CHEMICAL PROCESS SAFETY ENGINEERS

HIGH LEVEL SAFETY HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR THE PROPOSED DEVELOPMENT OF THE HENDRINA GREEN ENERGY FACILITIES, MPUMALANGA

6th October 2022

REPORT:	**SAFETY HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR THE PROPOSED DEVELOPMENT OF THE HENDRINA GREEN ENERGY FACILITIES IN MPUMALANGA**
ASSIGNMENT NO:	J2893M - 1
REPORT DATE:	6th October 2022
RISK ASSESSOR, REPORT: **Telephone:** **Email:**	Debra Mitchell 011 201 4783/5 mitcheld@ishecon.co.za
TECHNICAL SIGNATORY: **Telephone:** **Mobile phone:** **Email:**	Debra Mitchell 011 201 4783/5 082 428 8844 mitchelld@ishecon.co.za
CLIENT:	Enertrag SA (Pty) Ltd
INSTALLATION REPRESENTATIVE: **Phone:** **Email:**	Thirushan Nadar of WSP Africa on behalf of Enertrag SA (Pty) Ltd +27 11 361 1392 / 82 786 7819 Thirushan.Nadar@wsp.com
ADDRESS OF INSTALLATION:	Steve Tshwete Local Municipality of the Nkangala District Municipality
ADDRESS OF COMPANY:	53 Dudley Rd, Parkwood, Johannesburg, 2193

ISHECON cc, H4 Pinelands Office Park, Maxwell Drive, Modderfontein, Box 320 Modderfontein 1645
Tel: (011) 201 4785/83   Fax: (086) 549 0878 Cell: (082) 428-8844
Email: mitchelld@ishecon.co.za
CK 99/29022/23 VAT 4800182422

REPORT ADMINISTRATIVE RECORD

LIST OF ASSESSMENTS

Assessment	Rev. No.	Assessment Date	Description
SHE Risk Assessment	2	6^{th} October 2022	J2893M - 1 – Safety Health and Environmental Risk Assessment for The Proposed Development the Hendrina Green Energy Facilities in Mpumalanga - issued by ISHECON

CONTRIBUTORS

The validity, results and conclusions of this assessment are based on the expertise, skills and information provided by the following contributing team members:

NAME	ORGANISATION	DISCIPLINE
Thirshan Nadar	WSP in Africa	Environmental Assessment Practitioner
Sandhisha JayNarain	ENERTRAG	Snr Project Developer
Gideon Raath	ENERTRAG	Snr Project Developer

DISCLAIMER

Although every effort has been made by ISHECON to obtain the correct information and to carry out an appropriate, independent, impartial and competent study, it remains the responsibility of the Developer to ensure suitable Process Safety Measures are in place. ISHECON cannot be held liable for any accident or incident, due to negligence by the owner/operator, which directly or indirectly relates to the plant, equipment, facilities and systems analysed in this document and which may have an effect on the client or any other third party.

CONFIDENTIALITY

ISHECON will keep all information, results and findings confidential, and will not pass these on to other parties without the permission of the Client. However, ISHECON has legal accreditation obligations toward SANAS and the Chief Inspector of the Department of Employment and Labour, which include monthly notifications to them of completed Risk Assessments, as well as presenting Risk Assessments for auditing purposes on request. These obligations will be complied with under legal confidentiality arrangements with SANAS and Department of Employment and Labour, without notifying the Client. As Approved Inspection Authorities for Department of Employment and Labour, ISHECON is also under legal obligation to the Department of Employment and Labour to report any obvious violations of the OHS Act during site inspections.

RISK ASSESSMENT APPROVAL

This report is approved for issue by the undersigned Technical Signatory as per the ISHECON - Approved Inspection Authority – Appendix 2.1.

NAME	CAPACITY	REPORT DATE	SIGNATURE
D.C. Mitchell	Risk Assessment, Report preparation, Technical signatory	6^{th} October 2022	

EXECUTIVE SUMMARY

Enertrag SA (Pty) Ltd propose to establish a new Green Hydrogen and Ammonia Complex near Hendrinan Mpumalanga. The handling and storage of large quantities of ammonia, hydrogen, oxygen and nitrogen mean that the site has the potential to have major incidents which results in fires, explosions, toxic gas clouds and asphyxiating gas clouds etc. This assessment is a preliminary high level qualitative risk assessment (QRA) of the hazards posed by this type of facility. The facility is to be located approximately 10km west of the town of Hendrina in the Mpumalanga Province of South Africa. Site access is via the R38 which is approximately 3km from the proposed development area and the R542 adjacent the site

The Hendrina Green Hydrogen and Ammonia facilities, with a footprint of 25Ha, will consist of a water electrolysis plant that produces hydrogen and oxygen. There will be an air separation plant to produce nitrogen and oxygen. The hydrogen and nitrogen will then be fed into a Haber-Process to produce anhydrous ammonia. The ammonia will be refrigerated, stored and then despatched to customers. The intermediates of hydrogen, nitrogen and oxygen will also be stored in site.

At this stage there are three possible alternative locations for the Green Hydrogen and Ammonia facilities and these will be briefly evaluated in this assessment.

This risk assessment is conducted as a technical input into the EIA process to comply with the requirement for a high-level safety, health and environmental assessment.

1. METHODOLOGY

This assessment of risk comprises:

- Identification of the likely hazards and hazardous events related to the construction, operation and decommissioning of the installation using a checklist approach.
- Estimation of the likelihood/probability of these hazardous events occurring
- Estimation of the consequences (e.g. extent, magnitude, reversibility) of these hazardous events.
- Estimation of the risk and comparison against certain acceptability criteria.

For the purpose of this high-level risk assessment a general area visit was conducted. A desktop study of the available information, preliminary layouts of the facilities and associated locations, reports of related incidents and various literature sources was undertaken. The facility and the project were divided into the sections/phases and using a checklist approach the hazards in each section/phase were identified. Each identified hazard was then analysed in terms of causes, consequences, expected and suggested preventive and mitigative measures to be in place. Each hazard was qualitatively assessed using a qualitative risk ranking system.

2. FINDINGS

- This assessment has found that, in the event of accidents such as large releases of hydrogen, nitrogen, oxygen or ammonia, the proposed facilities have the potential to impact significantly on both employees and members of the public outside the site. Based on the current design information, worst case hydrogen events may have significant impacts up to 475m from the site and ammonia (stored cryogenically) up to 1.4km from the site. Note that worst case events are extremely unlikely and the chance of them occurring is similar to the average chance of being struck by lightning.

- Therefore, for Location Options 1 and 2 the risk assessment has found that provided suitable preventative and mitigative measures are in place and everything reasonably practicable has been done to reduce the risks both with the design and operation of the facilities, none of the identified potential risks need be intolerably high, i.e., from a SHE perspective no fatal flaws were found with the proposed Hendrina Green Energy Facilities at location 1 and 2.

- At Location Option 3 the closest farmsteads as less than 300m (north) from the site and the closest water course less than 250m (east). As a result of this proximity, this risk assessment suggests that it may be difficult to achieve suitable low risk levels and therefore Location Option 3 is not deemed suitable.

- From a SHE risk assessment point of view, where there is a choice of location that is further from public roads, water courses, isolated farmhouses or existing infrastructure, this would be preferred. The Option 1 alternative location for the Green Hydrogen and Ammonia facility is closer to the tar access road for the area as well as existing farm houses. Location Option 2 location is slightly more isolated and is therefore slightly preferred from a SHE risk perspective.

- Each of the hydrogen, air separation and ammonia plants have the potential to cause major accidents and the entire establishment should be classified as a Major Hazard Installation.

- The hydrogen system, and ammonia under exceptional circumstances, have the potential to lead to fires and explosion which may lead to domino failures of other equipment in close proximity.

3. RECOMMENDATIONS

The following recommendations have been made:

- The entire Green Hydrogen and Ammonia Establishment is an MHI and the necessary risk assessment, notifications, emergency response plans etc. as per the MHI Regulations, should be in place prior to commencement of construction.

- Initiate the Major Hazard Installation Quantitative Risk Assessment as soon as possible in the development process to ensure that risks to the public persons outside the site are as low as reasonably practicable. The MHI QRA can be used to assist with risk based design decisions.

- Note that the MHI regulations are under review and if the new regulations are promulgated before this Green Hydrogen and Ammonia facility is approved under the old regulations, compliance with the new regulation will be required which will entail, amongst other requirements, the obtaining of a license to operate.

- At any large major hazard installation, such as this facility, a full formal Process Safety Management (PSM) system should be implemented and maintained. Such a system should begin to be implemented prior to commencement of the basic engineering design, i.e. certain elements will require specific tasks of the design team.

- One element of PSM is that the design should be subject to a full Hazard and Operability Study (HAZOP) prior to commencement of procurement. A HAZOP is a detailed technical systematic study that looks at the intricacies of the design, the control system, the emergency system etc. and how these may fail under abnormal operating conditions. Additional safeguards may be suggested by the team doing the study.

- The hydrogen systems, and ammonia under exceptional circumstances, have the potential to lead to fires and explosions which may lead to domino failures of other equipment in close proximity, e.g. within 350m. From an overall Hendrina project risk reduction point of view, suitable separation, or other mitigation, should be considered in the design of the site layout, including proximity to other critical infrastructure such as the Battery Energy Storage Systems (BESS) and electrical substations connecting the wind turbines or solar facilities to the National Electricity Grid.

- Critical to the mitigation of any potential major accidents is a detailed, well-practiced Emergency Response plan. Such a plan, compliant with SANS 1514, should be in place and tested prior to commissioning.

- From a SHE risk assessment point of view alternative location Option 3 is deemed unsuitable, while Option 2 is slightly preferred over Option 1.

- The tables in Section 4 of this report contain some technical and system suggestions for managing and reducing risks. Ensure the items listed in these tables under preventative and mitigative measures are included in the design, operation and maintenance of the facilities.

- Despite the fact that worst case impacts may extend a significant distance, there are many technical features that can be considered during the design phase of the project to reduce the risks, e.g. rapid inventory isolation systems, use of higher reliability road tanker loading arms instead of hoses etc. Further risk reduction measures may be suggested by the MHI QRA once more detailed design information is available.

TABLE OF CONTENTS

GLOSSARY OF SOME TERMS POSSIBLY USED IN THIS REPORT

List of units, acronyms and abbreviations used in this report	Definition
BEI	Biological Exposure Index (Refers to values in blood or urine etc as per to OHS Act)
BESS	Battery Energy Storage System
BMS	Battery Management System
dB	Decibels
DEA	Department of Environmental Affairs
EIA	Environmental Impact Assessment
EMPr	Environmental Management Program
ERPG	Emergency Response Planning Guideline (a series of values in ppm or mg/m3 that indicates various levels health effects if exposed to this concentration for more than 60 minutes)
E-stop	Emergency stop button
HAZOP	Hazard and Operability Study
HBA	Hazardous Biological Agents (Refers to pathogens, parasites, cell cultures etc - Refer to OHS Act)
HCS	Hazardous Chemical Substances (Refers to a list of hazardous chemicals - Refer to OHS Act)
HV / MV	High Voltage / Medium Voltage
IDLH	Immediately Dangerous to Life and Health (a value in ppm or mg/m3 that indicates serious health effects if exposed to this concentration for more than 30 minutes)
kW	Kilowatts
kPa	Kilopascal
m	Metres
m^2	Metres squared
m^3	Metres cubed
NEMA	National Environmental Management Act, Act No. 107 of 1998
NFPA	National Fire Protection Agency
NRT Act	National Road Traffic Act, Act 93 of 1996 (Chapter 8 deals with transportation of dangerous goods) Note various SANS standards are incorporated into the regulations.
OEL	Occupational Exposure Limit (usually in ppm or mg/m3 in the air for each HCS as defined in the Hazardous Chemical Substances Regulations of the OHS Act)
OHS Act	Occupational Health and Safety Act, Act 83 of 1993
PV	Photo Voltaic
RA	Risk Assessment
RQ	Reportable Quantity in terms of NEMA to DEA
QC / QA	Quality Control or Quality Assurance
SANS	South African National Standards
SDS	Safety Data Sheet
SHE	Safety Health and Environment
SSLB	Solid State Lithium Batteries
TWA (8 hrs)	Time weighted average of 8 hrs
VRFB	Vanadium redox flow battery
WEF	Wind Energy Facility
WBGT Index	An index in degrees Celsius composed of fractions of the Wet Bulb, Globe and Dry Bulb Temperatures (Refer to Environmental Regulations under the OHS Act)

1. INTRODUCTION

1.1 SCOPE OF ASSESSMENT

Enertrag SA (Pty) Ltd propose to establish a new Green Hydrogen and Ammonia Complex near Hendrinan Mpumalanga. The handling and storage of large quantities of ammonia, hydrogen, oxygen and nitrogen mean that the site has the potential to have major incidents which results in fires, explosions, toxic gas clouds and asphyxiating gas clouds etc. This assessment is a preliminary high level qualitative risk assessment (QRA) of the hazards posed by this type of facility. The facility is to be located approximately 10km west of the town of Hendrina in the Mpumalanga Province of South Africa. Site access is via the R38 which is approximately 3km from the proposed development area and the R542 adjacent the site

The Hendrina Green Hydrogen and Ammonia facilities, with a footprint of 25Ha, will consist of a water electrolysis plant that produces hydrogen and oxygen. There will be an air separation plant to produce nitrogen and oxygen. The hydrogen and nitrogen will then be fed into a Haber-Process to produce anhydrous ammonia. The ammonia will be refrigerated, stored and then despatched to customers. The intermediates of hydrogen, nitrogen and oxygen will also be stored in site.

At this stage there are three possible alternative locations for the Green Hydrogen and Ammonia facilities and these will be briefly evaluated in this assessment.

1.2 EIA REGULATION SCOPE OF APPLICATION

This risk assessment is conducted as a technical input into the EIA process to comply with the requirement for a high-level safety, health and environmental assessment, and it does not necessarily comply with all the requirements of a specialist study as defined in Appendix 6 of the Amended Environmental Impact Assessment Regulations of 2014 under the National Environmental Management Act Nr. 107 of 1998.

Although this assessment is based on the best available information and expertise, ISHECON cc cannot be held liable for any incident that may occur on this installation and associated equipment which directly or indirectly relate to the work in this report.

1.3 RISK ASSESSMENT METHODOLOGY

This risk assessment will consider each technology type separately and in detail. However, considering the general risks posed by each technology, each of the possible locations will be assessed with respect to advising on preferred locations from a SHE perspective.

Risk is made up of two components:

- The probability of a certain hazardous event or incident occurring.
- The severity of the consequences of that hazardous event / incident.

Therefore, this assessment of risk comprises:

- Identification of the likely hazards and hazardous events related to the operation of the installation.
- Estimation of the likelihood/probability of these hazardous events occurring.
- Estimation of the consequences of these hazardous events.
- Estimation of the risk and comparison against certain acceptability criteria.

For the purpose of this high-level risk assessment a general area visit was conducted. A desktop study of the available information, preliminary facility locations, reports of related incidents and various literature sources was undertaken. Based on this information the facility and the project were divided into the following phases:

- construction,
- operation,
- de-commissioning (end of life).

This study makes use of a qualitative risk ranking system framework[1]. The method considers the nature of what causes the effect, what will be affected and how it will be affected.

NATURE OF IMPACT	DEFINITION
Beneficial / Positive	An impact that is considered to represent an improvement on the baseline or introduces a positive change.
Adverse / Negative	An impact that is considered to represent an adverse change from the baseline, or introduces a new undesirable factor.
Direct	Impacts that arise directly from activities that form an integral part of the Project (e.g. new infrastructure).
Indirect	Impacts that arise indirectly from activities not explicitly forming part of the Project (e.g. noise changes due to changes in road or rail traffic resulting from the operation of Project).
Secondary	Secondary or induced impacts caused by a change in the Project environment (e.g. employment opportunities created by the supply chain requirements).
Cumulative	Impacts are those impacts arising from the combination of multiple impacts from existing projects, the Project and/or future projects.

A safety and health risk assessment is focussed on hazards arising from the operation and their impact on humans, either employees or members of the public outside the site. By definition the nature of the chemical and machine hazards is negative, i.e., adverse impact on health and safety. Some of the impacts are immediate and direct such as effects of fires and explosions or exposure to high concentrations of chemicals (in health and safety we refer to these as acute impacts). Other impacts are longer term such as repeated exposure to low concentrations of harmful chemicals, noise etc. (in health and safety we refer to these as chronic impacts).

Using the checklist detailed in Table 1.3.1 the hazards in each section/phase were identified. Each identified hazard was then described by the assessor in terms of causes, consequences, preventive and mitigative measures in place.

Each hazard was qualitatively dimensioned and assessed using the method as per Table 1.3.2. There are five dimensioning criteria in this method:

a) The magnitude of impact on the processes of interest (i.e. human health and safety) e.g. no impact, moderate impact and will alter the operation of the process (e.g. injuries), very high impact and will destroy the process (e.g. fatalities).

b) The physical extent, e.g. will it be limited to the site or not.

c) The duration i.e. how long will the person bear the brunt of the impact.

d) Reversibility: an impact may either reversible or irreversible, e.g. fatalities are permanent, while it may be possible to recover from injuries.

[1] Adapted from a method developed by WSP to meet the combined requirements of international best practice and NEMA, Environmental Assessment Regulations, 2014, as amended (GN No.326) (the "EIA Regulations").

e) The probability of occurrence of the impact.

After dimensioning these aspects, a combined overall risk / significance was calculated for each hazard, See Table 1.3.3.

The impact significance without design controls, preventative and mitigation measures will be assessed. Impacts without mitigation measures in place are not representative of the proposed development's actual extent of impact and are included to facilitate understanding of how and why mitigation measures were identified.

The residual impact is what remains following the application of mitigation and management measures and is thus the final level of impact associated with the development.

Residual impacts also serve as the focus of management and monitoring activities during Project implementation to verify that actual impacts are the same as those predicted in this Report.

There are other specialist assessments being carried out as part of the environmental process, for example assessments in the field of impacts on fauna, terrestrial biodiversity, aquatic biodiversity etc. The focus of this study is on human health and safety with possible impacts from chemicals, fires, explosions etc. and on broad issues of chemical pollution, emissions and waste of resources.

TABLE 1.3.1 SAFETY, HEALTH AND ENVIRONMENTAL RISK ASSESSMENT CHECKLIST

NO	RISKS	DESCRIPTION OF TYPICAL HAZARDS	TYPICAL STANDARD (OHS ACT) OR KEY ISSUES
	HEALTH RISKS		
H1	Chronic Chemical or Biological Toxic Exposure	Continuous releases of toxic materials (Chemical or biological) Long term exposure to low concentrations Unsanitary or unhygienic conditions Diseases Harmful animals/insects	Do not exceed Occupational Exposure Limits and Biological Exposure Indices (OEL's, BEI's – OHS Act HCS an HBA Regulations) for continuous work time exposure to hazardous chemical substances and materials. Awareness of Hazardous biological agents (HBA).
H2	Noise	Continuous and peak exposure to high levels of noise	Continuous noise not to exceed 85dB at workstation (OHS Act Noise-Induced Hearing Loss Regulations) and 61dB at boundary of the site.
H3	Environmental	High temperatures in work areas Low temperatures in work areas High humidity in work areas	Wet bulk temperature (WBGT) index above 30 in summer and/or very cold less than 6 deg C in winter (OHS Act Environmental Regulations for Workplaces)
H4	Psychological	Inherently dangerous tasks Monotonous tasks High production pressure	
H5	Ergonomics	Bad ergonomic design, chronic or acute impact Vibration, repetitive impact	Maximum weight to lift 20 – 25kg
	SAFETY RISKS		
S1	Fire	Internal and external fire Small fire Large fires	Upper and lower flammability limits for materials. 12.5 kW/m2 for 1-minute leads to 1% fatalities. 37.5 kW/m2 leads to >90% fatalities and probable structural failure.
S2	Explosion	Internal explosions inside equipment Confined explosion inside structures Unconfined explosions outside	7 kPa overpressure leads to minor structural damage. 70 kPa leads to 90 % fatalities and probable structural failure.
S3	Acute Chemical or Biological Toxic Exposure	Large releases of toxic gases Exposure to high concentrations of harmful materials Asphyxiation inside a vessel Exposure to corrosive materials, burns	Immediately Dangerous to Life and Health values (IDLH) and Emergency Response Planning Guidelines (ERPG's) for all materials. Minimum oxygen levels.

NO	RISKS	DESCRIPTION OF TYPICAL HAZARDS	TYPICAL STANDARD (OHS ACT) OR KEY ISSUES
		Ingestion of poisonous materials	Low or high pH.
S4	Acute physical Impact or violent release of energy	Slips and trips Working at heights Moving equipment, objects or personnel	
S5	Generation impact	Electrocution Radiation sources Lasers Static Lightning	
	ENVIRONMENTAL RISKS		
E1	Emissions	Continuous emissions	Exceeding permitted emission levels
E2	Pollution	Unplanned pollution incidents causing immediate damage	Not transporting as per legislation (SANS10228/0229 and Haz. Subs. Act – Road Tanker Regs.) Hazmat requirements Reportable spill quantities NEMA Section 30
E3	Waste of resources	Water Power Other non-renewable resources (minerals) Biodiversity	Exceeding water consumption permits Peak demand requirements
	GENERAL RISKS		
G1	Aesthetics	Tall unsightly structures Glaring glass Odours	
G2	Financial	Risks of litigation Business collapse – recovery after emergency Sustainability	Business continuity Std SANS22301
G3	Security	Theft Hi-jacking Looting	
G4	Emergencies	Emergencies originating off-site (neighbours) Natural disasters	MHI Emergency Response Planning SANS1514
G5	Legal compliance		

TABLE 1.3.2 – SHE QUALITATIVE RISK ASSESSMENT MATRIX

a) The magnitude of impact on human health and safety and environmental pollution, quantified on a scale from 0-5, where a score is assigned.

SCORE	DESCRIPTION
0	small and will have no effect on the environment.
1	minor and will not result in an impact on processes.
2	low and will cause a slight impact on processes.
3	moderate and will result in processes continuing but in a modified way.
4	high (processes are altered to the extent that they temporarily cease).
5	very high and results in complete destruction of patterns and permanent cessation of processes.

b) The physical extent.

SCORE	DESCRIPTION
1	the impact will be limited to the site;
2	the impact will be limited to the local area;
3	the impact will be limited to the region;
4	the impact will be national; or
5	the impact will be international;

c) The duration, wherein it is indicated whether the lifetime of the impact will be:

SCORE	DESCRIPTION
1	of a very short duration (0 to 1 years)
2	of a short duration (2 to 5 years)
3	medium term (5–15 years)
4	long term (> 15 years)
5	permanent

d) Reversibility: An impact is either reversible or irreversible. How long before impacts on receptors cease to be evident.

SCORE	DESCRIPTION
1	The impact is immediately reversible.
3	The impact is reversible within 2 years after the cause or stress is removed; or
5	The activity will lead to an impact that is in all practical terms permanent.

e) The probability of occurrence, which describes the likelihood of the impact actually occurring.

SCORE	DESCRIPTION
1	very improbable (probably will not happen.
2	improbable (some possibility, but low likelihood).
3	probable (distinct possibility).
4	highly probable (most likely).
5	definite (impact will occur regardless of any prevention measures).

TABLE 1.3.3 – CALCULATION AND INTERPRETATION OF RISK / SIGNIFICANCE

The final assessment of the risk, i.e. the significance, of a particular impact is determined through combination of the characteristics described above (refer formula below)

Risk	=	Consequence	x	Likelihood
Significance	=	(Extent + Duration + Reversibility + Magnitude)	x	Probability

The risk (significance) can then be assessed as very low, low, medium, high or very high as follows:

OVERALL SCORE	SIGNIFICANCE RATING (NEGATIVE)	SIGNIFICANCE RATING (POSITIVE)	DESCRIPTION
4-15	Very Low	Very Low	Where the impact in negligible
16-30	Low	Low	Where this impact would not have a direct influence on the decision to develop in the area
31-60	Moderate	Moderate	Where the impact could influence the decision to develop in the area unless it is effectively mitigated
61-80	High	High	Where the impact must have an influence on the decision process to develop in the area
81-100	Very High	Very High	Where the impact would indicat a potentail fatal flaw

2. DESCRIPTIONS

2.1 ORGANISATION, SITE LOCATION AND SURROUNDING AREAS

2.1.1 ORGANIZATION

ENERTRAG South Africa (Pty) Ltd is a subsidiary of ENERTRAG SE, the German-based renewable energy company founded in 1992. ENERTRAG specializes in developing and operating high yield renewable energy projects and has an installed capacity of 760MW and over 500 employees. ENERTRAG is currently responsible for operating and managing 1000+ turbines around the world having projects in Germany, United Kingdom, France, Poland, Bulgaria, Belarus, and now South Africa. In 2011 ENERTRAG opened the world's first hybrid wind to hydrogen powerplant near their headquarters in Dauerthal, northern Germany.

2.1.2 LOCATION AND PHYSICAL ADDRESS

Hendrina Green Hydrogen and Ammonia Complex

Location 1:

Affected properties: Portion 3 of Dunbar 189IS. Steve Tshwete Local Municipality of the Nkangala District Municipality. GPS co-ordinates: $26^0$11'53.75" S $29^0$33'05.89" E

Location 2:

Affected properties: Portion 3 of Dunbar 189IS. & Portion 18 of Farm Weltevreden 193IS. Steve Tshwete Local Municipality of the Nkangala District Municipality. GPS co-ordinates: $26^0$12'15.14" S $29^0$33'39.31" E

Location 3:

Affected properties: Portions 14&5 of Farm Weltevreden 193IS. Steve Tshwete Local Municipality of the Nkangala District Municipality. GPS co-ordinates: $26^0$11'16.83" S $29^0$33'03.51" E

2.1.3 DESCRIPTION OF SITE AND SURROUNDINGS

The maps below show that the Green Hydrogen and Ammonia facilities are planned in relatively isolated locations. Activities in the area consist of farming and coal mining. The closest occupied farmhouse complex is:

- 900m to the west of the Hendrina Location Option 1,
- 1800m to the west of the Hendrina Location Option 2
- 300m northeast of the Hendrina Location Option 3. There are in general many more occupied facilities close to Location Option 3 than to the other options.

Residential areas of concentrated population are all over 10km from the site. The local access road (tar between the R542 in the northeast and the R35 in the southwest) runs 750 away to the west of Hendrina Location Option 1. From these tar access road there will be local gravel access roads to the actual sites

Figure 2.1.1 is a map of South Africa showing the location of the Hendrina Green Energy facilities.
Figure 2.1.2 shows the general area of interest in more detail.
Figure 2.1.3 is the development area showing the worst-case significant impact ranges of the Green Hydrogen and Ammonia Complex in relation of occupied facilities in the area.
Figure 2.1.4 is a typical layout of a green hydrogen and ammonia facility

Figure 2.1.1 - Map showing the location of Hendrina Green Energy facilities within Mpumalanga South Africa.

Figure 2.1.2 - The general area of interest for the facilities

Figure 2.1.3 – Worst case significant impact circles around the Green Hydrogen (Red) and Ammonia (Yellow) facilities - in Relation to the location of Farmhouses (Blue) in the area

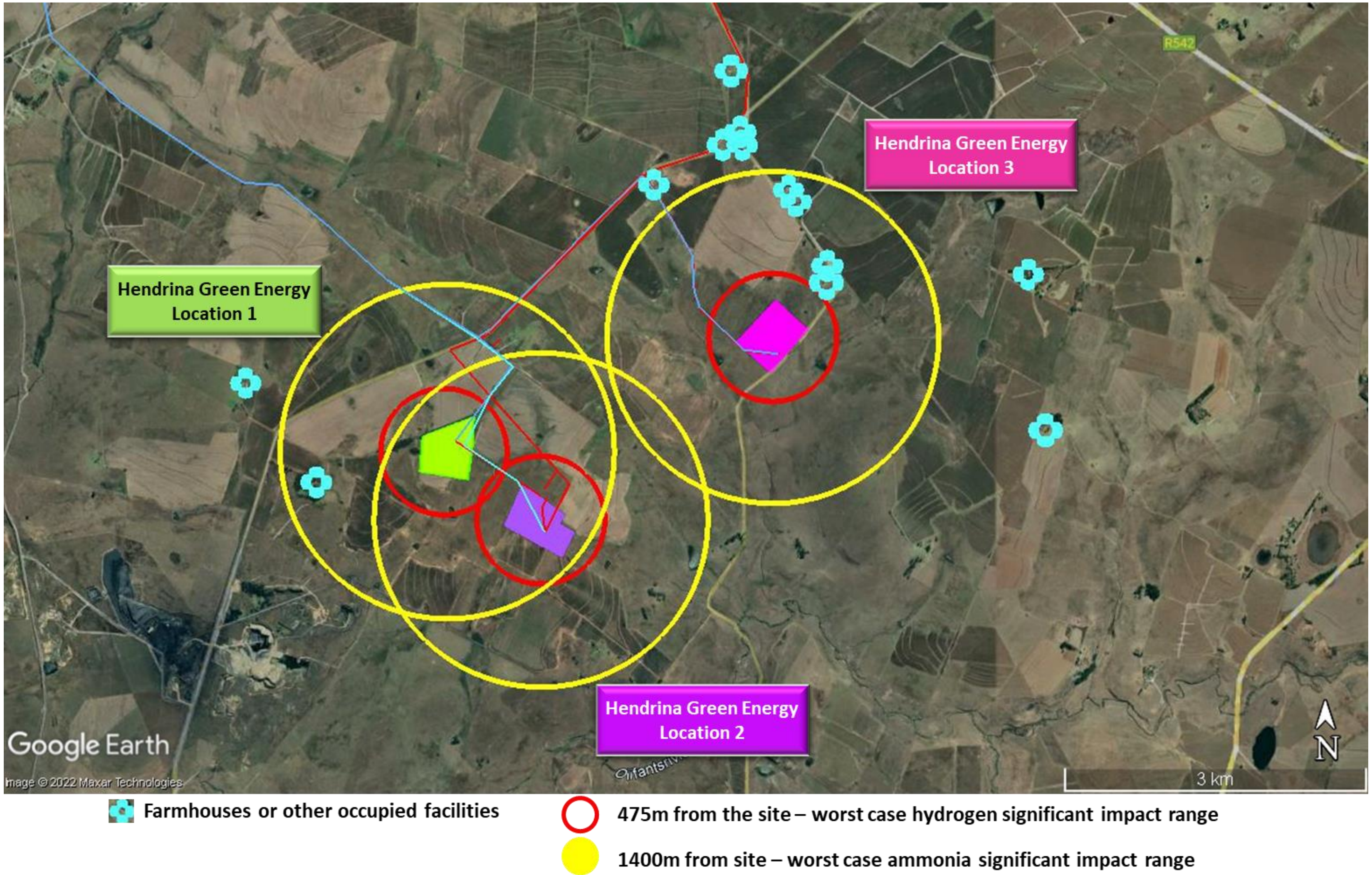
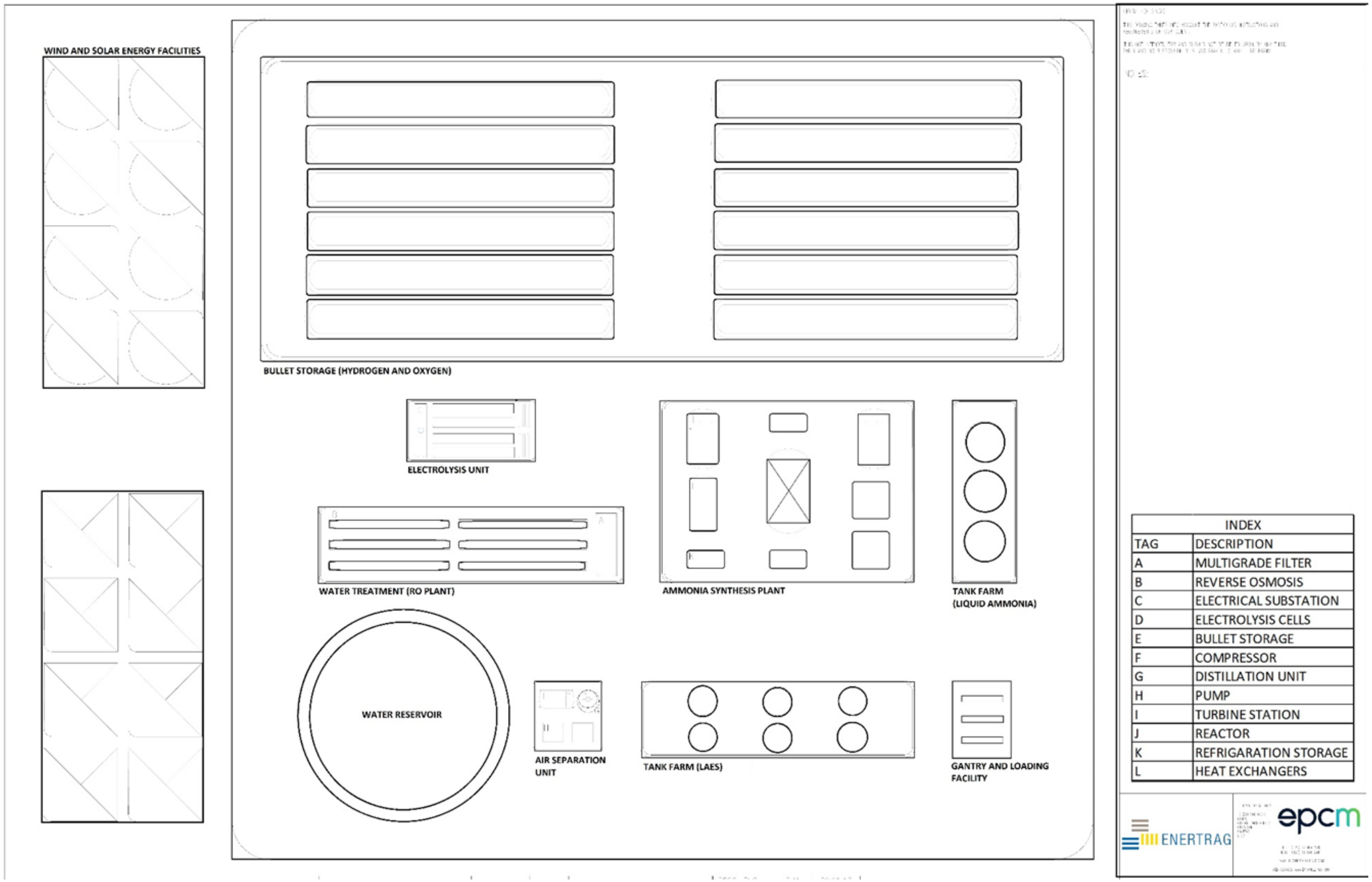


Figure 2.1.4 is a typical layout of the green energy facilities



2.2 TOPOGRAPHY, LAND-USE AND METEOROLOGY

2.2.1 TOPOGRAPHY

Refer to the relevant Environmental Impact Assessment specialist studies for details of flora and fauna as well as water resources in the area. Vegetation in the area is mostly farmlands with some grass and bushes closer to water courses.

The proposed sites are on relatively flat undulating ground. The areas selected for the facilities are flatter sections within the greater areas.

The area experiences heavy thunderstorms. There are no major rivers located close to the site. However, there are numerous small water courses in the area, generally draining towards the northwest into the Olifants River basin. All the proposed sites are over 200m from the closest tributaries.

Figure 2.2.1 Photos of the general area of the sites (close to location Option 1)

2.2.2 LAND-USE

Refer to the relevant Environmental Impact Assessment specialist studies for details of the agricultural activities and cultural aspects in the area.

The area is used intensely for agricultural activity. The closest occupied farmhouse complex is:

- 900m to the west of the Hendrina Location Option 1,
- 1800m to the west of the Hendrina Location Option 2
- 300m northeast of the Hendrina Location Option 3. There are in general many more occupied facilities close to Location Option 3 than to the other options.

Residential areas of concentrated population are all over 10km from the site.

There is active coal mining activity over 2km to the south location Options 1& 2.

The Green Hydrogen and Ammonia facilities will not use large amounts of land typically 25ha per site. The area is used intensely for agricultural activity.

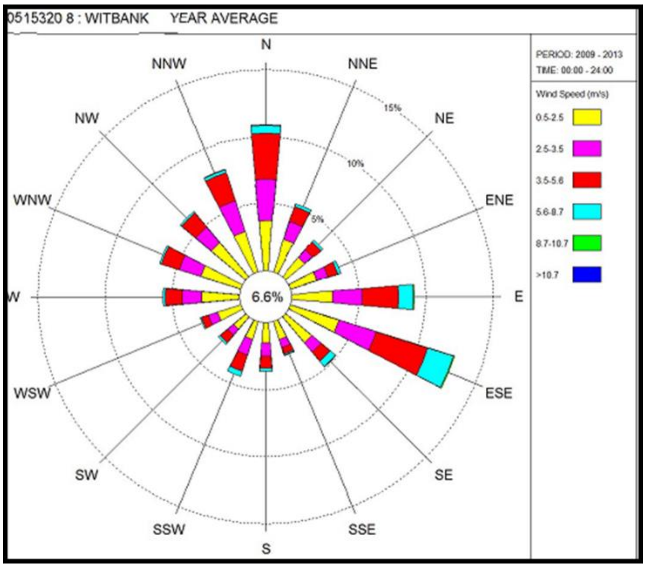
Across South Africa seismic activity is conceivable with Gauteng (man-made activity) the Western Cape (natural activity) being relatively higher risk areas. However, compared with aspects such as corrosion, human error etc. seismic activity is not usually a highly likely risk factor, refer to SANS 10160:2011, part 4. [Ref 24]. The proposed area is a low seismic area and civil / structural design of the facilities would not normally need to take major additional seismic protection into account.

2.2.3 METEOROLOGY

The site has typical highveld weather. Refer to the wind rose below in Figure 2.2.2 which is typical of the eastern highveld area (SA Weather Services). The dominant wind directions in the area blows from the north or from the southeast across the site towards the open land to the south or northwest.

Across South Africa, lightning strikes are conceivable as a source of ignition of major hazards, refer to SANS10313:2012 lightning strike density table. The lightning ground flash density (ground strike rate) in Ermelo (12.8 Flashes/km2/year) in very high. Nevertheless, ignition from on-plant sources is much more likely than lightning but lightning cannot be ignored as a source of risk particularly for tall structures in wide open flat areas.

Figure 2.2.1 Wind rose indicating the typical wind conditions for the Eastern Highveld area



2.3 PLANT AND PROCESSES

2.3.1 ORIGIN, MANUFACTURE, INSTALLATION, ERECTION AND DATE

Electrolysis to produce hydrogen is not a new technology, although is generally not used on a large commercial scale as production of hydrogen from methane is cheaper. The pressurized storage of hydrogen is common technology. The cryogenic cooling of air and separation into oxygen, nitrogen and argon is a process that has been commercially operational for many years at various locations around the world.

Similarly, the Haber-Bosch process used to produce ammonia from hydrogen and nitrogen has been commercially available for over a century.

The combination these three technologies, hydrogen electrolysis, LAES and Haber-Bosch, into a new arrangement in order to store and transport energy is however a relatively new concept. There have been a few demonstration plants built around the world. At this stage of the project development only the basic elements of the design are known, e.g. production rate, total storage capacities, possible range of operating pressures and temperatures etc. Details of the plant design, as would typically appear on piping and instrumentation diagrams, such as process conditions, control systems, emergency shutdown systems, and pipeline sizes are not yet available.

2.3.2 PLANT AND PROCESS DESCRIPTION

The Hendrina Hydrogen and Ammonia facilities are to be established for the sole purpose of developing, owning and operating a proposed 150MW electrolyser hydrogen production facility and green ammonia production facility, respectively. The project aims to produce up to 100 000 tons per annum (tpa) of green ammonia (NH3) synthesised from up to 20 000 tpa of green hydrogen. There could be up to 165 000 tpa of green oxygen, which may then either be resold in various forms.

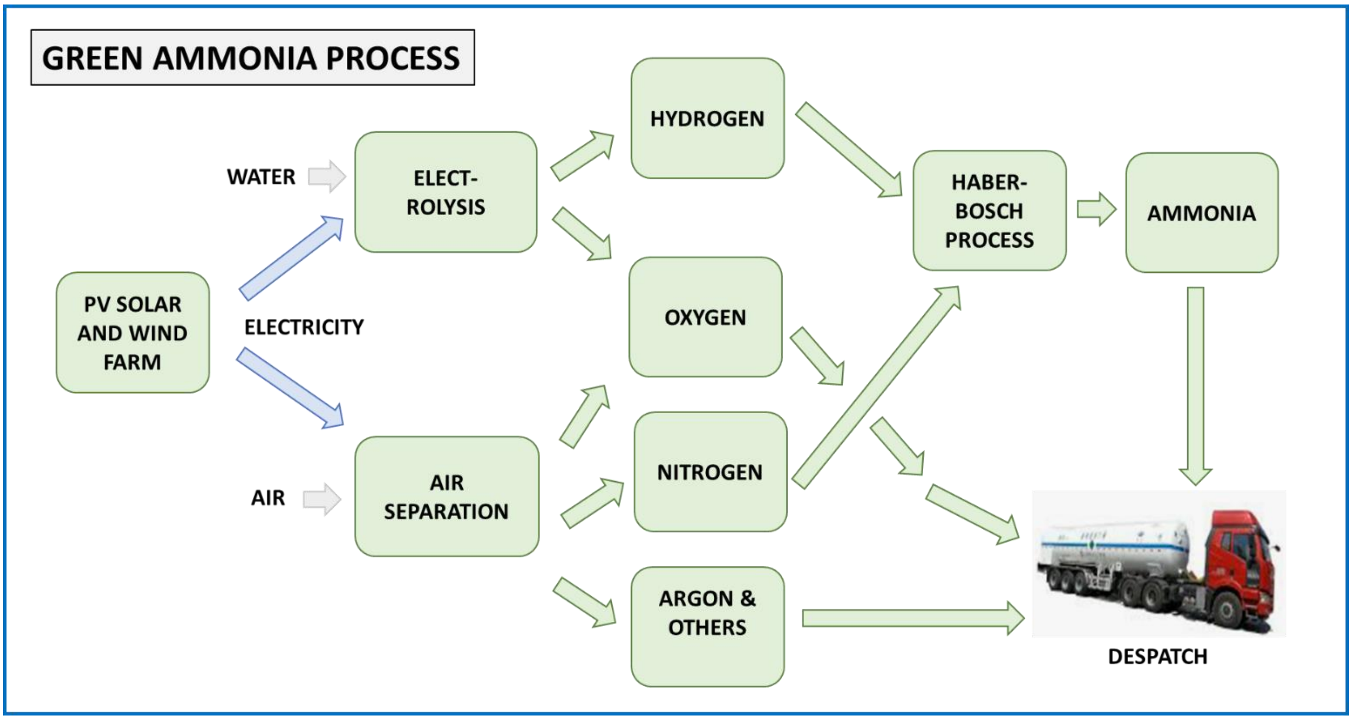
“Green” hydrogen and ammonia production differs from traditional production technologies in that the process relies exclusively on renewable resources (renewable energy) and for input air and water (feedstock), to produce commercially usable green hydrogen. The only major solid/liquid waste stream is the production of brine from the water treatment plant. Gaseous oxygen is generated as a by-product from the electrolyses process and maybe vented if it cannot be reused.

Ammonia is used as a stable ‘carrier’ of hydrogen, allowing hydrogen to be readily stored and transported, for further use as fuel and energy source.

The infrastructure required for the Hendrina Hydrogen and Ammonia facilities include the following:

- Water treatment unit and water reservoir.
- Electrolyser unit.
- Hydrogen and oxygen storage tank.
- Air separation unit.
- Liquid air energy system (LAES) for nitrogen storage.
- Ammonia processing unit and liquid ammonia storage tanks.
- Utilities, gantry and loading bay.

Figure 2.3.2.1 Simplified block flow diagram



<u>Electrolyser</u>

Water will be piped to the site (possibly from the Komati Power Station) where it will be filtered before being stored for use in the electrolysis plant. There will be a reverse osmosis plant on site to treat water to a suitable standard for use in the brine makeup to the electrolysers. The brine will be circulated into the electrolysis unit where the water molecules will be split into hydrogen and oxygen gases at the anodic and cathodic sides of the unit. The gases will disengage from the brine phase and be extracted from the electrolyser using extraction fans/compressors. Any waste brine will be crystalized and disposed of under suitable license.

<u>Hydrogen</u>

Hydrogen gas will then be compressed to about 200 bar and stored in one of up to 20 horizontal 40-ton storage tanks. The tanks will be specifically designed for hydrogen service and located in a dedicated storage area.

<u>Oxygen</u>

Oxygen gas generated on the other side of the electrolyser can either be vented or compressed and stored or cooled, condensed and stored cryogenically as a liquid.

Air Separation Plant

A standard air separation plant including cold box will be installed. The oxygen from the facility will join the oxygen from the electrolyser plant.

Nitrogen

Nitrogen will be stored cryogenically in one of 2 tanks of approximately 2000 tons each. Nitrogen liquid can be re-vapourized for use in the Haber-Bosch process and as purging gas throughout the plant.

Argon

Argon, present in the air, will be separated out in the air separation plant and at this stage it will be vented back to air.

Haber-Bosch Process

In the Haber-Bosch process nitrogen and hydrogen vapours are mixed in a catalytic reactor under 100 - 200 barg. To favour the production of ammonia, an operating temperature in the range of 350 - 525 °C is recommended. After production cooling and clean-up, the ammonia can be liquefied for ease of storage and safety. For this process it is assumed to be stored at cryogenically in one of three 1523-ton tanks. If the ammonia is stored at ambient conditions of 25°C and 10 bar, or if the cryogenic storage volumes are larger than stated above, then the worst case impact ranges quoted in this report will change.

LPG

There will be a need for hydrogen and ammonia pressure relief valves, hydrogen / ammonia purging etc. and for this purpose a flare may be required. LPG is likely to be needed to ensure a constant pilot flame in the flare.

Gantry and Road Tanker Loading

There will be an area where anhydrous ammonia, possibly nitrogen, oxygen and/or hydrogen may be loaded into various types of road tankers for despatch to customers, or importation for supply shortfall etc. On any site, the human interface is greatest at the gantry area and this area usually presents some of the highest risks. Therefore this facility will need to be state of the art with loading arms, break away couplings, curbing, gas detectors and emergency shut down systems, over fill protection etc.

Other

As part of the facility there will be various support utilities such as, a small sewage treatment plant, maybe a small boiler, workshops, admin buildings, diesel powered generator, diesel for trucks/forklifts electrical infrastructure and a flammable store (e.g. for paints and maybe cylinder) etc.

2.3.3 STAFF AND SHIFT ARRANGEMENT

At this stage the numbers of persons on site are unknown. However, the green ammonia plant is not likely manually intense processes and there are likely to be very few persons on site, mostly during the day for maintenance activities etc. This assessment as assumed a maximum of 100 persons on the entire facility during the day and 20 at night. If the project is constructed in phases, it is noted that there may be significantly more persons on the site doing construction adjacent operating facilities. This will need to be carefully planned to ensure limited exposure of construction personnel to operating hazards.

2.3.4 OPERATIONS AT THE FACILITY AND PHASES OF THE PROJECT

The Green Hydrogen and Ammonia facilities can be considered to have three main phases:

- Construction including transport to site and storage prior to installation,
- Operation including commissioning, maintenance, shutdown – restart,
- Decommissioning including repurposing and disposal.

The main processes undertaken in each of these stages can be summarized as follows together with some details:

TABLE 2.3.3 – Project Phase with Main Processes/Activities and Some Details of Likely Elements

No	PHASE	MAIN PROCESSES	DETAILS
1.1	Construction	Construction machines e.g. cranes, graders, cement trucks, diesel and oil storage	Graders to clear ground make roads, diggers for trenches foundations, cement mixers for civil works, cranes to place large items, diesel bowser for fuel for machines, oil for machines
1.2		Materials for the construction of the building and structure Equipment items for installations	Building materials such as bricks, cement, re-bar, I-beams, roof sheeting etc. Equipment such as tanks, pumps, piping etc. Electrical equipment such as transformers, pylons, cabling.
1.3		Waste e.g. packaging materials, paint	Materials and equipment will likely have protective coverings (Plastic, paper, cable ties etc) to remove during installation, paint waste (cans, brushes, solvents), building rubble
1.4		Construction camp	Temporary offices, canteens, ablutions
2.1	Operation	Chemical processes	Tanks, pumps and pipes containing brine, acids & alkalis, ammonia, hydrogen, nitrogen, oxygen.
2.2		Electrolyser processes	Connection equipment, switchgear, transformers
2.3		Product storage and despatch	Tanks, road tanker gantries, batching systems, filling arms
2.4		Support mechanical equipment	Air conditioners, fans, coolant, welding equipment, emergency flare systems
2.5		Control room, Site office and workshop	Computer control systems, Including potable water, 220V power, kitchen, sewage, tools and parts store etc
2.6		Support services	Dirt roads, access control fences, lights inside and outside, lightning protection, fire suppression/fighting systems, grass cutting, communication systems
2.7		Waste	Broken parts, storm water run-off, hot air from cooling systems, regular waste chemicals from water treatment, irregular maintenance or other spills, effluent treatment
3.1	Decommissioning	Liquid chemical waste	Waste chemical solution, transformer oils, coolants
		Solid chemical waste	Spent catalyst, air filters, gaskets, hoses
3.2		Electronic waste	Circuit boards, SCADA screens, computers
3.3		Building rubble - non-hazardous waste	Steel, copper, cement, major steel equipment and structures

3. HAZARD IDENTIFICATION AND ANALYSIS

3.1 MATERIAL HAZARDS

3.1.1 HAZARDOUS MATERIALS ON THE SITE

The bulk materials on the site were categorised according to SANS 10228 classes of dangerous substances, as detailed below in Table 3.1. refer to Appendix B for detailed hazardous properties of these materials, e.g. flammable range, toxicity levels.

Table 3.1: Summary of hazardous material inventories

Material	CAS number (UN number)	SANS10228 [Ref 2] Classification	Annual Through-put tons	Maximum Inventory tons	Maximum Single Storage Unit tons	Physical Form	Main Hazardous Events
Hydrogen	1333-74-0 1049	2.1 Flammable gas	20 000	800	40	Gas	Explosions Flash fires Jet fires
Ammonia	7664-41-7	2.3 Toxic gas	100 000	4 569	1 523	Gas and Cryogenic liquid	Toxic vapour clouds Explosion
Nitrogen	7727-37-9 1066	2.2 Non-flammable gas (Asphyxiant)	80 000	4 100	2 030	Gas and Cryogenic liquid	Asphyxiating vapour clouds
Oxygen	7782-44-7 1072	2.2 Non-flammable gas 5.1 Oxidizer	165 000	800	Vented (50t if stored)	Gas	Flammability enhancing vapour clouds
Miscellaneous packaged chemicals, solvents, LPG for flare, diesel for vehicles, acetylene in workshops etc.	Various	3 Flammable 2.1 Flammable gas	Negligible			Gas / Liquid	Pool fires

3.1.2 ENVIRONMENTAL HAZARDS

Due to the fact that most of the materials generated on this site are actually gases that occur naturally in the atmosphere (except ammonia) no major chemical pollution impact would be expected from catastrophic events.

Anhydrous ammonia is used by some agricultural operations as a fertilizer and may thus have nitrification effects on the vegetation in the area if accidentally released. It should be noted that the cryogenic materials are extremely cold and destruction of vegetation by freezing could be expected within approximately the same range as the adverse effects on humans. In a similar vein, hydrogen flash fires that extend off site will lead to destruction of vegetation and possible secondary veld fires.

As with any site with chemicals and equipment, a fire and the use of large amounts of firewater used in fighting fires on site, which may be severely contaminated and may then flow offsite into watercourses leading to offsite ground and water contamination. This needs to be considered in the on-site emergency plan.

3.1.3 HAZARDOUS MATERIAL INTERACTIONS

On any site where different materials are used, it is conceivable (however unlikely) that at some time certain materials may inadvertently be mixed with other materials. On this site no materials will be arriving in bulk road trucks or other containers. Uncontrolled mixing from offloading is therefore not conceivable. Mixing may happen due to process upsets or incorrect operation of the plant. Uncontrolled mixing of oxygen and hydrogen may lead to fires/explosions etc. Although extremely unlikely, if oxygen, nitrogen or argon are produced as by-products to be sold it may be possible to load products into the incorrect road tankers. Mixing of oxygen and ammonia may lead to a fire and explosion. This scenario is included in the catastrophic rupture scenario for ammonia road tankers.

The products and raw materials as they are normally stored are stable with no particular hazardous breakdown products.

3.2 PAST ACCIDENTS AND INCIDENTS RELEVANT TO MAJOR HAZARDS

3.2.1 SITE

The site will be new, so accidents or incidents have not occurred.

3.2.2 OTHER FACILITIES LOCAL AND INTERNATIONAL

Significant hazardous events have occurred at other similar or related installations around the world or with the MHI type materials that are used on site. Refer to Appendix B for selected accidents and incidents.

3.3 HAZARD ANALYSIS

A bow-tie type analysis was undertaken to identify the failure events, their causes, consequences, as well as the preventative and mitigative measures in place on the installation. A single Bow-Tie diagram has been compiled as shown in Figure 3.3.1 below. The same sequence then follows for typical events and the details are shown in Table 3.3.2

Figure 3.3.1 – Hazard Analysis – Simplified BOW-TIE for toxic vapours from ammonia leak

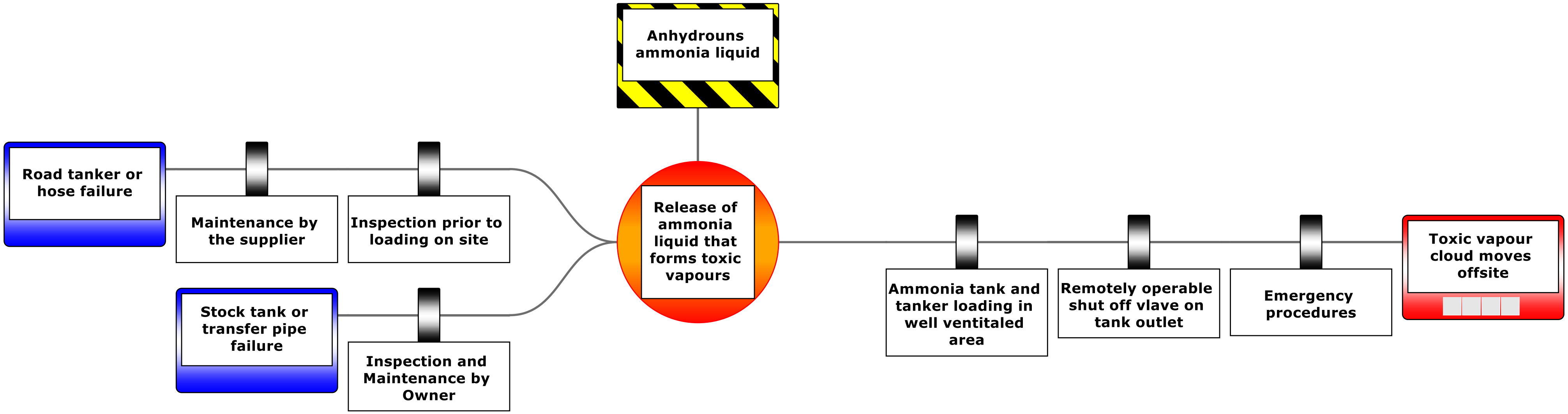


Table 3.3.2 – Hazard Analysis

HENDRINA GREEN ENERGY					
CONTAINMENT SYSTEM	**CAUSES**	**PREVENTATIVE MEASURES IN PLACE**	**HAZARDOUS FAILURE**	**MITIGATION MEASURES**	**OVERALL CONSEQUENCES**
Hydrogen	Wear and tear (Corrosion, hydrogen embrittlement) External fire	Designed to local and international standards in terms of: - materials of construction, - separation distances, - control system integrity, - hazardous area classification, - Process safety management system implemented. Inspected and maintained by owner as per pressurized equipment regulations. Grass / vegetation kept short in the area Well ventilated area Pressure control and relief system in place Specific access-controlled area with the greater sites access control. Major Hazard Installation registration and compliance with all requirements.	H_2 storage tanks Catastrophic rupture Large or small puncture Valve or flange leaking	Emergency procedures Hydrogen storage tanks in separate area	Possible flammable vapour cloud, flash fire, fireball, explosion, jet fire.
	Inadequate maintenance Impact – e.g. traffic collision Human error	Designed to local and international standards as for tanks above etc. Inspected and maintained by owner as per pressurized equipment regulations Operating instructions and training of competent staff Limited traffic on site	H_2 Transfer pipeline / exchangers / pumps / compressors - failure (rupture of leak)	Emergency procedures Detectors that will stop hydrogen production in the event of a hydrogen fire Flash back arrestors as necessary	Possible flammable vapour cloud, flash fire, fireball, explosion, jet fire.

HENDRINA GREEN ENERGY					
CONTAINMENT SYSTEM	**CAUSES**	**PREVENTATIVE MEASURES IN PLACE**	**HAZARDOUS FAILURE**	**MITIGATION MEASURES**	**OVERALL CONSEQUENCES**
	Over pressurize	Pressure and temperature control system with trips and interlocks Pressure relief valves	Pressure burst	Venting to flare	Pressure wave, damage to near-by equipment and possible secondary releases. Injuries / fatalities etc.
Oxygen	Wear and tear (Corrosion) External fire Impact – e.g. traffic collision Human error	Designed to local and international standards in terms of: - materials of construction, - separation distances, - control system integrity, - hazardous area classification, - Process safety management etc. Inspected and maintained by owner as per pressurized equipment regulations. Operating instructions and training of competent staff Grass / vegetation kept short in the area Well ventilated area Pressure control and relief system	O_2 vessels, transfer compressors pipelines etc. Catastrophic rupture Large or small puncture Valve or flange leaking	Emergency procedures Separation from combustible materials	Enhanced flammability of combustible materials, spontaneous ignition.
Nitrogen and Argon	Wear and tear (Corrosion) External fire Over pressure	Will be designed to local and international standards in terms of: - materials of construction, - control system integrity, - Process safety management etc. Inspected and maintained by owner as per pressurized equipment regulations. Grass / vegetation kept short in the area Pressure control and relief system Well ventilated area	N_2 storage tanks Argon storage tanks (if not vented) Catastrophic rupture Large or small puncture Valve or flange leaking	Emergency procedures	Possible asphyxiation

HENDRINA GREEN ENERGY					
CONTAINMENT SYSTEM	**CAUSES**	**PREVENTATIVE MEASURES IN PLACE**	**HAZARDOUS FAILURE**	**MITIGATION MEASURES**	**OVERALL CONSEQUENCES**
	Inadequate maintenance Impact – e.g. traffic collision Human error	Tank Inspected and maintained by owner as per pressurized equipment regulations Operating instructions and training of competent staff Limited traffic on site Pressure control and relief system	N_2 Transfer pipeline / exchangers / pumps / compressors - failure (rupture of leak)	Emergency procedures	Possible asphyxiation
Ammonia	Wear and tear (Corrosion) External fire	Grass / vegetation kept short in the area	NH_3 storage tanks Catastrophic rupture Large or small puncture Valve or flange leaking	Emergency procedures Ammonia storage tanks in separate area Cryogenic storage	Toxic gas release Possible flammable vapour cloud, flash fire, fireball, explosion. Injuries / fatalities etc.
	Inadequate maintenance Impact – e.g. traffic collision Human error	Designed to local and international standards in terms of: - materials of construction, - separation distances, - control system integrity, - hazardous area classification, - Process safety management system implemented. Inspected and maintained by owner as per pressurized equipment regulations. Well ventilated area Pressure control and relief system Specific access-controlled area with the greater sites access control. Major Hazard Installation registration and compliance with all requirements.	NH_3 Transfer pipeline / exchangers / pumps / compressors - failure (rupture of leak)	Emergency procedures Infra-red detectors that will stop hydrogen production in the event of a hydrogen fire Flash back arrestors as necessary	Toxic gas release Possible flammable vapour cloud, flash fire, fireball, explosion. Injuries / fatalities etc.
	Cryogenic system failure Runaway reaction Inadequate reaction – catalyst poisoning	Pressure and temperature control system with trips and interlocks Pressure relief valves	Pressure burst – vessels, reactor	Low pressure storage Venting to flare	Toxic gas release. Possible flammable vapour cloud, flash fire, fireball, explosion, Injuries / fatalities etc.

HENDRINA GREEN ENERGY					
CONTAINMENT SYSTEM	**CAUSES**	**PREVENTATIVE MEASURES IN PLACE**	**HAZARDOUS FAILURE**	**MITIGATION MEASURES**	**OVERALL CONSEQUENCES**
	Cooling failure				
Electrolyser	Inadequate separation of oxygen and hydrogen Shorting	Maintenance of electrolyser Rapid extraction of oxygen and hydrogen from the system using fans	Internal explosion	Separation from bulk storage tanks	Damage, possible injury and fatalities to person in the immediate vicinity
Air separation plant	Accumulation of organic material in the system	Monitoring, purging etc.	Internal explosion	Separation from bulk storage tanks	Damage, possible injury and fatalities to person in the immediate vicinity
Indoor areas	Leaks of hydrogen / ammonia / welding gases accumulate in buildings or congested structures before igniting	Plant area is well ventilated Ventilation on buildings	Confined explosion	Hydrogen ignites extremely easily and does not usually get a chance to accumulate in significant quantities	Damage, possible injury and fatalities to person in the building and the vicinity

Refer to APPENDIX A for worst case plots of some of the above potential accident scenarios for hydrogen and ammonia.

4. RISK ASSESSMENT

An analysis was undertaken to identify the failure events, their causes, consequences, as well as the preventative and mitigative measures in place on the proposed installation for all three phases of a typical project.

4.1 CONSTRUCTION PHASE (Excluding commissioning)

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 1:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Construction materials such as cement, paints, solvents, welding fumes, truck fumes etc. Consequences - Employee / contractor illness.	Construction	Negative	The construction phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993 specifically the Construction Regulations. SHEQ policy in place. A detailed construction risk assessment prior to work. SHE procedure in place. PPE to be specified. SHE appointees in place. Contractor's safety files in place and up to date. All necessary health controls/ practices to be in place, e.g. ventilation of welding and painting areas. SHE monitoring and reporting programs in place. Emergency response plan to be in place prior to beginning construction and to include aspects such as appointment of emergency controller, provision of first aid, first responder contact numbers.	Moderate	3	1	3	4	4	**44**	1	1	3	4	2	**18**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 2:	Human Health - exposure to noise	Causes - Drilling, piling, generators, air compressors. Consequences - Adverse impact on hearing of workers. Possible nuisance factor in near-by areas.	Construction	Negative	Health risk assessment to determine if equipment noise exceeds 85dB at workstation and 61dB at boundary of the site. Employees to be provided with hearing protection if working near equipment that exceeds these noise limits.	Easy	3	1	5	5	4	**56**	2	1	5	5	2	**26**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 3:	Human Health - exposure to temperature extremes and/or humidity	Causes - Heat during the day. Cold in winter. Consequence - Heat stroke. Hypothermia.	Construction	Negative	Construction site facilities to comply with Occupational Health and Safety Act 85 of 1993 specifically the thermal, humidity, lighting and ventilation requirements of the Environmental Regulations for Workplaces. Adequate potable water to be provided during all phases of the project. Bore hole, bowser and tank	Easy	3	2	3	1	2	**18**	2	2	3	1	1	**8**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
					or small water treatment plant may be required to provide potable water for the plants during all phases of the project.													
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 4:	Human Health - exposure to psychological stress	Causes - Large projects bring many contractor workers into a small, isolated community. Consequences – Lack of sufficient accommodation, entertainment etc. Increase in alcohol abuse, violence	Construction	Negative	Refer to Social Impact Assessments.	Easy	2	3	3	2	2	**20**	1	3	3	2	1	**20**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 5:	Human Health - exposure to ergonomic stress	Causes - Lifting heavy equipment. Awkward angles during construction. Consequences - Back and other injuries.	Construction	Negative	Training in lifting techniques. Ensure that despite the isolated location all the necessary equipment is available (and well maintained) during construction. Otherwise employees may revert to unsafe practices. Isolated location, maintenance of construction equipment to ensure safe operation is critical. Ensure this is in place prior to project beginning. Development of local service providers where possible. First aid provision on site.	Moderate	4	1	3	2	3	**30**	4	1	3	2	2	**20**
						Significance	**N2 - Low**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 6:	Human and Equipment Safety - exposure to fire radiation	Causes – Involvement in an external fire. Fire involving fuels used in construction vehicles or vehicles themselves (e.g. tyre fire). Fire due to uncontrolled welding or other hot-work Consequences - Injuries due to radiation especially amongst first responders and bystanders. Fatalities unlikely from the heat radiation as not highly flammable nor massive fire.	Construction	Negative	Fuels stored on site in dedicated, demarcated and bunded areas. Suitable fire-fighting equipment on site near source of fuel, e.g. diesel tank, generators, mess, workshops etc. The company responsible for the facility at this stage is to have: 1. Emergency plan to be in place prior to commencement of construction. 2.Fuel spill containment procedures and equipment to be in place. 3. Hot-work permit and management system to be in place.	Complex	4	2	3	5	4	**56**	4	2	3	5	2	**28**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	No credible causes	Construction	Negative		N/A	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 8:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Causes Human pathogens and diseases, sewage, food waste. Snakes, insects, wild and domesticated animals and harmful plants. Consequences - Illness and at worst without mitigation, possibly extending to fatalities. Effects can vary from discomfort to fatalities for venomous snakes or bee swarms etc	Construction	Negative	All necessary good hygiene practices to be in place, e.g. provision of toilets, eating areas, infectious disease controls. Policies and practice for dealing with known vectors of disease such as Aids, TB, COVID 19 and others. Awareness training for persons on site, safety induction to include animal hazards. First aid and emergency response to consider the necessary anti-venom, anti-histamines, topical medicines etc. Due to isolated locations some distance from town, the ability to treat with anti-venom and extreme allergic reactions on site is critical to mitigate the impacts	Complex	4	2	3	2	3	**33**	3	2	3	2	2	**20**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 9:	Human and Equipment Safety - exposure to violent release of kinetic or potential energy	Causes - Construction moving equipment, heavy loaded, elevated loads, working at heights Consequences - Injury or possibly fatality. Damage to equipment. Delays in starting the project, financial losses	Construction	Negative	The construction phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993 specifically the Construction Regulations. SHEQ policy in place. A detailed construction risk assessment prior to work. SHE procedure in place. PPE to be specified. SHE appointees in place. Contractors safety files in place and up to date. SHE monitoring and reporting programs in place. Standard construction site rules regarding traffic, reversing sirens, rigging controls, cordoning off excavations etc. Civil and building structures to National Building Regulations and building Standards Act 103 of 1977 SANS 10400 and other relevant codes. Other constructions such as roads, sewers etc also to relevant SANS standards. All normal procedures for working at heights, hot work permits, confined space entry, cordon off excavations etc to be in place before construction begins.	Complex	5	1	5	5	4	**64**	5	1	5	5	1	**16**

iSHEcon CHEMICAL PROCESS SAFETY ENGINEERS

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
					Emergency response plan to be in place before construction begins.													
							N4 - High						N2 - Low					
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Causes - Use of electrical machines, generators etc. Hot dry area static generation is highly likely. Lightning strike. Consequences - Electrocution. Ignition and burns. Injury and death. Damage electrical equipment.	Construction	Negative	Standard maintenance of condition of electrical equipment and safe operating instructions. Ability to shut off power to systems in use on site. If persons are decanting fuels or dealing with other highly flammable materials care should be taken regarding possible static discharge, installations to be suitably designed and maintained. Lightning strike rate in the study area is very high. Outside work must be stopped during thunderstorms. Lighting conductors may be required for the final installation, to be confirmed during design phase.	Complex	5	2	5	5	3	**51**	5	2	5	5	1	**17**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 11:	Environment - emissions to air	Causes - Dust from construction and generally hot dry area. Consequences - Adverse impact on employee health.	Construction	Negative	May need to use dampening on roads etc. as per normal construction practices. May need PPE (dust masks) for specific construction workers.	Easy	3	2	1	1	4	**28**	2	2	1	1	2	**12**
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 12:	Environment - emissions to water	Causes - Diesel for equipment, paints and solvents. Transformer oil spills. Sewage and kitchen/mess area wastewater. Consequences - Environmental damage, particularly to the surface and underground water in the area.	Construction	Negative	Normal construction site practices for preventing and containing fuels/paint/oil etc spills. Bunding under any temporary tanks, curbing under truck offloading areas and sealed surfaces (e.g. concrete) under truck parking area is particularly important. Spill clean-up procedures to be in place before commencing construction. Sewage and any kitchen liquids - containment and suitable treatment/disposal	Moderate	2	2	3	2	3	**27**	2	2	3	2	2	**18**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 13:	Environment - emissions to earth	Causes - Mess area and other solid waste. Consequences - Environmental damage.	Construction	Negative	There will be packaging materials that will need to be disposed of after the entire system is connected and commissioned as well as after regular maintenance. There will need to be waste segregation (e.g. electronic equipment, chemicals) and management on the site.	Easy	2	2	3	3	3	**30**	1	2	3	3	2	**18**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 14:	Environment - waste of resources e.g. water, power etc	Causes - Water usage not controlled. Equipment damaged. Consequences - Delays.	Construction	Negative	Water usage to be monitored on site during construction. Handling protocols to be provided by supplier. Water management plan and spill containment plans to be in place.	Easy	1	1	1	2	4	**20**	1	1	1	2	2	**10**
							N2 - Low						**N1 - Very Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Construction	Negative	Refer to visual impact assessment.	Moderate	2	2	3	3	3	**30**	2	2	3	3	3	**30**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 16:	Investors - Financial	Causes - Defective technology. Extreme project delays. Consequences - Financial loss	Construction	Negative	Design by experienced contractors using internationally recognized and proven technology. Project management with deviation monitoring.	Moderate	5	1	3	4	3	**39**	3	1	3	4	2	**22**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 17:	Employees and investors - Security	Causes - On route, potential hi-jacking of valuable load. On site, theft of construction equipment and installation facilities. Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglary.	Construction	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. Isolated location both helps and hinders security. Night lighting to be provided both indoors and outdoors where necessary.	Complex	4	1	3	2	4	**40**	3	1	3	2	3	**27**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 18:	Emergencies	Causes - Fires, explosions, noxious smoke, large spills, traffic accidents, equipment/structural collapse. Inadequate emergency response to small event leads to escalation. Consequences - Injuries turn to fatalities, small losses become extended down time.	Construction	Negative	All safety measures listed above. Emergency procedures need to be practiced prior to commencement of construction.	Complex	4	2	3	4	3	**39**	4	2	3	4	2	**26**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 19:	Investors - Legal	Green energy field is evolving quickly with new guides, codes and regulations happening at the same time as evolving technology. Consequences - Unknown hazards manifest due to using "cheaper supplier or less developed technology".	Construction	Negative	Use only internationally reputable technology suppliers who comply with all known regulations/guideline at the time of purchasing.	Moderate	3	1	3	3	4	**40**	3	1	3	3	2	**20**
						Significance	**N3 - Moderate**						**N2 - Low**					

The above risk assessment shows that provided the preventative and mitigative measures are incorporated, the construction phase of the project does not present any high risks nor any fatal flaws.

4.2 OPERATIONS PHASE (Including commissioning)

From the details of accidents that have happened at chemical plants in general, it is clear that many potential problems manifest during the commissioning phase when units are first powered up to test functionality. This phase is critical and all controls, procedures, mitigation measures etc that would be in place for full operation should be in place before commissioning commences.

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 1a:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Operation and maintenance materials spare parts, paints, solvents, welding fumes, transformers oils, lubricating oils and greases etc. Consequences - Occupational illness.	Operation	Negative	The operation and maintenance phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993. SHEQ policy in place. A detailed risk assessment of all normal operating and maintenance activities on site to be compiled, and form the basis of operating instructions, prior to commencing commissioning. SHE procedure in place, e.g. PPE specified, management of change, integrity monitoring. SHE appointees in place. Training of staff in general hazards on site. All necessary health controls/ practices to be in place, e.g. ventilation of confined areas, occupational health monitoring if required and reporting programs in place. Emergency response plan for full operation and maintenance phase to be in place prior to beginning commissioning and to include aspects such as: - appointment of emergency controller, - emergency isolation systems for electricity, - -emergency isolation and containment systems for electrolyte, - provision of PPE for hazardous materials response, - provision of emergency facilities for staff at the main office building, - provision of first aid facilities, - first responder contact numbers etc.	Moderate	2	1	3	4	5	**50**	1	1	3	4	2	**18**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 1b:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Slightly compromised equipment (e.g. small ammonia leaks) toxic vapours accumulate in buildings or structures, solids/liquids on surfaces. Maintenance of components, corrosive (e.g. water treatment chemicals) and mildly toxic liquid on surfaces. Consequences - Dermatitis, skin /eye/lung irritation.	Operation	Negative	Maintenance procedures will be in place should equipment need to be opened, e.g. pumps drained and decontaminated prior to repair in workshop etc. PPE will be specified for handling contaminated parts and other equipment on site. Training of staff in hazards of chemicals on site. Labelling of all equipment. Confined space entry procedures if entering tanks. Safety Data Sheets (SDSs) to be available on site. Operating manuals to be provided including start-up, shut-down, steady state, monitoring requirements. Maintenance manuals with make safe, decontamination and repair procedures. Proposed maintenance schedules daily, weekly, monthly, annual etc. Provided portable equipment for calibration and for testing/verification of defective equipment.	Complex	2	1	3	5	4	**44**	1	1	3	5	2	**20**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 2:	Human Health - exposure to noise	Causes - Moving parts inside buildings, pumps, compressors, cooling systems etc. Consequences - Adverse impact on hearing of workers. Nuisance factor at near -by residences or other activities.	Operation	Negative	Preferably design to ensure continuous noise does not exceed 85dB in the plant or at any other location on site or 61 dB at the site boundary, e.g. emergency generator, air compressor etc. Employees to be provided with hearing protection if working near equipment that exceeds the noise limits.	Easy	2	1	5	5	4	**52**	2	1	5	5	2	**26**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 3:	Human Health - exposure to temperature extremes and/or humidity	Causes - Heat during the day. Electrolysis plant and Haber process generate heat within enclosed building / structures. Cold in winter. Night work requires lighting. Consequences - Heat stroke. Hypothermia.	Operation	Negative	Building and container facilities to comply with Occupational Health and Safety Act 85 of 1993 specifically the thermal, humidity, lighting and ventilation requirements of the Environmental Regulations for Workplaces. Night work is likely. Suitable lighting to be provided including emergency lighting for safe building exit in the event of power failure. PPE for operations and maintenance staff to be suitable for the weather conditions. Adequate potable water to be provided during all phases of the project. PPE for operations and maintenance staff to be suitable for the weather conditions.	Easy	4	2	3	1	2	**20**	3	2	3	1	1	**9**
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 4:	Human Health - exposure to psychological stress	Causes - Isolated workstation and monotonous repetitive work. Consequences - Low performance, system productivity suffers.	Operation	Negative	Staff rotation to other activities within the site may be necessary. Performance monitoring of inspections / maintenance tasks in particular will be necessary.	Easy	2	3	3	2	2	**20**	1	3	3	2	1	**9**
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 5:	Human Health - exposure to ergonomic stress	Causes - Lifting heavy equipment. Awkward angles during maintenance, stretching reaching to high level and bending to low level. Working at height if equipment located on top of tanks, roofs or elevated electrical equipment (e.g. pylons). Consequences - Back and other injuries.	Operation	Negative	Training in lifting techniques. Training in working at heights. If equipment is at height (see OHS Act General Safety Regulation 6), ensure suitable safe (electrically and physically) ladders / harnesses etc. are available. Working at height procedure to be in place.	Easy	5	1	3	2	3	**33**	4	1	3	2	2	**20**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 6:	Human and Equipment Safety - exposure to fire radiation	Causes – Involvement in an external fire e.g. veld fire, maintenance vehicle fire, electrical systems fire. Operator negligence, mechanical failure or other cause of loss of containment of flammable hydrogen / ammonia. Enhance flammability due to leaks of oxygen. Incorrect extinguishing medium, escalate the fire. Consequences - Flash or jet fire. Radiation burns due to highly flammable materials on site. Possible offsite effects on members of the public. Damaged equipment. Contaminated fire water run-off. Fire spreads to other units or offsite if grass/vegetation not controlled.	Operation	Negative	Facilities to be declared a Major Hazard Installation and to comply with all the necessary regulatory requirements at the time, e.g. MHI QRA to be done by AIA to SANS 1461, Notifications/registration etc. Full Process Safety Management system with all elements to be implemented to international best practice, suitable for a Major Hazard Installation. Extremely flammable hydrogen systems to be designed to latest applicable international codes. Grass cutting and fire breaks around the installations to prevent veld fires. No combustible materials to be stored in or near the main chemical infrastructure especially hydrogen system. Separation of site diesel tank, transformers from hydrogen / ammonia and vice versa. Detailed FMEA/Hazop/Bowtie to done during design at the component level and system levels. Safety integrity level rating of equipment (failure probably) with suitable redundancy if required. Site Acceptance Testing as part of commissioning of each unit and the overall system. Hazardous Area Classification (SANS 10108) studies done and equipment suitably specified and maintained. Suitable ingress protection level provided for electrical equipment, e.g. IP55 - 66. Monitoring of critical parameters on SCADA, data needs to be stored for trend analysis. Protective systems are only as good as their reliability and functionality testing is important, e.g. testing that all plant alarms trips work. Emergency Response plan in compliance with SANS 1514 to be compiled, e.g. plan from transport and construction phase to be extended to operational phase to include the hazards of the systems containing large quantities of highly hazardous chemicals. See plots in APPENDIX A for preliminary plots, however the full MHI QRA will provide more details.	Complex	5	2	5	5	3	**51**	5	2	5	5	1	**17**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	Ingress of oxygen into hydrogen or ammonia systems, ignition and internal explosion. Loss of containment of hydrogen (possibly also ammonia), ignition and confined explosion within structures or semi confined if cloud drifts. Loss of containment of oxygen leading to enhance flammability. Consequences - Potential fatalities including possibly member of the public, significant impacts up to 475m from the site. Damage to nearby equipment, possible secondary events such a large toxic ammonia as clouds.	Operation	Negative	As for fire (impact 6) above. Occupied buildings risk assessment to confirm suitable location / design of main control room. Emergency response plan and employee training referred to above is critical and must be in place prior to commissioning. See plots in APPENDIX A for preliminary info but refer to the full MHI QRA for details.	Moderate	5	3	5	5	3	**54**	5	3	5	5	1	**18**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 7a:	Human and Equipment Safety - exposure to explosion over pressures	Transformer shorting / overheating / explosion. Consequences - Potential fatalities, e.g. amongst first responders. Damage to nearby equipment.	Operation	Negative	Electrical equipment will be specified to suit application. Emergency response plan and employee training referred to above is critical.	Moderate	5	1	5	5	2	**32**	5	1	5	5	1	**16**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 8:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Causes Human pathogens and diseases, sewage, food waste. Snakes, insects, wild and domesticated animals and harmful plants. Consequences - Illness and at worst without mitigation, possibly extending to fatalities. Effects can vary from discomfort to fatalities for venomous snakes or bee swarms etc	Operation	Negative	All necessary good hygiene practices to be in place, e.g. provision of toilets, eating areas, infectious disease controls. Policies and practice for dealing with known vectors of disease such as Aids, TB, COVID 19 and others. Awareness training for persons on site, safety induction to include animal hazards. First aid and emergency response to consider the necessary anti-venom, anti-histamines, topical medicines etc. Due to isolated locations some distance from town, the ability to treat with anti-venom and extreme allergic reactions on site is critical to mitigate the impacts	Moderate	4	1	3	2	3	**30**	3	1	2	2	2	**16**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 8a:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Causes - design or construction fault, mechanical failure, failure to follow correct procedures leading to loss of containment of hazardous chemicals (e.g. ammonia, nitrogen), large leaks, catastrophic failures, entry into unpurged confined spaces etc. Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to large numbers of fatalities for exposure to catastrophic releases, significant impacts up to 1.4km from the site.	Operation	Negative	Facilities to be declared a Major Hazard Installation see note 6 above. Suitable PPE (e.g. overalls, gloves, eyeglasses) to be specified for all operations in process areas. PPE to be increased (e.g. full-face shield, aprons, chemical suits) for operations that involve opening equipment and potential exposure, e.g. sampling, maintenance. All operators/maintenance staff trained in the hazards of chemicals on site and correct operating / maintenance procedures. Emergency Response Plan to be in place to SANS 1514. 24/7 helpline response available for customers of hazardous goods. Standard dangerous goods requirements for Hazmat labels. Shelter-in-place facilities to be provided for all persons on site. Offsite - closest potentially affected neighbours to be provided with emergency response information (i.e. shelter in place).	Moderate	5	3	5	5	4	**68**	5	3	3	5	1	**16**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
					See plots in APPENDIX A for preliminary information, but refer to MHI QRA for details.													
						Significance	**N4 - High**						**N2 - Low**					
Impact 9:	Human and Equipment Safety - exposure to violent release of kinetic or potential energy	Causes - Moving equipment, pumps, heavy equipment at elevation, nip points, working at heights. Traffic accidents. Earthquake / tremor. Consequences - Injury. Fatality in unlikely worst case, e.g. traffic accidents or fall from heights. Damage to equipment, spills, environment pollution	Operation	Negative	All moving equipment will be guarded/protected as per OHS Act requirements. Hot surfaces will be insulated for personnel protection. Maintenance equipment to be serviced and personnel suitably trained in the use thereof. Normally just small vehicles on site, bakkies, grass cutting, cherry-pickers etc. Possibly large cranes if large equipment or elevated structure removed/replaced. Traffic signs, rules etc in place on site. All normal working at heights, hot work permits, confined space entry, cordon off unsafe areas/works etc to be in place. Emergency response plan. Civil design to take seismic activity into account.	Moderate	5	1	5	5	3	**48**	5	1	5	5	1	**16**
							N3 - Moderate						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Causes - Use of electrical machines, generators etc. Hot dry area static generation is highly likely. Lightning strike. Consequences - Electrocution. Ignition and burns. Injury and death. Damage electrical equipment.	Operation	Negative	Design and operate to codes and guidelines for electrical installations, safe operations, PPE to suit etc. Electromagnetic fields, impact on other equipment e.g. testing devices, mobile phones – malfunction, permanent damage. Software also need to be kept as update to date as reasonably practicable. Consider suitably located Emergency stop buttons for the plant and the other equipment on site. PPE to consider static accumulation for entering the plant, and particularly in the hydrogen areas. Lightning strike rate in proposed development area is very high. All outside work must be stopped during thunderstorms. Lighting conductors may be required for the installation, to be confirmed during design	Complex	5	2	5	5	3	**51**	5	2	5	5	1	**17**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 11:	Environment - emissions to air	Oxygen and argon are by-products and may be vented. Cryogenic storage may release a small amount of stored material that cannot be re-condensed in the boil-off gas system. Production upsets may lead to imbalances resulting in venting or flaring of hydrogen, ammonia etc. During start-up / shut-down there may be venting / flaring of out of specification products.	Operation	Negative	Design to minimize heat ingress and loss of cryogenic fluids. Design of hydrogen and ammonia systems to minimise direct releases, e.g. flare excess.	Easy	3	1	1	1	3	**18**	3	1	1	1	1	**6**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
		Consequences: minor release of pollutants.																
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 12:	Environment - emissions to water	Causes – sources of possible water pollution are: water treatment and electrolysis brine waste, clean in place solutions, cooling water blow-down, floor washings, laboratory waste (if included in the design), maintenance waste, e.g. oils, spills from coolant systems, diesel trucks, transformers, parked vehicles – oil drips, fire water runoff control, kitchen waste and sewage, refrigerant release etc. Consequences - Pollution if not contained. Excessive disposal costs if emissions not limited.	Operation	Negative	Tank areas fully bunded to 110% of largest tank, or more. Curbing under truck offloading areas and sealed surfaces (e.g. concrete) under truck parking area is particularly important. Waste brine to be crystalized and disposed of under suitable license by 3rd party. Sewage and any kitchen liquids - containment and suitable treatment/disposal. Procedures for dealing with damaged/leaking equipment as well as clean-up of spills, hazmat services. Normal site practices for preventing and containing diesel/paint etc spills. Waste management plan to be in place e.g. liquid waste treatment or suitable removal and disposal will be provided. The National Environment Management Act (NEMA) has a list of substances with Reportable spill Quantities, ensure compliance with this. Storm water management system to be in place.	Moderate	3	2	3	2	3	**30**	3	2	3	2	2	**20**
						Significance	**N2 - Low**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 13:	Environment - emissions to earth	Causes - Mess area and admin solid waste. Packaging from new components. Spent catalyst, filters, hoses, gaskets and other old plant components. Consequences - Environmental damage.	Operation	Negative	There will need to be solid waste segregation (e.g. electronic equipment, chemicals, oil contaminated rags, paper, plastic) and management on the site.	Easy	2	2	3	3	3	**30**	2	2	3	3	1	**10**
						Significance	**N2 - Low**						**N1 - Very Low**					
Impact 14:	Environment - waste of resources e.g. water, power etc	Causes - Similar to construction phase. Water usage not controlled. Consequences - Delays. Excessive costs and disposal of large volumes of hazardous waste.	Operation	Negative	Water usage to be monitored on site. Water management plan and spill containment plans to be in place. Investigate End of Life plan for decommissioned equipment – reuse / recovery / repurpose.	Easy	2	1	1	2	4	**24**	2	1	1	2	2	**12**
							N2 - Low						**N1 - Very Low**					
Impact 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Construction	Negative	Refer to Visual Impact Assessment which is to include the Green Energy installation once design details are available	Moderate	3	2	3	4	4	**48**	1	2	3	4	2	**20**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 16:	Investors - Financial	Causes - Defective technology. Extreme project delays. Consequences - Financial loss	Operation	Negative	Design by experienced contractors using internationally recognized and proven technology. Project management with deviation monitoring. Project insurance.	Easy	5	1	3	4	3	**39**	3	1	3	4	2	**22**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 17a:	Employees and investors - Security	Causes - On route, potential hi-jacking of valuable and hazardous loads (e.g. road tanker of ammonia). On site, theft of equipment. Civil unrest or violent strike by employees. Cyber security attacks. Consequences - financial loss, ransom money lost, loss of life. Injury to burglars or members of the public if stolen hazardous loads not contained. Damage to equipment possibly setting off explosions or loss of containment incident on site.	Operation	Negative	Cyber security protection of plant control systems, firewalls etc. Consider motion detection lights and CCTV. The hazardous nature of the facility should be clearly indicated – e.g. Skull and Cross Bones or other signs. Isolated location both helps and hinders security. Night lighting to be provided both indoors and outdoors where necessary.	Moderate	3	1	3	2	4	**36**	3	1	3	2	2	**18**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 18:	Emergencies	Causes - Fires, explosions, toxic vapour clouds, asphyxiating vapour clouds, large spills, traffic accidents, equipment/structural collapse. Consequences - Inadequate emergency response to small event leads to escalation, injuries turn to fatalities, small losses become extended down time.	Operation	Negative	Major Hazard Installation Registration and compliance with all emergency response requirements. Full on-site Emergency Response Plan to be in place as per SANS 1514, e.g. emergency co-ordinator, first responder team, equipment (BA sets, hazmat suits), Command Centre etc. Ensure information is provided for the off-site emergency response plant to be compiled and implemented by local authorities. Emergency plan to be tested and fully operational before cold commissioning Annual MHI Emergency Drill. Monthly small emergency drills. Evacuation siren, audible at closest neighbouring farms, to be in place and tested weekly. Gas escape Shelter-in-place rooms to be designed and installed. Integrity levels to vary depending on location. Control room to be suitably located or made explosion proof, to also be airtight as a gas escape room. Firefighting systems to suitable international codes, e.g. NFPA. First aid facilities and due to isolated location on-site clinic / medical stabilization facilities ((e.g. medical oxygen, burn treatment, defibrillator). Escape door open outwards. More than one exit to be provided from buildings.	Complex	4	2	3	4	3	**39**	4	2	3	4	2	**26**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 19:	Investors - Legal	Causes - green energy field is evolving quickly with new guides, codes and regulations happening at the same time as evolving technology. Consequences - Unknown hazards manifest due to using "cheaper supplier or	Operation	Negative	Use only internationally reputable technology suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only latest state of the art technology systems are used.	Moderate	3	1	3	3	4	**40**	3	1	3	3	2	**20**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
		less developed technology".																
						Significance	N3 - Moderate						N2 - Low					

The above risk assessment shows that, provided the preventative and mitigative measures are incorporated, the operational phase of the project does not present any high risks nor any fatal flaws

4.3 DECOMMISSIONING PHASE

Chemical plant components may have a limited lifespan, there are damaged equipment etc. There could already be "waste" on the first day of commissioning and plans should be in place to deal with this. Ideally an End-of-Life plan needs to be in place before the first equipment is brought on site.

All decommissioning activities must comply with the relevant regulations at the time. Decommissioning will ultimately need to be informed by the regulatory requirements at the time, which may be different to present requirements. The impact rating are not possible to determine now given the uncertainties in mitigations applicable at that time, hence they have been left as neutral.

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 1:	Human Health - chronic exposure to toxic chemical or biological agents	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 2:	Human Health - exposure to noise	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 3:	Human Health - exposure to temperature extremes and/or humidity	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 4:	Human Health - exposure to psychological stress	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 5:	Human Health - exposure to ergonomic stress	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 6:	Human and Equipment Safety - exposure to fire radiation	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 8:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 9:	Human and Equipment Safety - exposure to violent release of kinetic or potential energy	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
							#N/A						**#N/A**					
Impact 10:	Human and Equipment Safety -	Similar to the construction and	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
	exposure to electromagnetic waves	operational phases - no new hazards.																
						Significance	**#N/A**						**#N/A**					
Impact 11:	Environment - emissions to air	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 12:	Environment - emissions to water	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 13:	Environment - emissions to earth	Causes - equipment reached end of life and may leak. Consequences - Environment damage, injuries, fatalities.	Decommissioning	Negative	Preventative maintenance system to be in place. End of Life shutdown procedure including a risk assessment of the specific activities involved. Preferably, re-purpose the equipment with associated Environmental impact considered. Disposal according to local regulations and other international directives applicable at the time.	Complex	4	3	3	5	4	**60**	4	3	3	5	2	**30**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 14:	Environment - waste of resources e.g. water, power etc	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 15:	Public - Aesthetics	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
Impact 16:	Investors - Financial	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 17:	Employees and investors - Security	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 18:	Emergencies	Similar to the construction and operational phases - no new hazards.	Decommissioning	Negative	Apply preventative and mitigative measures as per construction and operational phases.	Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 19:	Investors - Legal	Disposal of hazardous "waste" is rife with difficulties and numerous regulations that need to be complied with.	Decommissioning	Negative	Applicants should seek the opinion from a waste consultant on how to correctly dispose of hazardous waste.	Complex	3	1	3	3	4	**40**	3	1	3	3	3	**30**
						Significance	**N3 - Moderate**						**N2 - Low**					

The above risk assessment shows that, provided the preventative and mitigative measures are incorporated, the de-commissioning phase of the project does not present any high risks nor any fatal flaws.

5. CONCLUSIONS AND RECOMMENDATIONS

The tables in Section 4 contain all the recommended preventative and mitigative measures necessary to ensure risks are not unacceptably high.

Below are a few extracted items that are possibly of highest risks and therefore a priority.

5.1 CONCLUSIONS

- This assessment has found that, in the event of accidents such as large releases of hydrogen, nitrogen, oxygen or ammonia, the proposed facilities have the potential to impact significantly on both employees and members of the public outside the site. Based on the current design information, worst case hydrogen events may have significant impacts up to 475m from the site and ammonia (stored cryogenically) up to 1.4km from the site. Note that worst case events are extremely unlikely and the chance of them occurring is similar to the average chance of being struck by lightning.

- Therefore, for Location Options 1 and 2 the risk assessment has found that provided suitable preventative and mitigative measures are in place and everything reasonably practicable has been done to reduce the risks both with the design and operation of the facilities, none of the identified potential risks need be intolerably high, i.e., from a SHE perspective no fatal flaws were found with the proposed Hendrina Green Energy Facilities at location 1 and 2.

- At Location Option 3 the closest farmsteads as less than 300m (north) from the site and the closest water course less than 250m (east). As a result of this proximity, this risk assessment suggests that it may be difficult to achieve suitable low risk levels and therefore Location Option 3 is not deemed suitable.

- From a SHE risk assessment point of view, where there is a choice of location that is further from public roads, water courses, isolated farmhouses or existing infrastructure, this would be preferred. The Option 1 alternative location for the Green Hydrogen and Ammonia facility is closer to the tar access road for the area as well as existing farm houses. Location Option 2 location is slightly more isolated and is therefore slightly preferred from a SHE risk perspective.

- Each of the hydrogen, air separation and ammonia plants have the potential to cause major accidents and the entire establishment should be classified as a Major Hazard Installation.

- The hydrogen system, and ammonia under exceptional circumstances, have the potential to lead to fires and explosion which may lead to domino failures of other equipment in close proximity.

5.2 RECOMMENDATIONS

The following recommendations have been made:

- The entire Green Hydrogen and Ammonia Establishment is an MHI and the necessary risk assessment, notifications, emergency response plans etc. as per the MHI Regulations, should be in place prior to commencement of construction.

- Initiate the Major Hazard Installation Quantitative Risk Assessment as soon as possible in the development process to ensure that risks to the public persons outside the site are as low as reasonably practicable. The MHI QRA can be used to assist with risk based design decisions.

- Note that the MHI regulations are under review and if the new regulations are promulgated before this Green Hydrogen and Ammonia facility is approved under the old regulations, compliance with the new regulation will be required which will entail, amongst other requirements, the obtaining of a license to operate.

- At any large major hazard installation, such as this facility, a full formal Process Safety Management (PSM) system should be implemented and maintained. Such a system should begin to be implemented prior to commencement of the basic engineering design, i.e. certain elements will require specific tasks of the design team.

- One element of PSM is that the design should be subject to a full Hazard and Operability Study (HAZOP) prior to commencement of procurement. A HAZOP is a detailed technical systematic study that looks at the intricacies of the design, the control system, the emergency system etc. and how these may fail under abnormal operating conditions. Additional safeguards may be suggested by the team doing the study.

- The hydrogen systems, and ammonia under exceptional circumstances, have the potential to lead to fires and explosions which may lead to domino failures of other equipment in close proximity, e.g. within 350m. From an overall Hendrina project risk reduction point of view, suitable separation, or other mitigation, should be considered in the design of the site layout, including proximity to other critical infrastructure such as the Battery Energy Storage Systems (BESS) and electrical substations connecting the wind turbines or solar facilities to the National Electricity Grid.

- Critical to the mitigation of any potential major accidents is a detailed, well-practiced Emergency Response plan. Such a plan, compliant with SANS 1514, should be in place and tested prior to commissioning.

- From a SHE risk assessment point of view alternative location Option 3 is deemed unsuitable, while Option 2 is slightly preferred over Option 1.

- The tables in Section 4 of this report contain some technical and system suggestions for managing and reducing risks. Ensure the items listed in these tables under preventative and mitigative measures are included in the design, operation and maintenance of the facilities.

- Despite the fact that worst case impacts may extend a significant distance, there are many technical features that can be considered during the design phase of the project to reduce the risks, e.g. rapid inventory isolation systems, use of higher reliability road tanker loading arms instead of hoses etc. Further risk reduction measures may be suggested by the MHI QRA once more detailed design information is available.

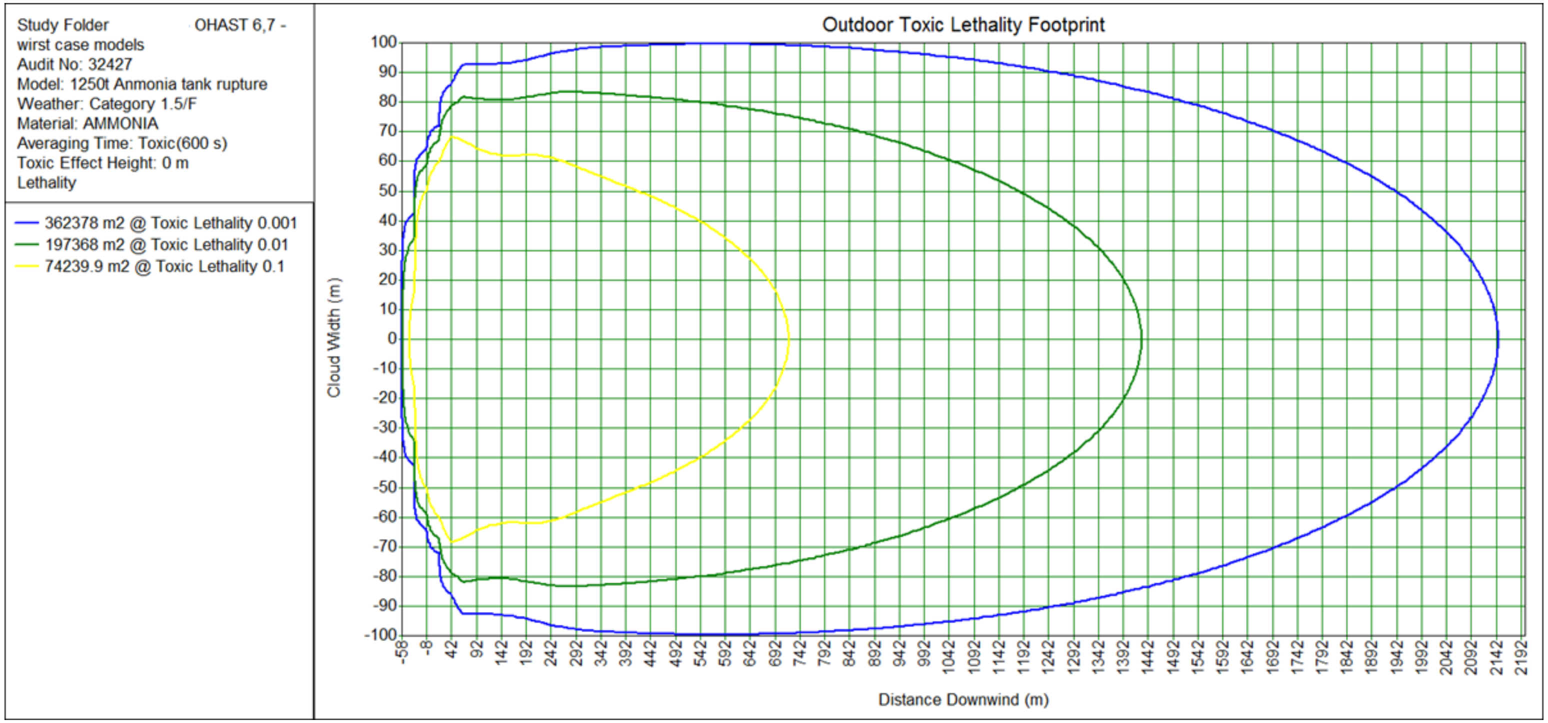
6 BIBLIOGRAPHIES

1. "Occupational Health and Safety Act and Regulations 85 / 1993", Sept 2003, Lex Patria, Butterworths, South Africa.
2. "National Environmental Management Act No 107 of 1998 and its Regulations. Government Gazette No 19519 of 27 November 1998.
3. "Environmental Impact Assessment Regulations 2014 as amended", Government Gazette No 326 of 7 April 2017.
4. SABS, "SANS 10228 – The Identification and Classification of Dangerous Goods for Transport", Standards South Africa, Pretoria, 2012.
5. SABS, "SANS 10234 – Globally Harmonize System of classification and labelling of chemicals (GHS)", SABS, Pretoria 2008.
6. SABS, "Supplement to SANS 10234 – List of classification and labelling of chemicals in accordance with the Globally Harmonize System (GHS)", SABS, Pretoria, 2008.
7. SABS, "SANS 10160: part 4: Basis of structural design and actions for buildings and industrial structures Part 4 seismic actions and general requirements for building", SABS, Pretoria, 2011.
8. SABS, "SANS10313: Protection against lightning – physical damage to structure and life hazard", SABS, Pretoria, 2012.
9. Pitblado, R and Turney, R, 1996, "Risk Assessment in the Process Industries", 2nd Ed, IChemE, Warwickshire.
10. SANS 1461: "Major Hazard Installations – Quantitative Risk Assessment", SABS, Pretoria, 2018
11. SANS 1514: "Major Hazard Installations – Emergency Response Plan", SABS, Pretoria, 2018
12. API 752, "Management of hazards associated with the location of process plant permanent buildings", 3rd Ed, Dec 2009.
13. Chemical Industries Association, "Guidance of the location and design of occupied buildings on chemical manufacturing sites", 3rd Ed, 2010, London.
14. Lees, F.P, 1996, "Loss Prevention in the Process Industries", 2nd Ed, Butterworth Heineman, Great Britain.
15. IChemE, 1999, "The Accident Database – version 4.1", CD-ROM, Rugby, UK.
16. British Compressed Gases Association, "A Method for Estimating the Offsite Risks from Bulk Storage of Liquefied Oxygen", BCGA 1999.

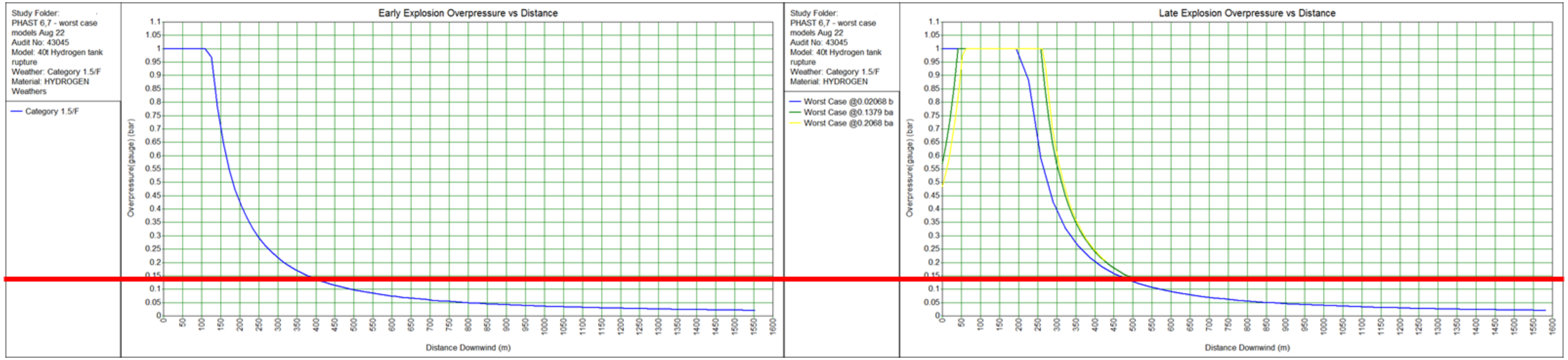
APPENDIX A

Preliminary <u>Approximations</u> of WORST-CASE Consequence Modelling
(Modelling done using DNV-GL software PHAST RISK 6.7)

CATASTROPHIC RUPTURE OF A LARGE AMMONIA TANK – Significant potentially lethal effects up to 1.4km from the tank (green plume)



CATASTROPHIC RUPTURE OF A LARGE HYDROGEN TANK – Potentially lethal effects up to 475m from the tank



APPENDIX B – HAZARDOUS PROPETIES OF MATERIALS AND ACCIDENTS THAT HAVE OCCUURRED

EXPLOSION, FLAMMABILITY AND REACTIVITY HAZARDS

Compound	BP at 1 atm (degC)	Density at 20deg C kg/m3	Vapour Press @ 20 deg C (Pa)	Flash Point (Deg C)	Flammable (Y/N)	Explosive limits in air (vol %)	Auto-ignition Temperature (Deg C)	Reactivity (H/M/L)
LPG	-40	590	Gas	-100	Y	2 – 9.5	450	L
Ammonia	-37	vapour	8500000	ND	Y	16 - 25 difficult to ignite due to high ignition energy 680 MJ	651 iron catalysed	H
Hydrogen	-253	0.067	-	-	Y	4 - 75	573.9	Embrittlement
Oxygen	-183	Gas	-	-	N (supports combustion)	-	-	H
Nitrogen or argon	-196	Gas	-	-	N	-	-	-

HEALTH HAZARDS ASSOCIATED WITH MATERIALS

With respect to the detrimental health effects of chemicals on the public, it is really only the inhalation effects that are relevant. Skin contact and ingestion effects are only applicable to workers who are in immediate contact with the chemicals. This is confirmed for this site, as there are no large storage vessels that could fail leading to either a spray or pool of immediately harmful liquid flowing off site.

Compound	Toxic Vapour Released	Inhalation Acute	Inhalation Chronic	Ingestion Contact Acute	Ingestion Contact Chronic
LPG	Carbon mon / di - oxide	Drowsiness and asphyxiation	None	Frostbite	None
Ammonia	Nitrous oxide, ammonia	Bronco spasm, pulmonary oedema, death	Bronchitis, interstitial fibrosis	Frostbite, corrosive burns, nausea	Ammonia
Hydrogen	None	asphyxiation, if atmosphere does not contain oxygen; dizziness, unconsciousness, or even death	None	Frostbite	None
Nitrogen	None	asphyxiation, if atmosphere does not contain oxygen; dizziness, unconsciousness, or even death	None	Frostbite	None
Oxygen	None	nausea, dizziness, irritation of lungs, pulmonary oedema, pneumonia, and collapse	None	Frostbite	None
Argon	None	asphyxiation, if atmosphere does not contain oxygen; dizziness, unconsciousness, or even death	None	Frostbite	None

iSHEcon CHEMICAL PROCESS SAFETY ENGINEERS

Compound	Odour Threshold (ppm)	Threshold Limit Value ** (ppm)	Short Term Exposure Limit *** (ppm)	Immediately Dangerous Value **** (ppm)	LC 50 (30 mins) (ppm)	ERPG 1 Value **** (mg/m3 ppm)	ERPG 2 Value (mg/m3ppm)	ERPG 3 Value (mg/m3 ppm)	PROBIT n	PROBIT k1	PROBIT k2
LPG	6	600	750								
Ammonia	5	25	35	1 000	6164	25	150	750	2	-16.21	1
Nitrogen and argon						769 000	832 000	869 000	5.2	-65.7	1
Oxygen	-	-	-	-	-	-	-	400 000	3.7	-30.6	0.71

** - TWA Threshold Limit Value – the time-weighted average for a worker exposed 8 hours per day for a 40-hour week

*** - STEL short-term exposure limit for a worker exposed to not more than the TWA but with a maximum of 4 excursions to this limit per day for a maximum duration of 15 minutes each with at least 60 minutes between exposures

**** - IDLH (Immediately Dangerous to Life and Health) a value that is believed on the basis of research to be immediately harmful to human health, (i.e. irrecoverable damage to health within 30 minutes' exposure)

***** - The ERPG (Emergency Response Planning Guidelines) values are established by the American Hygiene Association and are based on a 60-minute exposure.
The three categories have the following implications in terms of effects on people:
ERPG1 - below this concentration only minor irritation should be experienced by almost all persons
ERPG2 - below this value no permanent harm
ERPG3 - below this value permanent harm possible but fatalities are unlikely
ERPG values (and TEEL values) can be found through the AIHA website or the US Department of Energy website or the US EPA website.

d - where ERPG values or TEEL values are not available they have been derived using a DOW chemical guideline where ERPG2 = STEL or 3 * TWA, ERPG3 = LC50/30 or 5 * ERPG2, ERPG1 = Odour threshold or ERPG2/10, if there are different values the lower more conservative value has been used

~~ - Probit is an estimation of chance of death from exposure to a concentration of toxic material (c in ppm) for a period of time (t in mins)
PROBIT = k1 + k2 * ln (c^n t). Probit equation is based on actual or experimental data and can be found in literature references (e.g. the TNO Purple Book).

ACCIDENT AND INCIDENT INFORMATION

The accident data below is extracted from Lees [Ref 8] and the IChemE Accident Database version 4 of 1999 and Loss Prevention Bulletins.

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
May 1, 2001	Ramona, Oklahoma	Hydrogen	Release and Ignition of Hydrogen Following Collision of a Tractor-Semitrailer with Horizontally Mounted Cylinders and a Pickup Truck	1 death, 1 injury Evacuation of neighbourhood, $155k Financial Loss
Apr-10	Washington, USA	Hydrogen	A heat exchanger in the Naphtha hydrotreater unit ruptured releasing a mix of Hydrogen and Naphtha causing an explosion and a fire. Causality mainly advanced stages of high temperature (330-370C @ 4,000kPa) Hydrogen attack as well as minor corrosion issues.	7 deaths 0 Injuries 6-month shutdown
Apr-75	Essex, UK	Hydrogen	An explosion occurred in an electrolyser when the oxygen separator drum had ruptured under a pressure of 2000 Psi, this due to physical breakdown of cell blocks and the mixing of hydrogen and oxygen in flammable proportions.	1 death 2 Injuries
2019	Korea	Hydrogen	Hydrogen explosion at renewable hydrogen production facility The hydrogen buffer tanks that exploded were part of an experimental facility experimenting generation of renewable hydrogen from a water electrolyser coupled to solar panels. The three hydrogen tanks (40 m^3 capacity each at pressures of 1,2 MPa one of them and 0,7 MPa the two others) were receiving the hydrogen produced by the electrolyser. The 200 kW alkaline electrolyser had a capacity of 40 Nm^3/hr and delivered hydrogen at 1.2 MPa. The most plausible initiating cause was the defective functioning of the electrolyser's membrane, at lower power, which caused oxygen diffusing into the hydrogen stream.	3 deaths 6 Injuries
2012	Laboratory	Hydrogen	Membrane perforation in PEM FC cell A PEM FC short stack was tested in an R&I laboratory at elevated (1.8 A/cm^2) current density. A failure was detected automatically by the continuous monitoring of individual cell voltage. Which suddenly fell below a threshold value of 1.5 V, suggesting the onset of an electrical short-circuit. A sharp increase of hydrogen in the oxygen production was also detected and the power supply was shut down immediately to prevent the destruction of the stack. Destruction of a PEM FC short stack In the same R&I laboratory, another test at high current density (1.8 A/cm^2) induced a much bigger damage. The automaton used to monitor the system detected a failure situation in a sudden decrease of current and shut down the power supply. But it too late to avoid the destruction of the stack. The combustion of non-metallic cell components (MEAs and cell sealants) was total, leading to the formation of carbon deposits over the titanium bipolar plates. The electrolysis stack was destroyed by combustion within a few seconds.	None
2005	Japan	Hydrogen	An explosion occurred during the operation of a high-pressure hydrogen water electrolyser unit within a university campus (40 MPa, 30 Nm^3/h). The electrolysis cell burned down, pipes burst and the peripheral equipment scattered all over the facilities.	None.

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
			The titanium electrode in the electrolysis cell of the HHEG and/or hydrogen were burned, then water containing hydrogen flowed to the oxygen pipe. Two years before an explosion had already occurred on the site, in and older version of the electrolyser. Hydrogen had flowed into the oxygen separation tank because the water level had decreased between the tank and the electrolytic cells. As corrective measure, the holding water volume in new version of the electrolyser was increased. The new unit had started few days before the new accident.	
1998	UK	Hydrogen	Hydrogen-oxygen explosion An explosion occurred in the oxygen gas storage tank of the electrolysis plant, due to the entry of hydrogen into the oxygen system.	
2013	UK	Hydrogen	Explosion on the hydrogen line of an electrolyser The explosion occurred during cutting a purge pipe on a hydrogen manifold in the chlorine electrolysis room. The explosion was caused by ignition of a hydrogen-air mixture. Probably hydrogen was still present despite the previous purging with nitrogen, due to uncompleted purging procedure and/or hydrogen desorption from the steel of the manifold.	1 Injury
2010	UK	Hydrogen	Hydrogen explosion (mercury-based electrolysis) The explosion occurred when restarting the sodium chlorate production unit after maintenance, during which the mercury cells had remained under nitrogen purging. A hydrogen leak was detected on the nozzle of a cell collector. The nitrogen purging was stopped, to allow maintenance to intervene safely (avoiding anoxia hazards), but the power supply to electrolysis cells was not shut down again, as required by the procedures. The situation passed undetected because the wrong reading of the voltage of the cells (zero reading). Still under power, the cell produced hydrogen and oxygen. When the nitrogen purging was stopped for the repair, the two gases accumulated and mixed beyond the lower ignition limit, causing a large explosion occurred in the electrolysis room.	2 injuries
2008	UK	Hydrogen	Fire in electrolyser cells A leak of hydrogen in the electrolysis room followed by fire on three electrolysis cells (possibly started with an explosion). Injection of nitrogen the intervention of the firefighters of the site allowed the extinction of the fire	3 injuries

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
NA	NA	Oxygen	A worker filled up tires with oxygen instead of compressed air when it ignited as result of interaction between the oil/grease and oxygen.	1 Injury

NA	NA	Oxygen	A set of medical grade compressed air cylinders were incorrectly filled with oxygen which led to a narrow escape by a breathing apparatus using demolition worker.	0 death 0 Injuries 0 damage
NA	NA	Oxygen	A worker connected oxygen instead of compressed air to a hand tool, setting his clothes alight but otherwise not further negative effects reported.	0 death 0 Injuries
April 2021	Iraq	Oxygen	An oxygen cylinder burst leading to a fire in a hospital.	82 deaths
2013	UK - Bath	Oxygen	Fire in ICU due to oxygen release from faulty cylinder.	0 deaths
April 2021	India - Mumbai	Oxygen	Fire in ICU section of hospital	14 deaths

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
Dec 2000	Calcutta India	Ammonia	Leak on refrigeration system at food factory	2 deaths 100 injuries 1000 evacuate the area
Sept 1992	Haryana, India	Ammonia	Explosion in ammonia pipe	11 deaths 9 injuries
Aug 1992	Vratsa Bulgaria	Ammonia	Explosion in ammonia plant during maintenance	2 deaths 4 injuries
Mar 1992	Dakar Senegal	Ammonia	Explosion and fire in ammonia storage tank during offloading from road tanker. No BA sets available.	90 deaths 403 injuries
May 1990	Cuba	Ammonia	Rail tanker derailed releases cloud over village	3 deaths 374 injuries
Mar 1989	Lithuania USSR	Ammonia	Refrigerated storage tank ruptured without warning spilling 7000 tons of Liquid ammonia. Vapour ignited as it mixed with gas from ruptured LPG line. Fire spread to 35000t fertilizer making huge toxic cloud. Suspect ‘roll-over’.	7 deaths 57 injuries 3000 evacuated

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
July 1987	China	Ammonia	Road tanker exploded.	9 deaths 33 injuries 7000 m2 farmland destroyed
Jun 1985	Texas USA	Ammonia	Pressured storage tank ruptured.	4 deaths 23 injuries
Dec 1983	Mexico	Ammonia	Explosion in ammonia pipeline.	5 deaths 500 injuries
Oct 1980	Mexico	Ammonia	Road tanker transfer hose failure releasing 86 tons of ammonia	9 deaths 29 injuries 1000's evacuated
Dec 1978	USA	Ammonia	Train struck ammonia road tanker at level crossing leading to huge puncture	3 deaths 29 injuries
April 1978	USA	Ammonia	Road tanker hose rupture. Driver could not get to shut off valve due to gas. Flow out of tanker and backflow from storage.	1 death 19 injuries
Mar 1977	Mexico	Ammonia	Gas release spread offsite through sewers.	2 deaths 102 injuries 1000's evacuated
May 1976	Texas USA	Ammonia	Road tanker crashed off road.	5 deaths 49 injuries

DATE	PLACE	MATERIAL	DESCRIPTION	CONSEQUENCE
Nov 1983	Japan	LPG Propane	Restaurant gas tanks exploded	14 deaths, 27 injuries
2007		LPG	An LPG heater fell over and emitted a grey cloud before it exploded in a public area, injuring more than 300 and killing 75.	75 deaths 300 injuries
Jun 1983	Germany	LPG Propane	During road transport offloading the hose coupling broke. Fire.	1 death
1974		LPG	Incorrect road tanker hose connection, failure, gas release, flash fire, tanker explosion. Water deluge failed after 10 minutes.	2 deaths
2007		LPG	A forklift battery ignited a leak from 49 tonnes of LPG and various other flammables in a factory, this due to the non-compliance with the LPG code of practice, requiring suitably explosion proof equipment, of which the 48-volt forklift battery was not acceptable.	0
11-May-04	Glasgow	LPG	Corroded pipes leading to an LPG leak in the basement are the cause of an explosion which injured 30 and killed 9 in Glasgow	9 deaths 30 injuries