) exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures which can cause failure. Pressure vessel needs to be relieved, or failure would occur
35	Not included	Significant chance of fatality for people exposed instantaneously

4.1.5 Vapour cloud explosion calculations

A vapour cloud explosion is primarily defined by the environment in which the gas disperses. The explosive mass in the flammable gas cloud is taken as the maximum mass between the LFL[4] and UFL[5] concentration for that section of the cloud that overlaps a congested area, also for relatively low congested areas.

The peak side-on overpressure resulting from an explosion is estimated using the Multi Energy method option in the Effects® and Riskcurves® software.

In line with current recommendations for hydrogen risk assessment modelling[Ref 6], each ignited hydrogen release, additionally to the resulting fire scenario, is taken as resulting in deflagration overpressure. The Effects® Multi Energy (ME) model curve number 5 is used as representative of the environment for a hydrogen cloud in a low or medium congestion, involving 100% of the gas within the flammable range.

There is evidence that congested hydrogen clouds can detonate [Ref 6] and, while this is contrary to some opinions expressed in the literature, this possibility is included in the present QRA.

For cases where hydrogen gas is released into a high congested area and then ignites, ME model curve number 10 is used to model the hydrogen detonation. If dimensions of equipment in the congested area are unknown, it is conservatively assumed that 100% of the cloud is involved in the explosion. If dimensions of the congested area is known, the fraction of cloud involved in explosion is determined and ME model adjusted accordingly. In this study, congested areas

[4] Lower Flammable Limit
[5] Upper Flammable Limit

where detonation may occur have been identified for the electrolyser building and the hydrogen storage areas, and volume blockage ratios (VBRs) have been determined for these areas (see Appendix 1, assumption no. 11).

As per the methodology in SDAP21 [Ref 2], the risk of injury or fatality is calculated without taking into account any chance of escape from the incident.

The end point values relevant to SDAP21 [Ref 2] for explosion overpressure are presented in bold in Table 6.

Table 6: End point values and effects of explosion overpressure

Explosion overpressure (kPa(g))	Dangerous dose as per SDAP21	Effect
7	**To human safety**	**Damage to internal partitions & joinery. 10% probability of injury, no fatality**
14	**To the built environment**	**Houses uninhabitable and badly cracked. Potential for propagation at industrial facilities**
21	Not included	Reinforced structures distort, storage tanks fail. 20% chance of fatality to person in building
35	Not included	Houses uninhabitable, rail wagons & plant items overturned. Threshold of eardrum damage, 50% chance of fatality for a person in a building, 15% in the open
70	Not included	Complete demolition of houses. Threshold of lung damage, 100% chance of fatality for a person in a building or in the open

4.1.6 Effect of shelter or escape

Inclusion of the effect of available shelter or escape from a major incident is ignored for individual risk calculations, in line with international convention for quantitative hazard and risk assessment (including as per SDAP21[Ref 2]) for assessments that may affect the public.

4.2 RESULTS OF THE CONSEQUENCE ANALYSIS

The assessment of the dangerous dose to human health and the built environment is required to demonstrate compliance with performance outcomes PO1 to PO5 (refer to the SDAP21[Ref 2] risk criteria in Section 1.5).

The detailed results of the assessment of the dangerous dose associated with the Euroa H_2 Domestic Project are presented in Sections 4.2.1 to 4.2.17. The consequence analysis assesses a worst-case scenario (isolation fails with wind directed to the closest site boundary) as discussed in the detailed results below. A summary is provided in Table 7.

Within the confines of the information available for the Euroa H_2 Domestic Project at the FEED stage, the QRA has demonstrated the following:

- *Compliance with performance outcomes PO1 to PO3* in SDAP21 has been demonstrated, with the dangerous dose to human health not exceeding the threshold at off-site commercial, sensitive or vulnerable land use or land zone. No further analysis to demonstrate compliance with PO1 to PO3 is required
- *Compliance with performance outcome PO4* in SDAP21 has been demonstrated, with the dangerous dose to human health not exceeding the threshold at any known off-site open space land use or land zone. No further analysis to demonstrate compliance with PO3 is required
- *Compliance with performance outcomes* PO5 in SDAP21 for dangerous dose to the built environment has not been demonstrated, as the dangerous dose exceeds the threshold at an off-site industrial land use or land zone (discussed further in sections below).

  To demonstrate full compliance with PO5, an assessment of the individual fatality risk against the SDAP21 risk criteria is still required (as reported in Section 5).

Table 7: Summary results of the consequence assessment against performance criteria in PO1 to PO5 (subject to assumptions in Section 4.2.1 to 4.2.6)

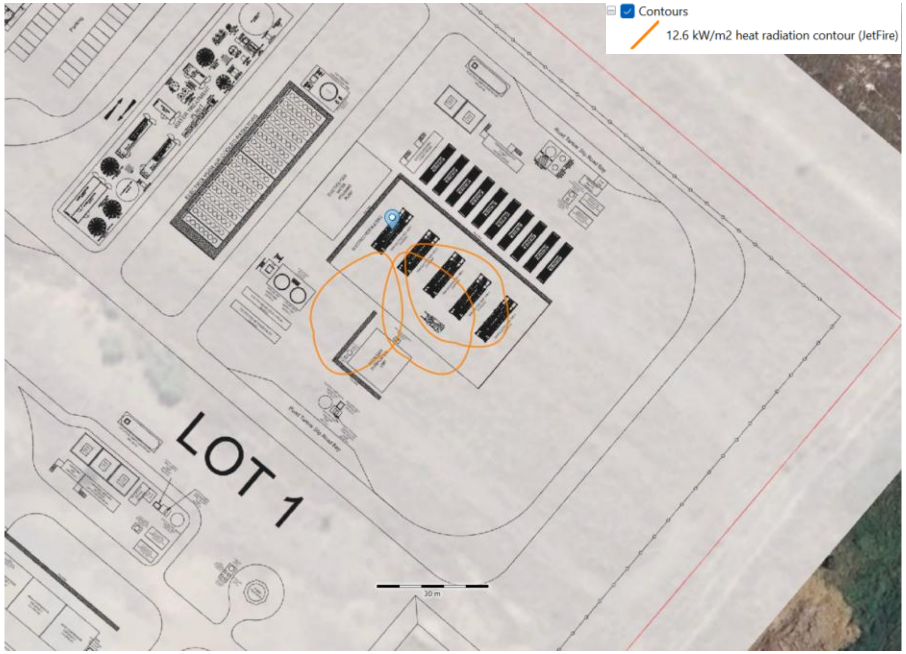
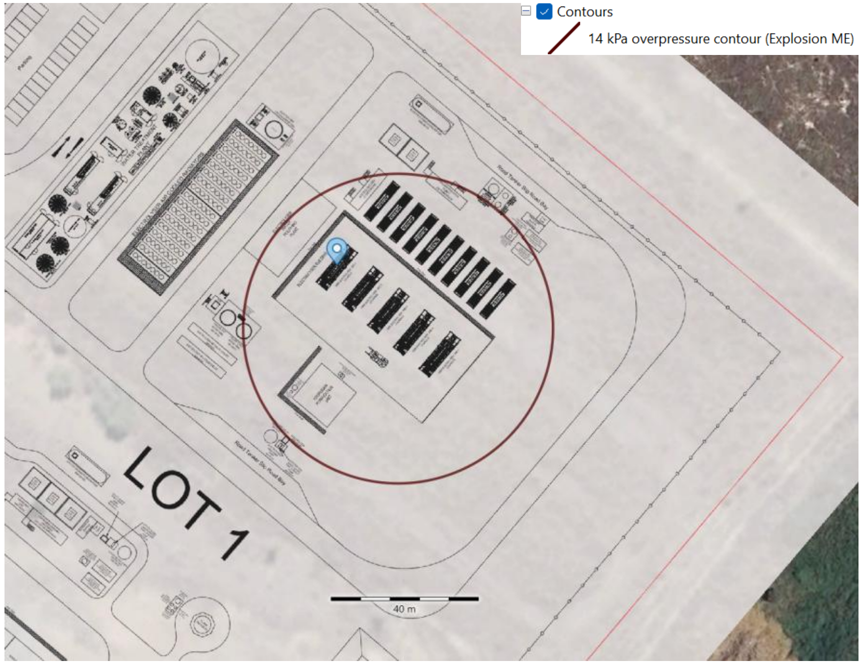
Plant, equipment pipeline	Type of off-site impact	Dangerous dose enters adjacent land used or zoned for (YES/NO)					Needs further analysis (YES / NO)	Representative scenarios to carry forward for likelihood and risk analysis
		Vulnerable use	Sensitive use	Commercial, community use	Open space use	Industrial use		
Electrolyser Skid	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Electrolyser to Purification Interunit Pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Hydrogen Gas Purifier	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Purification to Compression Interunit Pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Compression Inlet	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	YES	YES	Individual fatality risk assessment is required
Compression Outlet	Human health	NO	NO	NO	NO	NO	NO	-

Plant, equipment pipeline	Type of off-site impact	Dangerous dose enters adjacent land used or zoned for (YES/NO)					Needs further analysis (YES / NO)	Representative scenarios to carry forward for likelihood and risk analysis
		Vulnerable use	Sensitive use	Commercial, community use	Open space use	Industrial use		
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Compression to storage management interunit pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Storage Management Package	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Storage Management Package to Dispensing Compression Interunit Pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Dispensing Compression Inlet	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Dispensing Compression Outlet	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required

Plant, equipment pipeline	Type of off-site impact	Dangerous dose enters adjacent land used or zoned for (YES/NO)					Needs further analysis (YES / NO)	Representative scenarios to carry forward for likelihood and risk analysis
		Vulnerable use	Sensitive use	Commercial, community use	Open space use	Industrial use		
Dispensing compression to dispensing bay interunit pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	NO	YES	Individual fatality risk assessment is required
Dispensers	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	YES	YES	Individual fatality risk assessment is required
Storage Management Package to Hydrogen Storage Interunit Pipework	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	YES	YES	Individual fatality risk assessment is required
Hydrogen Storage	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	YES	YES	Individual fatality risk assessment is required
Tube trailer inc. loading hose	Human health	NO	NO	NO	NO	NO	NO	-
	Built environment	NO	NO	NO	NO	YES	YES	Individual fatality risk assessment is required

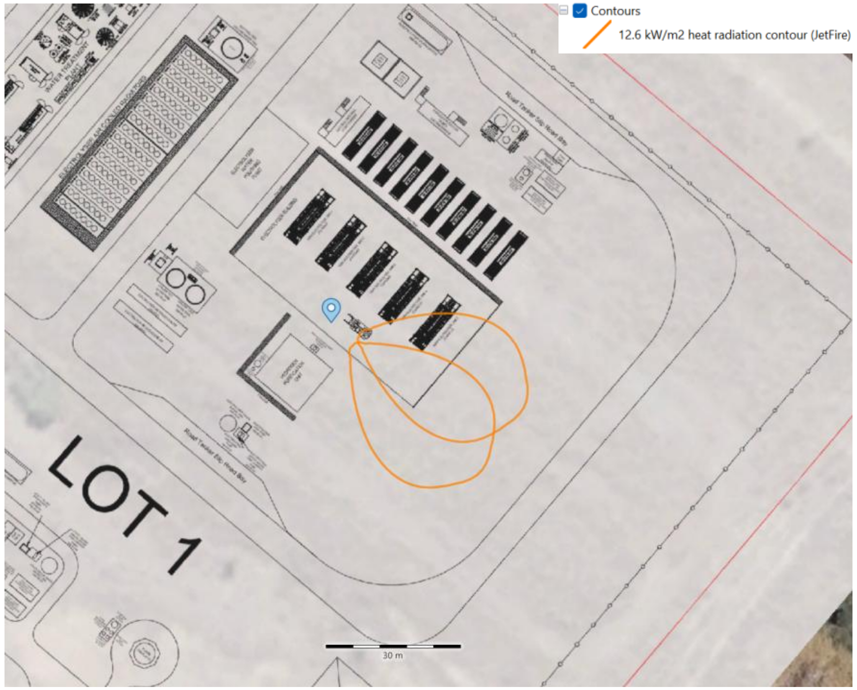
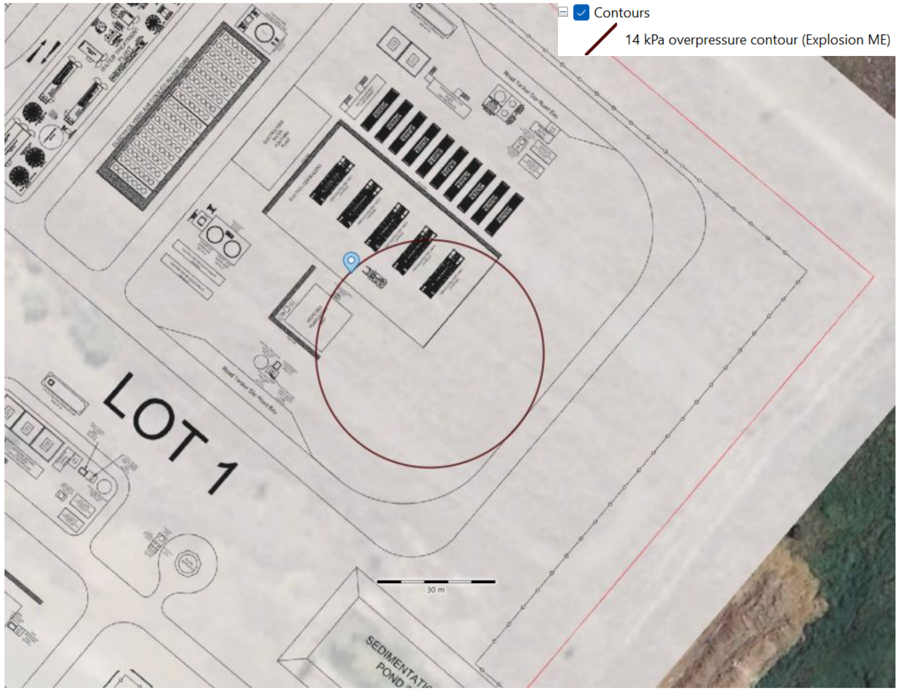
4.2.1 Release from the electrolyser skid

Figure 4-1 ISOL1A_ELS - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

<table>
<tr><th colspan="2">ISOL1A_ELS - Electrolyser Skid (2") – HP</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>ISOL1A_ELS as representative consequence for the electrolyser skid scenarios. Fire wall at electrolyser building assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within the Site Boundary.</td><td>ISOL1A_ELS as worst-case scenario output for VCE from the electrolyser skid with largest hydrogen mass in the congested area. Potential for gas accumulation at hydrogen storage packages. Detonation assessed as TNO MEM blast strength 10 and 86% of cloud involved in explosion as per VBR dimensions at electrolyser building (refer to Appendix 1, assumption no. 11). Overpressure contour stays within the Site Boundary.</td></tr>
</table>

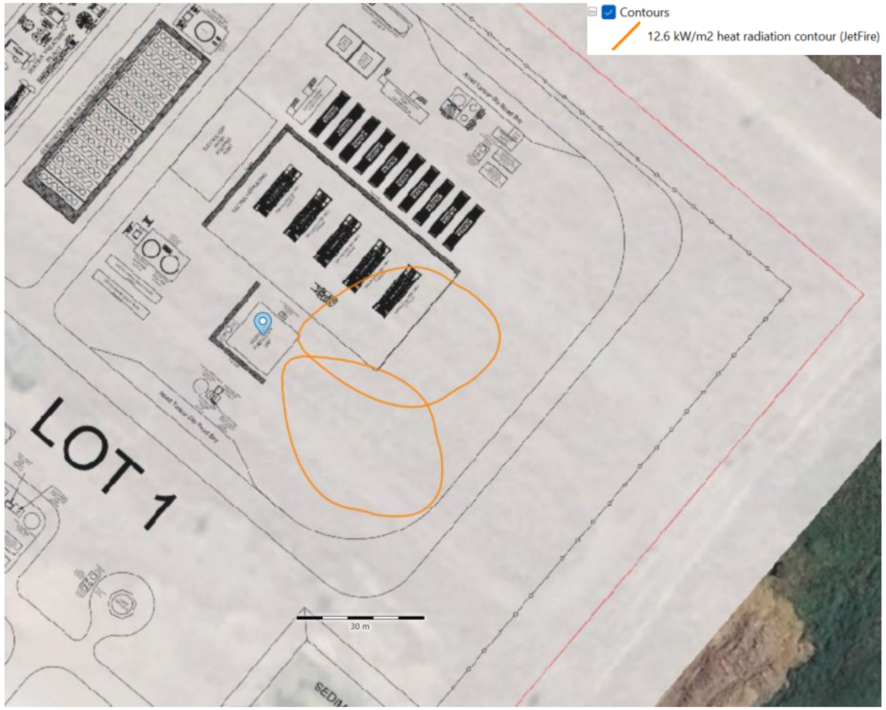
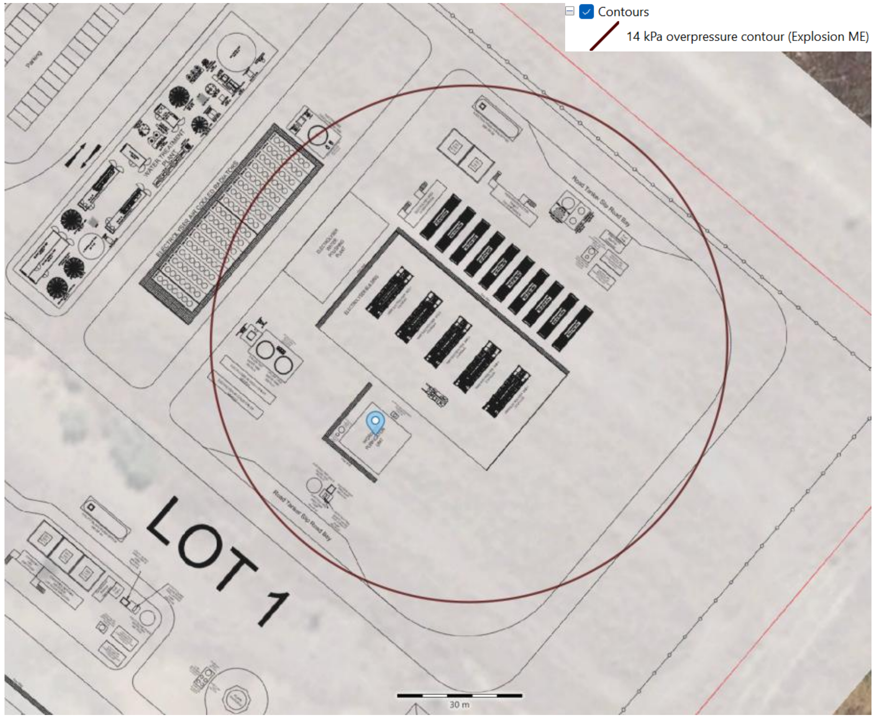
4.2.2 Release electrolyser to purification interunit pipework

Figure 4-2 ISOL1-2_PIP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL1-2_PIP - Electrolyser to purification interunit pipework	
	
Fire wall at the electrolyser building is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within the Site Boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.

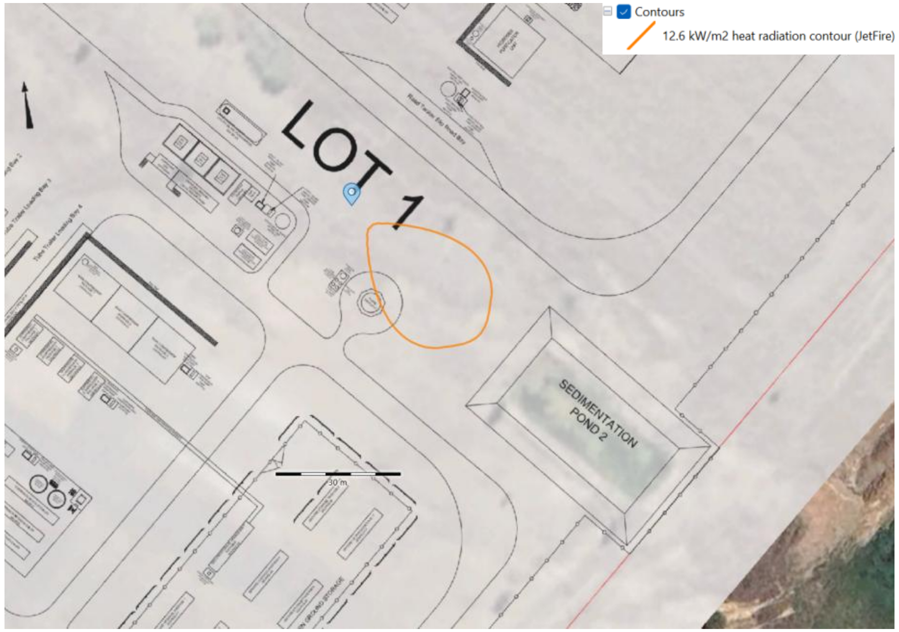
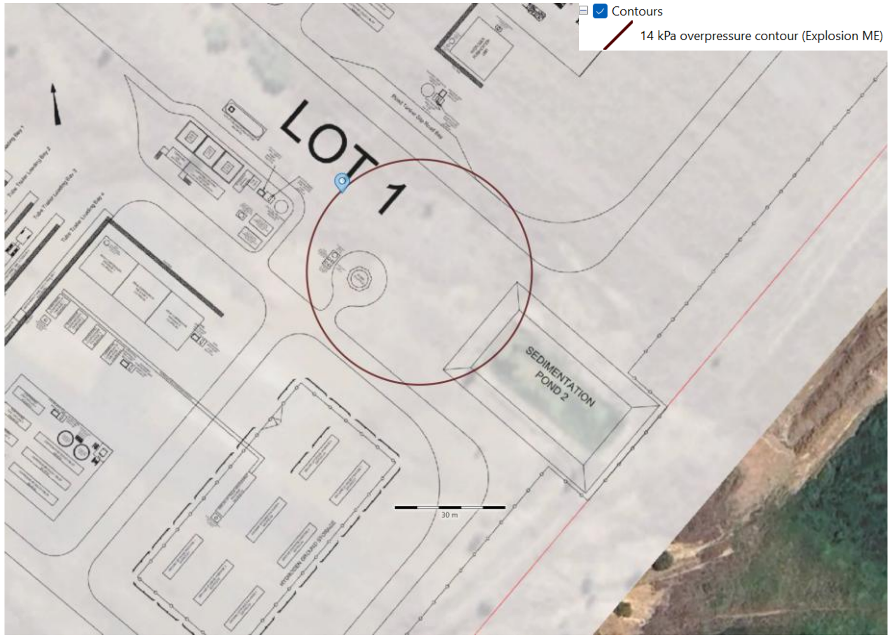
4.2.3 Release from hydrogen gas purifier

Figure 4-3 ISOL2_GSP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

<table>
<tr><th colspan="2">ISOL2_GSP - Hydrogen gas purifier</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Fire wall at the hydrogen purification unit assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within Site Boundary.</td><td>Potential for accumulation of vapour cloud into congested area at the electolysers. Conservatively assessed as worst-case overpressure scenario (TNO MEM blast strength 10 and 100% of cloud involved in explosion) as dimensions of hydrogen purification equipment unknown. Overpressure contour stays within Site Boundary.</td></tr>
</table>

4.2.4 Release from purification to compression interunit pipework

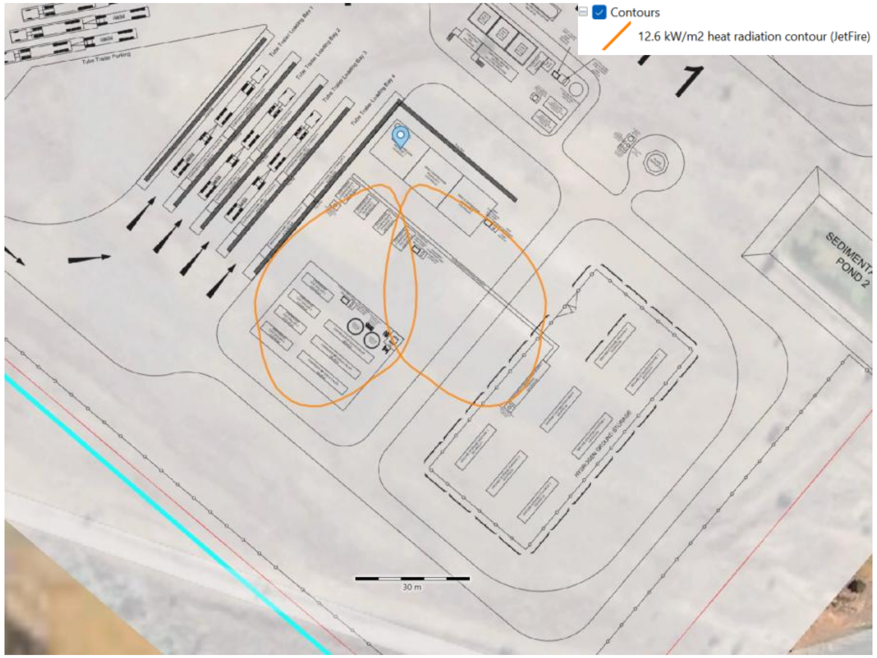
Figure 4-4 ISOL2-3_PIP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

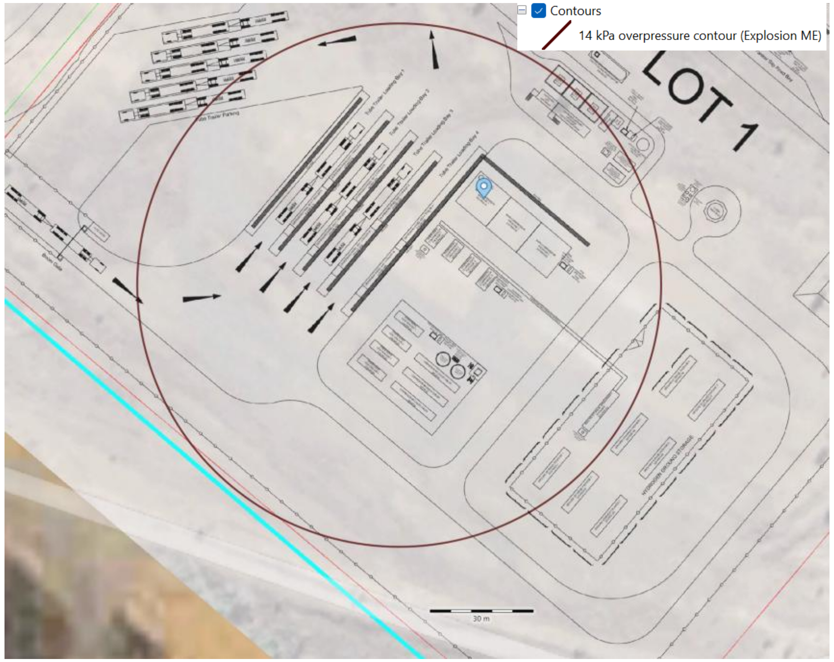
<table>
<tr><th colspan="2">ISOL2-3_PIP - Purification to compression interunit pipework</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Heat radiation contour shown towards Site Boundary only. Heat radiation contour stays within the Site Boundary</td><td>Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.</td></tr>
</table>

4.2.5 Release from compression inlet

Figure 4-5 ISOL3_CPI - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL3_CPI - Main compression inlet



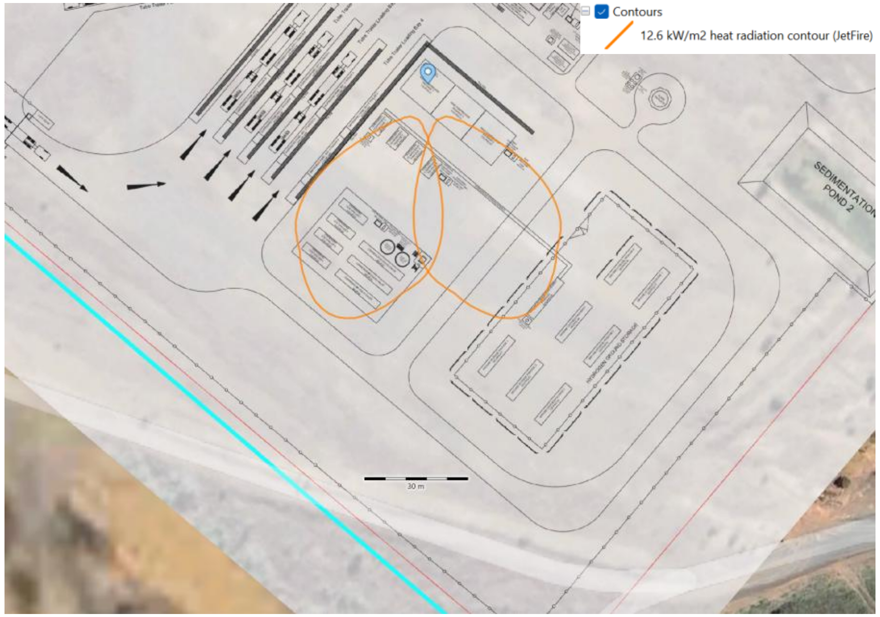


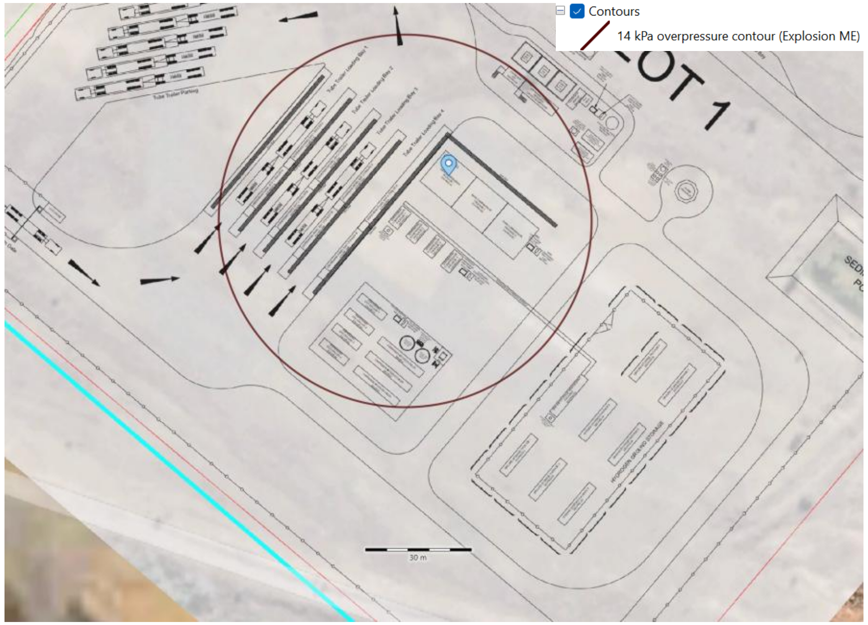
Fire wall at the main compression area assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown to be directed away from the fire wall. Heat radiation contour stays within the Site Boundary.	Potential for congested gas accumulation and confined vapour cloud explosion at various locations around the compression area. Conservatively assessed as worst-case overpressure scenario (TNO MEM blast strength 10 and 100% of cloud involved in explosion) as dimensions of equipment at each area unknown. Overpressure contour exceeds southwestern boundary (when modelled towards the closest Site Boundary).

4.2.6 Release from compression outlet

Figure 4-6 ISOL4_CPO - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL4_CPO - Main compression outlet



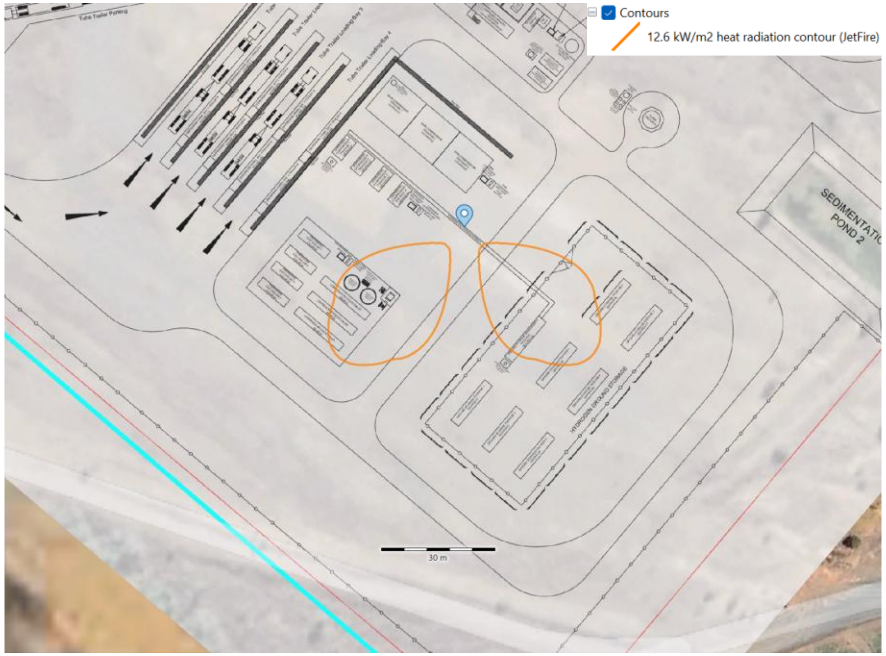
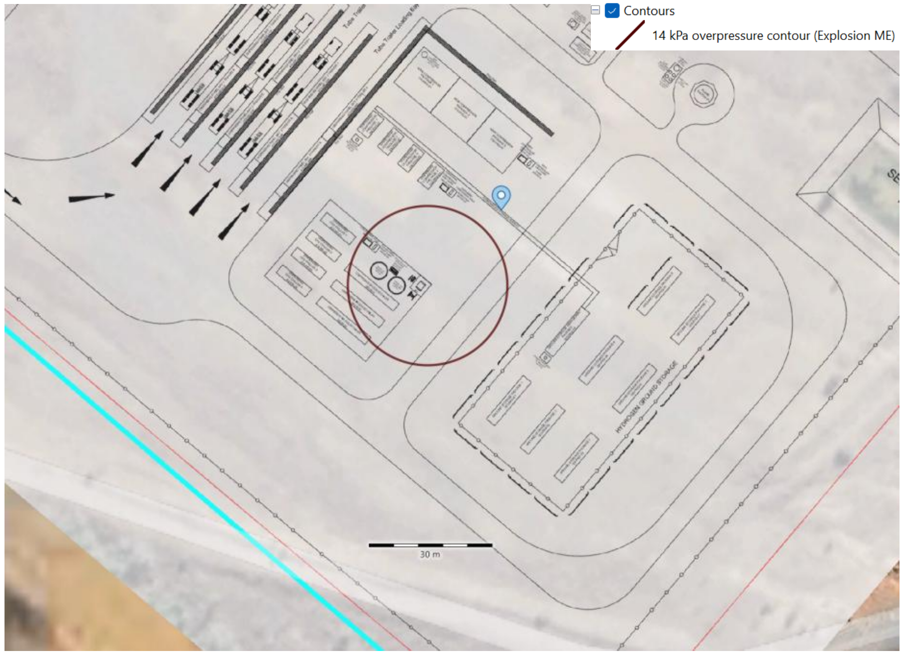


Fire wall at the main compression area is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within the Site Boundary.

Potential for congested gas accumulation and confined vapour cloud explosion at various locations around the compression area. Conservatively assessed as worst-case overpressure scenario (TNO MEM blast strength 10 and 100% of cloud involved in explosion) as dimensions of equipment at each area is currently unknown. Overpressure contour stays within the Site Boundary (when modelled towards the closest Site Boundary).

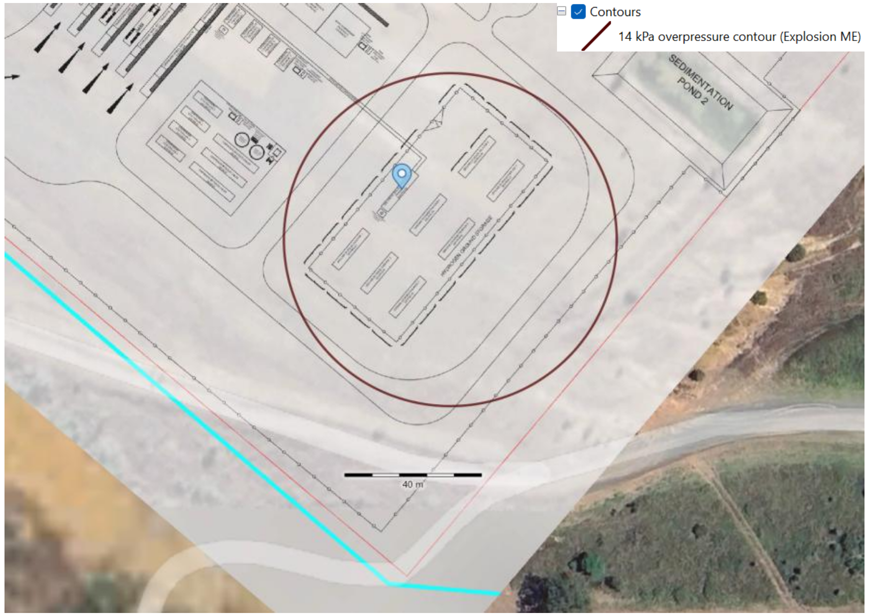
4.2.7 Release from compression to storage management package interunit pipework

Figure 4-7 ISOL4-5_PIP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

<table>
<tr><th colspan="2">ISOL4-5_PIP - Compression to storage management package interunit pipework</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Heat radiation contours shown as directed towards the Site Boundary. Heat radiation contour stays within the Site Boundary.</td><td>Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.</td></tr>
</table>

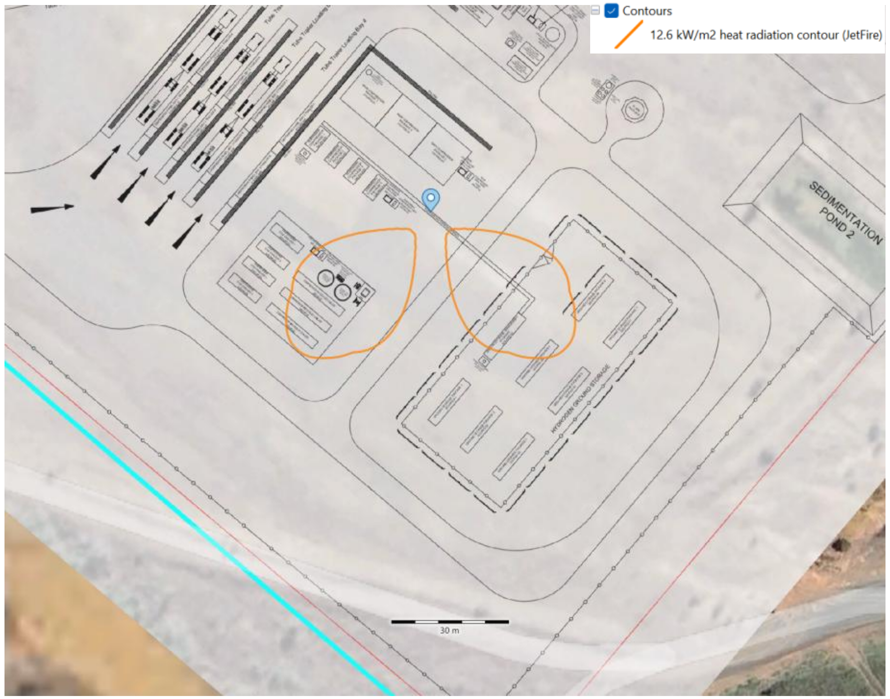
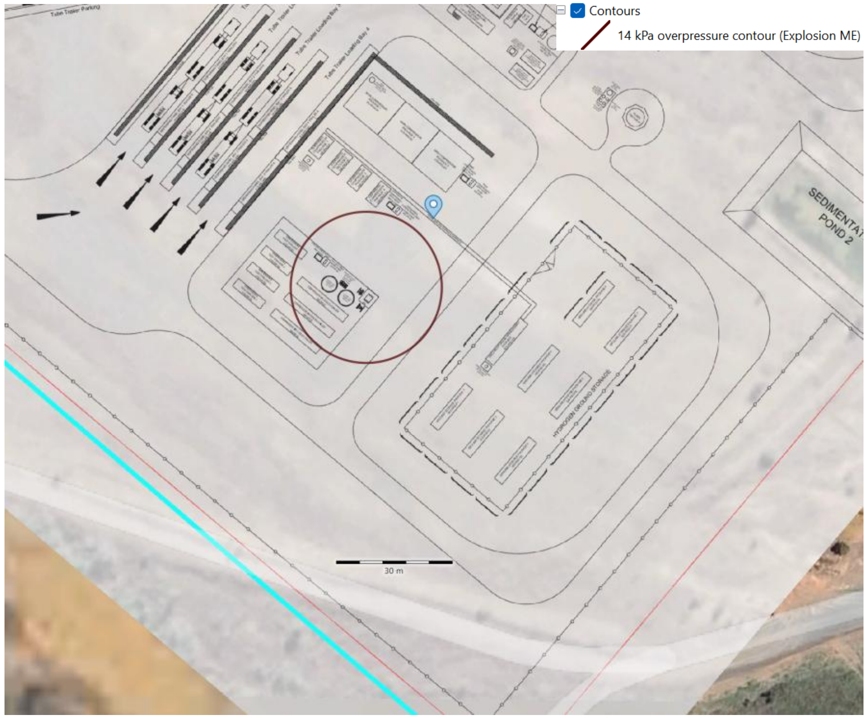
4.2.8 Release from storage management package

Figure 4-8 ISOL5_SMP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

<table>
<tr><th colspan="2">ISOL5_SMP - Storage management Package</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Heat radiation contour shown to be directed towards the Site Boundary. Heat radiation contour stays within the Site Boundary.</td><td>Potential for gas accumulation at hydrogen storage packages. Assessed as TNO MEM blast strength 10 with 76% of cloud involved in explosion as per VBR dimensions at hydrogen storage package area (refer to Appendix 1, assumption no. 11). Overpressure contour stays within the Site Boundary (when modelled towards the closest Site Boundary).</td></tr>
</table>

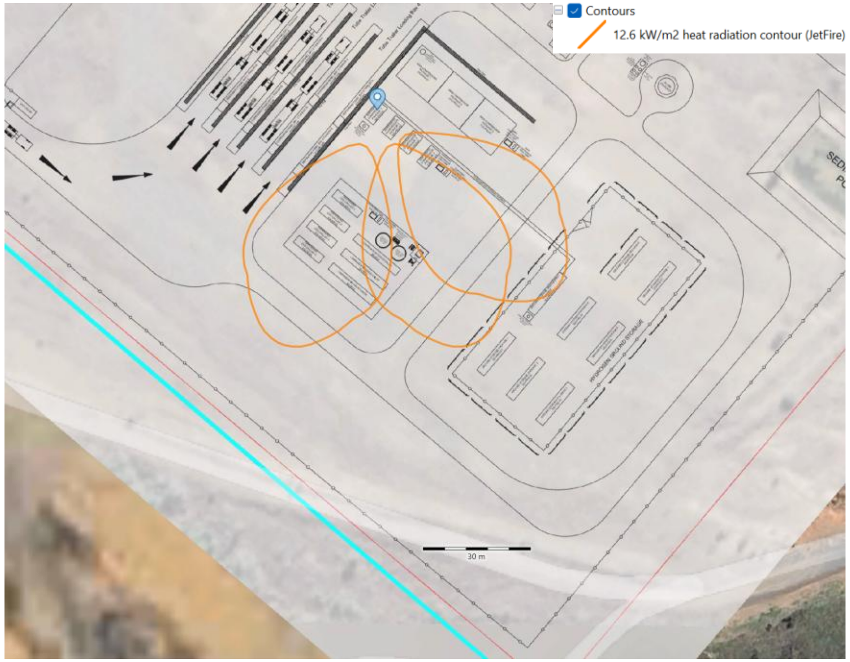
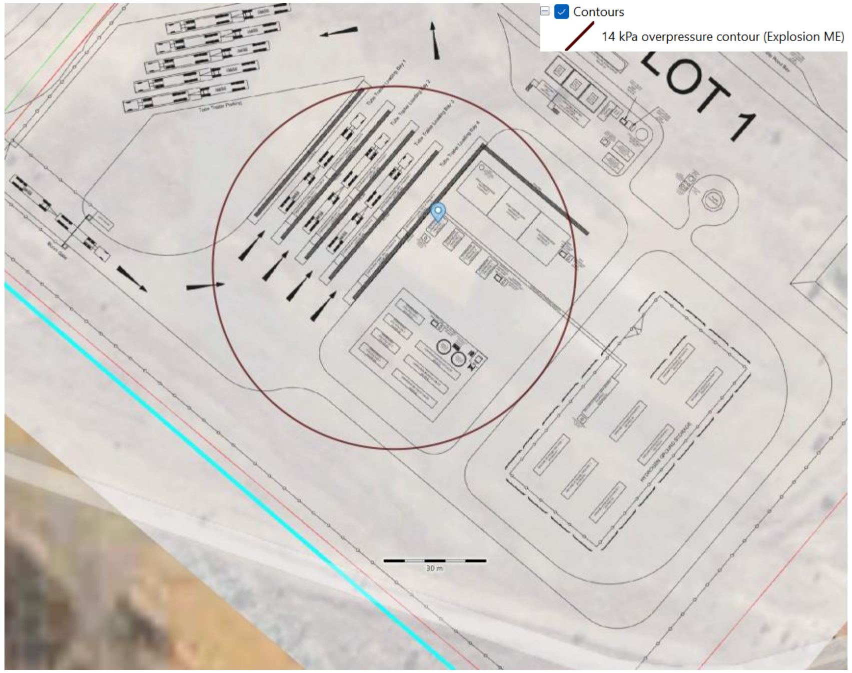
4.2.9 Release from storage management to dispensing compression interunit pipework

Figure 4-9 ISOL5-6_PIP - 12.6 kW/m2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL5-6_PIP - Storage management to dispensing compression interunit pipework	
	
Heat radiation contours shown towards the Site Boundary. Heat radiation contour stays within the Site Boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.

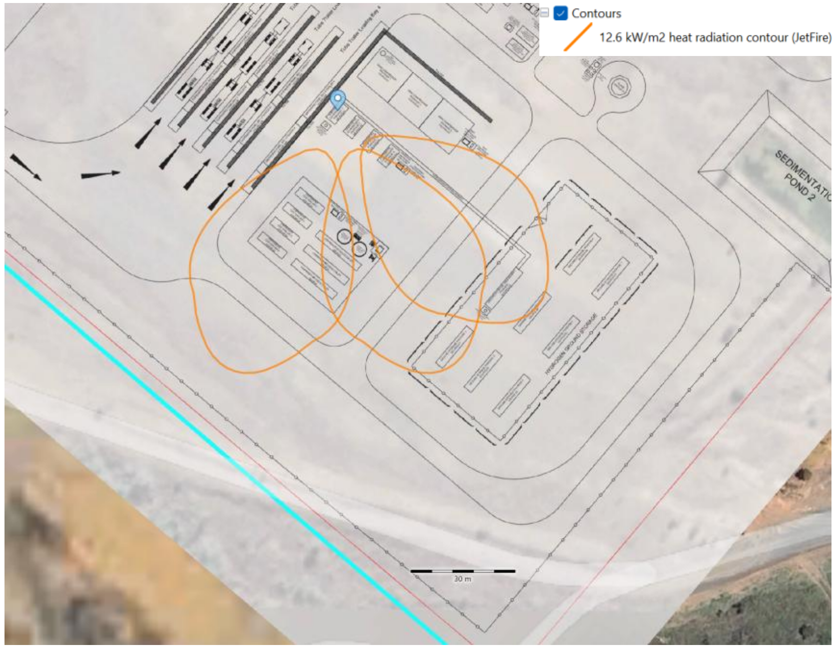
4.2.10 Release from dispensing compression inlet

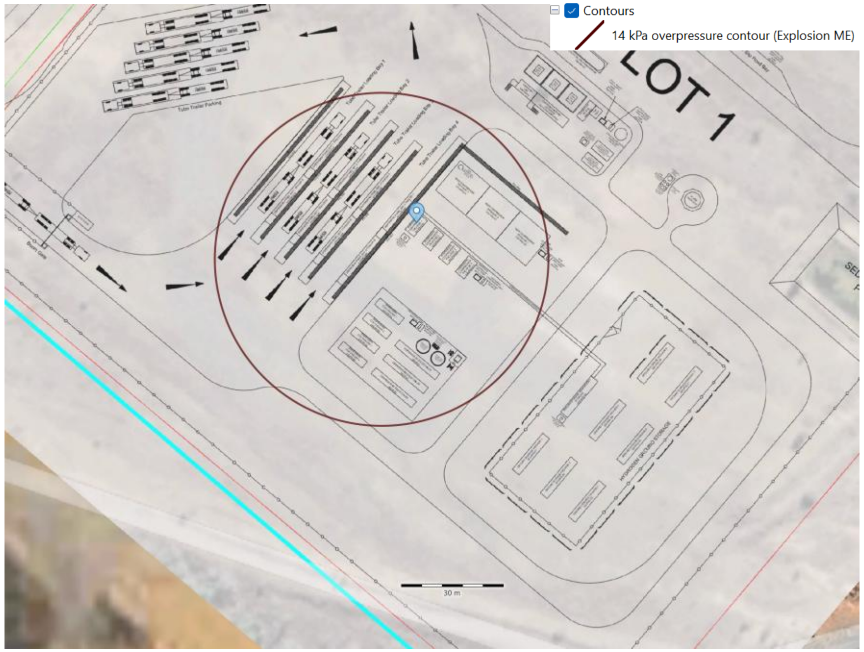
Figure 4-10 ISOL6_DCI - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

<table>
<tr><th colspan="2">ISOL6_DCI - Dispensing compression inlet</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Fire wall at dispensing compression area is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within the Site Boundary.</td><td>Potential for congested gas accumulation and confined vapour cloud explosion at various locations around the dispensing compression area. Conservatively assessed as worst-case overpressure scenario (TNO MEM blast strength 10 and 100% of cloud involved in explosion) as dimensions of equipment at each area are as yet unknown. Overpressure contour stays within Site Boundary (when modelled towards the closest Site Boundary).</td></tr>
</table>

4.2.11 Release from dispensing compression outlet

Figure 4-11 ISOL7_DCO - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

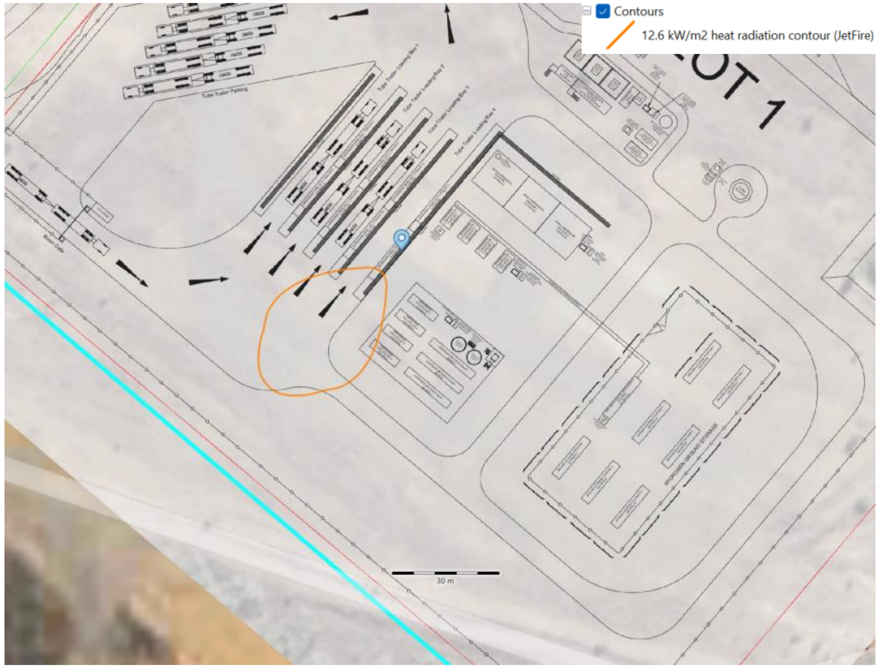
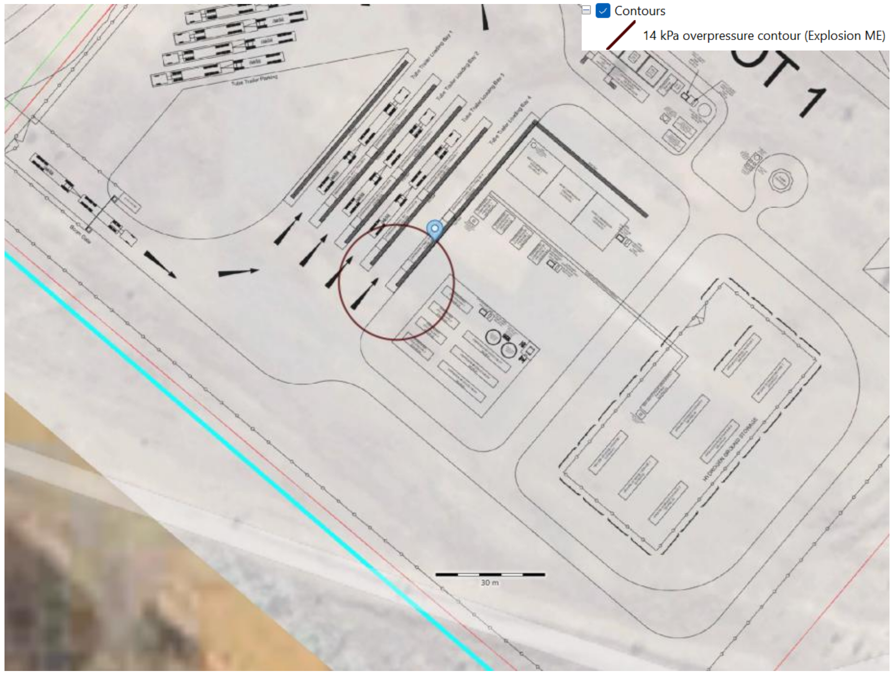
<table>
<tr><th colspan="2">ISOL7_DCO - Dispensing compression outlet</th></tr>
<tr><td>


</td><td>


</td></tr>
<tr><td>Fire wall at the dispensing compression area is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown for directions away from the fire wall. Heat radiation contour stays within Site Boundary.</td><td>Potential for congested gas accumulation and confined vapour cloud explosion at various locations around the dispensing compression area. Conservatively assessed as worst-case overpressure scenario (TNO MEM blast strength 10 and 100% of cloud involved in explosion) as dimensions of equipment at each area are as yet unknown. Overpressure contour stays within the Site Boundary (when modelled towards the closest Site Boundary).</td></tr>
</table>

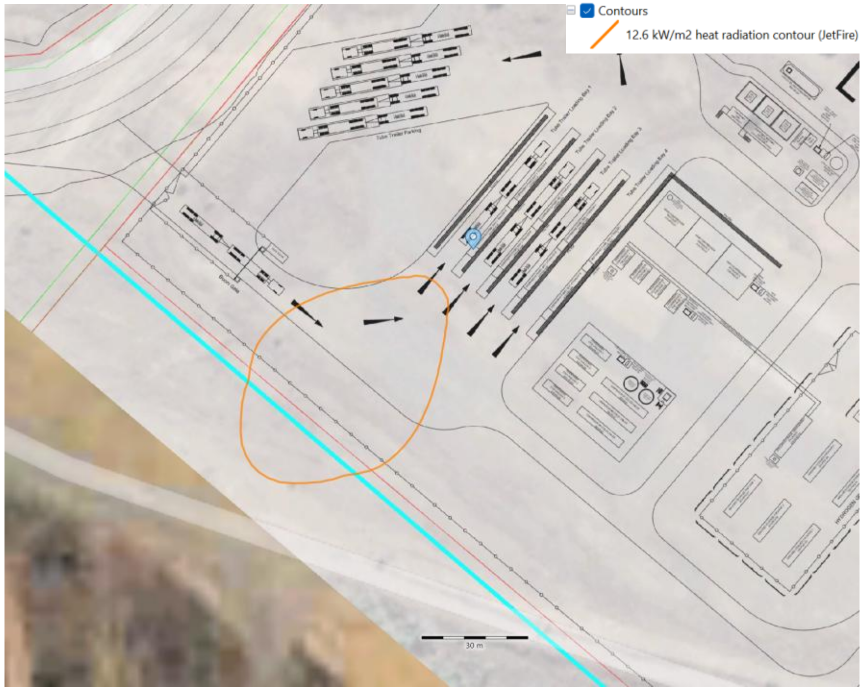
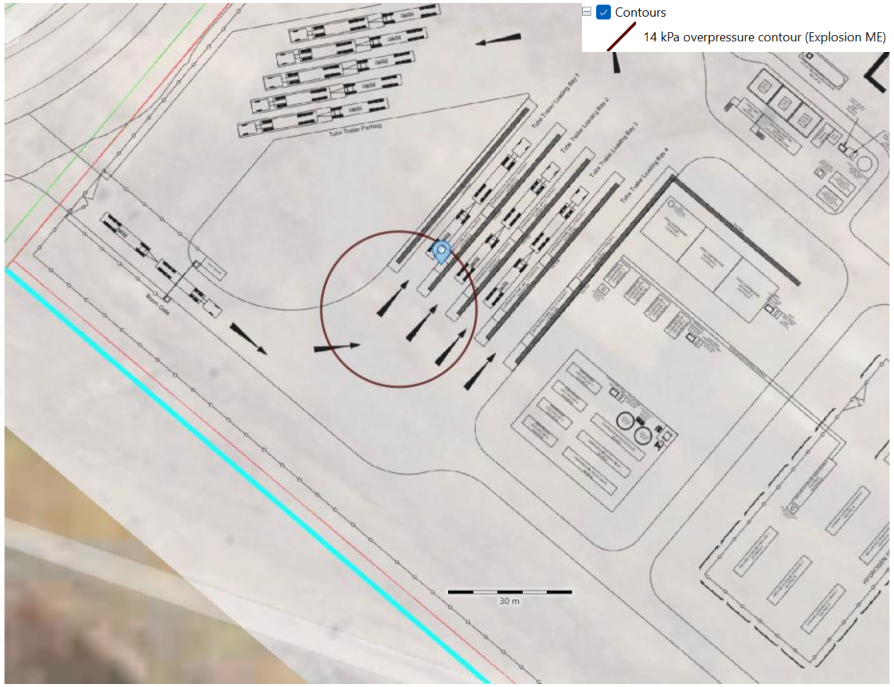
4.2.12 Release from compression to dispensing bay interunit pipework

Figure 4-12 ISOL7-8_PIP - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL7-8_PIP - Dispensing compression to dispensing bay interunit pipework	
	
Fire wall at dispensing bay area is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contours are therefore shown away from the fire wall and towards the closest Site Boundary. Heat radiation contour stays within the Site Boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.

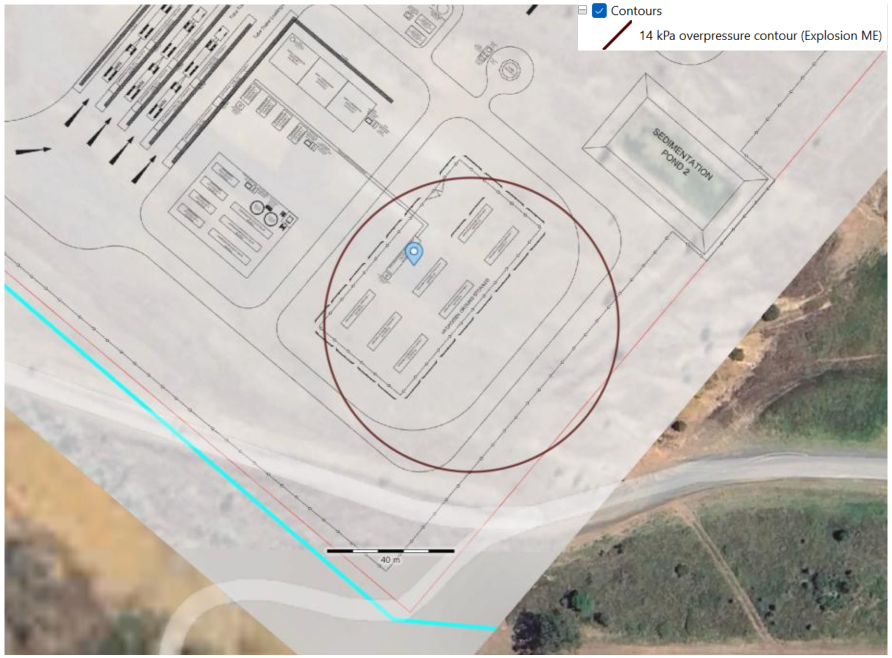
4.2.13 Release from dispensers

Figure 4-13 ISOL8_DIS - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL8_DIS - Dispensers	
	
Fire wall at the dispensers is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contour is therefore shown away from fire wall and towards closest Site Boundary. Heat radiation contour exceeds the southwestern boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour stays within the Site Boundary.

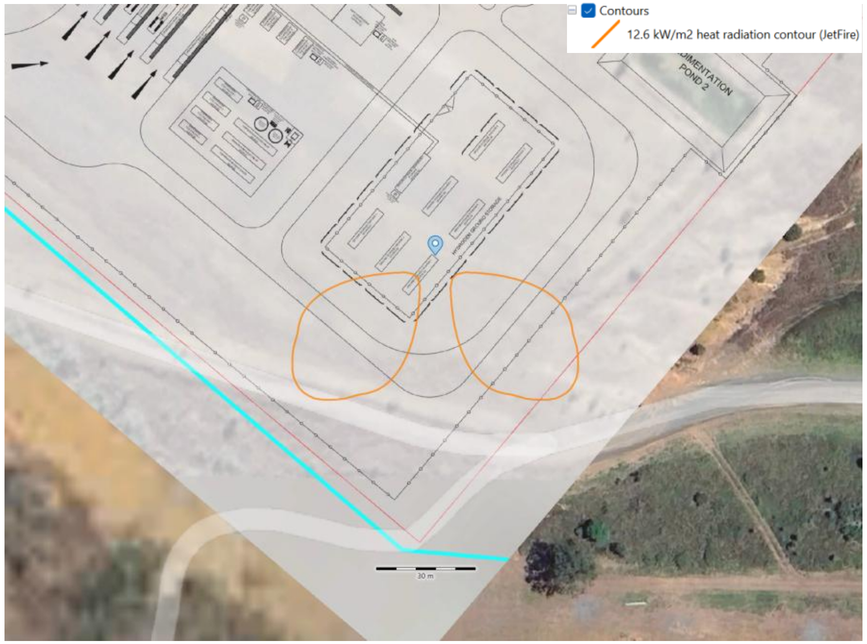
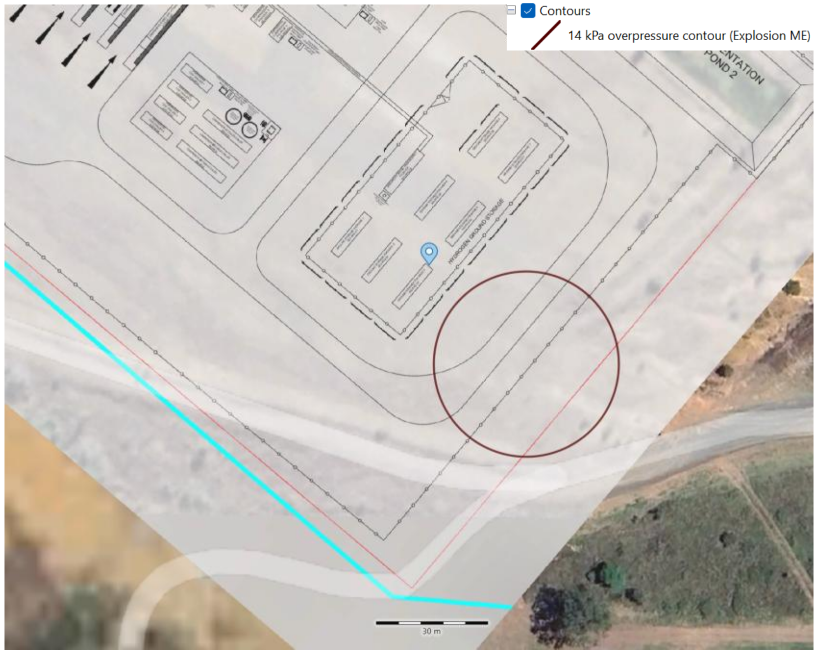
4.2.14 Release from storage management to storage pipework

Figure 4-14 ISOL5-9_PIP - 12.6 kW/m[2] Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL5-9_PIP - Storage management to hydrogen storage interunit pipework	
	
Heat radiation contour shown as directed towards the Site Boundary. Heat radiation contour stays within the Site Boundary.	Potential for gas accumulation at the hydrogen storage packages. Assessed as TNO MEM blast strength 10 and 76% of cloud involved in explosion as per VBR dimensions at hydrogen storage package area (refer to Appendix 1, assumption no. 11). Overpressure contour exceeds the southeastern boundary (when modelled towards the closest Site Boundary).

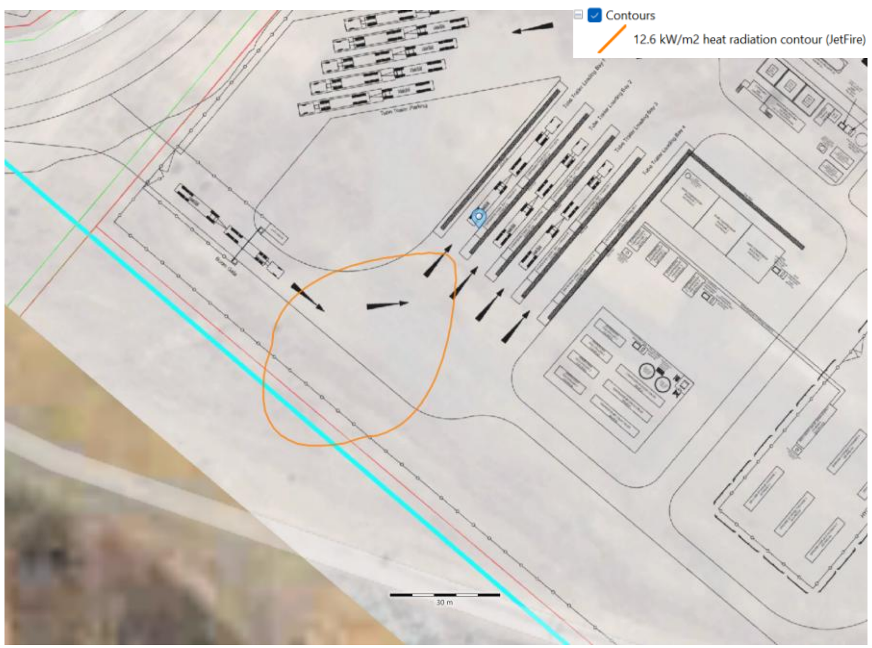
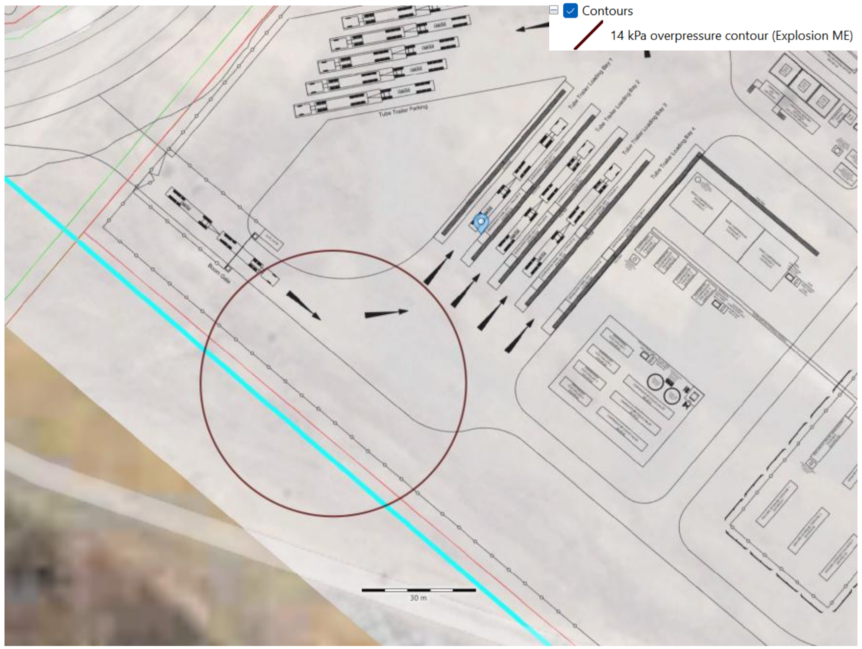
4.2.15 Release from hydrogen storage

Figure 4-15 ISOL9_STO - 12.6 kW/m² Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL9_STO - Hydrogen Storage	
	
Heat radiation contours shown towards Site Boundary. Heat radiation contour exceeds the southeastern boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour exceeds southeastern boundary (when modelled towards the closest Site Boundary).

4.2.16 Release from tube trailer inc. loading hose

Figure 4-16 ISOL10_TUB - 12.6 kW/m^2 Heat Radiation Contour (Jet Fire) & 14 kPa Overpressure Contour (Explosion)

ISOL10_TUB - Hydrogen tube trailer inc. loading hose	
	
Fire wall at the tube trailer and loading hose is assumed to be designed such that it is 100% effective at deflecting and/or absorbing heat radiation. Heat radiation contour is therefore shown away from fire wall and directed towards the closest Site Boundary only. Heat radiation contour exceeds the southwestern boundary.	Low congested gas accumulation and deflagration (TNO MEM blast strength 5). Overpressure contour exceeds the southwestern boundary (when modelled as directed towards the closest Site Boundary).

4.2.17 Consequence results summary

The results of the consequence assessment is provided in Appendix 2. The worst-case results of the Effects® modelling are detailed in Table 8. The dimensions are shown as measured downwind from the centre of the flammable cloud or the source of the jet fire.

Very stable Pasquil Stability Class (**F** with wind speeds of 0.5 metres/second) has been selected to represent the worst-case meteorological conditions. In each release case, the pre-defined wind direction is selected to direct the release to the closest Site Boundary.

The representative scenarios involve a full bore rupture release of pressurised hydrogen. The release is modelled as a loss of containment with isolation valves failing to close, resulting in release rates proportional to the pressure and the hole size.

Table 8: Distance to Dangerous Dose to the built environment for representative scenarios

Release scenario	Dangerous dose to built environment	Distance to dangerous dose, measured radially from the centre of flammable cloud or the source of the jet fire (m)	
		F0.5 with wind directed towards the closest Site Boundary	
		Worst case fire	Worst case deflagration /detonation
Electrolyser skid	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	41	65 (detonation)
Electrolyser to purification interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	46	57 (deflagration)
Hydrogen gas purifier	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	55	92 (detonation)
Purification to compression interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	43	60 (deflagration)
Compression inlet	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	72	111 (detonation)
Compression outlet	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	72	70 (detonation)
Compression to storage management package interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	47	45 (deflagration)
Storage management package	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	61	68 (detonation)

Release scenario	Dangerous dose to built environment	Distance to dangerous dose, measured radially from the centre of flammable cloud or the source of the jet fire (m)	
		F0.5 with wind directed towards the closest Site Boundary	
		Worst case fire	Worst case deflagration /detonation
Storage management to dispensing compression interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	49	44 (deflagration)
Dispensing compression inlet	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	70	71 (detonation)
Dispensing compression outlet	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	80	63 (detonation)
Dispensing compression to dispensing bay interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	53	31 (deflagration)
Dispensers	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	87	33 (deflagration)
Storage management to hydrogen storage interunit pipework	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	47	71 (detonation)
Hydrogen storage	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	57	62 (deflagration)
Tube trailer inc. loading hose	Radiant heat: 12.6kW/m^2 Overpressure: 14kPa	77	89 (deflagration)

Analysis of consequence distances shows that the dangerous dose to the built environment from worst-case a fire, deflagration or detonation associated with a loss of containment of hydrogen remains on site with the exception of the following two (2) worst-case release scenarios at the:

- Compression inlet, dispensers and tube trailer loading impacting the southwestern boundary of the site
- Storage Management Package to Hydrogen Storage Interunit Pipework and hydrogen storage impacting the southeastern boundary of the site

Recommendation: Review the requirements for fire and overpressure protection (e.g. implementation of earth berm) at the southwestern boundary and southeastern boundary of the site. Should an earth berm be installed, ensure a sizing review is completed during detailed design (consider use of CFD modelling when determining the design criteria).

The risk assessment is included in Section 5.

5 RISK ANALYSIS

5.1 INTRODUCTION AND THEORIES

5.1.1 Failure Rates

The standard leak frequencies in the HyRAM database [Ref 4] has been used for all plant and equipment handling hydrogen. The HyRAM database is currently regarded as the most relevant and up-to-date source of incident statistics for hydrogen plant and equipment.

The following methods are used in the likelihood assessment:

- The parts count of major equipment, piping/fittings is derived using a count of the number of components for each identified failure case within an isolatable inventory. This is completed by taking the component count based on piping and instrument diagrams available at the FEED-stage and multiplying by the release frequencies as defined in Table 9 below. A 20% contingency margin is then added to the calculated release frequencies to allow for changes during the design process.
- All vessels, process equipment and piping are assumed to be fully welded with the exception of high-pressure piping (operating at above 400barg) which consist of tubing with a cone and thread connection at every 6m length of pipling
- Process piping lengths are conservative engineering best-estimates at the FEED-design stage, as provided by UGL or the vendor.

Table 9: Equipment failures and associated frequencies – hydrogen (HyRAM, Sandia) [Ref 4]

Component	unit	Very Small	Minor	Medium	Major	Rupture
Compressor	Per compressor-year	1.00E-01	1.90E-02	6.40E-03	2.00E-04	3.00E-05
Vessel	Per vessel-year	1.80E-06	1.50E-06	9.60E-07	5.40E-07	2.80E-07
Filter	Per filter-year	2.20E-02	1.20E-02	1.10E-02	6.10E-03	6.10E-03
Flange	Per flange-year	6.10E-02	4.20E-03	2.00E-03	3.50E-05	1.20E-05
Hose	Per hose-year	6.20E-04	2.40E-04	2.00E-04	1.80E-04	1.00E-04
Joint	Per joint-year	3.60E-05	6.90E-06	9.10E-06	9.10E-06	8.00E-06
Pipe	Per m of piping-year	1.00E-05	4.70E-06	2.10E-06	9.40E-07	8.10E-07

Component	unit	Very Small	Minor	Medium	Major	Rupture
Valve	Per valve-year	3.00E-03	6.40E-04	1.00E-04	3.00E-05	1.20E-05
Instrument	Per instrument-year	8.00E-04	2.80E-04	1.70E-04	1.80E-04	1.10E-04

5.1.2 Likelihood and risk reduction factors

The risk reduction factors applied in the likelihood assessment are presented in Table 10 below.

Table 10: Risk reduction factors

Mitigation measure	Reduction factor	Used in the QRA
Automated plant trip and shutdown via automatic closure of isolation valves on process upset detection within system (e.g. due to a rupture or major leak causing a major loss of pressure)	0.05	Safety system assumed as minimum Safety Integrity Level 1 (SIL1) with a probability of failure on demand (PFD) of 0.05. Assumed to activate for rupture and major leak scenarios only, and not to activate for very small, minor and medium size release scenarios.
Automated plant trip and shutdown via automatic closure of isolation valves on gas leak detection or fire detection	0.05	Safety system assumed as minimum SIL1 with PFD of 0.05. Includes pressure blowdown (where relevant) upon activation.
Automated plant trip and shutdown via automatic closure of isolation valves on gas (LEL) detection.	0.05	Safety system assumed as minimum SIL1 with PFD of 0.05. Applied to delayed ignition scenarios only in the QRA for the applicable isolatable sections.
Automatic opening of blowdown valves upon emergency shutdown to relieve the gas inventory between the isolatable section to the flare header	-	A total time from initiation of blowdown valve opening to full valve opening is taken as 220 milliseconds[6] and set as the maximum release duration when assessing the isolated cases for the QRA.

Recommendation: Review the design of the safety instrumented systems during the detailed design phase using a Layer Of Protection Analysis (LOPA) methodology to ensure the required SIL

[6] *A. Veser, A. Friedrich, M. Kuznetsov, T. Jordan, N. Kotchourko, "Hydrogen Blowdown Release Experiments at Different Temperatures in the DISCHA-Facility", 9th International Conference on Hydrogen Safety (ICHS), Edinburgh, UK, 21–23 September 2021.*

rating is achieved (inc. meeting the SIL requirements e.g. probability of failure on demand of the safety instrumented function).

The detection and protection measures integrated into the plant design are detailed in Table 11 below.

Table 11: Detection and protection measures

Isolatable section	Gas (LEL) detection (Y/N)	Gas leak detection (Y/N)	Flame detection (Y/N)	Process upset detection within system (Y/N)	Isolation on confirmed (Y/N)	Blowdown on confirmed detection (Y/N)
Electrolyser Skid	Y	Y	Y	Y	Y	Y
Electrolyser to purification interunit pipework	N	Y	Y	Y	Y	Y
Gas Purifier	N	Y	Y	Y	Y	Y
Purification to compression interunit pipework	N	Y	Y	Y	Y	Y
Compression inlet	N	Y	Y	Y	Y	Y
Compression outlet	N	Y	Y	Y	Y	Y
Compression to storage management interunit pipework	N	Y	Y	Y	Y	Y
Storage management Package	N	Y	Y	Y	Y	Y
Storage management to dispensing compression interunit pipework	N	Y	Y	Y	Y	Y
Dispensing compression inlet	N	Y	Y	Y	Y	Y
Dispensing compression outlet	N	Y	Y	Y	Y	Y
Dispensing compression to dispensing bay interunit pipework	N	Y	Y	Y	Y	Y
Dispensers	N	Y	Y	Y	Y	Y
Storage management to storage pipework	N	Y	Y	Y	Y	Y
Storage	Y	Y	Y	Y	Y	Y
Tube trailer inc. loading hose	Y	Y	Y	Y	Y	Y

5.1.3 Risk assessment

For individual risk of fatality calculations, the output gives risk or frequency values at each grid point within the area defined using the grid increment defined at the start of the run.

The results of the risk calculations are presented as follows:

- *Individual fatality risk*: the likelihood of fatality to notional individuals at locations around the site, as a result of the defined fire/explosion scenarios. This is shown as contours on a map of the area. The units for individual risk are probability (of fatality) per million per year. By convention it is assumed that people are located outdoors, are always present and take no evasive action if an incident occurs. The results are presented cumulatively for all fire/explosion.

Two release cases are analysed in *Riskcurves®* and provided as a cumulative risk:

- *Isolated release*, i.e. controls work as intended and shutoff valves close on detection of a loss of containment or fire event. In this case, the amount of hazardous gas released is equal to the inventory between two shutoff valves. If a blowdown valve is fitted then the hazardous gas inventory would be released until full opening of the blowdown valve, whereby the remaining inventory would be vented to the flare header and safely dispersed (see Appendix 1, assumption no. 17 for blowdown opening time).

- *Non-isolated release*, i.e. the controls fail and the shutoff valves do not close as required. In this case, the inventory may be larger and may involve other upstream and downstream plant units. The amount of hazardous gas that may be released is determined as that available between mechanical controls (e.g. double dissimilar non return valves), and the "steady-state" scenario is considered. A steady-state is achieved where the release rate or the amount of gas in the vapour cloud would not increase by nominating further inventory. Double dissimilar non-return valves are assumed to be available at the main compression, dispensing compression and hydrogen storage.

The risk calculations were conducted at the FEED-stage of the Project. Significant design changes may impact the QRA results and it is likely that the QRA will need to be updated as per of the detailed design to confirm the findings in this QRA.

Recommendation: This quantitative risk assessment has been developed using the design assumptions for risk reduction at the FEED stage. Key assumptions include:

- Automatic closure of isolation valves on process upset detection within system (e.g. due to a rupture or major leak causing a major loss of pressure)

- Automatic closure of isolation valves on gas (LEL) detection, gas leak detection and/or fire detection

- Double dissimilar non-return valves are provided in the process to prevent backflow of hydrogen in the event of isolation failure (provided as a minimum at the main compression, dispensing compression and hydrogen storage)

- Automatic blowdown valves are provided to relieve the gas inventory between isolatable sections to the flare header.

Other key assumptions are detailed in Appendix 1.

The quantitative risk assessment should be reviewed and risk reduction measures verified as part of the detailed design.

5.2 Results

The results of the likelihood assessment is provided in Appendix 3.

The individual fatality risk contour, associated with the Euroa H_2 Domestic Project, is presented in Figure 5-1. This represents the total individual fatality risk calculated as the cumulative risk from all credible hazardous scenarios defined at the FEED stage of the project.

The 50 x 10^{-6} per year fatality risk contour is contained within the site.

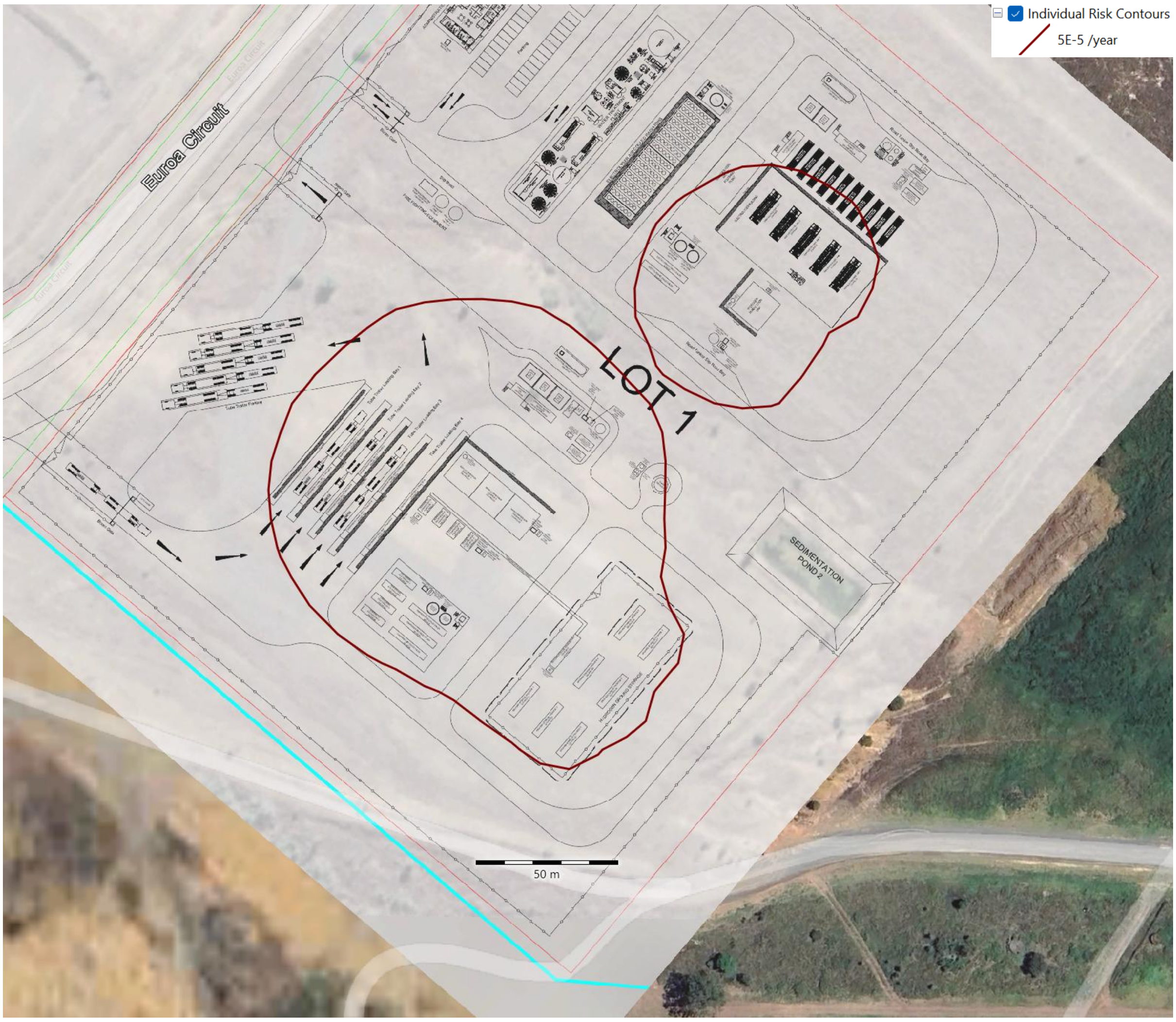


Figure 5-1: Individual risk contour for PO5, of 50 x 10^{-6} per year, for Euroa H_2 Domestic Project

6 MEETING PERFORMANCE OUTCOMES

Hazard identification, hazard analysis and risk analysis are the three primary tools for assessing the suitability of hazardous industry for a site.

The FEED stage QRA demonstrates that the risk from a facility can be designed to be tolerable when considering the surrounding land uses.

Table 12 details the results of the FEED stage QRA against the required performance outcomes as per SDAP2[Ref2]. The results demonstrate that the hazards and risk associated with the Euroa H_2 Domestic Project development can be appropriately and adequately managed without undue risk to human health and to the built environment. Relevant Australian Standards, industry best practice and sound engineering principles are available to develop industrial hydrogen plants and would be used throughout the design process to reduce risk so far as reasonably practicable.

These principles are consistent with the duties under the Work Health and Safety Act 2011. Specifically, section 22 duty for a designer: *the person who designs plant and structures is to ensure, so far as is reasonably practicable, that the plant or structure is designed without risks to health and safety of persons*.

The assessment completed at the FEED stage has identified foreseeable hazard scenarios associated with the development. Where applicable, consequences from the worst case credible hazardous scenarios have been quantitatively modelled ignoring risk reduction measures that would be included throughout the design process. As such, the assessment represents the worst-case situation for the development.

6.1.1 Performance outcomes for off-site impact at neighbouring land use

The performance outcome of the Euroa H_2 Domestic Project development against PO1 to PO5 is summarised below.

Table 12: Euroa H_2 Domestic Project Performance Outcomes PO1 to PO5 compliance

Off-site impact at neighbouring land use	Performance outcomes		Euroa H_2 Domestic Project compliance
	Dangerous dose	Risk assessment	
Vulnerable land use or land zoned for a vulnerable land use (childcare centre; community care centre; educational establishment; health care service; hospital; retirement facility)	PO1, PO2 and PO3: The hazardous chemical facility does not create a dangerous dose to human health with dangerous dose defined as follows: For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m² and/or 7 kPa.	Not applicable	The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any vulnerable, sensitive of commercial land use or land zoned for vulnerable, sensitive of commercial activity.
Sensitive land use or land zoned for a sensitive land use (community residence; dual occupancy; dwelling house; educational establishment; multiple dwelling; relocatable home park; residential care facility; rooming accommodation; short-term accommodation; tourist park)			
Commercial or community activity land use or land zoned for a commercial or community activity land use (shopping centre; shop; office; major sport, recreation and entertainment facility; market; showroom; tourist attraction; entertainment facility; place of worship; community use; theatre)			

Off-site impact at neighbouring land use	Performance outcomes		Euroa H_2 Domestic Project compliance
	Dangerous dose	Risk assessment	
Open space land use or land zoned for an open space land use (Outdoor sport and recreation; Park; environment facility; rural industry)	<u>PO4:</u> The hazardous chemical facility, does not create a dangerous dose to human health <u>with dangerous dose defined as follows:</u> For exposure to heat and/or overpressure from a fire or explosion: 4.7 kW/m^2 and/or 7 kPa	Where the dangerous dose cannot be cannot be eliminated, an individual fatality risk level of 10 x 10^{-6}/year and the societal risk criteria in figure 21.1 of SDAP21	The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any open space land use or land zoned for open space activity.
Industrial land use or land zoned for an industrial land use (an extractive industry; a high impact industry; a low impact industry; a marine industry; a medium impact industry; a research and technology industry; a service industry; a special industry; a warehouse.)	<u>PO5:</u> The hazardous chemical facility, does not create a dangerous dose to the built environment <u>with dangerous dose defined as follows:</u> Exposure to heat and/or overpressure from a fire or explosion: 12.5 kW/m^2 and/or 14 kPa	The hazardous chemical facility, does not create an individual fatality risk level of 50 x 10^{-6}/year	The dangerous dose from foreseeable major incidents at the Euroa H_2 Domestic Project development does not extend into any industrial land use or land zoned for industrial activity, with the exception of a worst-case release at the: • Compression inlet, dispensers and tube trailer loading impacting the southwestern boundary of the site • Storage Management Package to hydrogen storage interunit pipework and hydrogen storage impacting the southeastern boundary of the site This will be addressed with the implementation of earth berms at the southwestern and southeastern boundary of the site (see recommendation 1). The individual fatality risk level of 50 x 10^{-6}/year for the Euroa H_2 Domestic Project development does not extend into any off-site industrial land use or land zoned for industrial activity.

7 Conclusions and Recommendations

7.1 Overall Conclusion

The main hazards associated with the Euroa H_2 Domestic Project are associated with the production, storage and handling of flammable hydrogen gas and this forms the focus of the present study.

Hazards may arise in fixed plant, storage vessels and pipelines. The predominant mode in which a hazardous incident may occur is associated with a loss of containment (leak), where the release would generally only have the potential to cause injury or damage if it were ignited, resulting in a fire or an explosion.

The extent of the incident is determined by the size of the release and/or the rate at which the hazardous material is released.

The safety, efficiency and stability of Project would be achieved through the use of high level safety systems, automated detection and protection systems, and regular preventative maintenance programs.

This FEED stage QRA has found that the levels of hazards and risks from the Euroa H_2 Domestic Project can be managed within general Performance Outcomes defined in SDAP21, provided suitable fire and overpressure protection is implemented at the southwestern and southeastern boundaries of the site.

The potential incidents are understood and the design of the facilities would emphasise minimising the probability of an incident happening and mitigating an incident if it did occur.

7.2 Recommendations

It is recommended that the following safety considerations be included into the design process:

Recommendation 1: Review the requirements for fire and overpressure protection (e.g. implementation of earth berm) at the southwestern boundary and southeastern boundary of the site. Should an earth berm be installed, ensure a sizing review is completed during detailed design (consider use of CFD modelling when determining the design criteria).

Recommendation 2: Review the design of the safety instrumented systems during the detailed design phase using a Layer Of Protection Analysis (LOPA) methodology to ensure the required SIL rating is achieved (inc. meeting the SIL requirements e.g. probability of failure on demand of the safety instrumented function).

Recommendation 3: This quantitative risk assessment has been developed using the design assumptions for risk reduction at the FEED stage. Key assumptions include:

- Automatic closure of isolation valves on process upset detection within system (e.g. due to a rupture or major leak causing a major loss of pressure)
- Automatic closure of isolation valves on gas (LEL) detection, gas leak detection and/or fire detection
- Double dissimilar non-return valves are provided in the process to prevent backflow of hydrogen in the event of isolation failure (provided as a minimum at the main compression, dispensing compression and hydrogen storage)
- Automatic blowdown valves are provided to relieve the gas inventory between isolatable sections to the flare header.

Other key assumptions are detailed in Appendix 1.

The quantitative risk assessment should be reviewed and risk reduction measures verified as part of the detailed design.

8 REFERENCES

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5 Risan A, Pappas J, Dalheim J, *Guidelines for quantitative risk analysis of facilities handling hazardous substances,* Report for The Norwegian Directorate for Civil Protection (DSB), Vysus Norway AS, 19 November 2021

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