



**HIGH LEVEL SAFETY HEALTH AND ENVIRONMENTAL
RISK ASSESSMENT FOR THE DEVELOPMENT OF
BATTERY ENERGY STORAGE SYSTEMS ASSOCIATED
WITH THE PROPOSED VANDERKLOOF PHOTOVOLTAIC
(PV) AND BATTERY ENERGY STORAGE FACILITY NEAR
LUCKHOFF IN THE FREE STATE PROVINCE**

20th March 2025

REPORT:	HIGH LEVEL SAFETY HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR THE DEVELOPMENT OF BATTERY ENERGY STORAGE SYSTEMS ASSOCIATED WITH THE PROPOSED VANDERKLOOF PHOTOVOLTAIC (PV) AND BATTERY ENERGY STORAGE FACILITY NEAR LUCKHOFF IN THE FREE STATE PROVINCE
ASSIGNMENT NO:	J3796M
REPORT DATE:	20 th March 2025
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:	Vanderkloof Solar (Pty) Ltd
ENVIRONMENTAL ASSESSMENT PRACTITIONER:	Dale Holder of Cape EAPrac (Pty) Ltd 044 874 0365 / dale@cape-eaprac.co.za
INSTALLATION REPRESENTATIVE	Marshall Mabin marshall@merchant.energy 021 71 482 1315
ADDRESS OF INSTALLATION:	Letsemeng Local Municipality in the Xhariep District of the Free State Province
ADDRESS OF COMPANY:	1 Osborne Rd, Claremont, Cape Town 7708

REPORT ADMINISTRATIVE RECORD

LIST OF ASSESSMENTS

Assessment	Rev	Assessment Date	Description
SHE Risk Assessment	1	20 March 2025	J3796M – High Level Safety Health and Environmental Risk Assessment for The Development of Battery Energy Storage Systems associated with the Proposed Vanderkloof Photovoltaic (PV) and Battery Energy Storage System (BESS) Near Luckhoff in the Free State Province - 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
Marshall Mabin	Vanderkloof Solar (Pty) Ltd	Project Developer and Professional Scientist
Helen Watkins	SyteRE	Project Manager and Spatial Layout Planner
Dale Holder	Cape EAPrac	Environmental Assessment Practitioner

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 Contractor 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, 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	20 March 2025	

EXECUTIVE SUMMARY

Vanderkloof Solar (Pty) Ltd propose to develop the Vanderkloof Photovoltaic (PV) and Battery Energy Storage System (BESS) facility with five Battery Energy Storage Systems (BESS) to be located 2 km south of the town of Luckhoff in the Letsemeng Local Municipality in the Xhariep District of the Free State Province, South Africa. The site will be accessed via the R48.

The proposed Vanderkloof PV and BESS projects are subject to a Scoping and Environmental Reporting process as the development falls outside any Renewable Energy Development Zone (REDZ).

It is proposed that the Vanderkloof PV and BESS facilities will have a combined capacity of up to 2000MW and will connect into five new on-site substations located. This will then link into the Eskom grid. The BESS facilities of up to 2000MW / 8000MWh combined, will be located adjacent to the Substations.

The preferred battery technology is solid state Lithium-ion such as Lithium Iron Phosphate, Lithium Nickel Manganese Cobalt oxides or sodium-ion systems. Alternative technologies being considered include Redox flow (typically vanadium) as well as Liquid Metal (Ambri technology). The specific technology will only be determined following Engineering, Procurement and Construction (EPC) procurement.

In 2019, the Department of Forestry, Fisheries and the Environment (DFFE) requested that EIA applications for BESSs, either on their own or as part of a power generation (e.g., PV or wind) application, should include a high-level Risk Assessment of the BESS considering all applicable risks (e.g., fire, explosion, contamination, end-of life disposal etc).

This report summaries the high-level Safety, Health and Environmental (SHE) Risk Assessment conducted by ISHECON for the BESS installations at the proposed Vanderkloof PV and BESS Facilities.

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 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 layout of the facility and associated BESS alternative 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 study proceeded based on the assumption that redox flow batteries (typically vanadium) could be installed within a building and solid state batteries (typically lithium) and liquid metal batteries would be installed in containers. Flow batteries can also be installed in containers, but the building option has been chosen in order to highlight possible major differences between technologies.

GENERAL

- This Risk Assessment has found that for the BESS installations associated with the proposed Vanderkloof PV and BESS facility near Luckhoff in the Free State, provided suitable preventative and mitigative measures in place, none of the identified potential risks are excessively high, i.e., from a Safety, Health and Environment (SHE) perspective no fatal flaws were found with either type of technology (solid state - lithium-ion, redox flow – vanadium, or molten liquid metal - Ambri) and therefore from a SHE risk perspective there is no reason to prohibit the development.
- At a large facility, without installation of the state-of-the art battery technology that includes protective features, there can be significant risks to employees and first responders. The latest battery designs include many preventative and mitigative measures to reduce these risks to tolerable levels. (Refer to tables in Section 4 under preventative and mitigative measures). State-of-the-art technology should be used, i.e., not old technology that may have been prone to fire, explosion and loss of containment risks.
- 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.
- From an acute health and safety point of view, and ignoring the fact that this project may help to mitigate possible adverse impacts of climate change, create jobs and contribute to sustainable energy, the No-Go option will always be a preferred option since there are no immediate health and safety risks associated with not doing a project.

LITHIUM SOLID STATE CONTAINERIZED BATTERIES

- With lithium solid-state batteries, the most significant hazard with battery units is the possibility of thermal runaway and the generation of toxic and flammable gases. There have been numerous such incidents around the world with lithium-ion batteries at all scales and modern technology providers include many preventative and mitigative features in their designs, e.g. solid state electrolytes being one of these improvements. This type of event also generates heat which may possibly propagate the thermal runaway event to neighbouring batteries if suitable state of the art technology is not employed.
- The flammable gases generated may ignite leading to a fire which accelerates the runaway process and may spread the fire to other parts of the BESS or other equipment located near-by.
- If the flammable gases accumulate within the container before they ignite, they may eventually ignite with explosive force. This type of event is unusual with solid state batteries, but has happened with an older technology container installed at McMicken in the USA in 2019.

- Due to a variety of causes, thermal runaway could happen at any point during transport to the facility, during construction or operation / maintenance at the facility or during decommissioning and safe making for disposal.
- Due to the containerized approach as well as the usual good practice of separation between containers, which should be applied on this project, and therefore the likely restriction of events to one container at a time, the main risks are close to the containers i.e., to transport drivers, employees at the facilities and first responders to incidents.
- In terms of a worst conceivable case container fires, the significant impact zone is likely to be limited to within 10m of the container and mild impacts to 20m. Based on the current proposed layouts, impacts at the closest isolated farmhouses or other independent facilities are not expected. In addition any general access onsite facilities such as laydown areas have been located over 20m from the BESS area.
- In terms of a worst conceivable case explosion, the significant impact zone is likely to be limited to with 10m of the container and minor impacts such as debris within 50m. Based on the current proposed layouts, impacts at the closest isolated farmhouses or other independent facilities are not expected. In addition onsite structures such as buildings have been located over 50m from the BESS area, while substations have been located over 30m away.
- In terms of a worst reasonably conceivable toxic smoke scenario, provided the units are placed suitably far apart to prevent propagation from one unit to another and large external fires are prevented (i.e. grass cutting in place), the amount of material burning should be limited to one container at any one time. In this case, beyond the immediate vicinity of the fire, the concentrations of harmful gases within the smoke should be low. Occupied farm houses / developments should ideally be located over 500m from the BESS and public roads over 100m.
- For the Vanderkloof PV and BESS, the BESS locations are all over 100m from public roads and are positioned over 500m from any occupied farmhouse, and in this context the locations are therefore considered suitable in terms of toxic gas risks.

VANADIUM REDOX FLOW BATTERY INSTALLATIONS

- The most significant hazard with VRF battery units is the possibility of spills of corrosive and environmentally toxic electrolyte. Many preventative and mitigative features will be included in the design and operation, e.g., full secondary containment, level control/monitoring on bulk tanks, leak detection on equipment etc. (Refer to tables in section 4 under preventative and mitigative measures).
- For the Vanderkloof PV and BESS, the BESS locations are over 100m from any water course and 50m from most active boreholes. This is to be confirmed by the aquatic study and any active boreholes that are too close should be capped to prevent use of potentially contaminated ground water should there be an incident. With the above mitigations the locations are considered suitable in terms of spill management.
- VRF batteries do not present significant fire and electrical arcing hazards provided they are correctly designed, operated, maintained and managed. Suitable Battery Management System (BMS), safety procedures, operating instructions, maintenance procedures, trips, alarms and interlocks should be in

place. (Refer to tables in section 4 under preventative and mitigative measures).

LIQUID METAL BATTERY INSTALLATIONS

- The most significant hazard with liquid metal battery units is the possibility of injury to personnel mishandling hot items. Suitable on site procedures and PPE for operations and maintenance need to be in place.
- Fires in the event of battery leaks are not impossible, but these should be limited to the combustible materials in a container, e.g. cable coatings etc. and is not likely to be the result of thermal runaway of the battery. The fire is not inherently electrical and normal fire suppression could be used. Note water on hot surfaces would not be advised.
- For the Vanderkloof PV and BESS, the BESS locations are suitable for molten metal batteries.

TECHNOLOGY AND LOCATION OF BESS FACILITIES

- From a safety and health point of view, the above Risk Assessment shows that risks posed by VRFB systems may be slightly lower than those of SSL facilities, particularly with respect to fire and explosion risks. From an environmental spill and pollution point of view the VRFB systems present higher short-term risks than the SSL systems. Liquid metal batteries present lower risks than both the SSL and VRF battery systems as both the risks of fire and spills are significantly lower. However, the above conclusions may be due to the fact that the VRFB and Liquid Metal technology is not as mature as SSL technology and there is not as much operating experience and accident information available. Overall, from a SHE RA points of view, there is no specific preference for a type of technology.
- 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 other occupied facilities, this would be preferred. VRFB hazards are mostly related to possible loss of containment of electrolyte, SSL batteries to fires producing toxic smoke and fire fighting which may result in contaminated of firewater runoff and liquid metal hazards are mostly limited to onsite operational issues. The current chosen locations are suitably far from isolated farm houses, public roads, powerlines and water resources with a very low risk of any significant impacts.

CUMULATIVE IMPACTS

- Unless another BESS is installed within 500m of the BESS locations, cumulative impacts of other developments in the greater area do not affect the safety and health of employees, contractors of members of the public within the BESS impact zone. The same can be said of the BESS electrical infrastructure and grid connection.
- BESS 1 and BESS 5-1 are located within 200m of BESS 2 resulting in a large complex with about 835MW generating capacity. There could possibly be in excess of 1000 SSLB containers in this combined complex. There are no independent developments such as farm houses within 500m of any of these BESS installations and therefore no increase in offsite cumulative risks. However, all the onsite facilities for all three BESS installations, such as buildings, substations etc, are within the impact range of all three BESS installations. Cumulative risks on employees are therefore relevant and due to the high number of units there is a high risk of fires. Due to the isolated location, Emergency Response to battery fires is likely to be 'let it burn but prevent the spread'. Specific emergency Response

procedures should be in place to protect employees from toxic smoke, e.g. rehearsed emergency evacuation plans or even the provision of shelter in place facilities. Although they are part of the same facility, BESS 5.2. and 5.3 may pose similar onsite cumulative risks to BESS 5.3. buildings (possibly up to 800 containers in the complex and BESS 5.3 facilities partially within 500m of BESS 5.2) and therefore similar mitigation measures could be considered.

3. RECOMMENDATIONS

The following recommendations have been made:

- There are numerous different battery technologies, but using one consistent battery technology system for the BESS installations within the Vanderkloof PV and BESS facility, would allow for ease of training, maintenance, emergency response and could significantly reduce risks.
- Where reasonably practicable, state-of-the-art battery technology should be used with all the necessary protective features e.g., draining of cells during shutdown and standby-mode, full BMS with deviation monitoring and trips, leak detection systems.
- There are no fatal flaws associated with any of the proposed BESS installations for either of the three technology types.
- The tables in Section 4 of this report contains technical and systems suggestions for managing and reducing risks. Ensure the items listed in these tables under preventative and mitigative measures are included in the design.
- The overall design should be subject to a full Hazop prior to finalization of the design.
- For the VRFB systems an environmentally friendly method of filling the system with electrolyte upon startup and an end of life (and for possible periodic purging requirements) solution for the large quantities of hazardous electrolyte should be investigated, e.g., can it be returned to the supplier for re-conditioning.
- Prior to bringing any solid-state battery containers into the country, the contractor should ensure that:
 - An Emergency Response Plan is in place that would be applicable for the full route from the ship to the site. This plan would include details of the most appropriate emergency response to fires both while the units are in transit and once they are installed and operating.
 - An End-of-Life plan is in place for the handling, repurposing or disposal of dysfunctional, severely damaged batteries, modules and containers.
- The site layout and spacing between lithium solid-state containers should be such that it mitigates the risk of a fire or explosion event spreading from one container to another.
- Under certain weather conditions, the noxious smoke from a fire in a lithium battery container could travel some distance from the unit. The smoke will most likely be acrid and could cause irritation, coughing, distress etc. Close to the source of the smoke, the concentration of toxic gases may be high enough to cause irreversible harmful effects. Location of the facilities needs to ensure a suitable separation distance from public facilities/residences etc. The current proposed BESS locations are all over 500m from isolated farmhouses. All BESS locations are over 100m from busy public roads. The

risks of significant fire, explosion and toxic smoke impacts on members of the public is very low.

- Where there is a choice of alternative locations for the BESS, those that are further from water courses would be preferred. VRFB hazards are mostly related to possible loss of containment of electrolyte and solid-state systems may experience fires that may result in loss of containment of liquids or the use of large amounts of fire water which could be contaminated. One would not want these run-offs to enter water courses directly. The buffer distance between water bodies and the facilities containing chemicals should be set in consultation with a water specialist and is therefore not specified in this SHE RA. It should be noted that all the BESS locations are over 100m from the closest water courses and 50m from most active boreholes. Active boreholes within 50m could be capped to prevent possible use of contaminated ground water in the event of a spillage incident. With such mitigation measures the location can be considered suitable.
- For molten metal batteries the most significant hazards are to persons working with the facilities, e.g. operation and maintenance personnel. Suitable procedures will need to be in place and PPE to be specified.
- Due to the location of BESS 1, BESS 2 and BESS 5.1 within 500m of each other cumulative risks on employees are relevant. Due to the high number of battery containers there is a high risk of fires. As it is a remote isolated location, Emergency Response to battery fires is likely to be 'let it burn but prevent the spread'. Specific emergency Response procedures should be in place to protect employees from toxic smoke, e.g. rehearsed emergency evacuation plans or even the provision of shelter in place facilities. Similar mitigation measures could be considered for the BESS 5.2 and 5.3 complex, although the risks are not as significant as for the BESS 1,2 and 5.1 complex.
- Finally, once the BESS technology has been selected and further specifics of the final design are available, verify that all recommendations as provided in this risk assessment are adhered to, including the mitigation measures provided by the BESS supplier.

TABLE OF CONTENTS

1. INTRODUCTION	14
1.1 SCOPE OF ASSESSMENT	14
1.2 EIA REGULATION SCOPE OF APPLICATION	14
1.3 RISK ASSESSMENT METHODOLOGY	14
2. DESCRIPTIONS.....	22
2.1 ORGANISATION, SITE LOCATION AND SURROUNDING AREAS	22
2.1.1 ORGANIZATION	22
2.1.2 LOCATION AND PHYSICAL ADDRESS	22
2.1.3 DESCRIPTION OF SITE AND SURROUNDINGS	23
2.2 TOPOGRAPHY, LAND-USE AND METEOROLOGY	33
2.2.1 TOPOGRAPHY	33
2.2.2 LAND-USE	33
2.2.3 METEOROLOGY	33
2.3 PLANT AND PROCESSES	35
2.3.1 PROPOSED DESIGN - SOLID STATE BATTERIES – TYPICALLY LITHIUM-ION	35
2.3.2 PROPOSED DESIGN - REDOX FLOW BATTERIES – TYPICALLY VANADIUM	37
2.3.3 PROPOSED DESIGN – MOLTEN METAL BATTERIES – TYPICALLY AMBRI	40
2.3.4 STAFF AND SHIFT ARRANGEMENT	40
2.3.5 OPERATIONS AT THE BESS FACILITY AND PHASES OF THE BESS PROJECT	40
3. HAZARD IDENTIFICATION	43
3.1 LITHIUM-ION BATTERY CHEMICAL HAZARDS	43
3.1.1 LITHIUM BATTERIES IN GENERAL	43
3.1.2 LITHIUM BATTERY CHEMISTRY.....	43
3.1.3 HAZARD - THERMAL DECOMPOSITION	44
3.1.4 HAZARD - PROPAGATION	44
3.1.5 HAZARD - ELECTROLYTE LEAKS FROM LIQUID PHASE BATTERIES.....	45
3.1.6 HAZARD – ELECTRICAL SHOCK/ARC	46
3.2 VANADIUM REDOX FLOW BATTERY HAZARDS	46
At this stage, the preferred battery technology is Redox flow (typically vanadium chemistry).....	46
3.2.1 REDOX FLOW BATTERIES IN GENERAL	46
3.2.2 VANADIUM BATTERY CHEMISTRY	47
3.2.5 HAZARD – FIRE / DEFLAGRATION.....	49
3.2.6 HAZARD - HYDROGEN GENERATION	49
3.2.7 HAZARD – WASTE ELECTROLYTE	49
3.2.8 HAZARD - ELECTROLYTE LEAKS	49
3.3 LIQUID METAL BATTERY HAZARDS	50
3.3.1 LIQUID METAL BATTERIES IN GENERAL.....	50
3.3.2 LIQUID METAL BATTERY CHEMISTRY	50
3.3.3 HAZARD – HOT MOLTEN METAL	51
3.3.4 HAZARD – SHORTING THERMAL RUNAWAY	51
3.4 GENERAL - OTHER CHEMICALS OR HAZARDS	52
3.4.1 COOLING SYSTEMS	52
3.4.2 FIRE SUPPRESSION SYSTEMS.....	53
3.4.3 GENERAL ELECTRICAL AND ELECTRONIC EQUIPMENT	53
3.5 PAST ACCIDENTS AND INCIDENTS RELEVANT TO BESS.....	53
4. RISK ASSESSMENT	59

4.1	SOLID STATE BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY LITHIUM-ION	60
4.2	REDOX FLOW BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY VANADIUM.....	89
4.3	MOLTEN METAL BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY AMBRI SYSTEM	115
5.	CONCLUSIONS AND RECOMMENDATIONS	139
5.1	CONCLUSIONS	139
5.2	RECOMMENDATIONS.....	142
6	REFERENCES	144

GLOSSARY OF SOME TERMS POSSIBLY USED IN THIS REPORT

Units, acronyms, abbreviations	Definition
BA	Basic Assessment or Breathing Apparatus
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
°C	Degrees Celsius
dB	Decibels
DC / AC	Direct Current / Alternating Current
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
ERPG	Emergency Response Planning Guideline (a series of values in ppm or mg/m ³ that indicates various levels health effects if exposed to this concentration for more than 60 minutes)
E-stop	Emergency stop button
FP	Flash Point
HAZOP	Hazard and Operability Study
HBA	Hazardous Biological Agents (Refers to pathogens, parasites, cell cultures, etc., - Refer to the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) as amended)
HCS	Hazardous Chemical Substances (Refers to a list of hazardous chemicals - Refer to the OHS Act)
HV / MV	High Voltage / Medium Voltage
IDLH	Immediately Dangerous to Life and Health (a value in ppm or mg/m ³ that indicates serious health effects if exposed to this concentration for more than 30 minutes)
IMDG	International Marine Dangerous Good
km	Kilometres
kPa	Kilopascal
kW	Kilowatts
kWh	Kilowatt hour
m ³	Metres cubed
MW	Megawatts
MWh	Megawatt hour
NASA	National Aeronautics and Space Administration
NEMA	National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended
NFPA	National Fire Protection Agency
NRT Act	National Road Traffic Act, 1996 (Act No. 93 of 1996) as amended (Chapter 8 deals with transportation of dangerous goods) Note various South African National Standards are incorporated into the regulations.
OEL	Occupational Exposure Limit (usually in ppm or mg/m ³ 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, 1993 (Act No. 85 of 1993)
PPE	Personal Protective Equipment
ppm	Parts Per Million
PV	Photovoltaic
RA	Risk Assessment
RQ	Reportable Quantity in terms of NEMA to DFFE
QC / QA	Quality Control or Quality Assurance
SANS	South African National Standards
SDS	Safety Data Sheet
SHE (Q)	Safety, Health, Environment (Quality)
SSLB	Solid State Lithium Batteries

Units, acronyms, abbreviations	Definition
TWA (8 hrs)	Time weighted average of 8 hrs
VOC	Volatile Organic Carbons
VRFB	Vanadium redox flow battery
USA	United States of America
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

Vanderkloof Solar (Pty) Ltd propose to develop the Vanderkloof Photovoltaic (PV) and Battery Energy Storage System (BESS) facility with five Battery Energy Storage Systems (BESS) to be located 2 km south of the town of Luckhoff in the Letsemeng Local Municipality in the Xhariep District of the Free State Province, South Africa. The site will be accessed via the R48.

The proposed Vanderkloof PV and BESS projects are subject to a Scoping and Environmental Reporting process as the development falls outside any Renewable Energy Development Zone (REDZ).

It is proposed that the Vanderkloof PV and BESS facilities will have a combined capacity of up to 2000MW and will connect into five new on-site substations located. This will then link into the Eskom grid. The BESS facilities of up to 2000MW / 8000MWh combined, will be located adjacent to the on-site Substations.

The preferred battery technology is solid state Lithium-ion such as Lithium Iron Phosphate, Lithium Nickel Manganese Cobalt oxides or sodium-ion systems. Alternative technologies being considered include Redox flow (typically vanadium) as well as Liquid Metal (Ambri technology). The specific technology will only be determined following Engineering, Procurement and Construction (EPC) procurement.

In 2019, the Department of Forestry, Fisheries and the Environment (DFFE) requested that EIA applications for BESSs, either on their own or as part of a power generation (e.g., PV or wind) application, should include a high-level Risk Assessment of the BESS considering all applicable risks (e.g., fire, explosion, contamination, end-of life disposal etc).

This report summaries the high-level Safety, Health and Environmental (SHE) Risk Assessment conducted by ISHECON for the BESS installations at the proposed Vanderkloof PV and BESS Facilities.

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.

1.2 EIA REGULATION SCOPE OF APPLICATION

This Risk Assessment, with a focus on the requirements of the Occupational Health and Safety (OHS) Act, 1998 (Act 85 of 1993), is conducted as a technical input into the environmental basic assessment process for the proposed Vanderkloof PV and BESS, in order to comply with the requirement for a high-level Health and Safety Assessment, and it does not necessarily comply with all the requirements of a specialist study as defined in Appendix 6 of the Environmental Impact Assessment Regulations of 2014, as amended, under the National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended (NEMA).

1.3 RISK ASSESSMENT METHODOLOGY

This Risk Assessment will consider the technology in detail. However, considering the general risks posed by the 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 no area visit was conducted. A desktop study of the available information, preliminary BESS 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,
- decommissioning (end of life).

This study makes use of a qualitative risk ranking system framework¹. 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 Health and Safety Risk Assessment is focussed on hazards arising from the construction, operation and decommissioning of a facility 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.

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").

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 be reversible or irreversible, e.g., fatalities are permanent, while it may be possible to recover from injuries.
- 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 S&EIA process, for example assessments in the field of impacts on terrestrial biodiversity, including fauna and flora, aquatic biodiversity, avifauna 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.

Also note that in the realm of occupational health and safety the aspects of exposure, irreversible harm, cumulative impacts are all grouped into the broad term consequence. Clearly, if the possible consequence is death of an employee, then the impact is irreversible, the person irreplaceable and the effects are not cumulative. Unless a facility is classified under the Occupational Health and Safety Act, 1998 (Act 85 of 1993) as amended (OHS Act) as a Major Hazard Installation (MHI), which the BESS installation is not, with offsite impacts that can be cumulative (domino) effects, or if one BESS is located within 500m of another independently assessed BESS, safety is concerned with employee exposure due to one facility, i.e., cumulative impacts are not relevant.

In the context of acute SHE aspects (i.e., ignoring possible long term impacts of climate change, job creation and sustainable energy), if the project does not proceed, i.e., the No-Go option, then there are no negative impacts on human safety and health, and no negative impacts on the environment.

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 (OEL's) and Biological Exposure Indices (BEI's – OHS Act Hazardous Chemical Substances (HCS) and Hazardous Biological Agents (HBA) Regulations)) for continuous work time exposure to hazardous chemical substances and materials. Awareness of 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 Bulb Globe 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/m ² for 1-minute leads to 1% fatalities. 37.5 kW/m ² 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	Applicable South African Legislation	OHS Act

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)

$$\begin{aligned} \text{Risk} &= \text{Consequence} \times \text{Likelihood} \\ \text{Significance} &= (\text{Extent} + \text{Duration} + \text{Reversibility} + \text{Magnitude}) \times \text{Probability} \end{aligned}$$

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 is 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 indicate a potential fatal flaw

2. DESCRIPTIONS

2.1 ORGANISATION, SITE LOCATION AND SURROUNDING AREAS

2.1.1 ORGANIZATION

The Vanderkloof PV and BESS facilities will be part of Vanderkloof Solar (Pty) Ltd, which is a private company focusing on development and operation of renewable facilities. The company has experience in clean energy wind and solar PV projects.

2.1.2 LOCATION AND PHYSICAL ADDRESS

Solar PV 1 - BESS 1

Affected properties for the BESS 1: Remaining Extent of Annex Goemmansberg 634
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°47'29.63" S 24°47'12.11" E (centre of BESS area)

Solar PV 2 - BESS 2

Affected properties for the BESS 2: Remaining Extent of Goedman's Berg 39
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°47'40.46" S 24°47'14.98" E (centre of BESS area)

Solar PV 3 - BESS 3

Affected properties for the BESS 3: Remaining Extent of Bergrivier 1132
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°49'16.35" S 24°50'18.28" E (centre of BESS area)

Solar PV 4 - BESS 4

Affected properties for the BESS 4: Remaining Extent Brakleegte 654
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°49'11.98" S 24°51'28.53" E (centre of BESS area)

Solar PV 5 - BESS 5-1

Affected properties for the BESS 1: Remaining Extent of Goedman's Berg 39
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°47'40.62" S 24°47'32.12" E (centre of BESS area)

Solar PV 5 - BESS 5-2

Affected properties for the BESS 1: Portion 1 of Bergrivier 1132
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°50'29.86" S 24°51'17.62" E (centre of BESS area)

Solar PV 5 - BESS 5-3

Affected properties for the BESS 1: Portion 1 of Bergrivier 1132
Letsemeng Local Municipality in the Xhariep District of the Free State Province.
GPS co-ordinates: 29°50'47.25" S 24°51'31.44" E (centre of BESS area)

2.1.3 DESCRIPTION OF SITE AND SURROUNDINGS

The maps below show the planned location of the BESS facilities.

Figure 2.1.1 is a map of South Africa showing the location of the proposed Vanderkloof PV and BESS facilities.
Figure 2.1.2 is the farms (black outline) involved on the development area.

Figure 2.1.3 shows 500m circles around the proposed BESS Facilities (blue) as well as local farmsteads / occupied facilities with (red), unoccupied facilities with (orange), near-by water courses/bodies (green) and other relevant features such as power line (pink) and significant road (yellow).

Figure 2.1.4.1 to 6 – Layout of Buildings and Substations in Relation to the BESS 1, 2, 3, 4, 5-1, 5-2&3 and Key Aspects of the Surrounding Area

Figure 2.1.1 - Map showing the location of the proposed Vanderkloof PV and BESS within the Free State South Africa



Figure 2.1.2 - The general area of interest for the Vanderkloof PV and BESS Complex

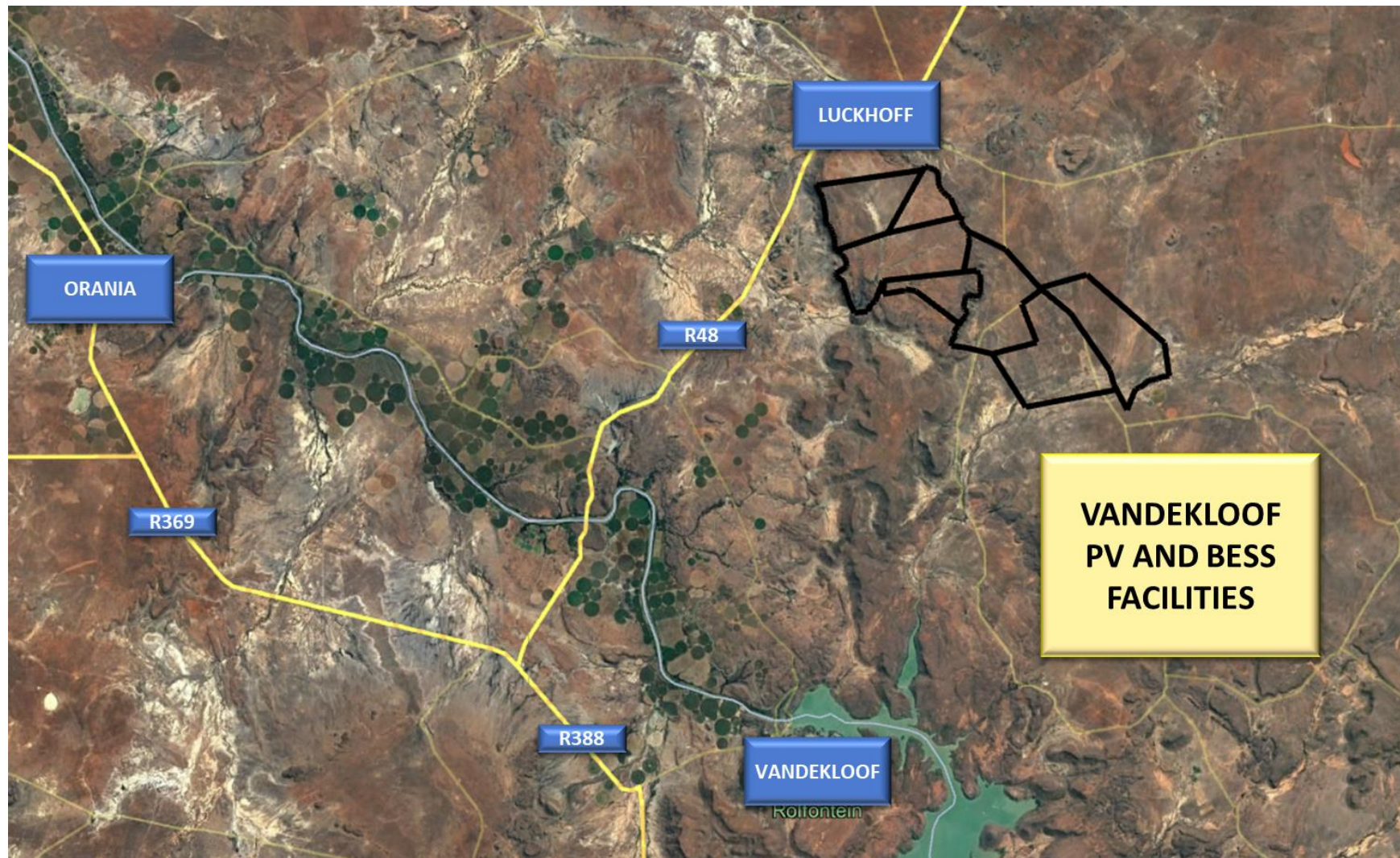


Figure 2.1.3 – Vanderkloof PV and BESS Complex - 500m circles around the BESS Facilities (Blue), Location of Occupied Farmhouses (Red), Location of unoccupied structures (Orange) and Water Courses/Bodies (Green), Power lines (pink) and significant Roads (yellow) in the immediate area

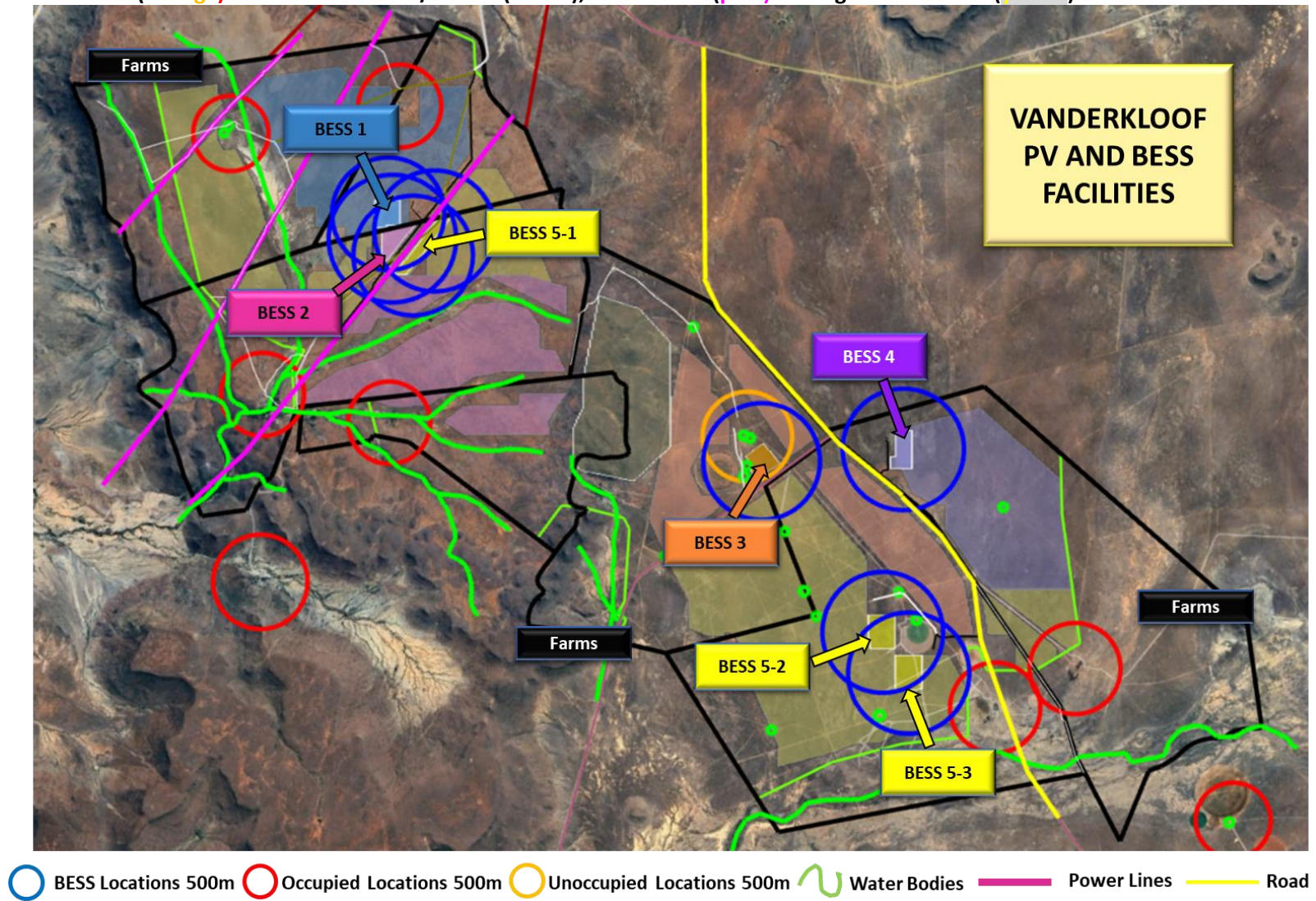


Figure 2.1.4.1 – Layout of Buildings and Substation in Relation to the BESS 1 and Key Aspects of the Surrounding Area

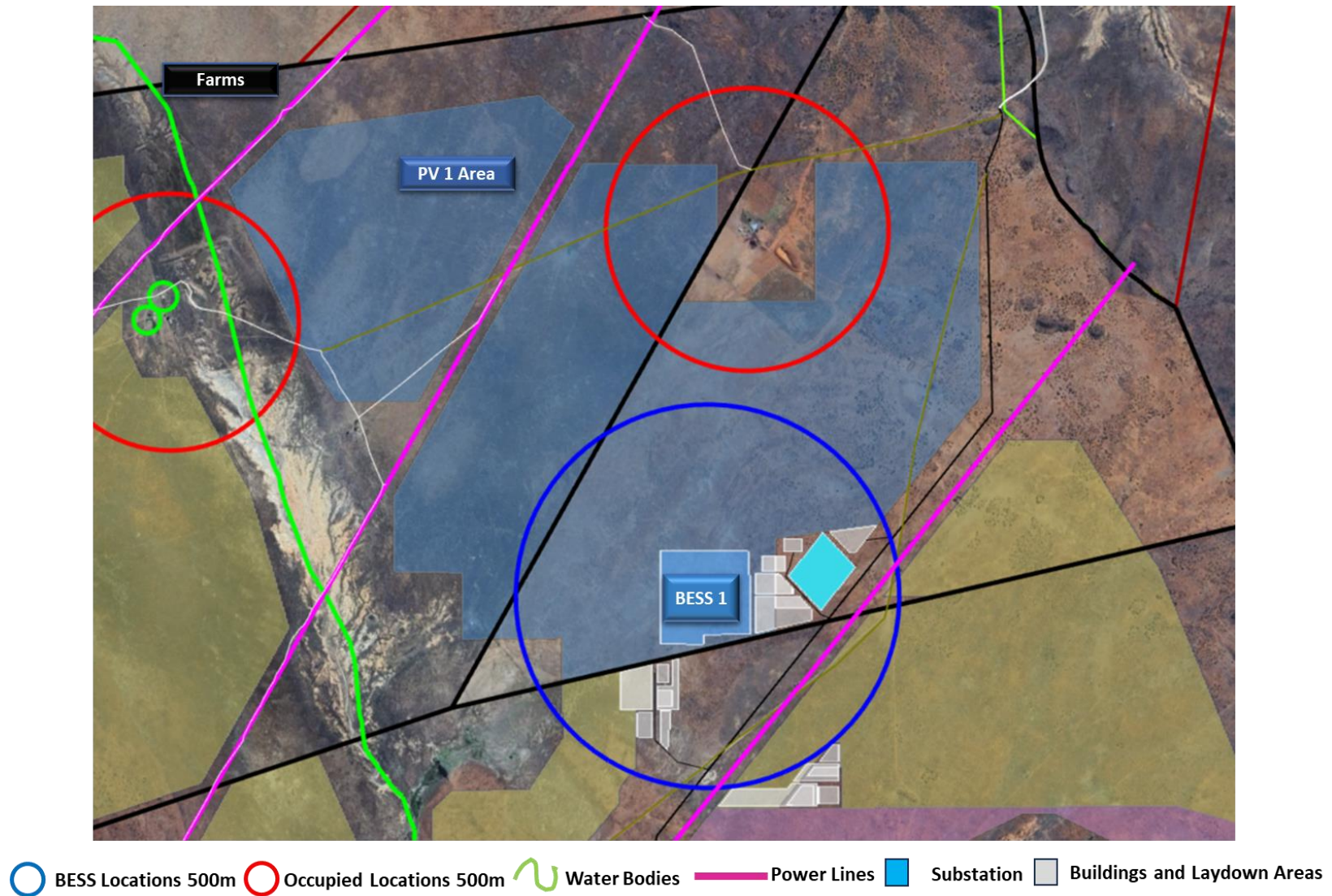


Figure 2.1.4.2 – Layout of Buildings and Substation in Relation to the BESS 2 and Key Aspects of the Surrounding Area

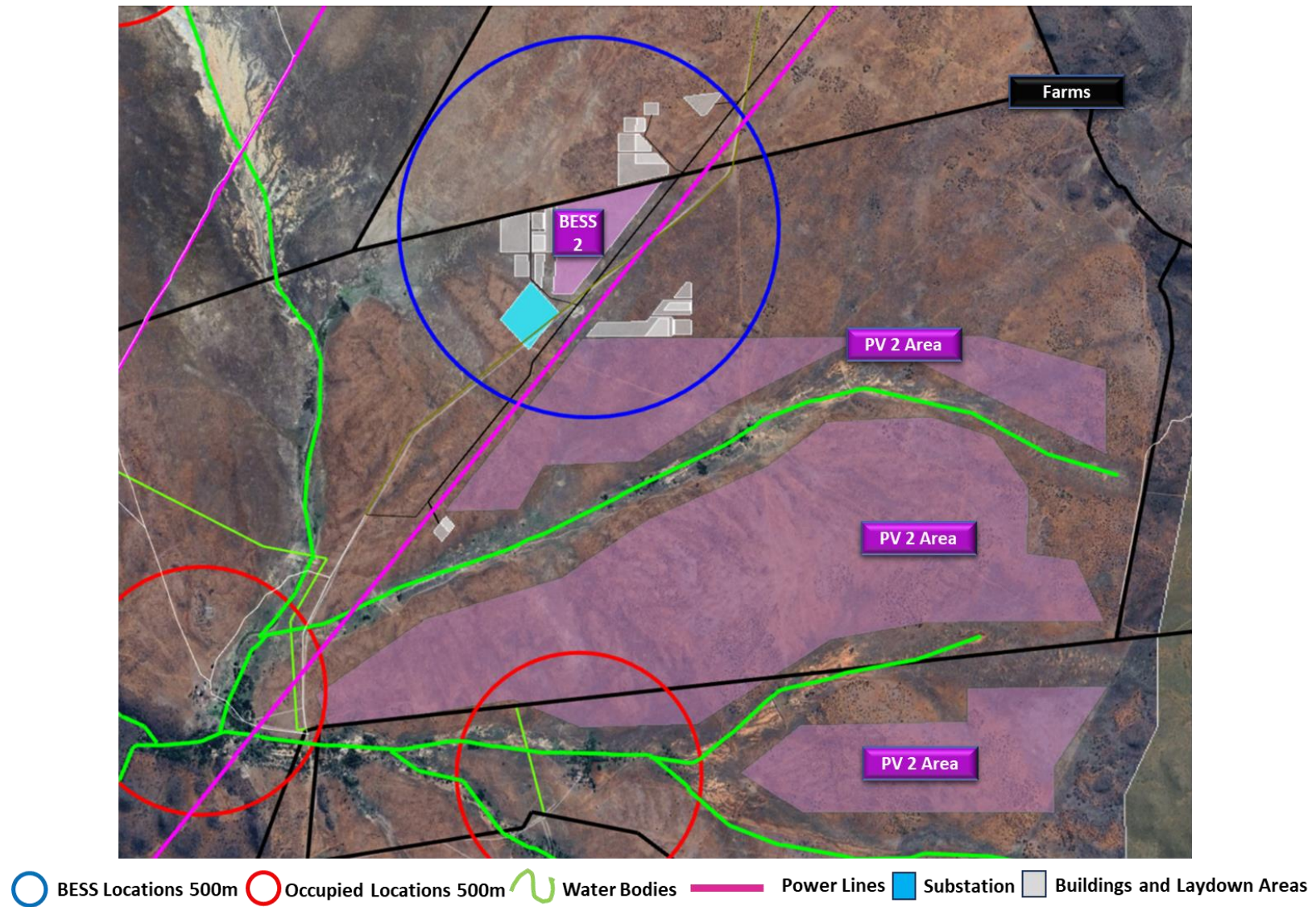


Figure 2.1.4.3 – Layout of Buildings and Substation in Relation to the BESS 3 and Key Aspects of the Surrounding Area

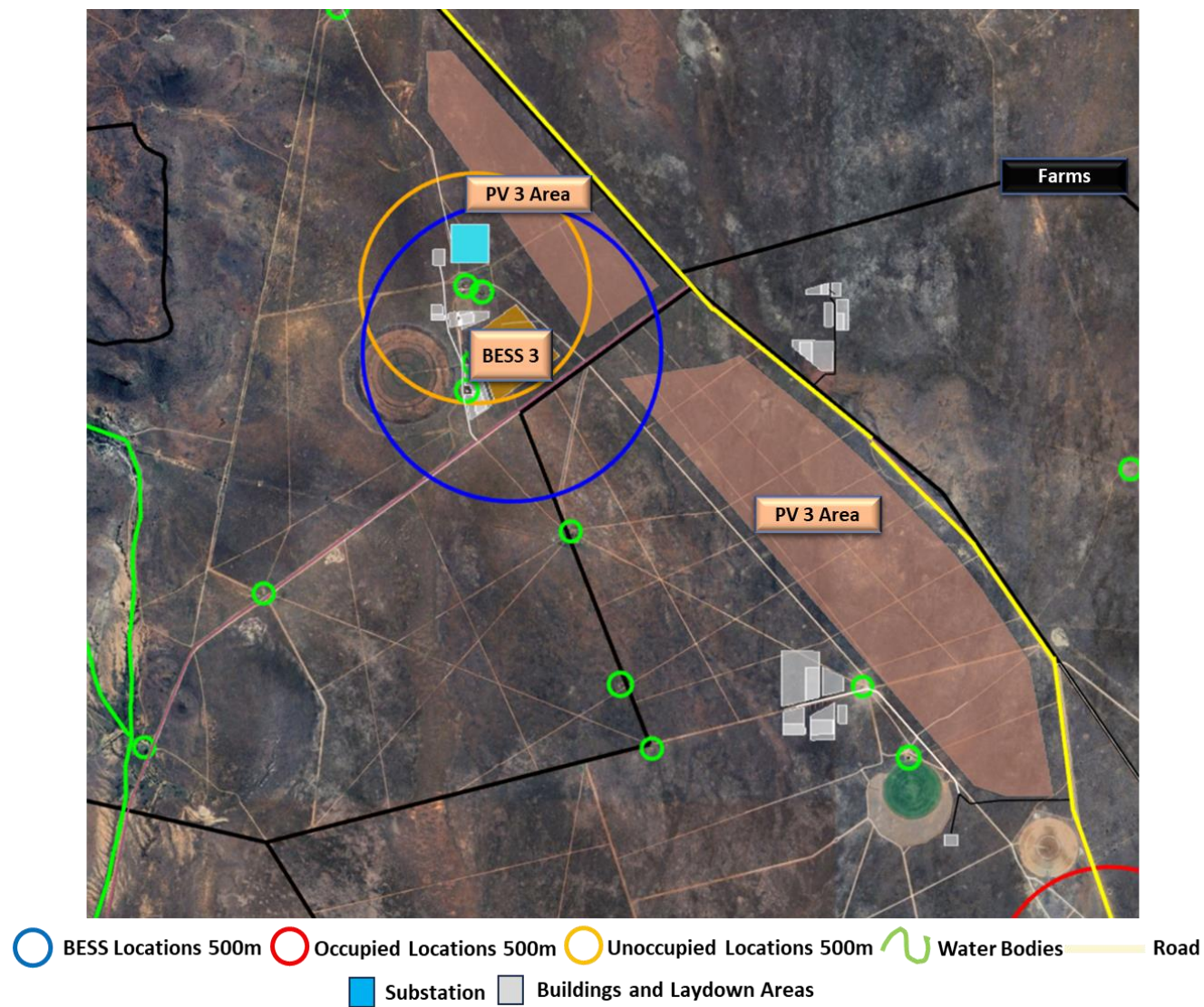


Figure 2.1.4.4 – Layout of Buildings and Substation in Relation to the BESS 4 and Key Aspects of the Surrounding Area

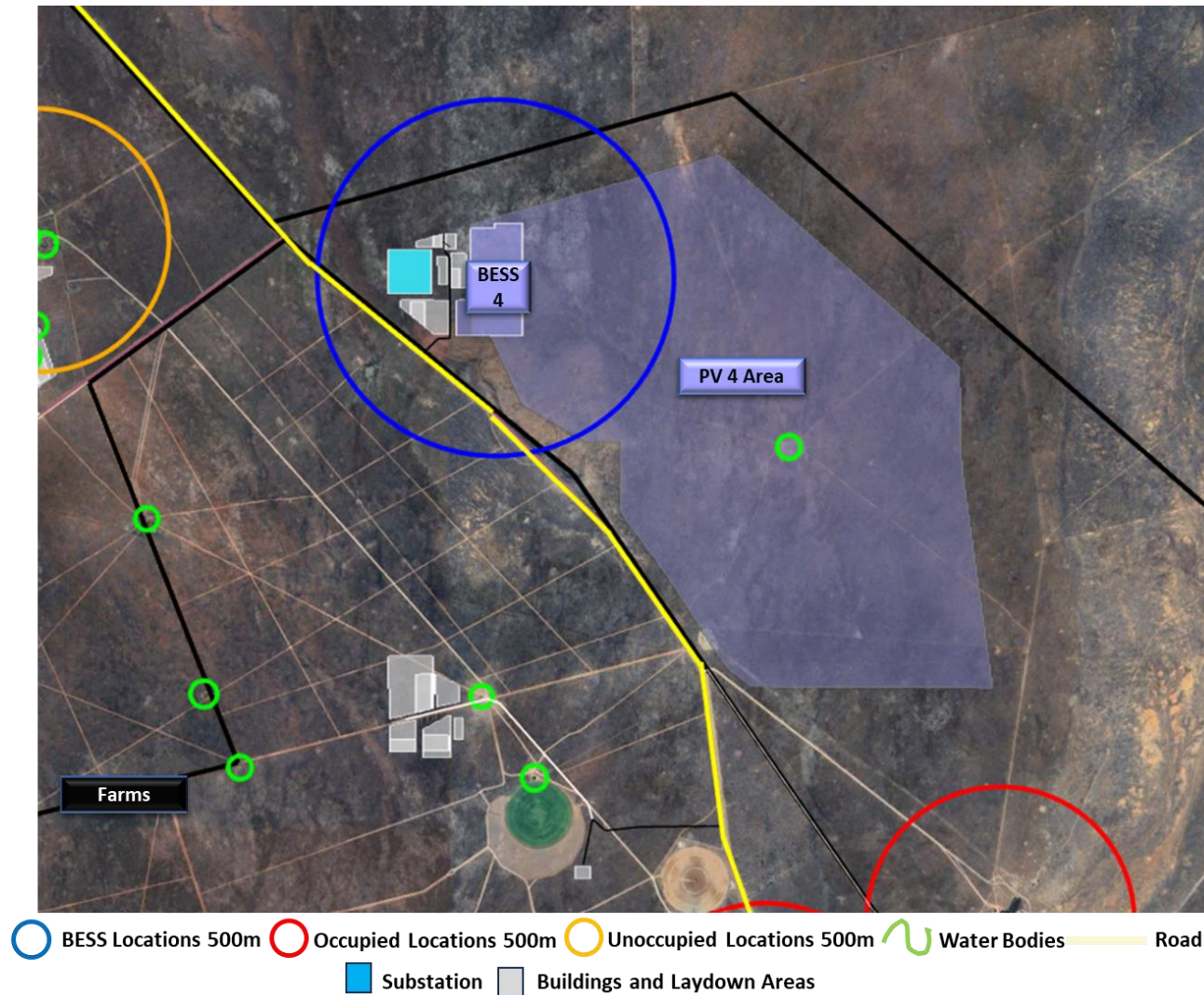


Figure 2.1.4.5 – Layout of Buildings and Substation in Relation to the BESS 5-1 and Key Aspects of the Surrounding Area

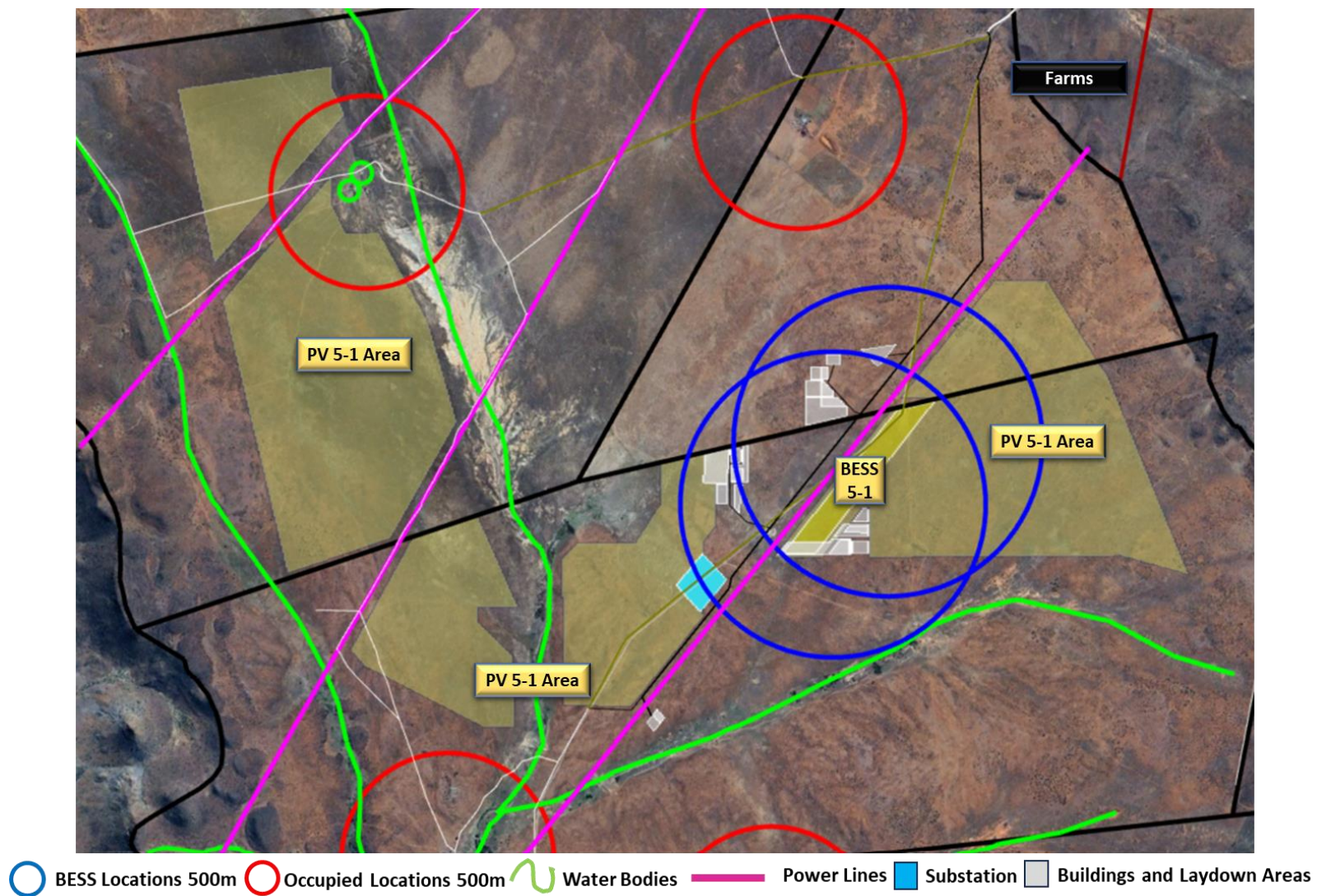
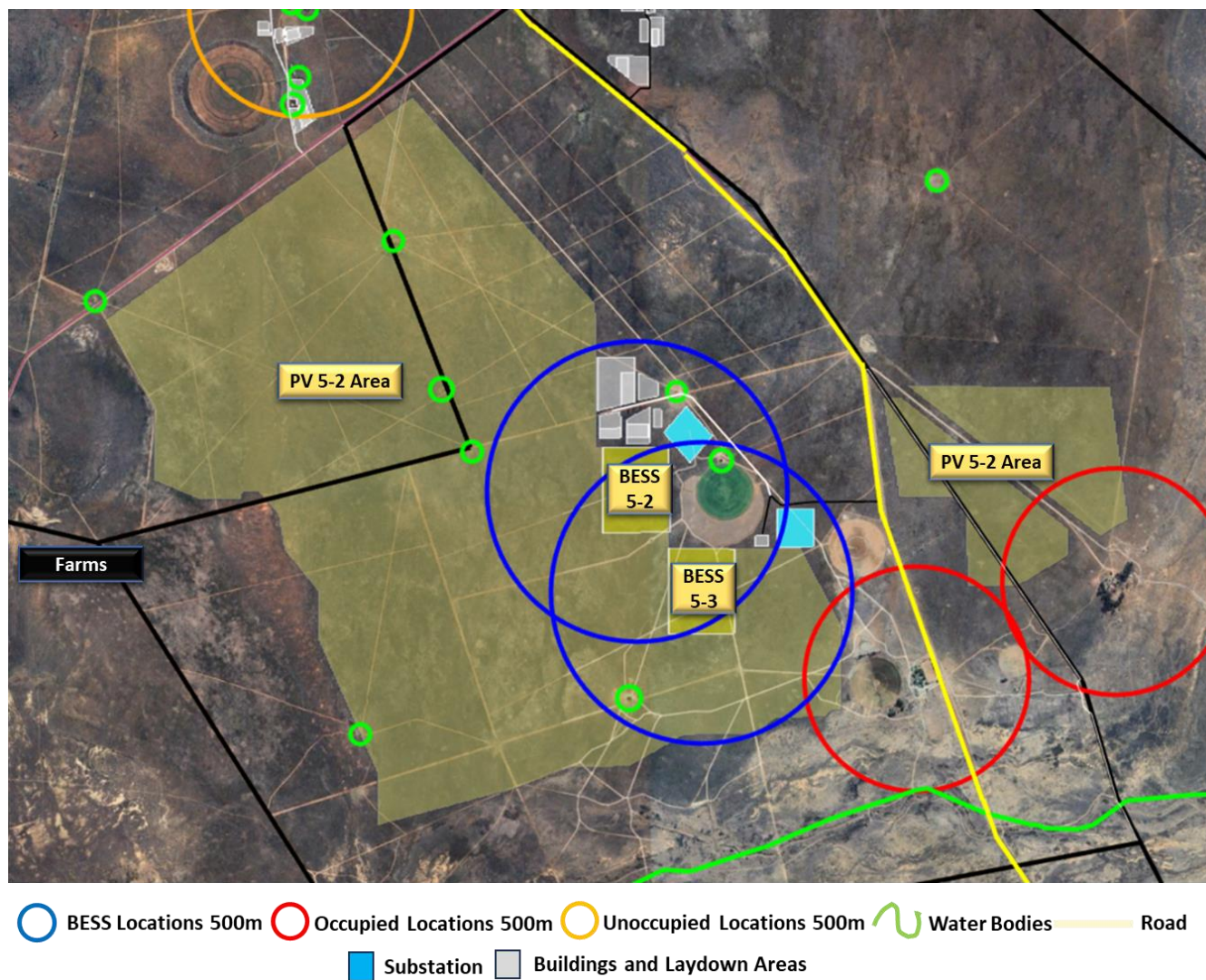


Figure 2.1.4.6 – Layout of Buildings and Substation in Relation to the BESS 5-2&3 and Key Aspects of the Surrounding Area



2.2 TOPOGRAPHY, LAND-USE AND METEOROLOGY

2.2.1 TOPOGRAPHY

The proposed site is on flat ground that is relatively high compared to the dry river valleys to the west and south.

Rainfall is in the summer with occasional thunderstorms. There are dry (seasonal) rivers on the southern and western sides of the development area with tributaries that drain from the development area. Due to the semi-arid nature of the area, these water sources, although seasonal, are critical. The closest watercourse to a proposed BESS is located over 500m south of BESS 5-1 and another is located approximately 1km west of BESS 1 & 2.

All the above rivers (dry) drain into the Orange River, and associated Vanderkloof dam, are located over 10km to the south of the proposed development area. There is a large and long irrigation canal that runs from the Orange River to agricultural lands north of Luckhoff. The canal runs south north approximately 1.5 km to the west of the development area.

There are numerous boreholes with water reservoirs (some out of commission) across the development area.

Vegetation in the area is mostly dry scrub, grass and bushes closer to water courses. Refer to the relevant EIA specialist studies for details of flora and fauna as well as water resources in the area. e.g. Aquatic Biodiversity Study.

2.2.2 LAND-USE

Refer to the relevant EIA specialist studies for details of the agricultural activities and cultural aspects in the area e.g., Agricultural Impact Study. The area is used very sparsely for agricultural activity, mostly livestock. There are few isolated farmstead developments with irrigated crops in the general area. The BESS 1, 2, 3 and 4 facilities will each occupy up to 12 ha and BESS 5-1, 2&3 together will each occupy up to 48 ha.

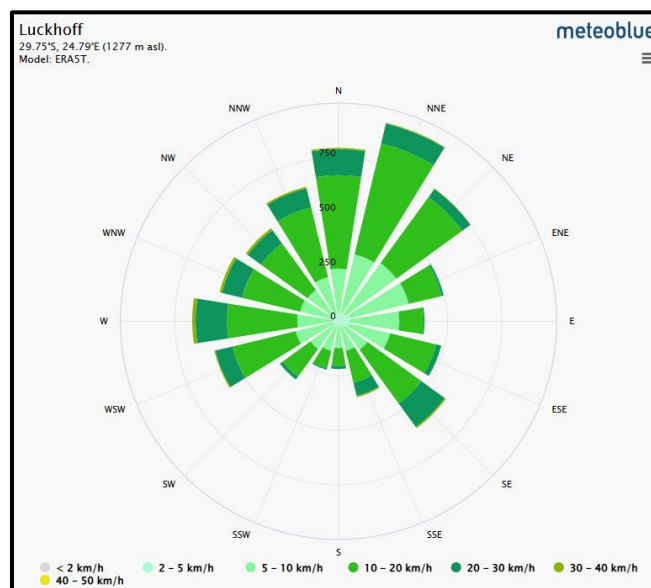
Across South Africa seismic activity is conceivable with the Free State / Gauteng (man-made activity) and the Western Cape (natural activity) being relatively higher risk areas. However, compared with aspects such as corrosion, human error etc. seismic activity is not usually a highly likely risk factor, refer to SANS 10160:2011, part 4. [Ref 24]. The civil / structural design of the BESS facilities would need to be designed in accordance with South African standards for seismic protection.

2.2.3 METEOROLOGY

The site is located 100km north of De Aar, 100km south of Kimberley and 150km west of Bloemfontein. In general the weather condition for these three locations is very similar so these weather conditions for either of these main centres (for which South Africa Weather Services can supply recent and reliable weather data) could also be applied to the site.

Refer to a wind rose below in Figure 2.2.1 and temperature and precipitation in Figure 2.2.2 (simulated historical climate and weather data from MeteoBlue).

Figure 2.2.1 Wind rose indicating the general wind conditions for the area

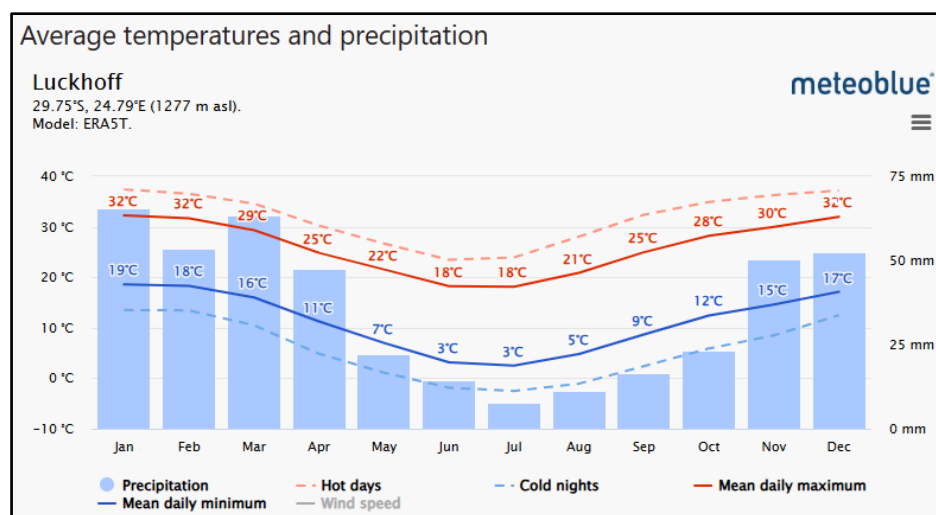


The key features of the weather patterns are:

- Winds which blow mostly from the north north east and west.
- Winds very seldom blow from south and east.
- High temperature low humidity conditions in summer during the day. Rainfall, although limited is in the summer.
- Cold conditions in winter with some precipitation.
- Temperature inversions, which trap air in a stagnant layer near the earth surface, occur on cold nights and early mornings.

The area has very little rain but long days with plenty of sunshine and summer daytime temperatures in the mid-thirties. Day night variations are typically 13 - 15 degrees Celsius.

Figure 2.2.2 Temperatures and Precipitation for the area



Across South Africa, lightning strikes are conceivable as a source of ignition of major hazards, refer to SANS10313:2012 lightning strike density table [Ref 7]. The lightning ground flash density in De Aar is 3.3 flashes/km²/year which is at the lower end of the spectrum in South Africa, e.g. Piet Retief is 15.1 flashes/km²/year and Boksburg as 12.1 flashes/km²/year while areas such as Cape Town are 0.1 flashes/km²/year. 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.

2.3 PLANT AND PROCESSES

All battery systems have an anode and a cathode with electrons migrating through an electrolyte to one electrode during charging and then towards the other during discharge. There are many different types of electrode arrangements, electrode and electrolyte chemistries and sizes of the installations, i.e. a myriad of technologies.

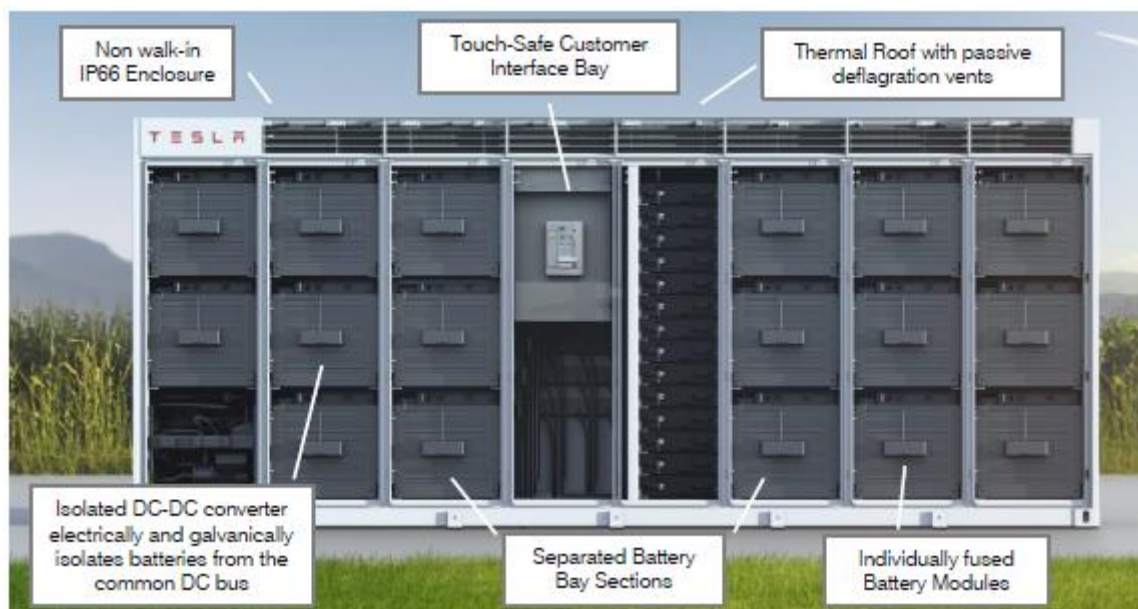
2.3.1 PROPOSED DESIGN - SOLID STATE BATTERIES – TYPICALLY LITHIUM-ION

One type of battery technology being considered for the BESS would be a Solid-State Battery which consists of multiple battery cells that are assembled together to form modules. Each cell contains a positive electrode, a negative electrode and an electrolyte which is mostly solid but can contain a small amount of liquid/polymer. The BESS will comprise of multiple battery units or modules housed in shipping containers and/or an applicable housing structure which is delivered pre-assembled to the project site. Containers are usually raised slightly off the ground and layout out is rows. They can be stacked if required although this may increase the risk of events in one container spreading to another container. Supplementary infrastructure and equipment may include substations, power cables, transformers, power converters, substation buildings & offices, HV/MV switch gear, inverters and temperature control equipment that may be positioned between the battery containers. The solid-state batteries that are being considered are Lithium-ion systems. The pictures in Figure 2.3.1.1 are typical BESS installations servicing renewable power farms. Figures 2.3.1.2 & 2.3.1.3 show typical battery modules in the BESS facility.

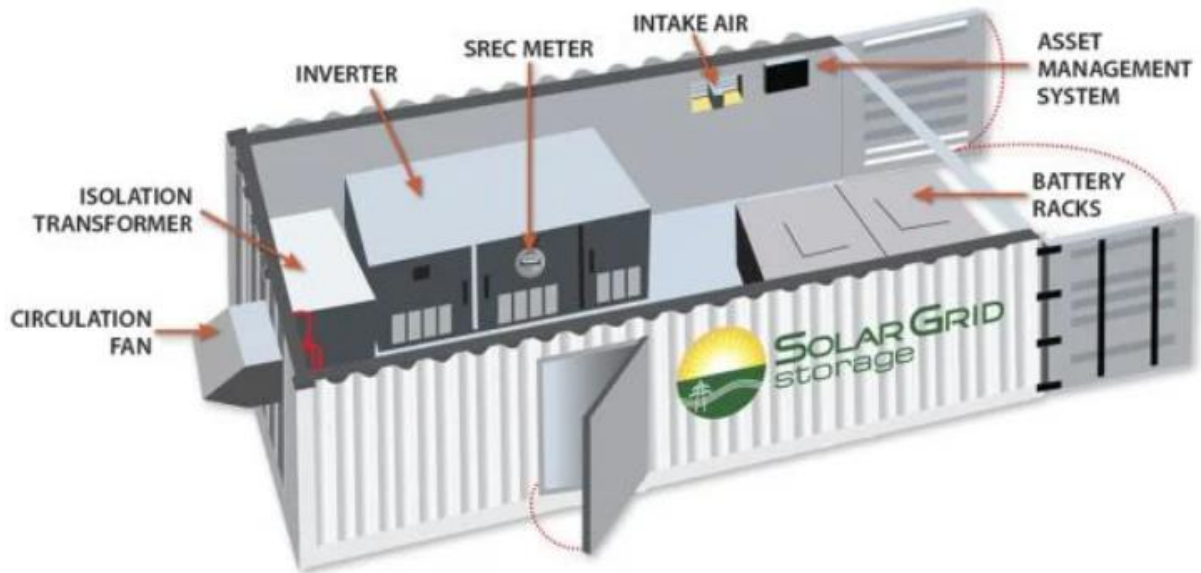
FIGURE 2.3.1.1 – Images of Typical BESS Systems Servicing Renewable Power Farms



FIGURE 2.3.1.2 – Typical Battery Modules in a BESS with the Separated Sections

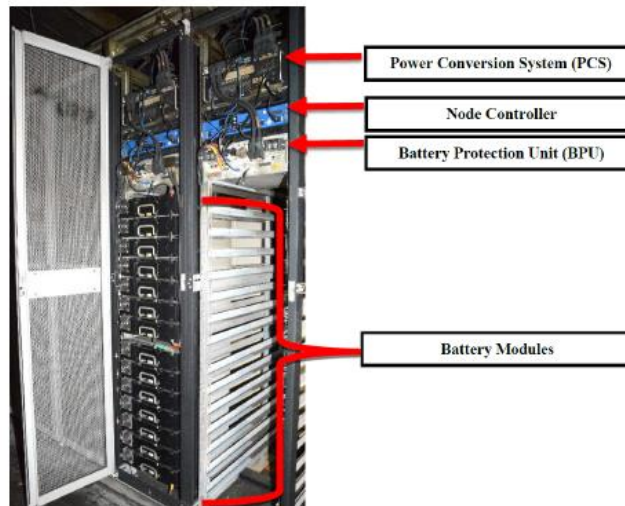


Source – Tesla MegaPack – Safety Overview



Source – Tesla MegaPack – Safety Overview

FIGURE 2.3.1.3 – Typical Battery Modules in a BESS with the Power Conversion Systems in with the Batteries



Source – DNV-GL McMicken Event Analysis

2.3.2 PROPOSED DESIGN - REDOX FLOW BATTERIES – TYPICALLY VANADIUM

One of the types of battery technology being considered for the Battery Energy Storage System (BESS) would be Redox Flow Batteries, typically Vanadium chemistry based (VRFB). These energy storage systems can be supplied either as containerized units or as a fixed installation within a building etc. In order to highlight the maximum differences between the possible technology types, this study is based on the assumption that redox flow batteries (typically vanadium based chemistry) would most likely be installed within a building using bulk tanks, while solid state batteries (typically lithium based chemistry) would be installed in shipping containers that have hundreds of individual batteries combined into packs. Redox flow batteries can be installed in containers

where the individual quantities of electrolyte involved would be smaller but still significant. For this project (2 000 MW) there could be up to 3 000 containers, each with six 25m³ tanks of electrolyte within the containers, hence approximately 450 000 m³ of electrolyte in the entire project. Each container acts as bund (secondary containment) able to hold at least the volume of one tank.. The pictures in Figure 2.3.2.1&2 are typical Redox Flow BESS installations.

FIGURE 2.3.2.1 – Images of Some Redox Flow BESS Systems – containerized systems or buildings with tanks of electrolyte and battery systems

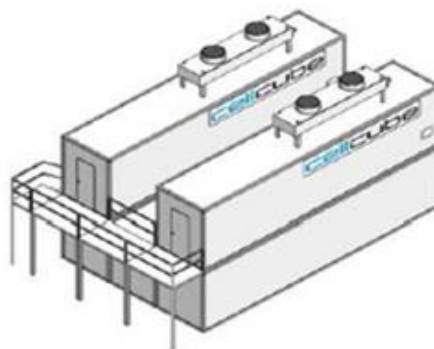


1 MW 4 MWh containerized vanadium flow battery owned by Avista Utilities and manufactured by UniEnergy Technologies



Source – Redox flow batteries for renewable energy storage, 21 Jan 2020, J Noak, N Roznyatovskaya, C Menictas, M Skyllas-Kazacos





Source – Bushveld Minerals and Energy – Energy Storage and Vanadium Redox Flow batteries 101 – 13 November 2018.
And general Product Info 2023

Within each unit, battery cells assembled together to form stacks, the image below showing a view of typical stack.

FIGURE 2.3.2.2 – Typical Battery Cell and Stack Set-up



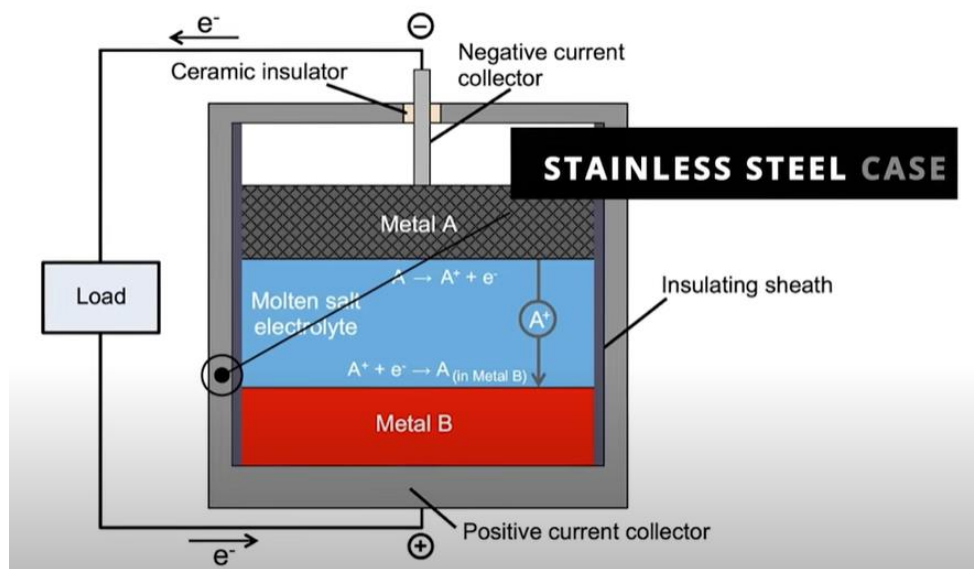
Stacks of a 2MW/20MWh vanadium redox flow battery at Fraunhofer ICT. Image:

2.3.3 PROPOSED DESIGN – MOLTEN METAL BATTERIES – TYPICALLY AMBRI

One of the types of battery technology being considered for the Battery Energy Storage System (BESS) would be Molten Metal batteries, typically the AMBRI Technology. These energy storage systems can be supplied as containerized units.

The liquid metal battery is comprised of a liquid calcium alloy anode, a molten salt electrolyte and a cathode comprised of solid particles of antimony. The picture in Figure 2.3.3.1 are typical Molten Metal batteries.

FIGURE 2.3.3.1 – Images of Molten Metal BESS Systems – containerized battery systems



2.3.4 STAFF AND SHIFT ARRANGEMENT

The BESS facilities will run 7 days a week for 24 hours a day. Although the system will be largely automated with a battery management system and electronic operator interface etc, it will still require attention from operators and maintenance staff. The facility will need routine checking / preventative and breakdown maintenance / grass cutting / security etc. During normal operations there are assumed to be approximately 10 persons on site during the day depending on the activities taking place and possibly one or two operators as well as security personnel at night.

2.3.5 OPERATIONS AT THE BESS FACILITY AND PHASES OF THE BESS PROJECT

The BESS 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 follow together with some details:

TABLE 2.3.4.1 – Project Phase with Main Processes/Activities and Some Details of Likely Elements

No	PHASE	MAIN PROCESSES	DETAILS
1.1	Construction of both types of battery technology	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 containers, diesel bowser for fuel for machines, oil for machines
1.2		Materials for the construction of the Vanadium Redox Flow Battery (VRFB) building itself	Building materials such as bricks, cement, re-bar, I-beams, roof sheeting etc.
		Equipment items for installations within the VRFB building	BESS equipment such as tanks, pumps, piping etc.
		Equipment items for containerized installation e.g., lithium battery containers	Electrical equipment such as transformers, pylons, cabling.
		Equipment items for containerized installation e.g., lithium battery containers	Battery containers
1.3		Waste e.g., packaging materials, paint	Electrical equipment such as transformers, pylons, cabling.
1.4		Construction camp	Connections, transformers, switches etc will likely have protective coverings (Plastic, paper, cable ties etc) to remove during installation, paint waste (cans, brushes, solvents), building rubble
2.1	VRFB Operation	Chemical electrolyte and electrode materials in the battery cell	Temporary offices, accommodation, ablutions
2.2		Battery cells, stacks	Tanks, pumps and pipes containing vanadium electrolyte.
2.3		Electronic equipment in building	The batteries will be able to generate up to 2 000 MW of power - combined.
2.4		Electrical equipment inside	The electrolyte storage will have capacity to dispatch up to 8 000 MWh ~ 3 000 containers.
2.5		Support mechanical equipment	Battery management system for monitoring of the batteries and control of the loading and unloading cycles
2.6		Electrical equipment outside	Power conversion system, connections, switches, cabling
2.7		Site office and workshop	Air conditioners, fans, coolant
2.8		Support services	Network interconnection equipment, switchgear, transformers
2.9		Waste	Including potable water, 220V power, kitchen, sewage, tools and parts store etc
2.10	Lithium-ion based Solid State Operation	Chemical electrolyte and electrode materials in the battery cell	Dirt roads, access control fences, lights inside the container and outside for general access lighting, fire suppression/fighting systems, grass cutting, communication systems
2.11		Battery cells, modules and racks typically in shipping containers	Broken parts, storm water run-off, hot air from battery and PCS cooling systems, waste electrolyte from maintenance or other spills
			Will be solid state lithium-ion batteries with limited liquid electrolyte quantities contained within the solid phase electrolyte
			The facilities are designed for 8 000 MWh having typically ~ 2 600 containers (for example, each Tesla Megapack has up to 3 MWh of storage and 1.5 MW of inverter capacity, other units only have a power rating of just over 0.7 MW per container)

2.12		Electronic equipment in container	Battery management system for monitoring of the batteries and control of the loading and unloading cycles
2.13		Electrical equipment in container or separate container	Power conversion system, connections, switches, cabling
2.14		Mechanical equipment in container(s)	Air conditioners, fans, filters, coolant
2.15		Electrical equipment outside the containers	Network interconnection equipment, switchgear, transformers
2.16		Site office and workshop	Including potable water, 220V power, kitchen, sewage, tools and parts store etc
2.17		Support services	Dirt roads, access control fences, lights inside the container and outside for general access lighting, fire suppression/fighting systems, grass cutting, communication systems
2.18		Waste	Broken parts, storm water run-off, hot air from battery and PCS cooling systems
2.19	Molten metal Operation	Chemical electrolyte and electrode materials in the battery cell	Battery casings containing solid particles of metals and salt electrolyte.
2.20		Battery cells, stacks	The batteries will be able to generate up to 2 000 MW of power. The electrolyte storage will have capacity to dispatch up to 8 000 MWh.
2.21		Electronic equipment in building	Battery management system for monitoring of the batteries and control of the loading and unloading cycles
2.22		Electrical equipment inside	Power conversion system, connections, switches, cabling
2.23		Support mechanical equipment	Air conditioners, fans, coolant
2.24		Electrical equipment outside	Network interconnection equipment, switchgear, transformers
2.25		Site office and workshop	Including potable water, 220V power, kitchen, sewage, tools and parts store etc
2.26		Support services	Dirt roads, access control fences, lights inside the container and outside for general access lighting, fire suppression/fighting systems, grass cutting, communication systems
2.27		Waste	Broken parts, storm water run-off, hot air from battery and PCS cooling systems, waste batteries (salts and solid metals) from maintenance or other spills
3.1	Decommissioning both types of battery technology	VRFB Liquid chemical waste	Waste electrolyte solution, transformer oils, coolants
		Solid State Lithium and Molten Metal chemical waste	Batteries, air filters, transformer oils, coolants
3.2		Electronic waste	Circuit boards, HMI screens
3.3		Building rubble - non-hazardous waste	Steel, copper, cement, equipment and structures
3.4		VRFB Hazardous waste	Contaminated equipment such as pumps, pipes, bund linings
3.5		Battery Containers	Shipping containers

3. HAZARD IDENTIFICATION

3.1 LITHIUM-ION BATTERY CHEMICAL HAZARDS

3.1.1 LITHIUM BATTERIES IN GENERAL

One of the battery types being considered by the project proponent is lithium-ion based batteries.

Lithium-ion based battery systems are becoming one of the dominant technologies for utility systems in Europe and America. For this reason, this assessment assumes that lithium-based batteries will be used in the BESS facilities.

Should sodium-based batteries be used, the hazards are likely to be similar to lithium-ion and molten metal batteries at a high level (e.g. fires with formation of noxious smoke, high operating temperatures with molten materials) but different in their details (composition of the smoke, escalation of fire with elemental molten sodium exposed to fire water). Technological advances ensure preventative measures are always improving (e.g. room temperature Na-S batteries, lithium-sulphur batteries) and if this sodium-based battery type is eventually chosen and should it be determined that mitigative measures over and above those listed in this report for lithium-ion batteries (e.g. separation distances) are needed (e.g. complete ban on water on the site so it cannot be used on fires by mistake), then these can be incorporated into the final design.

Primary (non-rechargeable) batteries use lithium metal anodes. Lithium is one of the lightest and most reactive metallic elements and is highly reactive towards water and oxygen. Exposure of lithium metal to water even as humidity can decompose exothermically to produce flammable hydrogen gas and heat. These lithium metal batteries are not used in BESS systems. However, if secondary batteries discussed below are charged at temperatures below 0 deg C, then lithium can plate out onto the anode surface and in this manner lithium metal could be present even in lithium-ion batteries.

Secondary, rechargeable lithium batteries, as used in bulk BESSs, use cathodes that contain lithium in the crystal structure of the cathode coating and/or lithium salts in an electrolyte that is in the battery. These are called lithium-ion batteries. Lithium-ion batteries operate at room temperature and have significant limitations outside the 0 – 50 deg range. The exact lithium-ion composition of the batteries can vary with suppliers. In addition, the technology allows for many combinations of chemistry to suit the particular application.

3.1.2 LITHIUM BATTERY CHEMISTRY

Generally, for all lithium-ion based batteries the anode is made of solid carbon (graphite) and the cathode of a solid lithium metal oxide or phosphate. So the cathode can be for example lithium iron phosphate or lithium nickel manganese cobalt.

In between the cathode and anode is an electrolyte through which the electrons migrate. This electrolyte can come in many different forms.

Lithium-ion liquid batteries generally have a liquid electrolyte that is typically a lithium salt in an organic solvent. The electrolytes are typically ethylene carbonate or di-ethyl carbonate. The flash points of these carbonates can vary from 18 – 145 deg C which means they can be highly flammable (FP < 60 deg C) or merely combustible if involved in an external fire (FP > 60 deg C). They may produce toxic and flammable gasses if involved in a fire.

Lithium-polymer batteries have a gel-like electrolyte that contains the lithium-ions in a flexible polymer, which is less flammable than the liquid solvent based system.

Lithium-solid state batteries have an electrolyte that contains the lithium-ions in a solid matrix that can be either an inorganic solid, solid polymer, polymer ceramic composite or a metal organic framework. These solid electrolyte have the advantage that they cannot leak out if the battery is damaged and that they can be made of non-flammable materials reducing the fire hazards. Some of the lithium compound in the electrolyte include lithium hexafluorophosphate, lithium perchlorate, lithium cobalt oxide etc.

3.1.3 HAZARD - THERMAL DECOMPOSITION

Upon heating of the contents of a battery due to shorting (e.g. due to dendrite formation, physical damage, water ingress etc), contaminants, external heat or exposure to water and reaction heat, the lithium salts in batteries can begin to break down exothermically to release either oxygen (oxidants) that enhances combustion, possibly leading to explosion, or fumes such as hydrogen fluoride or chlorine that are toxic.

These exothermic break down reactions are self-sustaining above a certain temperature (typically 70 deg C for liquid batteries and) and can lead to thermal run away. In this process the battery gets hotter and hotter, the decomposition reactions happen faster and faster and excessive hot fumes are generated in the battery. Eventually the pressure in the battery builds up to the point where those gases need to be vented, usually via the weakest point in the system. These vented fumes can be flammable due to vaporization of the electrolyte (especially if liquid solvents but generally if hydrocarbon based) and can ignite as a flash fire or fire ball (if large amounts) leading to the fire spreading to any surrounding combustible materials, e.g., plastic insulation on cables, the electrolyte, the electrodes and possibly even the plastic parts of the battery casing etc. If the vented flammable vapours do not ignite immediately, they can accumulate within the surrounding structures. If this flammable mixture is ignited later, e.g., due to a spark, this can lead to a violent explosion of the module, cabinet, room, container etc.

In addition to being flammable the vented gases will contain toxic components. These could include:

- the products of combustion such as carbon dioxide/monoxide, hydrogen cyanide,
- VOCs like benzene and ethylene,
- Depending on the exact battery chemical composition, decomposition products such as hydrogen fluoride, hydrogen chloride, phosphorous pentafluoride, phosphoryl fluoride and oxides of aluminium, cobalt, copper etc.

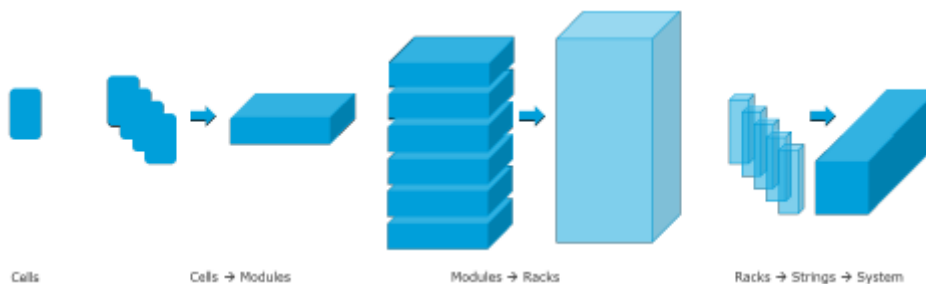
The temperature in the batteries and of these vented gases can be extremely high, e.g., > 600 deg C.

In the situation where oxygen is released internally as part of the decomposition (e.g., lithium perchlorate) the oxygen is available to react with the combustible electrolyte and if all this happens extremely fast in a self-sustaining manner within the confines of the device, an explosion of the device can occur with only localized impacts.

3.1.4 HAZARD - PROPAGATION

A BESS is composed of individual batteries which are combined into different size packs such as modules and racks, as illustrated on the diagram below.

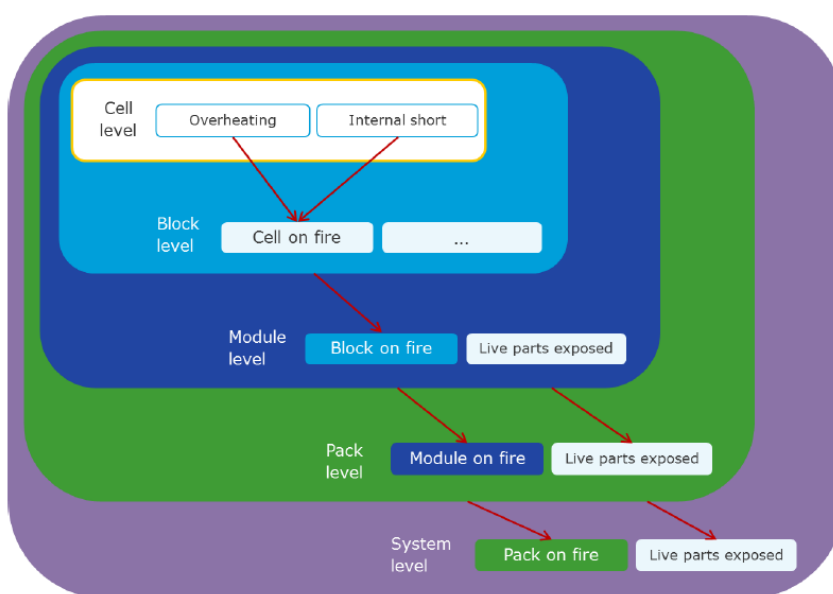
Figure 3.1.4.1 - Diagram of battery structure



Source DNV-GL McMicken Event Analysis

The very high temperature generated by one battery cell in thermal run away could lead to overheating of adjacent cells. This cell in turn then starts thermal decomposition and so the process propagates through the entire system, as illustrated on the diagram below.

Figure 3.1.4.2 - Diagram of battery fire propagation



Source – STALLION Report

In order to prevent propagation, there are separation requirements between cells, modules, etc. Separation could be with physical space or insulating materials, etc.

3.1.5 HAZARD - ELECTROLYTE LEAKS FROM LIQUID PHASE BATTERIES

In the case of liquid or polymer batteries, although extremely unlikely due to the structure of the batteries, should electrolyte liquid leak out of the batteries, it can be potentially flammable as well as corrosive etc. If ignited as fire, or explosion, the smoke would contain toxic components. If unignited it can still be extremely harmful especially if its decomposition products include hydrofluoric acid (sulphur dioxide etc).

One of the main safety advantages of solid state batteries is that flammable electrolyte leaks are not possible.

3.1.6 HAZARD – ELECTRICAL SHOCK/ARC

Electrical shock presents a risk to workers and emergency responders, if the energy storage system cannot be “turned off”. This is referred to as “stranded energy” and presents unique hazards. Arc flash or blast is possible for systems operating above 100 V. Li-ion systems operate from 48 - 1000 V, depending on the battery design.

3.2 VANADIUM REDOX FLOW BATTERY HAZARDS

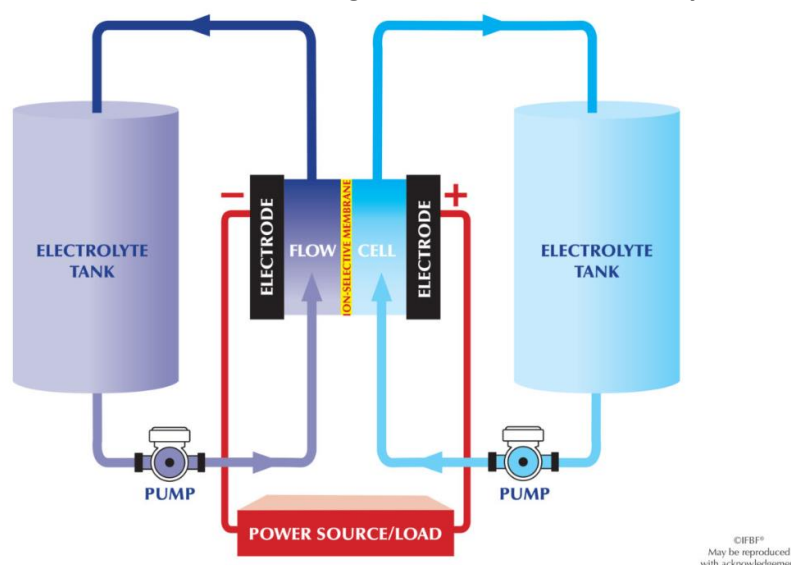
At this stage, the preferred battery technology is Redox flow (typically vanadium chemistry).

3.2.1 REDOX FLOW BATTERIES IN GENERAL

All electrochemical energy storage systems convert electrical energy into chemical energy when charging, and the process is reversed when discharging. With conventional batteries, the conversion and storage take place in closed cells. With redox flow batteries, however, the conversion and storage of energy are separated. Redox flow batteries differ from conventional batteries in that the energy storage material is conveyed by an energy converter. This requires the energy storage material to be in a flowable form. In redox flow batteries, charging and discharging processes can take place in the same cell. Redox flow batteries thus have the distinguishing feature that energy and power can be scaled separately. The power determines the cell size, or the number of cells and the energy is determined by the amount of the energy storage medium. In theory, there is no limit to the amount of energy that can be produced and/or stored thereby allowing for scalability of these systems.

Figure 3.2.1 shows the general operating principle of redox flow batteries. The energy conversion takes place in an electrochemical cell which is divided into two half cells. The half cells are separated from each other by an ion-permeable membrane or separator, so that the liquids of the half cells mix as little as possible. The separator ensures a charge balance between positive and negative half cells, ideally without the negative and positive active materials coming into direct contact with each other. In fact, however, separators are not perfect so some cross-over of the active materials always occurs and this leads to the self-discharge effect.

FIGURE 3.2.1 – Schematic Diagrams of Redox Flow BESS Systems



Source – International Flow Battery Forum

3.2.2 VANADIUM BATTERY CHEMISTRY

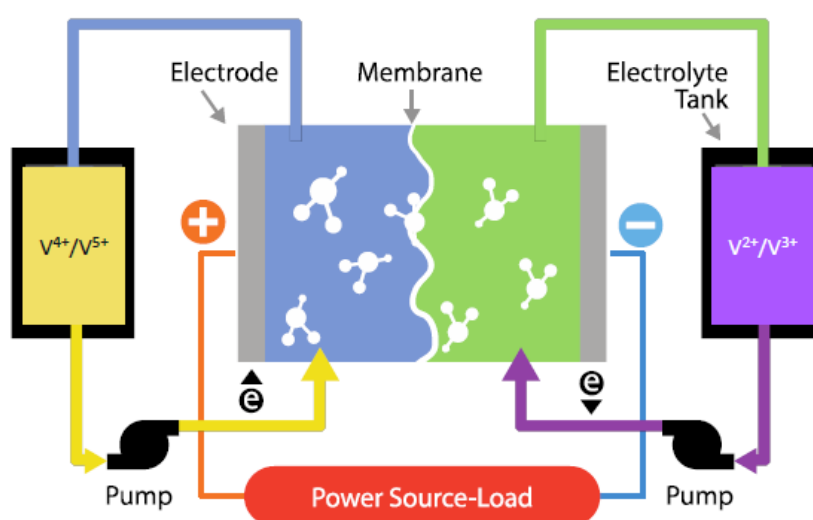
The vanadium redox battery (VRB), also known as the vanadium flow battery (VFB) or vanadium redox flow battery (VRFB), is a type of rechargeable flow battery that employs vanadium ions in different oxidation states to store chemical potential energy. The vanadium redox battery exploits the ability of vanadium to exist in solution in four different oxidation states, and uses this property to make a battery that has just one electroactive element instead of two.

The possibility of creating a vanadium flow battery was explored by Pissort in the 1930s, https://en.wikipedia.org/wiki/Vanadium_redox_battery NASA researchers in the 1970s, and Pellegrini and Spaziant in the 1970s, but none of them were successful in demonstrating the technology. The first successful demonstration of the all-vanadium redox flow battery which employed vanadium in a solution of sulfuric acid in each half was by Maria Skyllas-Kazacos at the University of New South Wales in the 1980s. In redox flow batteries, the electrodes should not participate in the reactions for energy conversion and should not cause any further side reactions (e.g., undesirable gas formation). Most redox flow batteries are therefore based on carbon electrodes.

The redox pair $\text{VO}_2^+/\text{VO}_2$ are at the positive electrode and the redox pair $\text{V}^{2+}/\text{V}^{3+}$ at the negative electrode. The use of the same ions in the positive and negative electrolytes permits relatively high concentrations of active material. It also overcomes the cross-contamination degradation issues which plague other flow type batteries. The energy storage solution consists primarily of vanadium sulphate in a diluted (2mol/L) sulphuric acid (possibly containing a low concentration of phosphoric acid) and is therefore roughly comparable to the acid of lead/acid batteries. The energy density is limited by the concentration of the pentavalent VO_2^+ .

The vanadium redox flow battery is without doubt the best investigated and most installed redox flow battery. For several reasons, including their relative bulkiness, most vanadium batteries are currently used for grid energy storage, i.e., attached to power plants or electrical grids. Currently, there are over 100 VRFB installations globally with an estimated capacity of over 209,800 kWh of energy and the use of vanadium in energy storage applications has doubled to 2.1% of the global vanadium consumption in 2018.

FIGURE 3.2.2 – Schematic Diagrams of Vanadium Redox Flow BESS



Source: IEEE Spectrum: "It's Big and Long-Lived, and It Won't Catch Fire: The Vanadium Redox-Flow Battery", 26 October 2017

3.2.3 HAZARD – TOXICITY AND CORROSIVITY

The electrolyte in the VRFB system is corrosive. It is composed of a sulphuric acid-based solution similar to common automotive lead acid batteries. Unlike traditional lead-acid batteries, VRBs do not include lead. Therefore, VRBs do not have the toxicity issues of lead that conventional car batteries have. The only potential source of human toxicity in a VRB is Vanadium.

Vanadium in various physio-chemical states can have a relatively high aquatic and human toxicity. Acute oral exposure to high doses can lead to hemorrhaging, while chronic exposure leads to adverse effects on the digestive system, kidneys and blood (diarrhea, cramps etc.).

Inhalation hazards lead to irritation of the respiratory tract, bronchospasm, pulmonary congestion. There is little evidence that vanadium compounds are reproductive toxics or teratogens. There is also no evidence that it is carcinogenic (Source USA EPA Risk Assessment Information Systems, Toxicity Profiles, Vanadium 1998).

In the electrolyte the concentration levels of Vanadium are so low that when it is mixed into liquid form in the final product and put into operation, the VRB is deemed non-toxic. In addition, VRBs have a lower concentration of sulfuric acid than traditional lead-acid batteries. Vanadium poses a hazard when it is in powder form, i.e. when making up the electrolyte solution. The Vanderkloof facilities will purchase electrolyte already made up and there will be no solid vanadium powder on site.

Toxicity or corrosion risks may be present from off-gassing produced by over-heating aqueous or vaporized electrolytes. In addition, flow batteries in fire scenarios may generate toxic gas from the combustion of hydrocarbons, plastics, or acidic electrolytes. Refer to sections on fire below for mitigation measures.

3.2.4 HAZARD – ELECTRICAL SHOCK/ARC

Electrical shock presents a risk to workers and emergency responders, if the energy storage system cannot be “turned off”. This is referred to as “stranded energy” and presents unique hazards. Arc flash or blast is possible for systems operating above 100 V.

In the area of shock hazard, a flow battery produces Voltage only when electrolytes are in a cell stack. For most designs, if the motors are turned off and fluids drained from the cell stack, then the cell stacks have no measurable Voltage at the terminals. This happens not only when the battery is forcible turned off but also in the standby mode as vanadium batteries do not include any metal plates to hold the chemical reactions / charges / Voltage and can be fully drained when not in use.

If not fully drained, vanadium flow batteries are also unique in terms of short circuiting in that the internal dynamics of the battery are such that the energy discharge is limited to the fluid in the battery at any given time and the is typically less than 1% of the total stored energy. Therefore, together with the relatively low energy density of the vanadium electrolyte, the immediate release of energy, which occurs as a result of electrical shorting, is somewhat limited. The high heat capacity of the aqueous electrolyte is also beneficial in limiting the temperature rise.

Vanadium flow batteries have been tested under dead-short conditions resulting in normal operation with no danger to either equipment or personnel.

3.2.5 HAZARD – FIRE / DEFLAGRATION

Over 50% of the electrolyte solution is made up of water, which gives the electrolyte a non-flammable property. In the event of short circuiting, intense heat or high pressure, it is unlikely for the battery to catch fire. There is no “thermal runaway” risk when compared to other battery technologies.

Whilst some heat may be discharged from the battery, it will not be at a level that is deemed unsafe.

Like all other RFBs, VRFBs also have a battery management system. A battery management system ensures optimum and safe conditions for battery operation. Often a heat management system is integrated to avoid too high or too low temperatures.

3.2.6 HAZARD - HYDROGEN GENERATION

As with all other aqueous batteries, aqueous energy storage media from redox flow batteries are also subject to water limitations. In case of too high voltage or more precisely too high or too low half-cell potentials, the water is decomposed into its components, hydrogen and oxygen.

The generation of hydrogen in particular is often present as a very small but undesirable side reaction and causes a charge carrier imbalance between positive and negative half-cells, which leads to a slow loss of capacity. It also presents a fire / explosion hazard although in most cases it can be safely vented.

With VRFB, due to the flowability of the energy storage medium, the reaction products that would normally remain in the half-cell can be transported out of the cell and stored in separate tanks thus allowing the capability for a higher capacity than that attainable with conventional batteries. In addition, any deviations from safe operating parameter will trigger the shutdown of the system pumps ceasing to charge the electrolyte and thereby reducing the chances of accidental H₂ generation. In addition, the thermal mass of the electrolyte tanks can provide an additional barrier to overcharging conditions by allowing ambient temperature during the discharge times to cool the VRFB for the next charge cycle.

3.2.7 HAZARD – WASTE ELECTROLYTE

Unfortunately, pentavalent vanadium ions have a tendency to react with each other, which leads to the formation of larger molecules which precipitate as solids and can thus damage the system. The reaction depends on the temperature and the concentration of VO₂⁺ (state of charge) but is also a function of the proton concentration. Temperature and concentrations therefore need to be controlled within specified ranges.

Should the concentration of undesirable components increase in the electrolyte, a part may need to be purged and replaced with fresh electrolyte. There may be facilities for regenerating purged electrolyte or it may have to be disposed of to a suitable hazardous waste facility.

3.2.8 HAZARD - ELECTROLYTE LEAKS

Leaks must be expected in any hazardous-fluid handling equipment. Secondary containment is typically designed into the system and standard corrosive PPE is required for handling liquid. Reliable leak detection, warning alarms, and containment is paramount. As with any chemicals plant, a suitable design with detection, alarm and trip instrumentation that has been subject to thorough Hazop study should be in place, e.g., detection of dry running of pumps, detection of dead heading of pumps, prevention of reverse flow, detection of drop in tank levels etc.

3.3 LIQUID METAL BATTERY HAZARDS

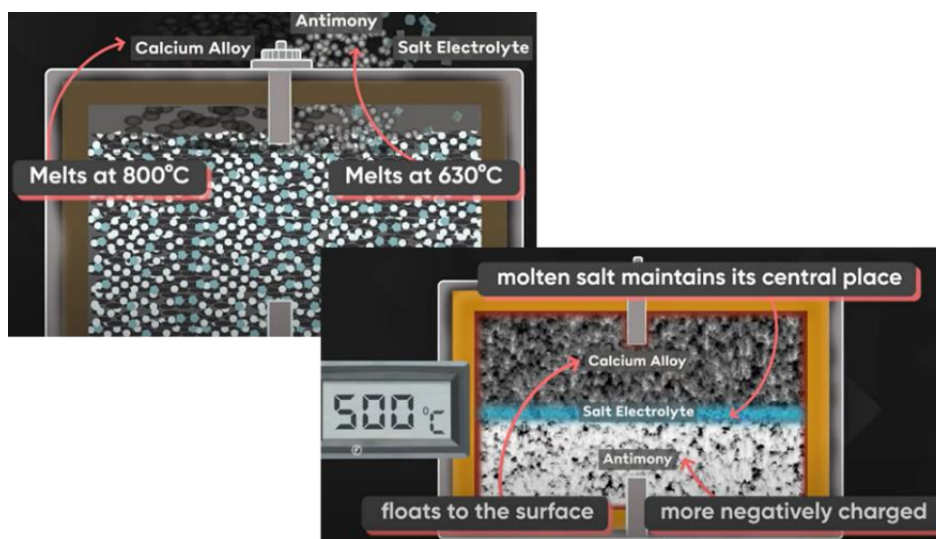
3.3.1 LIQUID METAL BATTERIES IN GENERAL

All electrochemical energy storage systems convert electrical energy into chemical energy when charging, and the process is reversed when discharging. The liquid metal battery is comprised of a liquid metal anode, a molten salt electrolyte and a liquid metal cathode.

3.3.2 LIQUID METAL BATTERY CHEMISTRY

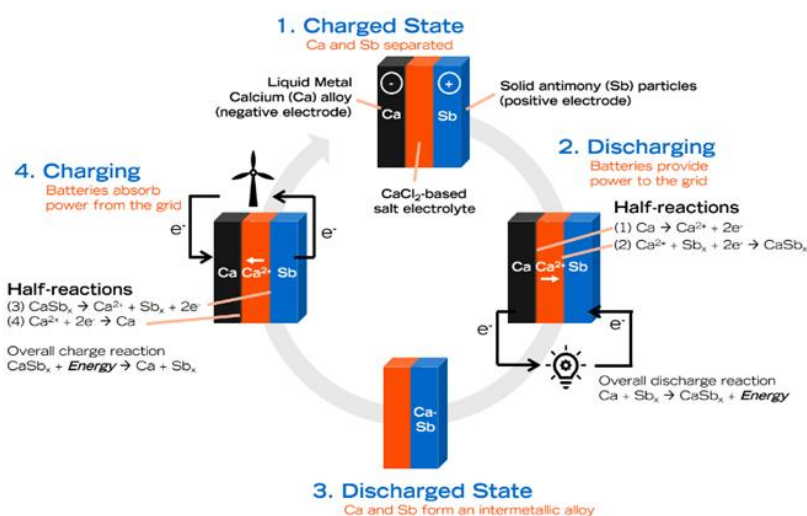
Using the Ambri technology as a basis, the liquid metal battery is comprised of a liquid calcium alloy anode, a molten salt electrolyte and a cathode comprised of solid particles of antimony. The active materials in Ambri's cells reversibly alloy and de-alloy while charging and discharging. The system requires an initial charge to get the materials into a molten form, from where they separate into anode and cathode due to different densities.

FIGURE 3.3.1 – Schematic Diagrams of Molten Metal BESS System



The negative electrode — the top layer in the battery — is a low-density liquid metal that readily donates electrons. The positive electrode — the bottom layer — is a high-density liquid metal that's happy to accept those electrons. And the electrolyte — the middle layer — is a molten salt that transfers charged particles but won't mix with the materials above or below. Because of the differences in density and the immiscibility of the three materials, they naturally settle into three distinct layers and remain separate as the battery operates.

FIGURE 3.2.2 – Schematic Diagrams of AMBRI BESS System



Source –AMBRI website

Ambri's commercial systems will be packaged in 550 – 1150 VDC containers with up to 1 MWh of capacity.

3.3.3 HAZARD – HOT MOLTEN METAL

Liquid metal batteries require high temperatures to liquify electrodes e.g. 800 deg C, and maintain the high conductivity of molten salt electrolytes. This makes thermal management of the units critical to continued steady operation. In addition heat loss and hot surfaces are a concern. The batteries are encased in ceramic which reduces heat loss and this is within a stainless steel casing for safe handling (i.e. prevent breakage of the ceramic). Should the ceramic be cracked or broken molten metal may seep through the crack into the outer stainless steel casing. Due to the corrosive nature of the molten salt (potassium and or sodium chloride with stainless steels susceptible to stress corrosion cracking with chlorides at high temperatures) this may eventually lead to failure of the outer casing and leakage of hot metal onto equipment/floors etc below. The molten metal will very quickly solidify but should there be any combustible materials in its path, e.g. cabling, racking these may catch fire. However, since it is a conventional fire, not an electric fire, it could be addressed with conventional fire-fighting protection systems.

There is no need for operators to be near or to work on the batteries when they are hot. Maintenance will require the batteries to be cooled down and certainly procedures will need to be in place to ensure personnel do not access hot battery parts.

During transportation, cells are shipped at ambient temperature and are inactive; they have zero cell Voltage and are unable to pass current, offering significant safety advantages during assembly and transport.

There are possible new cell chemistries under investigation which may be available in the future e.g. a cell using a positive electrode of a lead-bismuth alloy, a negative electrode of sodium metal, and an electrolyte of a mixed hydroxide-halide. The cell operated at just 270 C — more than 400 C lower than the magnesium (calcium) -antimony battery while maintaining the same three naturally separating liquid layers.

3.3.4 HAZARD – SHORTING THERMAL RUNAWAY

The electrolyte is thermodynamically stable with the electrodes, avoiding unwanted side reactions such as film-formation that can degrade the performance of other cell chemistries. Furthermore, the negative

electrode is fully consumed when discharged, and then is reformed on every cycle, resulting in a highly repeatable process with no memory effect.

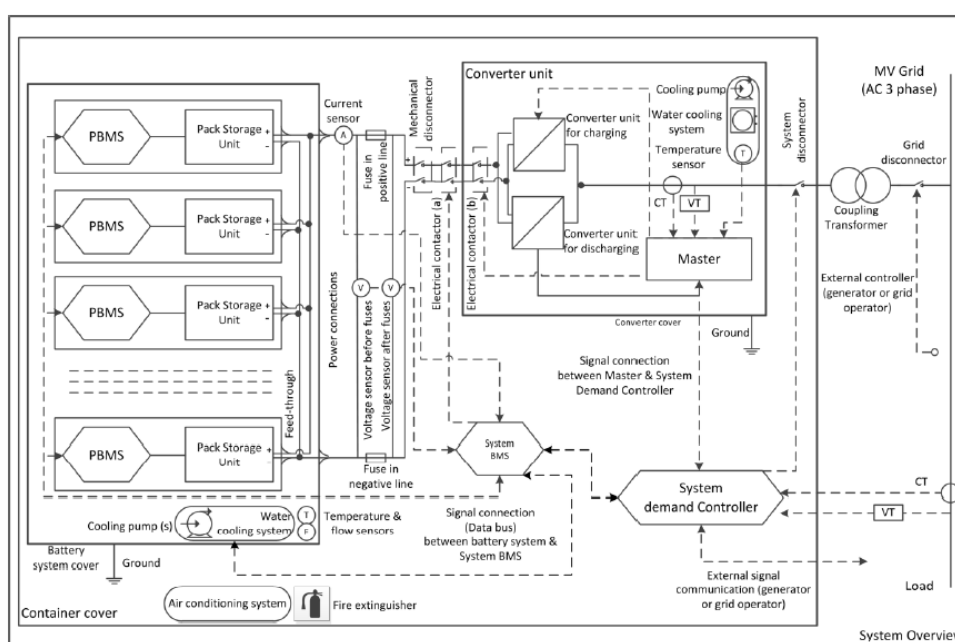
Cells are also highly tolerant of over-charging or over-discharging, and are not subject to thermal runaway, electrolyte decomposition, or electrolyte off-gassing, each of which could lead to significant safety events. Therefore, Ambri batteries are not explosive, combustible or temperature sensitive. No level of overcharging, over-discharging, short circuiting or temperature has caused any safety concerns with these cells.

However, there are challenges with ensuring a hermetically sealed battery particularly with the expansion and contraction of the materials of construction over the temperature range. Oxygen in the molten mixture may lead to formation of unwanted by-products reducing the efficiency of the battery and increasing the corrosivity of the molten metal/salt.

3.4 GENERAL - OTHER CHEMICALS OR HAZARDS

The BESS is composed not only of the batteries, but also electrical connections, switches, power converters, cooling systems etc. The diagram below shows a typical complex system for a battery facility.

Figure 3.4.1 – Details of Typical BMS



Source – STALLION reports

3.4.1 COOLING SYSTEMS

Due to the need to keep the batteries within a specified temperature range most of the containerized modular system have built-in air-conditioning systems while the VRFB building systems may have cooling water systems. Some have only fans for air cooling with filters to remove dust prior to cooling. Others, particularly those in hot environments requiring more cooling, may have refrigerant-based systems. These would have a refrigerant circuit usually containing non-flammable non-toxic refrigerant such as R134a (simple asphyxiant) etc as well as a low hazard circulating medium such as an ethylene glycol-based coolant. At high temperatures above 250 deg C R134 may decompose and may generate hydrogen fluoride and other toxic gases. Ethylene glycol is really only harmful if swallowed. In the environment it breaks down quickly and at low concentrations that would typically occur from occasional small spills, it has no toxicity.

3.4.2 FIRE SUPPRESSION SYSTEMS

Although these are only effective for some fire scenarios, some of the solid-state containerized systems come fitted with “Clean agent” fire suppressant systems. These are pressurized containers of powder/gases that are released into the container to snuff a fire and do not leave a residue on the equipment. Some containers have water sprinkler systems installed to quench thermal run-away reactions.

In general fire fighters may respond with water cannons/hydrants, foam systems etc. Such responses may generate large amount of contaminated and hazardous water runoff. A system to contain as much of this as possible should be in place.

3.4.3 GENERAL ELECTRICAL AND ELECTRONIC EQUIPMENT

Whatever the configuration of the battery containers/ buildings there will be electrical and electronic equipment in the battery compartment, the battery building as well as outside. In some installations the main electrical equipment such as the power conversion system is in a separate compartment separated by a fire wall. In others it can be in a separate container. Wherever there is electrical equipment there is a possibility of shorting and overheating and fire.

3.5 PAST ACCIDENTS AND INCIDENTS RELEVANT TO BESS

The following events occurred with various types of batteries, e.g., liquid lithium-ion as well as some solid state batteries, and are included for the purpose of possible ideas on how things may go wrong with equipment around the batteries themselves:

1. There have been sodium-sulphur fires in Japanese installations. One such event was at the Tsukuba Plant, (Joso City, Ibaraki Prefecture) of Mitsubishi Materials Corporation where molten material leaked from a battery cell causing a short between battery cells in an adjoining block. As there was no fuse between cells the current continued to flow, with the whole battery module catching fire. Hot molten material melted the battery cell casings inside the battery overflowing to the modules below, causing the fire to spread further.
2. There have been exploding, melting Samsung smartphone lithium-ion liquid/polymer batteries.
3. A tesla electric battery powered car caught fire, see image below. Initially, a metal object penetrated the battery causing damage leading to short circuiting and thermal runaway. There was an alarm and the driver warned by on-board computer to park car safely and exit. The runaway did not propagate to the other battery compartment due to separation measures installed. Fire fighters actually made the fire worse by their action to open the battery system to try and get water into it. This allowed air in and the flames to spread to the rest of the car. By way of comparison the American National Fire Protection Agency (NFPA) has stated that there are approximately 90 fires per billion kilometers driven with internal combustion engine cars as compared to the Tesla electric car with only 2 fires per billion driven kilometers.

Figure 3.5.1 – Photo of Tesla battery fire scene



Source STALLION Report

4. 2010 a UPS Airlines cargo plane from Dubai crashed after a fire started in a large undeclared lithium battery shipment (unknown if liquid, polymer or solid state). Since not declared, the batteries were not handled in any special manner as would be required if they were a declared hazardous load. There have been two other fires on flights containing lithium battery cargo. In all cases the fire went from small to uncontrolled in less than 30 minutes.
5. 2013 the lithium batteries installed two separate Air Japan Boeing 787 Dreamliners ignited resulting in fires, while on the ground in one case and in-flight in the other.
6. In August 2012, there was a fire at night at the Kahuku wind farm in Hawaii with an advanced lead-acid battery system installed indoors. The fire department were called several hours later and attempted, unsuccessfully to extinguish the fire with dry powder. The fire fighters faced thick smoke and could not enter the building for several hours because it was unclear whether the batteries were emitting toxic fumes
7. February 2012 during commission of a Wind BESS in Arizona USA a fire started. The cause is unknown but the fire did not spread beyond the shipping container.
8. 10 August 2016 in Wisconsin USA a fire started in the DC power control compartment of a BESS under construction. The fire department arrived and applied alcohol resistant foam to extinguish the fire. The fire did not spread to the batteries. As the system was in commissioning the fire suppression system in the PCS was not yet functional.
9. 11 November 2017 Lithium based BESS in Belgium caught fire during commissioning. Fitted fire detection and extinguishing system failed to contain the fire. The fire department was called and rapidly extinguished the fire to prevent it from spreading to adjacent containers.

Figure 3.5.2 – Photo of Lithium battery fire scene



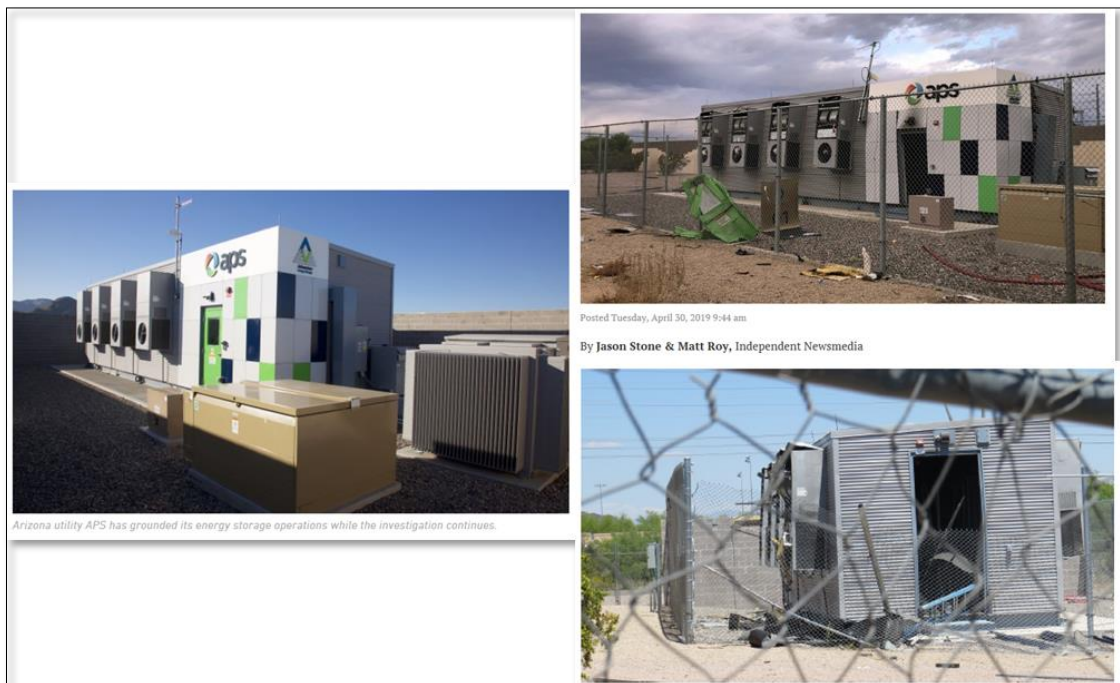
A fire engulfs a lithium-ion battery system at an Engie test site in Belgium, Nov. 11.

Photo Credit: MrJoostvanL/ YouTube

10. 19 April 2019 explosion at utility company Arizona Public Service's (APS) Wind battery facility in Surprise, Arizona. The incident on April 19, 2019, started when there were reports at around 17:00 of smoke from the building housing the BESS. A few hours later, at approximately 20:04, an explosion occurred from inside the BESS. Nine people were injured. The factual conclusions reached by the investigation into the incident were:

- The suspected fire was actually an extensive cascading thermal runaway event, initiated by an internal cell failure within one battery cell in the BESS: cell pair 7, module 2, rack 15.
- It is believed to a reasonable degree of scientific certainty that this internal failure was caused by an internal cell defect, specifically abnormal Lithium metal deposition and dendritic growth within the cell.
- The total flooding clean agent fire suppression system installed in the BESS operated early in the incident and in accordance with its design. However, clean agent fire suppression systems are designed to extinguish incipient fires in ordinary combustibles. Such systems are not capable of preventing or stopping cascading thermal runaway in a BESS.
- As a result, thermal runaway cascaded and propagated from cell 7-2 through every cell and module in Rack 15, via heat transfer. This propagation was facilitated by the absence of adequate thermal barrier protections between battery cells, which may have stopped or slowed the propagation of thermal runaway.
- The uncontrolled cascading of thermal runaway from cell-to-cell and then module-to-module in Rack 15 led to the production of a large quantity of flammable gases within the BESS. Analysis and modelling from experts in this investigation confirmed that these gases were sufficient to create a flammable atmosphere within the BESS container.
- Approximately three hours after thermal runaway began, the BESS door was opened by firefighters, agitating the remaining flammable gases, and allowing the gases to make contact with a heat source or spark. This led to the explosion.

Figure 3.5.3 – Photo of lithium battery explosion scene



Source DNV-GL McMicken Event Analysis

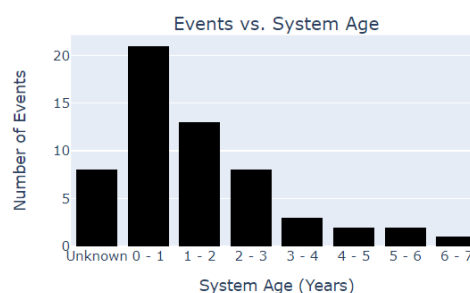
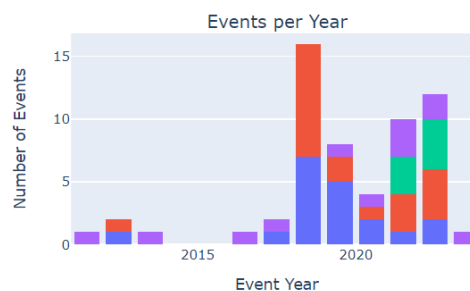
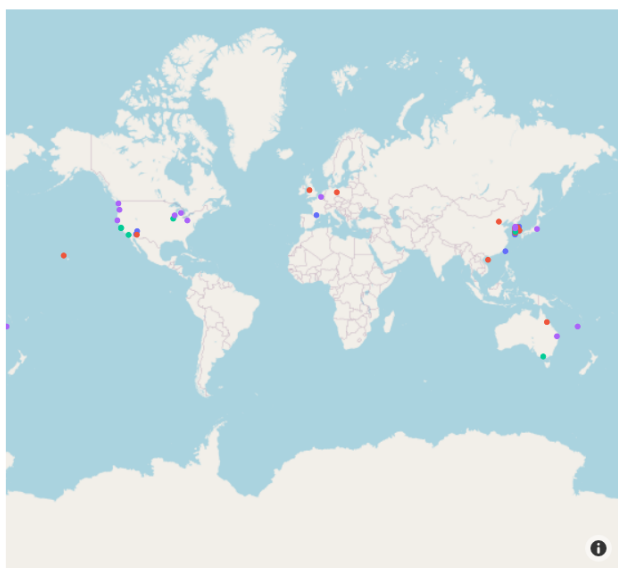
11. Records (By WoodMac) indicate that there are approximately 200 BESS systems in the USA and there have been 2 -3 fires in the last 5 -10 years. This is an event frequency of 0.001 - 0.003 events per unit per year. DNV-GL in their quantitative risk analysis of BESS sites found that considering all the latest

(2019) safety features the theoretical event frequency should be as low as 0.00001 events/unit/year i.e., 2 orders of magnitude lower than the actual values.

12. Korea has installed over 1200 energy storage systems as part of the clean energy programs. In December 2018 a lithium BESS caught fire at a cement plant in Jecheon. It was the 15th fire in 2018 in Korea. As of June 2019, there had been 23 fires at Korean facilities. The faults were reported to be with the incorrect installation of battery management systems and electrical systems and not due to the batteries themselves. Assuming these BESS systems have on average been in place for 5 years then the event frequency is approximately 0.004 events per unit per year. This correlates to the high value estimated for the USA data. This data is also two orders of magnitude higher than the DNV theoretical prediction on 0.00001 events/unit/year.
13. The Electric Power Research Institute (EPRI) of California USA maintains a list of Battery released accidents on its Wiki-Storage Page. The EPRI is an independent non-profit energy research, development and deployment organization that is funded by organizations around the world including the energy sector, academia and governments. The graphs and lists below summarize some of the incidents and the three accidents described in more below the table are typical of the types of accidents recorded.

Table 3.5.4 – List of Battery Accidents

System Size ■ < 5MWh ■ 5 - 50 MWh ■ 50 MWh < ■ Unknown



Location	Energy (MWh)	Power (MW)	Application	Installation	Event Date	System Age (yr)	State During Accident	Source
US, PA, Millvale			Solar Integration	Urban	30 January 2023		Operational	WTAE
South Korea, Jeollanam-do, Yeongam-gun, Geumjeong-myeon	251		Solar Integration	Rural	27 December 2022	1.8	Operational	E2News.com
South Korea, Jeollanam-do, Damyang-gun, Mujeong-myeon, Deokgok-ri	9.1	2.5	Solar Integration	Rural	8 December 2022	5.5	Operational	E2News.com
China, Hainan	50	25	Solar Integration		20 October 2022	0	Commissioning	china5e.com
US, CA, Moss Landing	730	182.5	Energy Shifting, Ancillary Services	Substation	20 September 2022	0.5	Operational	KSBW News
South Korea, Incheon		103	Energy Shifting	Factory	6 September 2022		Operational	Teller Report
US, CA, Rio Dell			Solar Integration / Backup	Rural	3 August 2022	4	Operational	KRCR
US, AZ, Chandler	40	10		Substation	18 April 2022	3	Operational	AZ Central
US, CA, Valley Center	560	140		Substation	5 April 2022	0.2	Operational	Valley Road Runner
Longjing, Taichung City, Taiwan	1	1	Solar Integration	Power Plant	30 March 2022	2	Operational	Economic Daily

US, CA, Moss Landing	400	100	LG Energy Solution	Solar Integration	Power Plant	13 February 2022	1	Operational	KSBW News
South Korea, Gunwi-gun, Gyeongsangbuk-do	1.5	0.45	LG Energy Solution	Solar integration	Rural	17 January 2022	3	Operation. Fully charged	E2News
South Korea, Nam-gu, Ulsan	50	10	SK Innovation	Peak Load Reduction	Urban	12 January 2022	2	Operational	E2News
US, CA, Moss Landing	1,200	300	LG Energy Solution	Solar Integration	Power Plant	4 September 2021	0.8		Vistra
Australia, Victoria, Geelong	450	300	Tesla	Grid Stability	Rural	30 July 2021	0	Construction, Commissioning	ABC News
US, IL, LaSalle	72	72	LFP	Frequency Regulation	Rural	19 July 2021	1.6		The Times
Germany, Neuhausen	5	5	[LFP]	Solar Integration and Frequency Regulation	Indoor/Hangar	18 July 2021	5		RBB 24
Boulouparis, New Caledonia, France				Solar Integration	Rural	13 July 2021			FranceTVInfo.fr
US, MI, Standish				Demand Charge Mgmt	Substation	19 April 2021	0	Installation	WSGW
China, Beijing	25		Gotion High-Tech [LFP]	Solar Integration	Commerce Area	16 April 2021	2	Construction, Commissioning	CTIF Accident Analysis

- a) There have been three incidents at the Moss Landing Power plants PG&E battery storage facility in the USA where there are 256 TESLA Mega Packs installed. The latest involved one pack which caught alight and burned out five hours later. Firefighting approach was to let the pack burn out. Near-by communities were warned to shelter-in-place and the adjacent highway shutdown due to possible toxic smoke. Only one mega pack burned out and the fire did not spread.

Figure 3.5.5 – Photo of Tesla Megapack fire scene



- b) There was a small fire at the new Terra-Gen battery storage facility on Valley Centre Road USA. A small electrical failure produced some smoke which triggered the protection systems. Those worked exactly as planned and the failure was contained to a single battery module (meaning literally a single battery which is about the size of a DVD case). The safety systems worked exactly as planned and in addition the enclosure next to the one with the problem shut down because it also detected the smoke.
- c) The fire broke out during testing of a 13-tonne Tesla lithium megapack at the Victorian Big Battery site near Geelong Australia. A 13-tonne lithium battery was engulfed in flames, which then spread to an adjacent battery bank. This event indicates that if the battery pack units are not suitably separated the heat from one fire can set off an adjacent unit.

Figure 3.5.6 – Photo of Tesla Megapack fire scene - Electric Power Research Institute



- 14. As molten metal batteries are a new technology there is to date no record of accidents and includes.

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 SOLID STATE BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY LITHIUM-ION

TABLE 4.1.1 - CONSTRUCTION PHASE (Excluding commissioning which is part of operations)

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
							Raw Risk						Residual Risk					
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. Safety, Health, Environment and Quality (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. OHS Act Noise Induced hearing Loss Regulations. Employees to be provided with hearing protection if working near equipment that exceeds the noise limits.	Easy	3	1	5	5	4	56	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
							Raw Risk						Residual Risk					
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 for employees to be provided during all phases of the project. Bore hole, bowser and tank or small water treatment plant may be required to provide potable water for the BESS installation staff during all phases of the project.	Easy	3	2	3	1	2	18	2	2	3	1	1	8
Significance							N2 - Low						N1 - Very Low					
Impact 4:	Human Health - exposure to psychological stress	Causes - Large projects bring many contractor workers into a community. Consequences – Lack of sufficient accommodation, entertainment etc. Increase in alcohol abuse, violence	Construction	Negative	Refer to Social Specialist Study for this project.	Easy	2	3	3	2	2	20	2	3	3	2	2	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 all the necessary equipment is available (and well maintained) during construction. Otherwise employees may revert to unsafe practices. Maintenance of construction equipment to ensure safe operation is critical. Ensure this is in place prior to project beginning. 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
							Raw Risk						Residual Risk					
Impact 6a:	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 6b:	Human and Equipment Safety - exposure to fire radiation	Causes - Solid state battery containers damaged on route e.g., dropped in port (drops do happen about 1/2000 containers) and importing possibly < 2600 containers for the site. With this it is possible, although unlikely, that one will be dropped, traffic accident on-route. Involvement in an external fire e.g., at the port or on route. Data indicates	Construction	Negative	Solid state battery design includes abuse tests such as drop test, impact, rapid discharge, etc. Propagation tests for systems, e.g., heat insulating materials between cells/modules. Factory acceptance test prior to leaving manufacture. Batteries are usually stored at 50% charge to prolong life but may be shipped fully discharged. This level of detail should be understood so as to assess the risk during transport and storage. The company responsible for the battery installation should ensure suitably competent transport companies are appointed. The company responsible for transportation should ensure: - Compliance with National Road Traffic Act , 1996 (Act 93 of 1996) as amended (NRT Act) regulation 8 – dangerous goods. - Port Authorities should be alerted to the overall project and the hazardous nature of the contents of battery containers being imported. Note. If, as per one	Complex	5	2	5	5	4	68	5	2	5	5	1	17

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
							Raw Risk						Residual Risk					
		<p>installed facility events are 0.001/year. Transport of up to 430 units per installation assumed to take 4 weeks each so f= 0.03 - once in 30 years so likelihood is moderate. Transport of 2600 units for the entire complex assumed to take 4 weeks each so f= 0.2 - once in 5 years so likelihood is high.</p> <p>Consequences – Injuries due to radiation especially amongst first responders and bystanders. Fatalities unlikely from the heat radiation as not highly flammable nor massive fire (refer to noxious smoke in APPENDIX A below for the major impact).</p>			<p>of the typical suppliers (Tesla) indications, the containers are classified as International Marine Dangerous Good (IMDG) Class 9 – the containers will not receive any special care in the ports and may be stored next to flammables. Port emergency response in particular need training on mitigating battery hazards.</p> <p>Prior to bringing any containers into the country, the company responsible for the battery installation (possibly via appointed contractors) should ensure that an Emergency response plan is in place for the full route from the ship to the site. Drivers trained in the hazards of containerized batteries.</p> <p>The Emergency plan must determine and address:</p> <ul style="list-style-type: none">- What gases would be released in a fire and are there inhalation hazards.- Extinguishing has two important elements, put out fire and to provide cooling. Different approaches may be needed for small fire, e.g., put out, and for large fires, e.g., cool with copious quantities of water. Note inert gases and foam may put out the initial fire but fail to control thermal runaway or to cool the batteries resulting in reignition.- What initial fire extinguishing medium should be used.- Whether there are any secondary gases or residues from use of extinguishers.- If water is appropriate, determine if the system needs outside connections to sprinklers inside the container.- First responders need to know what media to use, especially if water is totally unsuitable and if there are no connection points for water, etc.- Must the container be left unopened or opened.- PPE to be specified including possible exposure to chemicals and fumes as well as radiate heat.- Containment of residues/water/damaged equipment.- Suitable safe making and disposal plan for after the event, i.e., how do responders deal with partially charged damage units, contaminated surfaces (e.g., HF residues).													

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
							Raw Risk						Residual Risk					
Significance							N4 - High						N2 - Low					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	Causes - With solid state lithium containers, flammable gases generated by thermal run away reach explosive limits. Ignition on hot surfaces, static. Consequences - Potential fatalities amongst first responders. Damage to container, transport truck or other nearby items, e.g., other container in the port.	Construction	Negative	During transport this is only likely to happen due to possible inappropriate emergency response, e.g., opening containers when they may be the type that should be left to burn out. For simplicity one transport route would be preferable. The route needs to be assessed in terms of responding local services, rest places for drivers, refuelling if required, break down services available etc. Once an import route has been chosen, e.g., Richards Bay or Durban or Gqeberha and along N2/N3/N11/N10 etc, then the appointed transport company should ensure key emergency services on route could be given awareness training in battery fire/accident response. Emergency response planning and training referred to above may be important for key locations such as the mountain passes / tunnels.	N/A	5	4	5	5	3	57	5	4	5	5	1	19
Significance							N3 - Moderate						N2 - Low					
Impact 8a:	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.	Complex	4	2	3	2	3	33	3	2	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
							Raw Risk						Residual Risk					
Impact 8b:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	<p>Causes - Damaged solid-state batteries release fumes, leak electrolyte, are completely broken exposing hazardous chemicals. Thermal runaway and hazardous fumes released.</p> <p>Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive burns or lung damage.</p>	Construction	Negative	<p>Appointed transport company to ensure transport in accordance with Regulation 8 of the National Road Traffic Act 93 of 1996, Dangerous Goods. Not permitted to transport prescribed goods in manner not consistent with the prescriptions, e.g., consignor and consignee responsibilities. Prescription found in SANS 10228/29 and international codes for battery transport etc.</p> <p>Transport in sealed packages that are kept upright, protected from movement damage etc.</p> <p>Also packaged to ensure no short-circuiting during transport.</p> <p>Transport to prevent excessive vibration considerations as battery internal may be damaged leading to thermal run-away during commissioning. Pre-assembled containers will most likely be supplied.</p> <p>These will be fitted with the necessary protective measures by the supplier considering marine and road transport as well as lifting, setting down etc.</p> <p>Route selection to consider possible incidents along the way and suitable response, e.g., satellite tracking, mobile communication, 24/7 helpline response.</p> <p>Standard dangerous goods requirements for Hazmat labels, Trem cards, driver trained in the hazards of the load.</p> <p>Likelihood similar to fire above.</p>	Complex	4	3	3	5	3	45	4	3	3	5	2	30
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
							Raw Risk						Residual Risk					
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	<p>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.</p> <p>SHEQ policy in place.</p> <p>A detailed construction Risk Assessment prior to work.</p> <p>SHE procedures in place.</p> <p>PPE to be specified.</p> <p>SHE appointees in place.</p> <p>Contractors safety files in place and up to date.</p> <p>SHE monitoring and reporting programs in place.</p> <p>Standard construction site rules regarding traffic, reversing sirens, rigging controls, cordoning off excavations, etc.</p> <p>Civil and building structures to National Building Regulations and Building Standards Act 103 of 1977 (NBRBS Act) as amended, SANS 10400 and other relevant codes.</p> <p>Other constructions such as roads, sewers, etc., also to relevant SANS standards.</p> <p>All normal procedures for working at heights, hot work permits, confined space entry, cordon off excavations, etc., to be in place before the relevant construction task begins.</p> <p>Emergency response plan to be in place before construction begins.</p>	Complex	5	1	5	5	4	64	5	1	5	5	1	16
							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	<p>Standard maintenance of condition of electrical equipment and safe operating instructions.</p> <p>Ability to shut off power to systems in use on site.</p> <p>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.</p> <p>Lightning strike rate in the study area is low.</p> <p>Outside work must be stopped during thunderstorms.</p> <p>Lighting conductors may be required for the final installation, to be confirmed during design phase.</p>	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
							Raw Risk						Residual Risk					
Significance							N3 - Moderate						N2 - Low					
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 where reasonably practicable 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. Battery containers damaged. Consequences - Delays.	Construction	Negative	Water usage to be monitored on site during construction. Handling protocols to be provided by battery supplier. End of Life plan needs to be in place before any battery containers enter the country as there may be damaged battery unit from day 1. Water management plan and spill containment plans to be in place.	Easy	1	1	1	2	4	20	1	1	1	2	2	10

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
							Raw Risk						Residual Risk					
							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.	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 but hazardous load. On site, theft of construction equipment and battery installation facilities. Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglars. Damage to equipment possibly setting off thermal runaway.	Construction	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g., Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal batteries. 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 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
							Raw Risk						Residual Risk					
Impact 18:	Emergencies	Causes - Fires, explosions, toxic 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	If batteries are stored at 50% charge, thermal run away can happen while in storage on site waiting for installation. In addition, if involved in an external fire thermal run away can happen even with uncharged batteries. Except during shipping, ideally the units should not be stored any closer to each other than they would be in the final installation so that propagation is prevented, i.e. laydown area needs to be considered. The company in charge of the containers at each stage in the transport process needs to be very clear so that responsibility for the integrity of the load and protection of the persons involved in transfer and coordination of emergency response on-route. E.g., if purchased from Tesla where does hand over occur to the South African contractor / owner, at the factory door in USA, at the port in RSA, at the site fence. For example, who will be accountable if there's thermal runaway event on a truck with a container that stops in a small town for driver refreshments	Complex	4	2	3	5	4	56	4	2	3	5	2	28
Significance							N3 - Moderate						N2 - Low					
Impact 19:	Investors - Legal	Causes Battery 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 battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only state of the art battery systems are used and not old technologies prone to fires/explosions etc.	Moderate	3	1	3	3	4	40	2	1	3	3	2	18
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.

TABLE 4.1.2 - OPERATIONAL PHASE (Including Commissioning)

From the details of accidents that have happened both with BESS installations and 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
							Raw Risk						Residual Risk					
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	<p>The operation and maintenance phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993.</p> <p>SHEQ policy in place.</p> <p>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.</p> <p>SHE procedure in place, e.g., PPE specified, management of change, integrity monitoring.</p> <p>SHE appointees in place.</p> <p>Training of staff in general hazards on site.</p> <p>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.</p> <p>Emergency response plan for full operation and maintenance phase to be in place prior to beginning commissioning and to include aspects such as:</p> <ul style="list-style-type: none"> - 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. 	Easy	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
							Raw Risk						Residual Risk					
Impact 1b:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Compromised battery compartments vapours accumulate in the containers, solids/liquids on surfaces. Maintenance of battery components, corrosive and mildly toxic liquid on surfaces. Consequences - Dermatitis, skin /eye/lung irritation.	Operation	Negative	<p>Solid state batteries sealed, individual batteries in modules which are also sealed, pre-packed in the container.</p> <p>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 battery parts and other equipment on site.</p> <p>Training of staff in hazards of chemicals on site.</p> <p>Possible detectors with local alarms if regulated occupational exposure limits are exceeded etc prior to entry for inspection of battery containers.</p> <p>Labelling of all equipment.</p> <p>Confined space entry procedures if entering tanks.</p> <p>There needs to be careful thought given to procedures to be adopted before entering into the BESS or a container particularly after a BMS shut down where there may be flammable or toxic gases present, a fire etc.</p> <p>Safety Data Sheets (SDSs) to be available on site.</p> <p>Operating manuals to be provided including start-up, shut-down, steady state, monitoring requirements.</p> <p>Maintenance manuals with make safe, decontamination and repair procedures.</p> <p>Proposed maintenance schedules e.g., checklists for weekly, monthly, annual etc.</p> <p>Provided portable equipment for calibration and for testing/verification of defective equipment, e.g., volt/current meters, infrared camera</p>	Complex	3	1	3	5	4	48	1	1	3	5	2	20
Significance							N3 - Moderate						N2 - Low					
Impact 2:	Human Health - exposure to noise	Causes - Moving parts inside containers, buildings, pumps, compressors, cooling systems etc. Consequences - Adverse impact on hearing of workers. Nuisance factor at	Operation	Negative	<p>Design to ensure continuous noise does not exceed 85dB within the facilities or at any other location on site or 61 dB at the site boundary, e.g., emergency generator, air compressor, etc., OHS Act Noise Induced Hearing Loss Regulations.</p> <p>Employees to be provided with hearing protection if working near equipment that exceeds the noise limits.</p>	Easy	2	1	5	5	4	52	2	1	5	5	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
							Raw Risk						Residual Risk					
		near -by residences or other activities.																
Significance							N3 - Moderate						N2 - Low					
Impact 3:	Human Health - exposure to temperature extremes and/or humidity	Causes - Heat during the day. Batteries generate heat within enclosed building / containers. 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. Ensure containers are temperature controlled as required to remain within the optimal battery operating temperature range. Lighting to be provided inside any buildings, inside the containers, possibly linked to the door opening and outdoors where necessary. Adequate potable water to be provided during all phases of the project. 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.	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 - 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 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
							Raw Risk						Residual Risk					
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 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 6a:	Human and Equipment Safety - exposure to fire radiation	Causes – Involvement in an external fire e.g., veld fire, maintenance vehicle fire, electrical systems fire. Manufacturing defects or damage to battery leading to shorting and heating. High humidity condensation of water or ingress of water or flooding leading to shorting. Dust accumulation on electrical parts leading to overheating. Excessive electrical loads - surges Operator abuse BMS failure or	Operation	Negative	Grass cutting and fire breaks around the BESS installations to prevent veld fires. No combustible materials to be stored in or near the batteries or electrical infrastructure. Separation of site diesel tank, transformers from BESS and vice versa. There are BESS design codes from the USA and standards of practice that can be used e.g., UL9540, NFPA 855 and DNV GL RP 43. Detailed FMEA/Hazop/Bowtie to be 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. Abuse tests conducted by supplier. BMS should be checking individual cell Voltage as well as stack, module, container, system Voltage/current etc. BMS tripping the cell and possibly the stack/ building unit or module/rack/container, if variations in Voltage. Diagnostics easily accessible. Diagnostics able to distinguish cell from stack or cell from module faults. Protective systems are only as good as their reliability and functionality testing is important, e.g., testing that all battery trips actually work.	Complex	5	1	5	5	4	64	5	1	5	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
							Raw Risk						Residual Risk					
		<p>software failure. Incorrect extinguishing medium, escalate the fire.</p> <p>Consequences - Contaminated run off.</p> <p>Radiation burns unlikely to be severe as no highly flammable materials on site, except if fire water is used on molten sodium.</p> <p>Damaged equipment.</p> <p>Fire spreads to other units or offsite if grass/vegetation not controlled.</p>			<p>Fire resistant barrier between the batteries and the PCS side if in the same container, or separate containers.</p> <p>Suitable ingress protection level provided for electrical equipment, e.g., IP55 - 66. If air cooling into container, suitable dust filters to be provided.</p> <p>Smoke detectors linked to BMS & alerts in control room.</p> <p>Effects of battery aging to be considered. Solid state battery life starts to be impacted above 40 deg C and significant impacts above 50 deg C with thermal runaway starting at 65-70 deg C. BMS trips system at 50 deg C. Temperature monitoring to be in place.</p> <p>Regular infrared scanning. Data needs to be stored for trend analysis.</p> <p>Accident data indicates an event frequency of 0.001 per battery container and with 325 – 430 containers per installation this would mean an event once in two - three years, i.e. a high probability event. For the entire complex of 2600 containers this could mean a fire up to once every six months a high probability event.</p> <p>Provided the BMS is operating the BESS should shut down and that should limit the propagation of the fire from one battery unit to the next.</p> <p>Provided the containers are suitable separated the fire should not spread to adjacent containers.</p> <p>Separation usually set during design based on fire modelling from the battery supplier.</p> <p>Provided fire training has taken place most events will be small not resulting in injuries, but this is possible if the event is not controlled.</p> <p>Prior to commencement of cold commissioning, emergency plan from transport and construction phase to be extended to operational phase and to include the hazards of the electrically live system.</p> <p>Procedure to address solid state container fires - extinguishing, ventilating, entering as appropriate or not. PPE for container firefighting include fire retardant, chemically resistant, nitrile gloves, antistatic acid resistant boots, full face shields, BA</p>													

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
							Raw Risk						Residual Risk					
					<p>sets.</p> <p>A planned fire response to prevent escalation to an explosion or an environmental event.</p> <p>Suitable supply of fire extinguishing medium and cooling medium, NOTE in some cases (e.g. molten sodium-ion batteries) water must not be used.</p> <p>Consider fire water for cooling adjacent equipment – BESS units.</p> <p>Can use fogging nozzles to direct smoke.</p> <p>Ensure procedures in place for clean up after event</p> <p>Lingering HF and other toxic residues in the soil and on adjacent structures.</p> <p>Procedures to be in place for IR scanning (or other suitable method) to determine if batteries are still smouldering / are sufficient cooled to handle as batteries may still be active some weeks after an event.</p> <p>Smoke or gas detector systems that are not part of the original battery container package, need to be linked to the main control panel for the entire system so that issues can be detected and responded to rapidly.</p>													
Significance							N4 - High						N2 - Low					
Impact 6b:	Human and Equipment Safety - exposure to fire radiation	Causes - Power Conversion System (PCS – DC to AC) cooling failure electrical fire. Consequences - Fire starts in PCS or another section or room and spreads to battery area.	Operation	Negative	Modern lithium container design put the PCS in another part of the container with a fire rated wall separating it from the battery. Alternately the PCS is another container altogether.	Moderate	5	2	5	5	4	68	5	2	5	5	1	17
Significance							N4 - High						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
							Raw Risk						Residual Risk					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	<p>Cause 1 - Transformer shorting / overheating / explosion.</p> <p>Cause 2 - Flammable gases generated by thermal run away reach explosive limits. Ignition on hot surfaces, static.</p> <p>Lithium Cobalt Oxide generates O₂ during decomposition – escalation.</p> <p>Consequences - Potential fatalities amongst first responders. Damage to container or other nearby items, e.g., other container.</p>	Operation	Negative	<p>Electrical equipment will be specified to suit application.</p> <p>Emergency response plan and employee training referred to above is to be in place.</p> <p>This is only really likely to happen due to possible inappropriate emergency response, e.g., opening containers when they may be the type that should be left to burn out.</p> <p>Modern state of the art containers have ventilation systems for vapours.</p> <p>Undertake a hazardous area classification of the inside of the container to confirm the rating of electrical equipment, due to possible leaks of electrolyte or generation of flammable gases under thermal run away. Emergency response plan and employee training referred to above is critical.</p> <p>Suitable training of selected emergency responders who may be called out to the facilities is critical.</p> <p>NOTE. Refer to Appendix A for an initial approximation of worst-case possible explosion impact zones.</p>	Moderate	5	1	5	5	2	32	5	1	5	5	1	16
Significance							N3 - Moderate						N2 - Low					
Impact 8a:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	<p>Causes Human pathogens and diseases, sewage, food waste.</p> <p>Snakes, insects, wild and domesticated animals and harmful plants.</p> <p>Consequences - Illness and at worst without mitigation, possibly extending to fatalities.</p> <p>Effects can vary from</p>	Operation	Negative	<p>All necessary good hygiene practices to be in place, e.g., provision of toilets, eating areas, infectious disease controls.</p> <p>Policies and practice for dealing with known vectors of disease such as Aids, TB, COVID 19 and others.</p> <p>Awareness training for persons on site, safety induction to include animal hazards.</p> <p>First aid and emergency response to consider the necessary anti-venom, anti-histamines, topical medicines etc.</p>	Moderate	4	1	3	2	3	30	3	1	2	2	2	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
							Raw Risk						Residual Risk					
		discomfort to fatalities for venomous snakes or bee swarms etc																
Significance							N2 - Low						N2 - Low					
Impact 8b:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	<p>Causes - Damaged batteries components, leak electrolyte, are completely broken exposing hazardous chemicals. Hazardous fumes released on thermal run away see fire above.</p> <p>Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive burns for large exposure.</p> <p>In the case of toxic fumes, serious lung damage.</p>	Operation	Negative	<p>Acid resistant PPE (e.g., overalls, gloves, eyeglasses) to be specified for all operations in electrolyte 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.</p> <p>All operators/maintenance staff trained in the hazards of chemicals on site.</p> <p>Batteries contained, modules contained and all inside a container that acts as bund.</p> <p>Refer to fire above as all the protective measures apply to prevent toxic smoke.</p> <p>Refer to fire above as all the measures apply to mitigate toxic smoke.</p> <p>24/7 helpline response.</p> <p>Standard dangerous goods requirements for Hazmat labels.</p> <p>All operators/maintenance staff trained in the hazards.</p> <p>NOTE Refer to Appendix A for an initial approximation of worst case possible noxious smoke impact zones.</p>	Moderate	4	3	3	5	3	45	3	3	3	5	2	28
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
							Raw Risk						Residual Risk					
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	<p>Apart from pumps, no major moving parts during operation.</p> <p>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.</p> <p>Traffic signs, rules etc in place on site.</p> <p>All normal working at heights, hot work permits, confined space entry, cordon off unsafe areas/works etc to be in place.</p> <p>Emergency response plan.</p> <p>Civil design to take seismic activity into account.</p>	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
							Raw Risk						Residual Risk					
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	Codes and guidelines for electrical insulation. Suitable PPE to be specified. Low Voltage equipment (e.g., batteries) separated from high Voltage (e.g., transmission to grid). Ensure trained personnel and refer to guideline – IEE 1657 – 2018. Ensure compliance with Eskom Operating Regulations for high Voltage systems including access control, permit to work, safe work procedures, live work, abnormal and emergency situations, keeping records. 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 facility and the other equipment on site. PPE to consider static accumulation for entering the facility, and particularly the battery containers especially after a high temperature shut down where there could possibly be flammable materials. The procedures for responding to alarm and auto shut down on containers, needs to consider that there may be a dangerous environment inside and how to protect personnel who may enter to respond. Lightning strike rate in proposed development area is low. All outside work must be stopped during thunder storms. 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	Not expected on a normal basis. Refrigerant may be an asphyxiant if accidentally released indoors it can	Operation	Negative	Especially after any warning alarms have gone off, but possibly even normally the container could be treated as entering a confined space and similar procedures could be in place, e.g., do not enter alone, gas testing prior to entering, ensure adequate ventilation	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
							Raw Risk						Residual Risk					
		accumulate and displace oxygen.																
Significance							N2 - Low						N1 - Very Low					
Impact 12:	Environment - emissions to water	Causes - Cooling water blow-down. Laboratory waste (if included in the design). Maintenance waste, e.g., oils. Spills from batteries, coolant system, diesel trucks, transformers. Parked vehicles – oil drips. Fire water runoff control. Kitchen waste and sewage. Refrigerant release. Consequences - Pollution if not contained. Excessive disposal costs if emissions not limited.	Operation	Negative	Bunding under any outdoors tanks, curbing under truck offloading areas and sealed surfaces (e.g., concrete) under truck parking area is particularly important. Sewage and any kitchen liquids - containment and suitable treatment/disposal. Procedures for dealing with damaged/leaking equipment as well as clean-up of spills. 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. Spill clean-up procedures to be in place before bringing container on site, including spill kits – non-combustible materials, hazmat disposal. The National Environment Management Act (NEMA) has a list of substances with Reportable spill Quantities, ensure compliance with this.	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. Disposal of solid-state batteries. Consequences - Environmental damage.	Operation	Negative	Implement waste segregation (e.g., electronic equipment, chemicals, domestic) 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 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
							Raw Risk						Residual Risk					
Impact 14:	Environment - waste of resources e.g., water, power etc	Causes - Similar to construction phase. Disposal of batteries or components. Disposal of containers. 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. Handling protocols to be provided by supplier of batteries. Water management plan and spill containment plans to be in place. Investigate end of Life plan for solid state batteries - reuse / recovery / reconditioning. Similarly, for decommissioned containers – reuse / recovery / repurpose	Easy	1	1	1	2	4	20	1	1	1	2	2	10
							N2 - Low						N1 - Very Low					
Impact 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Operation	Negative	Refer to Visual Impact Assessment which is to include the BESS installation once design details are available	Easy	1	2	4	4	2	22	1	2	4	4	2	22
Significance							N2 - Low						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.	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
							Raw Risk						Residual Risk					
Impact 17a:	Employees and investors - Security	Causes - On route, potential hi-jacking of valuable but hazardous load. On site, theft of construction equipment and battery installation facilities. Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglars. Damage to equipment possibly setting off thermal runaway.	Operation	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. Consider motion detection lights and CCTV. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g., Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal batteries. 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 17b:	Employees and investors - Security	Causes - Cyber security attacks aimed at the National Electricity Grid. Consequences - Ransom of the National Electricity Grid.	Operation	Negative	Cyber security needs monitoring. Remote access to system needs to be negotiated and controlled. Password controls, levels of authority etc. Protection of the National Electricity Grid from Cyber-attacks accessing through the BESS. Cyber emergency procedures – should be in place prior to commissioning.	Complex	4	4	3	1	4	48	4	4	3	1	2	24
						Significance	N3 - Moderate						N2 - Low					
Impact 18:	Emergencies	Causes - Fires, explosions, toxic smoke, large spills, traffic accidents, equipment/structural collapse. Inadequate emergency response to small event leads	Operation	Negative	All safety measures listed above. Emergency procedures need to be practiced prior to commencement of operations. Escape doors should swing open outwards and not into the container. Doors should be able to be hooked open when persons are inside the container, i.e. they should not be automatically self-closing. More than one exit from buildings. Storage of spare batteries (e.g., in stores on site or	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
							Raw Risk						Residual Risk					
		to escalation. Consequences - Injuries turn to fatalities, small losses become extended down time.			elsewhere) also needs to consider possible thermal run away.													
Significance							N3 - Moderate						N2 - Low					
Impact 19:	Investors - Legal	Causes Battery 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".	Operation	Negative	Use only internationally reputable battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only state of the art battery systems are used and not old technologies prone to fires/explosions etc.	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 operational phase of the project does not present any high risks nor any fatal flaws.

TABLE 4.1.3 - DECOMMISSIONING PHASE

Battery components may have a limited lifespan, there may be 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 container / 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
							Raw Risk						Residual Risk					
Impact 1:	Human Health - chronic exposure to toxic chemical or biological agents	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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
							Raw Risk						Residual Risk					
						Significance	#N/A						#N/A					
Impact 5:	Human Health - exposure to ergonomic stress	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	As per construction and operational phases.	Easy	1	1	1	1	1	4	1	1	1	1	1	4
							#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
							Raw Risk						Residual Risk					
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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 11:	Environment - emissions to air	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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 - Batteries / equipment reached end of life and may leak. Consequences - Environment damage from heavy metal ions.	De-commission	Negative	End of Life shutdown procedure including a Risk Assessment of the specific activities involved. Where possible re-purpose the solid-state batteries / containers and equipment with associated environmental impact considered. Disposal according to local regulations and other directives such as the European Batteries Directive. End of life, which is affected by temperature and time, cycles etc, should be predefined and the monitoring should be in place to determine if it has been reached.	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.	De-commission	Negative	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	De-commission	Negative	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
							Raw Risk						Residual Risk					
		operational phases - no new hazards.																
Significance							#N/A						#N/A					
Impact 16:	Investors - Financial	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	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.

4.2 REDOX FLOW BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY VANADIUM

TABLE 4.2.1 - CONSTRUCTION PHASE (Excluding commissioning which is part of operations)

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
							Raw Risk						Residual Risk					
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		1	3	4	4	44	1	1	3	4	2	18
							Significance						N3 - Moderate					
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 the noise limits.	Easy	3	1	5	5	4	56	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
							Raw Risk						Residual Risk					
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 or small water treatment plant may be required to provide potable water for the employees during all phases of the project.	Easy	3	2	3	1	2	18	2	2	3	1	1	8
Significance							N2 - Low						N1 - Very Low					
Impact 4:	Human Health - exposure to psychological stress	Causes - Large projects bring many contractor workers into a community. Consequences – Lack of sufficient accommodation, entertainment etc. Increase in alcohol abuse, violence	Construction	Negative	Refer to Social Specialist Studies for this project.	Easy	2	3	3	2	2	20	2	3	3	2	2	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 all the necessary equipment is available (and well maintained) during construction. Otherwise employees may revert to unsafe practices. Maintenance of construction equipment to ensure safe operation is critical. Ensure this is in place prior to project beginning. 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
							Raw Risk						Residual Risk					
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
							Raw Risk						Residual Risk					
Impact 8a:	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.	Complex	4	2	3	2	3	33	3	2	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
							Raw Risk						Residual Risk					
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	<p>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.</p> <p>SHEQ policy in place.</p> <p>A detailed construction Risk Assessment prior to work.</p> <p>SHE procedure in place.</p> <p>PPE to be specified.</p> <p>SHE appointees in place.</p> <p>Contractors safety files in place and up to date.</p> <p>SHE monitoring and reporting programs in place.</p> <p>Standard construction site rules regarding traffic, reversing sirens, rigging controls, cordoning off excavations etc.</p> <p>Civil and building structures to National Building Regulations and building Standards Act 103 of 1977 SANS 10400 and other relevant codes.</p> <p>Other constructions such as roads, sewers etc also to relevant SANS standards.</p> <p>All normal procedures for working at heights, hot work permits, confined space entry, cordon off excavations etc to be in place before construction begins.</p> <p>Emergency response plan to be in place before construction begins.</p>	Complex	5	1	5	5	4	64	5	1	5	5	1	16
							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	<p>Standard maintenance of condition of electrical equipment and safe operating instructions.</p> <p>Ability to shut off power to systems in use on site.</p> <p>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.</p> <p>Lightning strike rate in the study area is low.</p> <p>Outside work must be stopped during thunderstorms.</p>	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
							Raw Risk						Residual Risk					
					Lighting conductors may be required for the final installation, to be confirmed during design phase.													
Significance							N3 - Moderate						N2 - Low					
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 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
							Raw Risk						Residual Risk					
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. Battery equipment damaged. Consequences - Delays.	Construction	Negative	Water usage to be monitored on site during construction. Handling protocols to be provided by battery 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
Significance							N2 - Low						N1 - Very Low					
Impact 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Construction	Negative	Visual impact assessment to include BESS installation when design details become available. Confirm any height limitations for VRFB BESS building (if utility scale)	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	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 but hazardous load. On site, theft of construction equipment and battery installation facilities.	Construction	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g., Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal	Complex	4	1	3	2	4	40	3	1	3	2	3	27

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
							Raw Risk						Residual Risk					
		Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglars. Damage to equipment possibly setting off thermal runaway.			batteries. Night lighting to be provided both indoors and outdoors where necessary.													
Significance							N3 - Moderate						N2 - Low					
Impact 18:	Emergencies	Causes - Fires, explosions, toxic 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
Significance							N3 - Moderate						N2 - Low					
Impact 19:	Investors - Legal	Causes Battery field is evolving quickly with new guides, codes and regulations happening at the same time as evolving technology. Consequences -	Construction	Negative	Use only internationally reputable battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only state of the art battery systems are used and not old technologies prone to fires/explosions etc.	Moderate	3	1	3	3	4	40	2	1	3	3	2	18

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
							Raw Risk						Residual Risk					
		Unknown hazards manifest due to using "cheaper supplier or less developed technology".																
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.

TABLE 4.2.2 - OPERATIONAL PHASE (Including Commissioning)

From the details of accidents that have happened both with BESS installations and 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
							Raw Risk						Residual Risk					
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	<p>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.</p> <p>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.</p> <p>SHE procedure in place, e.g., PPE specified, management of change, integrity monitoring.</p> <p>SHE appointees in place.</p> <p>Training of staff in general hazards on site.</p> <p>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.</p> <p>Emergency response plan for full operation and maintenance phase to be in place prior to beginning commissioning and to include aspects such as:</p> <ul style="list-style-type: none"> - 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. 	Easy	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
							Raw Risk						Residual Risk					
Impact 1b:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Compromised battery compartments vapours accumulate in the containers, solids/liquids on surfaces. Maintenance of battery components, corrosive and mildly toxic liquid on surfaces. Consequences - Dermatitis, skin /eye/lung irritation.	Operation	Negative	VRFB Batteries facilities normally within buildings but may be containerized. 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 battery 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 e.g., checklists for weekly, monthly, annual etc. Provided portable equipment for calibration and for testing/verification of defective equipment, e.g., volt/current meters, infrared camera	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 containers, buildings, pumps, compressors, cooling systems etc. Consequences - Adverse impact on hearing of workers. Nuisance factor at near -by residences or other activities.	Operation	Negative	Design to ensure continuous noise does not exceed 85dB within the facilities 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
							Raw Risk						Residual Risk					
Impact 3:	Human Health - exposure to temperature extremes and/or humidity	Causes - Heat during the day. Batteries generate heat within enclosed building / containers. 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 for VRFB. 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 - 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 ta height if equipment located on top of electrolyte 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
							Raw Risk						Residual Risk					
Impact 6a:	Human and Equipment Safety - exposure to fire radiation	Causes – Involvement in an external fire e.g., veld fire, maintenance vehicle fire, electrical systems fire. Manufacturing defects or damage to battery leading to shorting and heating. High humidity condensation of water or ingress of water or flooding leading to shorting. Dust accumulation on electrical parts leading to overheating. Excessive electrical loads - surges Operator abuse BMS failure or software failure. Incorrect extinguishing medium, escalate the fire. Consequences - Contaminated run off. Radiation burns. No affected bystanders. Damaged equipment. Fire spreads to other units or offsite if grass/vegetation not controlled.	Operation	Negative	Grass cutting and fire breaks around the BESS installations. No combustible materials to be stored in or near the batteries or electrical infrastructure, e.g., separation of site diesel tank. Fire resistant barrier between the batteries and the PCS side if in the same container. Design codes from USA and standards of practice UL9540, NFPA 855 and DNV GL RP 43. 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. BMS should be checking individual cell Voltage as well as stack, module, container, system Voltage/current etc. BMS tripping the cell and possibly the stack/ building unit or module/rack/container, if variations in Voltage. Diagnostics easily accessible. Diagnostics able to distinguish cell from stack or cell from module faults. As per SANS Standards, suitable ingress protection (IP) level provided for electrical equipment, e.g., IP55 - 66. If air cooling into container / building, suitable dust filters to be provided if needed. Smoke detectors may be needed linked to BMS and alerts in the main control room. Effects of battery aging to be considered. Temperature monitoring, regular infrared scanning. Data stored for trend analysis. Protective systems functionality testing. Prior to commencement of cold commissioning, emergency plan from transport and construction phase to extended to operational phase and to include the hazards of the electrically live system. Procedure to address suitable extinguishing media, ventilating, entering container as appropriate or not. PPE for firefighting may need to include fire retardant, chemically resistant, nitrile gloves, antistatic acid resistant boots, fill face shields, BA sets. A planned fire response to prevent escalation to an environmental event is critical. Suitable fire extinguishing medium, cooling medium and adequate supply of both is critical e.g., cooling adjacent equipment and can use fogging nozzles to direct smoke. Ensure procedures in place to clean up after event Lingering toxic residues in the soil and on adjacent structures.	Complex	5	1	5	5	3	48	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
							Raw Risk						Residual Risk					
Impact 6b:	Human and Equipment Safety - exposure to fire radiation	Causes - Power Conversion System (PCS – DC to AC) cooling failure electrical fire. Consequences - Fire starts in PCS or another section or room and spreads to battery area.	Operation	Negative	VRFB building systems PCS in another area separating it from the batteries and other equipment	Moderate	5	2	5	5	3	51	5	2	5	5	1	17
Significance							N3 - Moderate						N2 - Low					
Impact 7:	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 to be in place.	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
							Raw Risk						Residual Risk					
Impact 8a:	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.	Moderate	4	1	3	2	3	30	3	1	2	2	2	16
Significance							N2 - Low						N2 - Low					
Impact 8b:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Causes - Damaged batteries components, leak electrolyte, are completely broken exposing hazardous chemicals. Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive burns for large exposure.	Operation	Negative	Corrosion resistant PPE (e.g., overalls, gloves, eyeglasses) to be specified for all operations in electrolyte 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. Electrolyte contained, modules contained inside a building that is banded. 24/7 helpline response. Standard dangerous goods requirements for Hazmat labels. All operators/maintenance staff trained in the hazards.	Moderate	4	3	3	5	3	45	3	3	3	5	2	28
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
							Raw Risk						Residual Risk					
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	<p>Apart from pumps, no major moving parts during operation.</p> <p>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.</p> <p>Traffic signs, rules etc in place on site.</p> <p>All normal working at heights, hot work permits, confined space entry, cordon off unsafe areas/works etc to be in place.</p> <p>Emergency response plan.</p> <p>Civil design to take seismic activity into account.</p>	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
							Raw Risk						Residual Risk					
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	Codes and guidelines for electrical insulation. PPE to suit. Low Voltage equipment (e.g., batteries) separated from high Voltage (e.g., transmission to grid). Ensure trained personnel and refer to guideline – IEE 1657 – 2018. Ensure compliance with Eskom Operating Regulations for high Voltage systems including access control, permit to work, safe work procedures, live work, abnormal and emergency situations, keeping records. 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 facility and the other equipment on site. PPE to consider static accumulation for entering the facilities, and particularly the battery containers especially after a high temperature shut down where there could possibly be flammable materials. The procedures for responding to alarm and auto shut down on containers, needs to consider that there may be a dangerous environment inside and how to protect personnel who may enter to respond. Lightning strike rate in proposed development area is low. All outside work must be stopped during thunder storms. 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	Not expected on a normal basis. Refrigerant may be an asphyxiant if accidentally released indoors it can	Operation	Negative	Especially after any warning alarms have gone off, but possibly even normally the container could be treated as entering a confined space and similar procedures could be in place, e.g., do not enter alone, gas testing prior to entering, ensure adequate ventilation	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
							Raw Risk						Residual Risk					
		accumulate and displace oxygen.																
Significance							N2 - Low						N1 - Very Low					
Impact 12:	Environment - emissions to water	<p>Causes - Cooling water blow-down. Laboratory waste (if included in the design). Maintenance waste, e.g., oils. Spills from batteries, coolant system, diesel trucks, transformers. Parked vehicles – oil drips. Fire water runoff control. Kitchen waste and sewage. Refrigerant release. VRFB electrolyte purging.</p> <p>Consequences - Pollution if not contained. Excessive disposal costs if emissions not limited.</p>	Operation	Negative	<p>Electrolyte areas fully bunded to 110% of largest tank, or more.</p> <p>Bunding under any outdoors tanks, curbing under truck offloading areas and sealed surfaces (e.g., concrete) under truck parking area is particularly important.</p> <p>Sewage and any kitchen liquids - containment and suitable treatment/disposal.</p> <p>Procedures for dealing with damaged/leaking equipment as well as clean-up of spills.</p> <p>Normal site practices for preventing and containing diesel/paint etc spills.</p> <p>Waste management plan to be in place e.g., liquid waste treatment or suitable removal and disposal will be provided.</p> <p>Spill clean-up procedures to be in place before bringing container on site, including spill kits – non-combustible materials, hazmat disposal.</p> <p>The National Environment Management Act (NEMA) has a list of substances with Reportable spill Quantities, ensure compliance with this.</p> <p>Process controls in place to prevent contamination and deterioration of electrolyte leading to excessive purging.</p> <p>Ensure proposed locations of the BESS facilities are a suitable distance from the closest water course. In the event of a major spill if this is too close it may not allow time for mitigation to be taken. Adequate secondary and possibly tertiary containment systems may then be needed on site.</p>	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
							Raw Risk						Residual Risk					
Impact 13:	Environment - emissions to earth	Causes - Mess area and other solid waste. Disposal of battery components. Consequences - Environmental damage.	Operation	Negative	Implement waste segregation (e.g., electronic equipment, chemicals, domestic) and management on the site. During commissioning there will be a need for bulk transport of electrolyte to site and transfer of electrolyte into the tanks within the containers. Suitable secondary containment of possible spills / overfills etc. during this transfer process will need to be in place.	Easy	2	2	3	3	4	40	2	2	3	3	2	20
Significance							N3 - Moderate						N2 - Low					
Impact 14:	Environment - waste of resources e.g., water, power etc	Causes - Similar to construction phase. Disposal of batteries or components. Disposal of containers. Water usage not controlled. Excessive purging of deteriorated or contaminated electrolyte. Consequences - Delays. Excessive costs and disposal of large volumes of hazardous waste.	Operation	Negative	Water usage to be monitored on site. Handling protocols to be provided by supplier of electrolyte. Water management plan and spill containment plans to be in place. Investigate End of Life plan for electrolyte - reuse / recovery / reconditioning. Similarly, for decommissioned containers / 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	Visual impact assessment to include BESS installation when design details become available. Confirm any height limitations for VRFB BESS building (if utility scale)	Moderate	3	2	3	4	4	48	1	2	3	4	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
							Raw Risk						Residual Risk					
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.	Easy	5	1	3	4	3	39	3	1	3	4	2	22
Significance							N3 - Moderate						N2 - Low					
Impact 17a:	Employees and investors - Security	Causes - On route, potential hi-jacking of valuable but hazardous load. On site, theft of construction equipment and battery installation facilities. Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglars. Damage to equipment possibly setting off thermal runaway.	Operation	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. Consider motion detection lights and CCTV. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g., Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal batteries. 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 17b:	Employees and investors - Security	Causes - Cyber security attacks aimed at the National Electricity Grid. Consequences - Ransom of the National Electricity Grid.	Operation	Negative	Cyber security needs monitoring. Remote access to system needs to be negotiated and controlled. Password controls, levels of authority etc. Protection of the National Electricity Grid from Cyber-attacks accessing through the BESS. Cyber emergency procedures – should be in place prior to commissioning.	Complex	4	4	3	1	4	48	4	4	3	1	2	24
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
							Raw Risk						Residual Risk					
Impact 18:	Emergencies	Causes - Fires, explosions, toxic 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.	Operation	Negative	All safety measures listed above. Emergency procedures need to be practiced prior to commencement of operations. Escape doors should swing open outwards and not into the building/container. More than one exit 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 Battery 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".	Operation	Negative	Use only internationally reputable battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only state of the art battery systems are used and not old technologies prone to fires/explosions etc.	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 operational phase of the project does not present any high risks nor any fatal flaws.

TABLE 4.2.3 - DECOMMISSIONING PHASE

Battery components may have a limited lifespan, there may be damaged equipment, waste electrolyte 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 electrolyte / container / 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
							Raw Risk						Residual Risk					
Impact 1:	Human Health - chronic exposure to toxic chemical or biological agents	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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	Similar to the construction and	De-commission	Negative	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
							Raw Risk						Residual Risk					
	psychological stress	operational phases - no new hazards.																
Significance							#N/A						#N/A					
Impact 5:	Human Health - exposure to ergonomic stress	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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
							Raw Risk						Residual Risk					
	potential energy																	
							#N/A						#N/A					
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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 11:	Environment - emissions to air	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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 - Batteries / electrolyte / equipment reached end of life and may leak. Consequences - Environment damage from heavy metal ions.	Construction	Negative	End of Life shutdown procedure including a Risk Assessment of the specific activities involved. Where possible re-purpose the batteries / containers and equipment with associated Environmental impact considered. Disposal according to local regulations and other directives such as the European Batteries Directive. End of life, which is affected by temperature and time, cycles etc, should be predefined and the monitoring should be in place to determine if it has been reached.	Complex	4	3	3	5	4	60	4	3	3	5	2	30
						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
							Raw Risk						Residual Risk					
Impact 14:	Environment - waste of resources e.g., water, power etc	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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 16:	Investors - Financial	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	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.

4.3 MOLTEN METAL BATTERY ENERGY STORAGE SYSTEMS – TYPICALLY AMBRI SYSTEM

TABLE 4.3.1 - CONSTRUCTION PHASE (Excluding commissioning which is part of operations)

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. Contractors 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	The construction phase will be the noisy phase of the project. No extreme construction envisaged, normal road, industrial building type construction similar to what would take place in an industrial area. Health risk assessment to determine if equipment continuous 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 the noise limits. Due to rural nature of site, construction is unlikely to continue at after sunset.	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 or small water treatment plant may be required to provide potable water for the plants during all phases of the project.	Easy	3	2	3	1	2	18	2	2	3	1	1	8
Significance							N2 - Low						N1 - Very Low					
Impact 4:	Human Health - exposure to psychological stress	Causes - Large projects bring many contractor workers into a community. Consequences – Lack of sufficient accommodation, entertainment etc. Increase in alcohol abuse, violence	Construction	Negative	Depending on size of contract and scope, project may need to provide regular/periodic transport to town and nearby cities. Local community involvement and as far as possible preferably use of local persons as contract workers on the project.	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 construction. Consequences - Back and other injuries..	Construction	Negative	Training in lifting techniques. Ensure that all the necessary equipment is available (and well maintained) during construction. Otherwise employees may revert to unsafe practices. Maintenance of construction equipment to ensure safe operation is critical. Ensure this is in place prior to project beginning. Development of local service providers. First aid provision on site.	Moderate	4	1	3	2	3	30	4	1	3	2	2	20
Significance							N2 - Low						N2 - Low					

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 banded areas. Suitable fire-fighting equipment on site near source of fuel, e.g. diesel tank, generators, mess, living quarters, workshops etc Emergency plan to be in place prior to commencement of construction. Fuel spill containment procedures and equipment to be in place. 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 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. Prior to construction determine the dangerous species in the area and what responses are needed to bites/exposure/attacks. 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.	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. Emergency response plan to be in place before construction begins.	Complex	5	1	5	5	4	64	5	1	5	5	1	16

							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 low. Outside work must be stopped during thunder storms. 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 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 waste water. 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. Battery equipment damaged. Consequences - Delays.	Construction	Negative	Water usage to be monitored on site during construction. Handling protocols to be provided by battery 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 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Construction	Negative	Limited height for electrical infrastructure. Visual impact assessment to include BESS installation when design details become available. Battery containers single storey as physical space is not a constraint that would require stacking of containers. Containers likely to be painted white, not left as reflective steel.	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	Construction	Negative	Design by experienced contractors using internationally recognized and proven technology. Project management with deviation monitoring. Project insurance for construction phase.	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 but hazardous load. On site, theft of construction equipment and battery installation facilities. Civil unrest or violent strike by employees. Consequences - Theft.	Construction	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g. Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal batteries. Night lighting to be provided both indoors and outdoors where necessary.	Complex	4	1	3	2	4	40	3	1	3	2	3	27

		Injury to burglars. Damage to equipment possibly setting off thermal runaway.																	
Significance							N3 - Moderate						N2 - Low						
Impact 18:	Emergencies	Causes - Fires, explosions, toxic 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. Small events not handled correctly and escalate into larger events. Emergency procedures need to be practiced prior to commencement of construction.	Complex	4	2	3	4	3	39	4	2	3	4	2	26	
Significance							N3 - Moderate						N2 - Low						
Impact 19:	Investors - Legal	Causes Battery 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 battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only latest state of the art battery system are used.	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.

TABLE 4.3.2 - OPERATIONAL PHASE (Including Commissioning)

From the details of accidents that have happened both with BESS installations and 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	<p>The operation and maintenance phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993.</p> <p>SHEQ policy in place.</p> <p>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.</p> <p>SHE procedure in place, e.g. PPE specified, management of change, integrity monitoring.</p> <p>SHE appointees in place.</p> <p>Training of staff in general hazards on site.</p> <p>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.</p> <p>Emergency response plan for full operation and maintenance phase to be in place prior to beginning commissioning and to include aspects such as:</p> <ul style="list-style-type: none"> - 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. 	Easy	2	1	3	4	5	50	1	1	3	4	2	18
						Significance	N3 - Moderate						N2 - Low					

Impact 1b:	Human Health - chronic exposure to toxic chemical or biological agents	Causes - Compromised battery compartments vapours accumulate in the containers, solids/liquids on surfaces. Maintenance of battery components, corrosive and mildly toxic liquid on surfaces. Consequences - Dermatitis, skin /eye/lung irritation.	Operation	Negative	Molten Metal Batteries facilities normally containerized. Maintenance procedures will be in place should equipment need to be opened, e.g. cooling down the entire container prior to entry, decontaminated prior to repair in workshop etc. PPE will be specified for handling battery 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 cooled battery containers? 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, e.g. volt/current meters, infrared camera	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 containers, buildings, pumps, compressors, cooling systems etc. Consequences - Adverse impact on hearing of workers. Nuisance factor at near -by residences or other activities.	Operation	Negative	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 3:	Human Health - exposure to temperature extremes and/or humidity	Causes - Heat during the day. Batteries generate heat within enclosed building / containers. 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. PPE for operations and maintenance staff to be suitable for the weather conditions. Lighting to be provided inside the building, inside the containers, possibly linked to the door opening and outdoors where necessary. Suitable lighting to be provided including emergency lighting for safe building exit in the event of power failure. Adequate potable water to be provided during all phases of the project.	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 - 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 electrolyte 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, 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 6a:	Human and Equipment Safety - exposure to fire radiation	<p>Causes – Involvement in an external fire e.g. veld fire, maintenance vehicle fire, electrical systems fire. Manufacturing defects or damage to battery leading to shorting and heating. High humidity condensation of water or ingress of water or flooding leading to shorting. Dust accumulation on electrical parts leading to overheating. Operator abuse. BMS failure or software failure. Molten metal leaks onto combustible material (e.g. cables, supports) starts fire. Incorrect extinguishing medium, escalate the fire. Consequences - Contaminated run off. Radiation burns unlikely to be severe as no highly flammable materials on site. No affected bystanders. Damaged equipment. Fire spreads to other units or offsite if grass/vegetation not controlled.</p>	Operation	Negative	<p>Grass cutting and fire breaks around the BESS installations to prevent veld fires. No combustible materials to be stored in or near the batteries or electrical infrastructure. Separation of site diesel tank, transformers from BESS and vice versa. Fire resistant barrier between the batteries and the PCS side if in the same container, or separate containers. Design codes from USA and standards of practice UL9540, NFPA 855 and DNV GL RP 43. 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. BMS should be checking individual cell Voltage as well as stack, module, container, system Voltage/current etc. BMS tripping the cell and possibly the stack/ building unit or module/rack/container, if variations in Voltage. Diagnostics easily accessible. Diagnostics able to distinguish cell from stack or cell from module faults. Suitable ingress protection level provided for electrical equipment, e.g. IP55 - 66. If air cooling into containers (not with hot molten metal which will likely need to stay hot) / building, suitable dust filters to be provided if needed. Smoke detectors may be needed linked to BMS and alerts in the main control room. Effects of battery deterioration to be considered. Temperature monitoring to be in place. Regular infrared scanning. 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 battery plant trips actually work. Refer to construction phase above and apply. Emergency plan from transport and construction phase to be extended to operational phase and to include the hazards of the electrically live system. Procedure to address suitable extinguishing media, ventilating, entering container as appropriate or not. PPE for fire-fighting may need to include fire retardant, chemically resistant, nitrile gloves,</p>	Complex	5	1	5	5	3	48	5	1	5	5	1	16
------------	---	---	-----------	----------	--	---------	---	---	---	---	---	----	---	---	---	---	---	----



					antistatic acid resistant boots, fill face shields, BA sets. A planned fire response to prevent escalation to an environmental event is critical. Suitable fire extinguishing medium, and cooling mediums and adequate supply of both is critical. Consider fire water for cooling adjacent equipment – BESS units. Can use fogging nozzles to direct smoke. Clean up after event Linger toxic residues in the soil and on adjacent structures.													
Significance						N3 - Moderate						N2 - Low						

Impact 6b:	Human and Equipment Safety - exposure to fire radiation	Causes - Power Conversion System (PCS – DC to AC) cooling failure electrical fire. Consequences - Fire starts in PCS or another section or room and spreads to battery area.	Operation	Negative	Modern container design put the PCS in another part of the container with a fire rated wall separating it from the battery. Alternately the PCS is another container altogether. Failure of cooling on PCS or fires on other electrical equipment such as cooling system pump motors etc, and failure to trip the entire system and raise the alert.	Moderate	5	2	5	5	3	51	5	2	5	5	1	17
Significance							N3 - Moderate						N2 - Low					
Impact 7:	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 8a:	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.	Moderate	4	1	3	2	3	30	3	1	2	2	2	16
Significance							N2 - Low						N2 - Low					

CHEMICAL PROCESS SAFETY ENGINEERS																		
Impact 8b:	Human and Equipment Safety - exposure to acute toxic chemical and biological agents	Causes - Damaged batteries components, leaked solids, completely broken exposing hazardous chemicals. Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive or heat burns for large exposure.	Operation	Negative	Corrosion resistant PPE (e.g. overalls, heat gloves, eye glasses) to be specified for all operations in battery 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 hot surfaces, hot metals, corrosive chemicals and of all other chemicals on site. Molten metal contained within ceramic and stainless steel casing as well as overall outer container which acts as final bund. Material will solidify soon after leak. 24/7 helpline response. Standard dangerous goods requirements for Hazmat labels. All operators/maintenance staff trained in the hazards.	Moderate	4	3	3	5	3	45	3	3	3	5	2	28
Significance						N3 - Moderate						N2 - Low						
Impact 9:	Human and Equipment Safety - exposure to violent release of kinetic or potential energy	Causes - Moving equipment, heavy equipment at elevation, nip points, working at heights. Traffic accidents. Extremely hot surfaces. Consequences - Injury. Fatality in unlikely worst case, e.g. traffic accidents or fall from heights or exposed to molten metal. Damage to equipment, spills, environment pollution.	Operation	Negative	NOTE handling of hot batteries to be forbidden, cooling down times/temperatures to be specified in procedures. Suitable PPE (heat resistant) to be specified. No major moving parts during operation. 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.	Moderate	5	1	5	5	3	48	5	1	5	5	1	16
						N3 - Moderate						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.	Operation	Negative	Codes and guidelines for electrical insulation. PPE to suit. Low Voltage equipment (e.g. batteries) separated from high Voltage (e.g. transmission to grid). Trained personnel – IEE 1657 – 2018. Eskom Operating Regulations for high Voltage systems including access control, permit to work, safe work procedures, live work, abnormal and emergency situations, keeping records. Electromagnetic fields, impact on other equipment e.g. testing devices, mobile phones – malfunction, permanent damage. Software also needs maintenance, patches, updates. 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 the battery containers especially after a high temperature shut down where there could possibly be flammable materials. The procedures for responding to alarm and auto shut down on containers, needs to consider that there may be a dangerous environment inside and how to protect personnel who may enter to respond. Lightning strike rate in proposed development area is low. All outside work must be stopped during thunder storms. 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	Not expected on a normal basis. Refrigerant may be an asphyxiant if accidentally released indoors it can accumulate and displace oxygen.	Operation	Negative	Especially after any warning alarms have gone off, but possibly even normally the container / refrigeration room could be treated as entering a confined space and similar procedures could be in place, e.g. do not enter alone, gas testing prior to entering, ensure adequate ventilation.	Easy	3	1	1	1	3	18	3	1	1	1	1	6
Significance							N2 - Low						N1 - Very Low					

Impact 12:	Environment - emissions to water	Causes - Cooling water blow-down. Laboratory waste (if included in the design). Maintenance waste, e.g. oils. Spills from batteries, coolant system, diesel trucks, transformers. Parked vehicles – oil drips. Fire water runoff control. Kitchen waste and sewage. Refrigerant release. Consequences - Pollution if not contained. Excessive disposal costs if emissions not limited.	Operation	Negative	Molten metal solidifies rapidly upon release and can be easily collected. Container acts as bund. Bunding under any outdoors tanks (e.g. diesel), curbing under truck offloading areas and sealed surfaces (e.g. concrete) under truck parking area is particularly important. Sewage and any kitchen liquids - containment and suitable treatment/disposal. Procedures for dealing with damaged/leaking equipment as well as clean-up of spills. 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. Ensure proposed locations of the BESS facilities are a suitable distance from the closest water course. In the event of a major fire where water is used it should allow time for mitigation (secondary containment) to be taken.	Moderate	3	2	3	2	3	30	3	2	3	2	2	20
Significance							N2 - Low					N2 - Low						
Impact 13:	Environment - emissions to earth	Causes - Mess area and other solid waste. Disposal of battery components. Consequences - Environmental damage.	Operation	Negative	There will be packaging materials that will need to be disposed of 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	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. Disposal of batteries or components. Disposal of containers. Water usage not controlled.	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 electrolyte/electrodes/battery casings - reuse / recovery / reconditioning. Molten metal electrodes/electrolyte has an expected long lie (Easy	2	1	1	2	4	24	2	1	1	2	2	12

		Consequences - Delays. Excessive costs and disposal of large volumes of hazardous waste.			>20years) Similarly, for decommissioned containers / equipment – reuse / recovery / repurpose														
							N2 - Low						N1 - Very Low						
Impact 15:	Public - Aesthetics	Causes - Bright surfaces reflecting light. Tall structures in a flat area. Consequences - Irritation.	Construction	Negative	Limited height for electrical infrastructure. Sheeting likely to be painted, not left as reflective steel. Confirm height limitations for electrical infrastructure, in terms of visual aspects. Visual impact assessment to include BESS installation when design details become available. Containers single storey as physical space is not a constraint that would require stacking of containers. Containers likely to be painted white, not left as reflective steel.	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 for construction phase. Project insurance.	Easy	5	1	3	4	3	39	3	1	3	4	2	22	
Significance							N3 - Moderate						N2 - Low						
Impact 17a:	Employees and investors - Security	Causes - On route, potential hi-jacking of valuable but hazardous load. On site, theft of construction equipment and battery installation facilities. Civil unrest or violent strike by employees. Consequences - Theft. Injury to burglars.	Operation	Negative	Fencing around electrical infrastructure to SANS standard and Eskom Guidelines. Consider motion detection lights and CCTV. The hazardous nature of the electrical and battery equipment should be clearly indicated – e.g. Skull and Cross Bones or other signs. The location is isolated and security will be necessary. Solid state batteries may be more susceptible to easy theft than flow or hot metal batteries. Night lighting to be provided both indoors and outdoors where necessary.	Moderate	3	1	3	2	4	36	3	1	3	2	2	18	

		Damage to equipment possibly setting off thermal runaway.																	
Significance							N3 - Moderate						N2 - Low						
Impact 17b:	Employees and investors - Security	Causes - Cyber security attacks aimed at the National Electricity Grid. Consequences - Ransom of the National Electricity Grid.	Operation	Negative	Cyber security needs monitoring. Remote access to system needs to be negotiated and controlled. Password controls, levels of authority etc. Protection of the National Electricity Grid from Cyber-attacks accessing through the BESS. Cyber emergency procedures – should be in place prior to commissioning.	Complex	4	4	3	1	4	48	4	4	3	1	2	24	
Significance							N3 - Moderate						N2 - Low						
Impact 18:	Emergencies	Causes - Fires, explosions, toxic 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.	Operation	Negative	All safety measures listed above. Small events not handled correctly and escalate into larger events. Emergency procedures need to be practiced prior to commencement of operations. Escape door open outwards, doors hooked open when persons inside. More than one exit 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 Battery 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".	Operation	Negative	Use only internationally reputable battery suppliers who comply with all known regulations/guideline at the time of purchasing. Ensure only latest state of the art battery system are used.	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 operational phase of the project does not present any high risks nor any fatal flaws.

TABLE 4.3.3 - DECOMMISSIONING PHASE

Battery components may have a limited lifespan, there could be damaged equipment, waste electrolyte 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 electrolyte / container / 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
							Raw Risk						Residual Risk					
Impact 1:	Human Health - chronic exposure to toxic chemical or biological agents	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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
							Raw Risk						Residual Risk					
						Significance	#N/A						#N/A					
Impact 5:	Human Health - exposure to ergonomic stress	Similar to the construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	As per construction and operational phases.	Easy	1	1	1	1	1	4	1	1	1	1	1	4
							#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
							Raw Risk						Residual Risk					
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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 11:	Environment - emissions to air	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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 - Batteries / electrolyte / equipment reached end of life. Consequences - Environment damage from heavy metal ions.	Construction	Negative	End of Life shutdown procedure including a Risk Assessment of the specific activities involved. Where possible re-purpose the batteries / containers and equipment with associated Environmental impact considered. Disposal according to local regulations and other directives such as the European Batteries Directive. End of life, which is affected by temperature and time, cycles etc, should be predefined and the monitoring should be in place to determine if it has been reached.	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.	De-commission	Negative	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	De-commission	Negative	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
							Raw Risk						Residual Risk					
		operational phases - no new hazards.																
Significance							#N/A						#N/A					
Impact 16:	Investors - Financial	Similar to the Construction and operational phases - no new hazards.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	Negative	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.	De-commission	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 study proceeded based on the assumption that redox flow batteries (typically vanadium) could be installed within a building and solid state batteries (typically lithium) and liquid metal batteries would be installed in containers. Flow batteries can also be installed in containers, but the building option has been chosen in order to highlight possible major differences between technologies.

5.1.1 GENERAL

- This Risk Assessment has found that for the BESS installations associated with the proposed Vanderkloof PV and BESS facility near Luckhoff in the Free State, provided suitable preventative and mitigative measures in place, none of the identified potential risks are excessively high, i.e., from a Safety, Health and Environment (SHE) perspective no fatal flaws were found with either type of technology (solid state - lithium-ion, redox flow – vanadium, or molten liquid metal - Ambri) and therefore from a SHE risk perspective there is no reason to prohibit the development.
- At a large facility, without installation of the state-of-the art battery technology that includes protective features, there can be significant risks to employees and first responders. The latest battery designs include many preventative and mitigative measures to reduce these risks to tolerable levels. (Refer to tables in Section 4 under preventative and mitigative measures). State-of-the-art technology should be used, i.e., not old technology that may have been prone to fire, explosion and loss of containment risks.
- 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.
- From an acute health and safety point of view, and ignoring the fact that this project may help to mitigate possible adverse impacts of climate change, create jobs and contribute to sustainable energy, the No-Go option will always be a preferred option since there are no immediate health and safety risks associated with not doing a project.

5.1.2 LITHIUM SOLID STATE CONTAINERIZED BATTERIES

- With lithium solid-state batteries, the most significant hazard with battery units is the possibility of thermal runaway and the generation of toxic and flammable gases. There have been numerous such incidents around the world with lithium-ion batteries at all scales and modern technology providers include many preventative and mitigative features in their designs, e.g. solid state electrolytes being

one of these improvements. This type of event also generates heat which may possibly propagate the thermal runaway event to neighbouring batteries if suitable state of the art technology is not employed.

- The flammable gases generated may ignite leading to a fire which accelerates the runaway process and may spread the fire to other parts of the BESS or other equipment located near-by.
- If the flammable gases accumulate within the container before they ignite, they may eventually ignite with explosive force. This type of event is unusual with solid state batteries, but has happened with an older technology container installed at McMicken in the USA in 2019.
- Due to a variety of causes, thermal runaway could happen at any point during transport to the facility, during construction or operation / maintenance at the facility or during decommissioning and safe making for disposal.
- Due to the containerized approach as well as the usual good practice of separation between containers, which should be applied on this project, and therefore the likely restriction of events to one container at a time, the main risks are close to the containers i.e., to transport drivers, employees at the facilities and first responders to incidents.
- In terms of a worst conceivable case container fires, the significant impact zone is likely to be limited to within 10m of the container and mild impacts to 20m. Based on the current proposed layouts, impacts at the closest isolated farmhouses or other independent facilities are not expected. In addition any general access onsite facilities such as laydown areas have been located over 20m from the BESS area.
- In terms of a worst conceivable case explosion, the significant impact zone is likely to be limited to with 10m of the container and minor impacts such as debris within 50m. Based on the current proposed layouts, impacts at the closest isolated farmhouses or other independent facilities are not expected. In addition onsite structures such as buildings have been located over 50m from the BESS area, while substations have been located over 30m away.
- In terms of a worst reasonably conceivable toxic smoke scenario, provided the units are placed suitably far apart to prevent propagation from one unit to another and large external fires are prevented (i.e. grass cutting in place), the amount of material burning should be limited to one container at any one time. In this case, beyond the immediate vicinity of the fire, the concentrations of harmful gases within the smoke should be low. Occupied farm houses / developments should ideally be located over 500m from the BESS and public roads over 100m.
- For the Vanderkloof PV and BESS, the BESS locations are all over 100m from public roads and are positioned over 500m from any occupied farmhouse, and in this context the locations are therefore considered suitable in terms of toxic gas risks.

5.1.3 VANADIUM REDOX FLOW BATTERY INSTALLATIONS

- The most significant hazard with VRF battery units is the possibility of spills of corrosive and environmentally toxic electrolyte. Many preventative and mitigative features will be included in the design and operation, e.g., full secondary containment, level control/monitoring on bulk tanks, leak

detection on equipment etc. (Refer to tables in section 4 under preventative and mitigative measures).

- For the Vanderkloof PV and BESS, the BESS locations are over 100m from any water course and 50m from most active boreholes. This is to be confirmed by the aquatic study and any active boreholes that are too close should be capped to prevent use of potentially contaminated ground water should there be an incident. With the above mitigations the locations are considered suitable in terms of spill management.
- VRF batteries do not present significant fire and electrical arcing hazards provided they are correctly designed, operated, maintained and managed. Suitable Battery Management System (BMS), safety procedures, operating instructions, maintenance procedures, trips, alarms and interlocks should be in place. (Refer to tables in section 4 under preventative and mitigative measures).

5.1.4 LIQUID METAL BATTERY INSTALLATIONS

- The most significant hazard with liquid metal battery units is the possibility of injury to personnel mishandling hot items. Suitable on site procedures and PPE for operations and maintenance need to be in place.
- Fires in the event of battery leaks are not impossible, but these should be limited to the combustible materials in a container, e.g. cable coatings etc. and is not likely to be the result of thermal runaway of the battery. The fire is not inherently electrical and normal fire suppression could be used. Note water on hot surfaces would not be advised.
- For the Vanderkloof PV and BESS, the BESS locations are suitable for molten metal batteries.

5.1.5 TECHNOLOGY AND LOCATION OF BESS FACILITIES

- From a safety and health point of view, the above Risk Assessment shows that risks posed by VRFB systems may be slightly lower than those of SSL facilities, particularly with respect to fire and explosion risks. From an environmental spill and pollution point of view the VRFB systems present higher short-term risks than the SSL systems. Liquid metal batteries present lower risks than both the SSL and VRF battery systems as both the risks of fire and spills are significantly lower. However, the above conclusions may be due to the fact that the VRFB and Liquid Metal technology is not as mature as SSL technology and there is not as much operating experience and accident information available. Overall, from a SHE RA points of view, there is no specific preference for a type of technology.
- 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 other occupied facilities, this would be preferred. VRFB hazards are mostly related to possible loss of containment of electrolyte, SSL batteries to fires producing toxic smoke and fire fighting which may result in contaminated of firewater runoff and liquid metal hazards are mostly limited to onsite operational issues. The current chosen locations are suitably far from isolated farm houses, public roads, powerlines and water resources with a very low risk of any significant impacts.

5.1.6 CUMULATIVE IMPACTS

- Unless another BESS is installed within 500m of the BESS locations, cumulative impacts of other developments in the greater area do not affect the safety and health of employees, contractors of members of the public within the BESS impact zone. The same can be said of the BESS electrical infrastructure and grid connection.
- BESS 1 and BESS 5-1 are located within 200m of BESS 2 resulting in a large complex with about 835MW generating capacity. There could possibly be in excess of 1000 SSLB containers in this combined complex. There are no independent developments such as farm houses within 500m of any of these BESS installations and therefore no increase in offsite cumulative risks. However, all the onsite facilities for all three BESS installations, such as buildings, substations etc, are within the impact range of all three BESS installations. Cumulative risks on employees are therefore relevant and due to the high number of units there is a high risk of fires. Due to the isolated location, Emergency Response to battery fires is likely to be 'let it burn but prevent the spread'. Specific emergency Response procedures should be in place to protect employees from toxic smoke, e.g. rehearsed emergency evacuation plans or even the provision of shelter in place facilities. Although they are part of the same facility, BESS 5.2. and 5.3 may pose similar onsite cumulative risks to BESS 5.3. buildings (possibly up to 800 containers in the complex and BESS 5.3 facilities partially within 500m of BESS 5.2) and therefore similar mitigation measures could be considered.

5.2 RECOMMENDATIONS

The following recommendations have been made:

- There are numerous different battery technologies, but using one consistent battery technology system for the BESS installations within the Vanderkloof PV and BESS facility, would allow for ease of training, maintenance, emergency response and could significantly reduce risks.
- Where reasonably practicable, state-of-the-art battery technology should be used with all the necessary protective features e.g., draining of cells during shutdown and standby-mode, full BMS with deviation monitoring and trips, leak detection systems.
- There are no fatal flaws associated with any of the proposed BESS installations for either of the three technology types.
- The tables in Section 4 of this report contains technical and systems suggestions for managing and reducing risks. Ensure the items listed in these tables under preventative and mitigative measures are included in the design.
- The overall design should be subject to a full Hazop prior to finalization of the design.
- For the VRFB systems an environmentally friendly method of filling the system with electrolyte upon startup and an end of life (and for possible periodic purging requirements) solution for the large quantities of hazardous electrolyte should be investigated, e.g., can it be returned to the supplier for re-conditioning.
- Prior to bringing any solid-state battery containers into the country, the contractor should ensure that:

- An Emergency Response Plan is in place that would be applicable for the full route from the ship to the site. This plan would include details of the most appropriate emergency response to fires both while the units are in transit and once they are installed and operating.
 - An End-of-Life plan is in place for the handling, repurposing or disposal of dysfunctional, severely damaged batteries, modules and containers.
- The site layout and spacing between lithium solid-state containers should be such that it mitigates the risk of a fire or explosion event spreading from one container to another.
 - Under certain weather conditions, the noxious smoke from a fire in a lithium battery container could travel some distance from the unit. The smoke will most likely be acrid and could cause irritation, coughing, distress etc. Close to the source of the smoke, the concentration of toxic gases may be high enough to cause irreversible harmful effects. Location of the facilities needs to ensure a suitable separation distance from public facilities/residences etc. The current proposed BESS locations are all over 500m from isolated farmhouses. All BESS locations are over 100m from busy public roads. The risks of significant fire, explosion and toxic smoke impacts on members of the public is very low.
 - Where there is a choice of alternative locations for the BESS, those that are further from water courses would be preferred. VRFB hazards are mostly related to possible loss of containment of electrolyte and solid-state systems may experience fires that may result in loss of containment of liquids or the use of large amounts of fire water which could be contaminated. One would not want these run-offs to enter water courses directly. The buffer distance between water bodies and the facilities containing chemicals should be set in consultation with a water specialist and is therefore not specified in this SHE RA. It should be noted that all the BESS locations are over 100m from the closest water courses and 50m from most active boreholes. Active boreholes within 50m could be capped to prevent possible use of contaminated ground water in the event of a spillage incident. With such mitigation measures the location can be considered suitable.
 - For molten metal batteries the most significant hazards are to persons working with the facilities, e.g. operation and maintenance personnel. Suitable procedures will need to be in place and PPE to be specified.
 - Due to the location of BESS 1, BESS 2 and BESS 5.1 within 500m of each other cumulative risks on employees are relevant. Due to the high number of battery containers there is a high risk of fires. As it is a remote isolated location, Emergency Response to battery fires is likely to be 'let it burn but prevent the spread'. Specific emergency Response procedures should be in place to protect employees from toxic smoke, e.g. rehearsed emergency evacuation plans or even the provision of shelter in place facilities. Similar mitigation measures could be considered for the BESS 5.2 and 5.3 complex, although the risks are not as significant as for the BESS 1,2 and 5.1 complex.
 - Finally, once the BESS technology has been selected and further specifics of the final design are available, verify that all recommendations as provided in this risk assessment are adhered to, including the mitigation measures provided by the BESS supplier.

6 REFERENCES

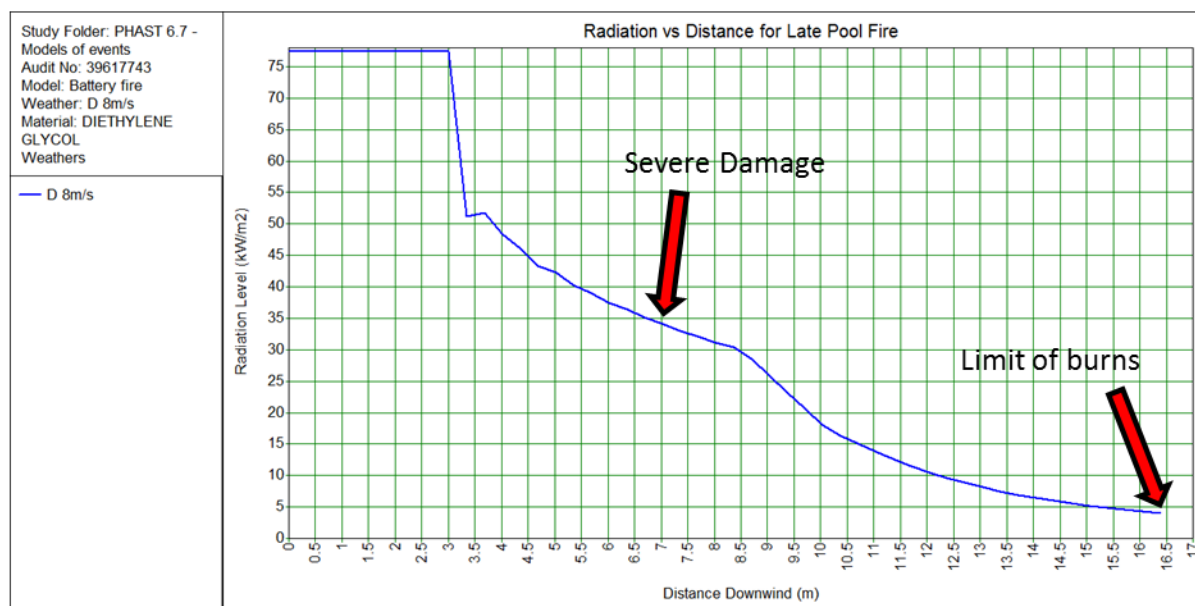
1. "National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended (NEMA) and the NEMA EIA Regulations, 2014, as amended. Government Gazette No 19519 of 27 November 1998.
2. "Environmental Impact Assessment Regulations, 2014, as amended", Government Gazette No 326 of 7 April 2017.
3. SABS, "SANS 10228 – The Identification and Classification of Dangerous Goods for Transport", Standards South Africa, Pretoria, 2012.
4. SABS, "SANS 10234 – Globally Harmonize System of classification and labelling of chemicals (GHS)", SABS, Pretoria 2008.
5. SABS, "Supplement to SANS 10234 – List of classification and labelling of chemicals in accordance with the Globally Harmonize System (GHS)", SABS, Pretoria, 2008.
6. 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.
7. SABS, "SANS10313: Protection against lightning – physical damage to structure and life hazard", SABS, Pretoria, 2012.
8. DNV-GL, Recommended Practice – Safety, operation and performance of grid-connected energy storage systems, DNVGL-RP-0043, September 2017
9. IEC, "IEC 62619 – Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety Requirements or secondary lithium cells and batteries for use in industrial applications", Feb 2017.
10. Hare, G. "Batteries – What's the Problem", Brandz, Fire and Emergency New Zealand Research Report 174. Jan 2020.
11. DNV-GL, 'McMicken Battery Energy Storage Systems Event – Technical Analysis and Recommendations, July 2020.
12. DNV-GL, 'Quantitative risk analysis for battery energy storage sites", 17 May 2019.
13. Energy Response Solutions, "Energy Storage Systems Safety - Comparing Vanadium Redox Flow and Lithium-ion Based Systems ", Aug 2017.
14. Wikipedia, "Vanadium redox Batteries".
15. Bushveld Minerals and Energy, "Energy Storage and Vanadium Redox Flow batteries 101", 13 November 2018.
16. Whitehead A.H, Rabbow T.J, Trampert M, Pokorny P, "Critical safety features of the vanadium redox flow battery", Volume 351, 31 May 2017, Pages 1-7.
17. ESI AFRICA, "The vanadium redox flow battery, a leading technology in energy storage", Aug 8, 2019.
18. Noak J, Roznyatovskaya N, Menictas C and Skyllas-Kazacos AM, "Redox flow batteries for renewable energy storage", 21 Jan 2020.
19. Global Sustainable Energy Solutions, "Battery Storage Systems: What are their chemical hazards?", GSES Technical Papers, 2016, www.gses.com.au.
20. University of Washington Environment Health and Safety, "Lithium Battery Safety", www.ehs.washington.edu, April 2018.
21. Hesler, P & Travers, K.A., "Lithium-ion Battery Energy Storage Systems - The risks and how to manage them", AIG, 17 July 2019.
22. Verhaegh, N., van de Burgt, J., Tiggelman, A and Mulder G. "STALLION Handbook on safety assessment for large Scale, stationary, grid-connected Lithium -ion energy Storage Systems", Arnhem, March 2015.
23. TESLA, Battery Emergency Response Guide (Lithium-ion), 17 Dec 2019.
24. Tesla, MegaPack – Datasheet Safety Overview.
25. St John, J, "SunEdison Buys Wind Grid Storage for Battery-Backed PV and Wind Power", Greentechmedia.com, 5 March 2015.
26. Energy Storage Association, "Operation Risk Management in the US Energy Storage Industry: Lithium-Ion Fire and Thermal Event Safety", Sept 2019
27. AMBRI website.

APPENDIX A

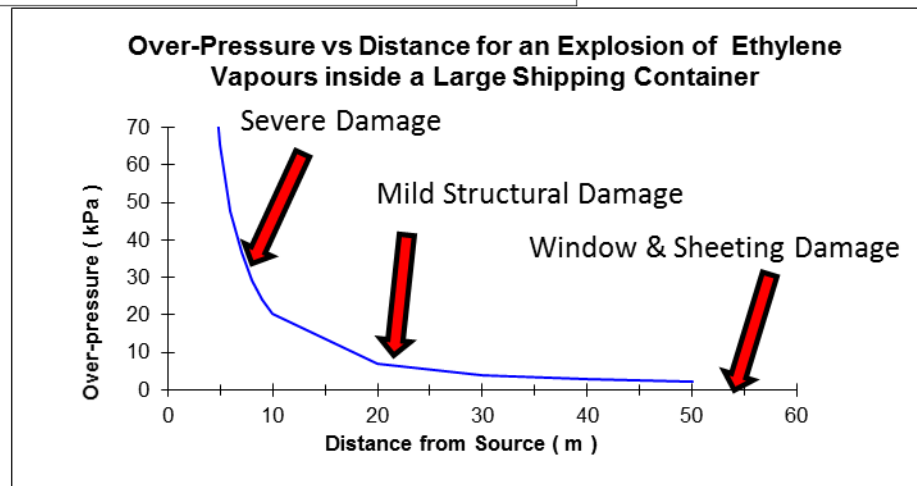
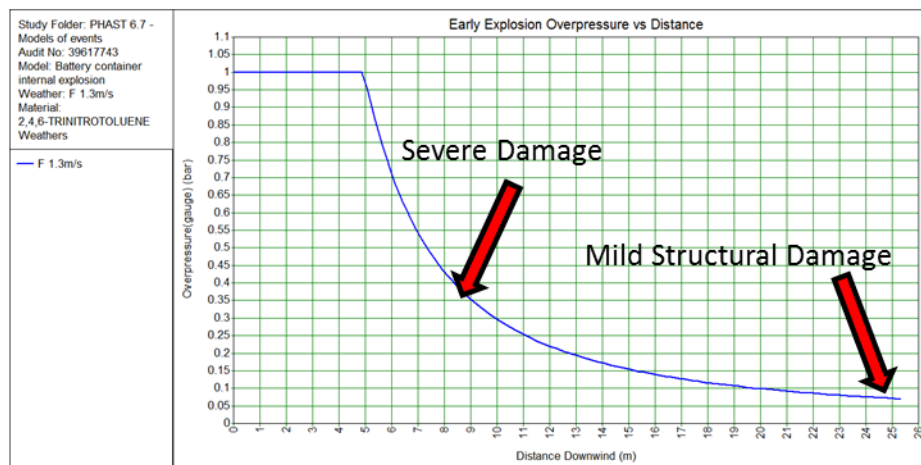
Preliminary Approximations of Absolute WORST-CASE Consequence and Risk Modelling (Modelling done using DNV-GL software PHAST RISK 6.7)

PLEASE NOTE – the modelling, especially the noxious smoke modelling, is an approximation.

Approximation of WORST-CASE Radiation Levels from an Entire Container on Fire



Approximation of WORST-CASE Explosion Over pressures from an Entire Container Explosion



Approximation of Maximum Concentration of Carbon Monoxide in Noxious Smoke Cloud from Lithium Container Fire 200ppm is the Nuisance Level, 500ppm is potentially harmful

