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HIGH LEVEL SAFETY HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR THE PROPOSED DEVELOPMENT OF BATTERY ENERGY STORAGE SYSTEMS AT THE MERCURY SOLAR PV CLUSTER NEAR VILJOENSKROON, FREE STATE

27th May 2022

REPORT:	**SAFETY HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR THE PROPOSED DEVELOPMENT OF BATTERY ENERGY STORAGE SYSTEMS AT THE MERCURY SOLAR PV CLUSTER NEAR VILJOENSKROON FREE STATE**
ASSIGNMENT NO:	J3057M
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REPORT ADMINISTRATIVE RECORD

LIST OF ASSESSMENTS

Assessment	Rev. No.	Assessment Date	Description
SHE Risk Assessment	1	27th May 2022	J3057M - 1 – Safety Health and Environmental Risk Assessment for The Proposed Development of Battery Energy Storage Systems at The Mercury Solar PV Cluster Near Viljoenskroon Free State - issued by ISHECON
SHE Risk Assessment	0	April 2022	J3057M - 1 – DRAFT - Safety Health and Environmental Risk Assessment for The Proposed Development of Battery Energy Storage Systems at The Mercury Solar PV Cluster Near Viljoenskroon Free State - 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 who are responsible for the design, operation and maintenance of the plant and equipment:

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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	27th May 2022	

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EXECUTIVE SUMMARY

Mulilo Renewable Project Developments (Pty) Ltd (hereafter referred to as Mulilo) propose to develop the Mercury Solar Photovoltaic (PV) Cluster to be located approximately 20km south of Klerksdorp and 20km north of the town of Viljoenskroon. The facilities will be in the Moqhaka Local Municipality in the Fezile Dabi District Municipality in the northern Free State Free State Province of South Africa with access is via the R76 which is adjacent the southern end of the site.

The cluster will consist of five proposed solar PV projects, three in the north of the area and two in the south. The five projects are: Vlakfontein Solar PV1 up to 100MW; Zaaiplaats Solar PV up to 120MW; Hormah Solar PV1 Up to 120; Kleinfontein Solar PV1 up to 120 MW; and Ratpan Solar PV1 up to 80MW. It is proposed that facilities will connect to the nearby Mercury Main Transmission Substation (MTS) through a high voltage (HV) powerline, or via a Loop in Loop Out (LILO) connection to the existing

Each project will include a Battery Energy Storage Systems (BESS) of up to 120MW each with up to eight hours of storage (960MWh). Initially both solid state and redox flow batteries were considered but solid-state systems were favoured for various environmental and economic reasons. Two alternative solid state battery chemistries are being considered, either Lithium-ion (SSL) or Sodium-Ion e.g. Sodium-Sulphur (NaS).

Associated infrastructure and equipment may include small diesel-powered generators, substations, power cables, transformers, power converters, substation buildings & offices, HV/MV switch gear, inverters and other control equipment that may be positioned within the battery containers / separate dedicated containers / the battery building.

In 2019, the Department of Forestry, Fisheries and the Environmental (DFFE) requested that EIA applications for BESS systems, 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 battery storage facility considering all applicable risks (e.g., fire, explosion, contamination, end-of life disposal etc).

This report summaries the high-level Safety Health and Environmental Risk Assessment conducted by ISHECON for the proposed Battery Energy Storage Systems at the Mercury solar 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 site visit was not conducted. A desktop study of the available information, preliminary layouts of the facilities and associated BESS 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 applied widely in the chemical industry.

2. FINDINGS

GENERAL

- This risk assessment has found that with suitable preventative and mitigative measures in place, none of the identified potential risks are excessively high, i.e., from a SHE perspective no fatal flaws were found with the proposed Lithium-ion or Sodium-Ion Solid-state BESS installations at the Mercury Solar PV Cluster near Viljoenskroon.
- 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 as it presents higher 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.

LITHIUM-ION or SODIUM-ION SOLID STATE CONTAINERIZED BATTERIES

- With solid-state batteries, the most significant hazard is the possibility of thermal runaway and the generation of toxic and flammable gases. There have been numerous such incidents around the world with batteries at all scales and modern technology providers include many preventative and mitigative features in their designs. 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 installation.
- If the flammable gases accumulate within the container before they ignite, they may eventually ignite with explosive force. This type of event is unusual 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 are not expected.

- 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 are not expected.

- 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, 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. **All the proposed BESS installation's locations are over 500m from any occupied farmhouse.** Therefore, the risks posed by BESS to the closest isolated farmhouses are negligible.

- The Ratpan Solar PV1 BESS location is immediately adjacent the R76 access road which is also located downwind in the dominant wind direction from Hormah Solar PV1 BESS. Therefore, plans should be in place to limit public traffic on the R76 road in the event of a fire situation at any of the BESS facilities.

3. RECOMMEDNATIONS

The following recommendations have been made:

- There are numerous different battery technologies but using one consistent battery technology system for all the BESS installations associated with the Mercury PV facilities would allow for easy of training, maintenance, emergency response and could significantly reduce risks in a remote location.

- 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.

- Neither sodium-ion or lithium-ion solid state battery technology type presents any safety or health fatal flaws, so either type could be used.

- 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.

- Prior to bringing any solid-state battery containers into the country:
  - An Emergency Response Plan should be 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 should be in place for the handling, repurposing or disposal of dysfunctional, severely damaged batteries, module and containers.

- The site layout and spacing between 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 solid-state 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.

    - All the current proposed BESS locations are over 500m from isolated farmhouses.
    - Ratpan Solar PV1 substation / BESS facilities are immediately adjacent a public road (R76) and the R76 is down wind in the dominant wind direction from the Hormah PV1 substation / BESS. If these locations are chosen, there should be plans in place to stop traffic on this road in the event of a BESS fire and toxic smoke possibly extending over the road.

- Where there is a choice of alternative locations for the BESS, those that are further from water courses would be preferred. 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 course / sources directly. The buffer distance between water bodies / boreholes etc and the facilities containing chemicals should be set in consultation with a water specialist and is therefore not specified in this SHE RA.

- Any bulk diesel storage for generators / vehicles should be fully bunded and the generators designed with the OHS Act noise limitations in mind.

- Finally, it is suggested once the technology has been chosen and more details of the actual design are available, that this risk assessment be updated.

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GLOSSARY OF SOME TERMS POSSIBLY USED IN THIS REPORT

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

Mulilo propose to develop the Mercury Solar PV Cluster to be located approximately 20km south of Klerksdorp and 20km north of the town of Viljoenskroon. The facility will be in the Free State Province of South Africa with access is via the R76 which is adjacent the southern end of the site.

The facility will consist of five Solar PV projects, Vlakfontein Solar PV1 up to 100MW; Zaaiplaats Solar PV up to 120MW; Hormah Solar PV1 Up to 120; Kleinfontein Solar PV1 up to 120 MW; and Ratpan Solar PV1 up to 80MW. It is proposed that facilities will connect to the nearby Mercury Transmission Substation through a high voltage (HV) powerline.

Each project will include a Battery Energy Storage System (BESS) of up to 120MW with up to eight hours of storage (960MWh). Two alternative types are being considered, i.e., either Solid State Lithium-ion (SSL) or Solid-State Sodium-Ion e.g. Sodium-Sulphur (NaS). For SSL batteries this would mean multiple containerised units. These battery containers may either be distributed throughout the PV field, or they may be centralized in an area near the substation.

Associated infrastructure and equipment may include small diesel-powered generators, substations, power cables, transformers, power converters, substation buildings & offices, HV/MV switch gear, inverters and other control equipment that may be positioned within the battery containers / separate dedicated containers / the battery building.

In 2019, the Department of Forestry, Fisheries and the Environmental (DFFE) requested that EIA applications for BESS systems, 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 battery storage facility considering all applicable risks (e.g., fire, explosion, contamination, end-of life disposal etc).

This report summaries the high-level Safety Health and Environmental Risk Assessment conducted by ISHECON for the proposed Solid-State Lithium (SSL) Battery Energy Storage Systems systems at the proposed Mercury solar 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 is conducted as a specialist study to comply with the requirement for a high-level health and safety assessment in Appendix 6 of the Amended Environmental Impact Assessment Regulations of 2014 under the National Environmental Management Act Nr. 107 of 1998.

1.3 RISK ASSESSMENT METHODOLOGY

Risk is made up of two components:

- The probability of a certain hazardous event or incident occurring.

- The severity of the consequences of that hazardous event / incident.

Therefore, this assessment of risk comprises:

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

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

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

This study makes use of a qualitative risk ranking system framework adapted from a method developed by WSP to meet the combined requirements of international best practice and NEMA, Environmental Impact Assessment Regulations, 2014, as amended (GN No. 326) (the "EIA Regulations"). The method considers the nature of what causes the effect, what will be affected and how it will be affected.

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

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

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

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

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

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

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

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

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.

Please note that this is not a detailed environmental impact assessment as this is not within ISHECON's area of expertise. There are other specialist assessments being carried out as part of the environmental process, for example assessments in the field of impacts on fauna, terrestrial biodiversity, aquatic biodiversity etc. The focus of this study is on human health and safety with possible impacts from chemicals, fires, explosions etc.

TABLE 1.3.1 SAFETY, HEALTH AND ENVIRONMENTAL RISK ASSESSMENT CHECKLIST

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

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

TABLE 1.3.2 – SHE QUALITATIVE RISK ASSESSMENT MATRIX

a) The magnitude of impact on ecological processes, quantified on a scale from 0-5, where a score is assigned.

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

b) The physical extent.

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

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

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

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

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

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

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

TABLE 1.3.3 – CALCULATION AND INTERPRETATION OF RISK / SIGNIFICANCE

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

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

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

OVERALL SCORE	SIGNIFICANCE RATING (NEGATIVE)	SIGNIFICANCE RATING (POSITIVE)	DESCRIPTION
< 30 points	Low	Low	where this impact would not have a direct influence on the decision to develop in the area
31 - 60 points	Moderate	Moderate	where the impact could influence the decision to develop in the area unless it is effectively mitigated
> 60 points	High	High	where the impact must have an influence on the decision process to develop in the area

2. DESCRIPTIONS

2.1 ORGANISATION, SITE LOCATION AND SURROUNDING AREAS

2.1.1 ORGANIZATION

Mulilo Group Holdings is a South African renewable energy developer and strategic equity investor. The company was formed in 2008 with a specific focus in wind and solar PV technologies. Mulilo develops, builds, owns and operates large scale renewable projects throughout South Africa and currently have 180MW of solar PV and 240MW of wind facilities operational. Mulilo expect to continue this steady growth with a pipeline of more than 3GW under development. Mulilo has formed partnerships with many experienced international organisations, such as Total Energies and the Industrial Development Corporation, allowing them access to industry leading technical, financial and equity resources.

2.1.2 LOCATION AND PHYSICAL ADDRESS

The five Mercury solar clusters are all located within the Moqhaka Local Municipality in the Fezile Dabi District Municipality in the norther Free State.

Mercury North

NAME OF CLUSTER	AFFECTED FARMS	GPS CO-ORDINATES OF SUBSTATION / BESS:
100MW Vlakfontein Solar PV1	Vlakfontein Nr 15 The Remainder of Jackalsfontein Nr 443	27^{0}00’17.02” S 26^{0}51’17.44” E
120MW Zaaiplaats Solar PV1	The Remainder of the Farm Zaaiplaats No 190 Portion 2 of the Farm Fraai Uitzicht No 189 3	27^{0}00’21.20” S 26^{0}49’25.75” E
120MW Kleinfontein Solar PV1	Portion 1 of the Farm Kleinfontein No 369	27^{0}00’34.19” S 26^{0}48’57.67” E

Mercury South

NAME OF CLUSTER	AFFECTED FARMS	GPS CO-ORDINATES OF SUBSTATION / BESS:
120MW Hormah Solar PV1	Portion 2 of the Farm Hormah No 276	27^{0}02’38.92” S 26^{0}48’33.77” E
80MW Ratpan Solar PV1	The Remainder of the Farm Ratpan No 441	27^{0}03’44.47” S 26^{0}49’47.31” E

2.1.3 DESCRIPTION OF SITE AND SURROUNDINGS

The maps below show that the PV farms with associated substations / BESS facilities are planned in rural agriculturally developed locations. The closest occupied farmhouse complex is 800m north of the Vlakfontein Solar PV 1 substation / BESS. Residential areas of concentrated population, i.e. towns, are all over 20km from the site. The access road R76 runs through the southern cluster of the Mercury facilities.

Figure 2.1.1 is a map of South Africa showing the location of the Mercury Solar PV complex.
Figure 2.1.2 shows the general area of interest in more detail.
Figure 2.1.3 is the development area showing the location of the Substation / BESS facilities.
Figure 2.1.4 shows 500m circles around the nearby farmsteads (red) and the proposed locations of the substation / centralized BESS facilities (blue) at the individual Mercury sites.

Figure 2.1.1 - Map showing the location of the Mercury Solar PV Cluster with Southern Africa.

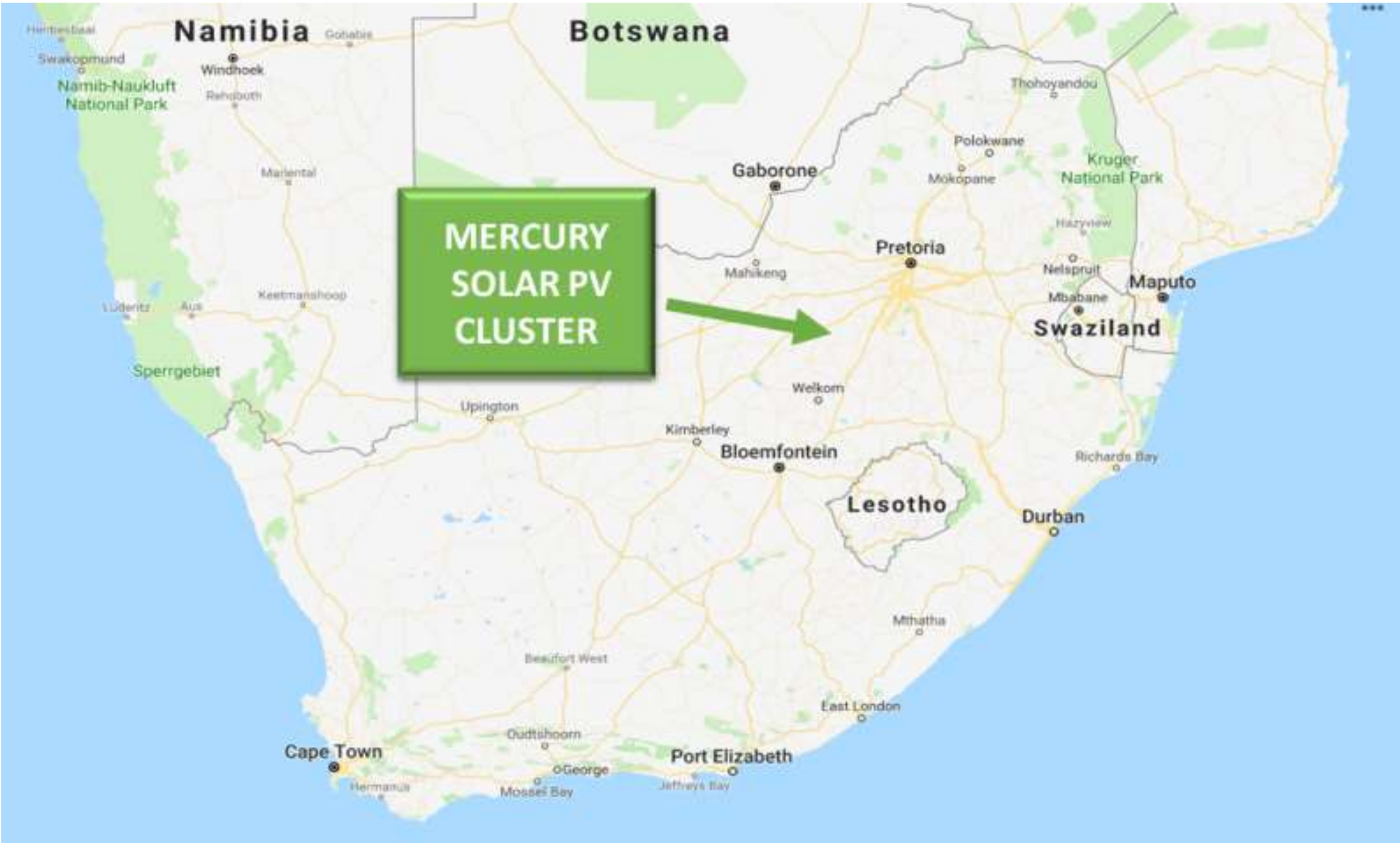


Figure 2.1.2 - The general area of interest for the facilities

Figure 2.1.3 – Location of the facilities within the Cluster

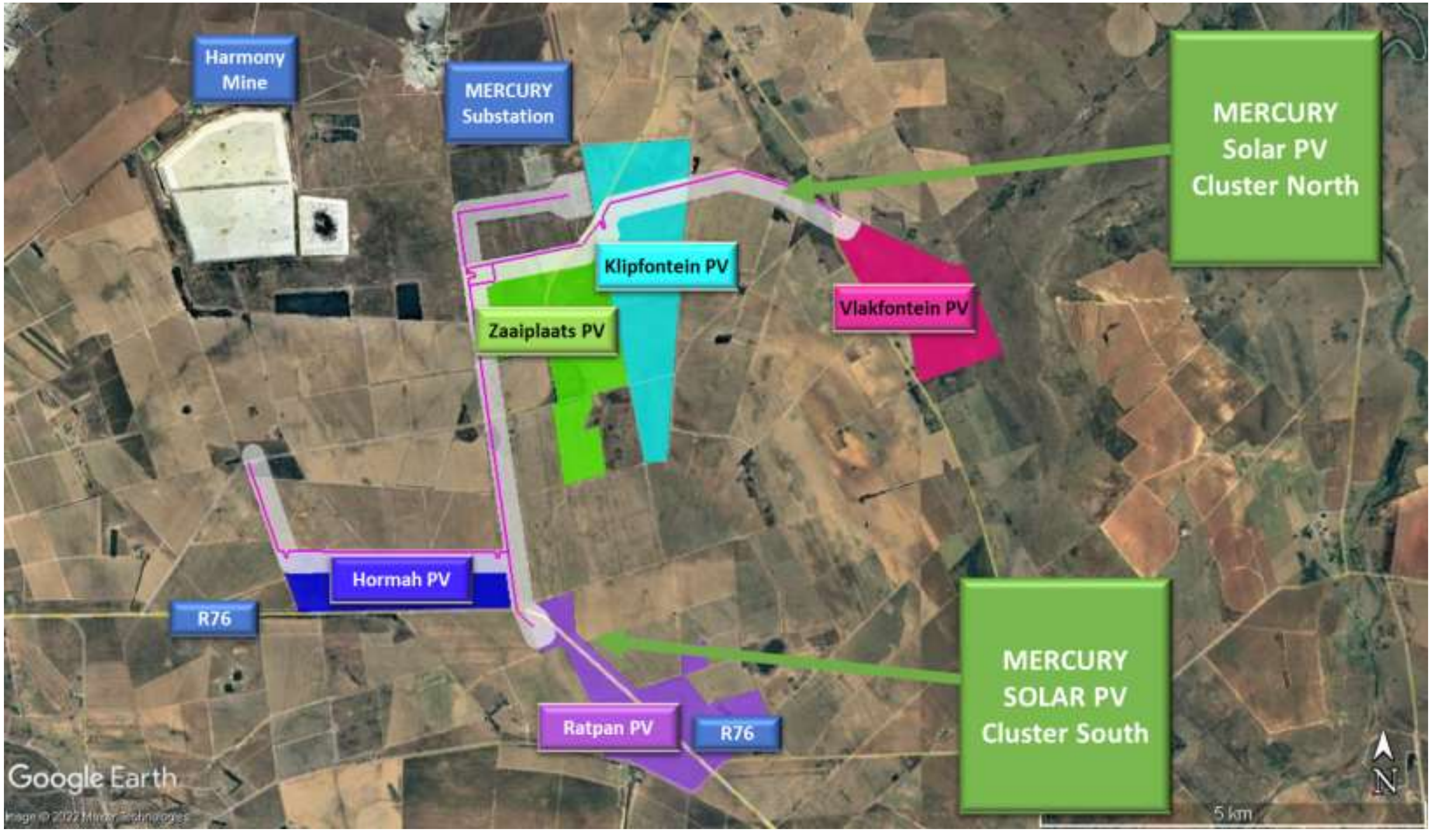
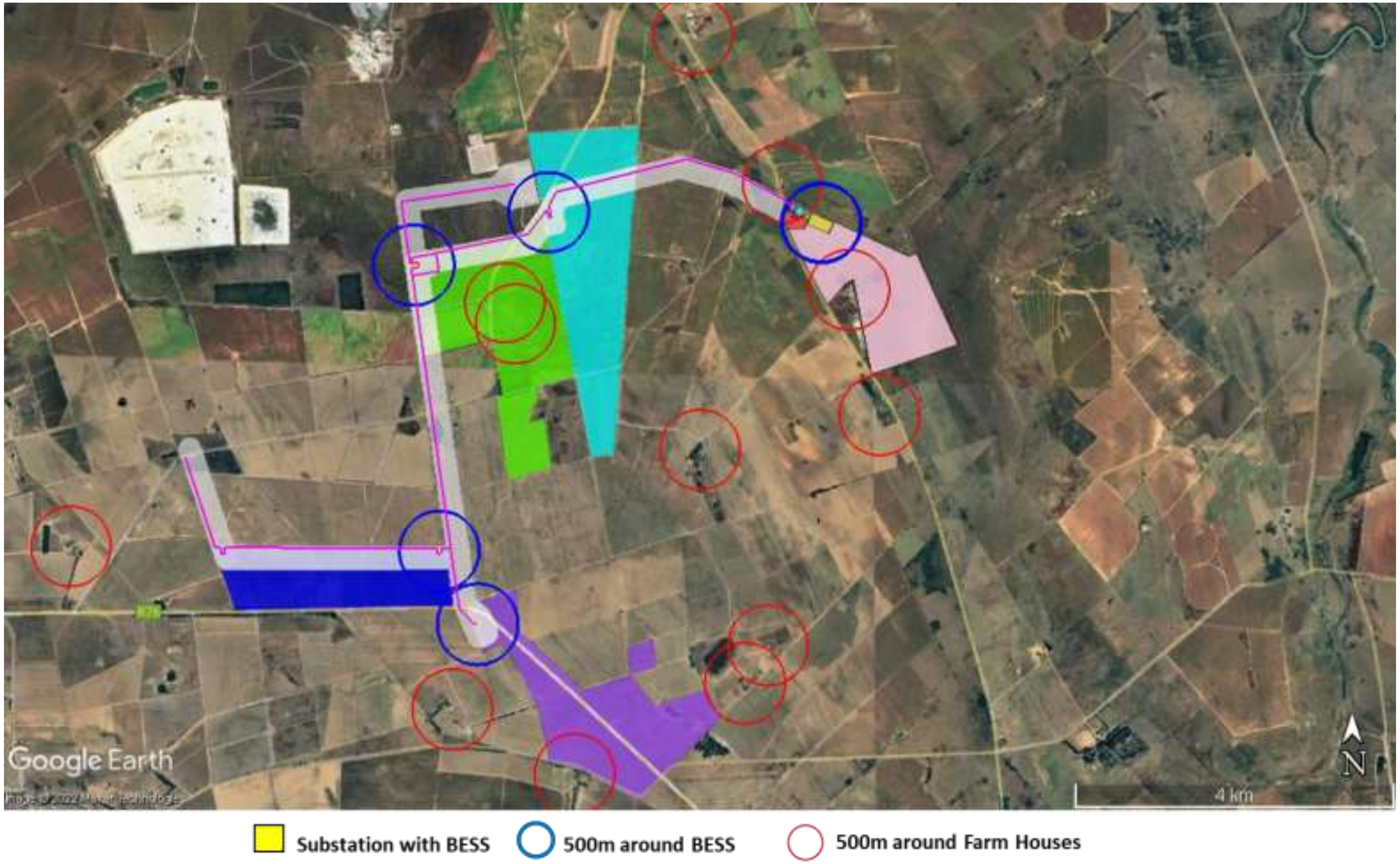


Figure 2.1.4 – 500m circles around Farmhouses (red) in the area in relation to the Location of the Substation / centralized BESS (blue)



2.2 TOPOGRAPHY, LAND-USE AND METEOROLOGY

2.2.1 TOPOGRAPHY

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

The proposed sites are on relatively flat undulating ground. The areas selected for the BESS facilities (and other significant infrastructure such as substations and Gen-sets) are flatter sections within the greater areas.

The area experiences heavy thunderstorms. There are no major rivers located close to the site. However, there are numerous small water courses in the area, generally draining towards the north into the Vaal River basin. The Vaal River itself is over 5km to the north. All the proposed substation / BESS sites are over 300m from the closest tributaries. Of the BESS installations the Vlakfontein Solar PV1 substation / BESS is located the closest to a small tributary draining the area.

2.2.2 LAND-USE

Refer to the relevant Environmental Impact Assessment specialist studies for details of the agricultural activities and cultural aspects in the area. The BESS facilities will not use large amounts of land. The area currently demarcated for substation / BESS is typically less than 5 ha per site, if centralized AC couped systems are installed as opposed to distributed DC coupled BESS facilities.

The general area is used intensely for agricultural activity. There is mining activity, Harmony gold mine, over 2.5km to the north of Mercury North facilities.

There are approximately a dozen farmhouse complexes in the general area, however none of these are located within 500m of any of the proposed substation / BESS facilities. In general, the farms homesteads at the southern cluster are further than at the northern cluster. The closest farmhouse complex in the vicinity of the southern cluster substations is over 1km away, while in the north the closest farmhouse is approximately 800m northwest of the Vlakfontein Solar PV1 substation and the next is 1km southeast of the Zaaiplaats Solar PV1 substation / BESS.

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

2.2.3 METEOROLOGY

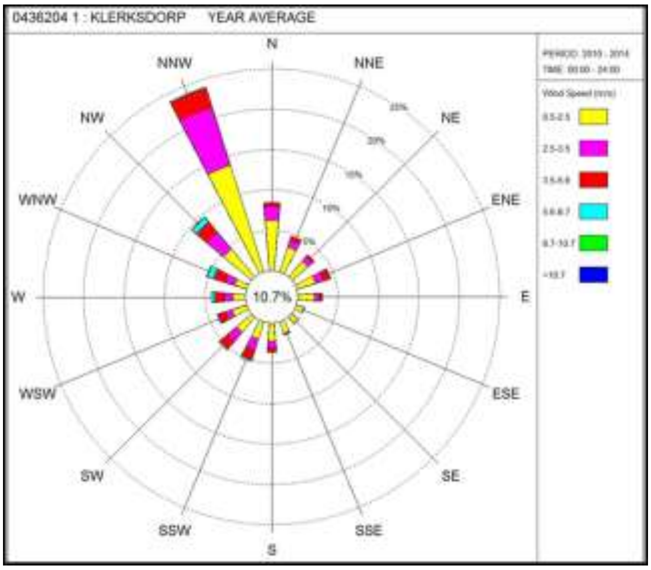
The site is between Klerksdorp and Viljoenskroon. Refer to the wind rose below in Figure 2.2.2 (SA Weather Services).

The dominant wind direction in the area blows from the northwest, north northwest and north across the site towards the farmlands to the south and southeast. This would mean if there were a fire at the Zaaiplaats Solar PV1 installation the wind might carry the noxious smoke towards the farmhouses 1km to the southeast. Winds seldom blow from the east, south or west towards the closest farmhouses to the other sides of the substation / BESS facilities.

Ratpan Solar PV1 substation / BESS facilities are immediately adjacent a public road (R76) and the R76 is down wind in the dominant wind direction from the Hormah PV1 substation / BESS. If these locations are chosen, there should be plans in place to stop traffic on this road in the event of a BESS fire and noxious smoke possibly extending over the road.

Across South Africa, lightning strikes are conceivable as a source of ignition of major hazards, refer to SANS10313:2012 lightning strike density table. The lightning ground flash density (ground strike rate) in the Klerksdorp area (8.3 Flashes/km2/year) is moderately high. Generally, ignition from on-plant sources is much more likely than lightning but lightning cannot be ignored as a source of risk particularly for tall structures in wide open flat areas.

Figure 2.2.1 Wind rose indicating the general wind conditions for the Area (use Klerksdorp data)



2.3 PLANT AND PROCESSES

For the BESS, both Solid State Batteries and Redox Flow Batteries (RFB) were initially considered. RFB technology was found to be less preferable, for various reasons including economic as well as logistical concerns regarding storage of electrolytes and possible triggers of storing dangerous goods. Therefore the preferred Battery technology is SSB. The solid-state BESS will make use of either Lithium-Ion or Sodium-Ion chemistries as follows:

- Lithium-ion batteries (LFP/NMC or others, and Lithium capacitors/Electrochemical capacitors (LiC)) (Li-Ion); and/or
- Sodium-ion (e.g. Sodium Sulphur batteries (NaS)).

In addition there are two electrical coupling options:

- DC coupling where the battery units are distributed throughout the PV field and/or
- AC coupled where the BESS containers are centralized into one area.

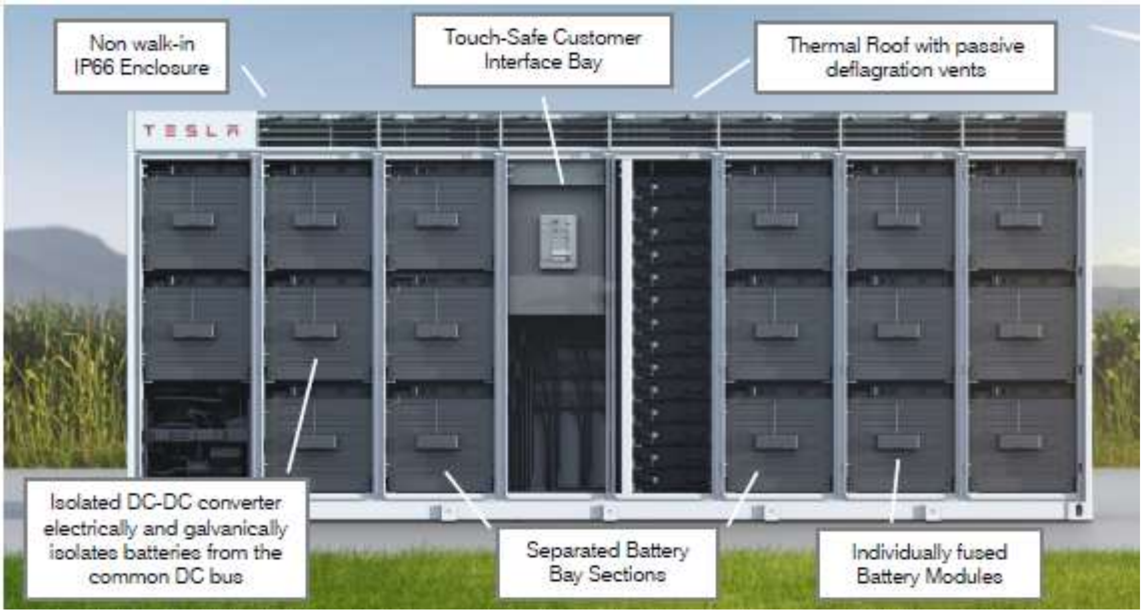
This study focuses on the hazards of the AC coupled system where risks are concentrated and will use lithium-ion as the basis since it is the preferred alternative (differences with sodium-sulphur will be highlighted were necessary).

2.3.1 PROPOSED DESIGN SOLID STATE BATTERIES

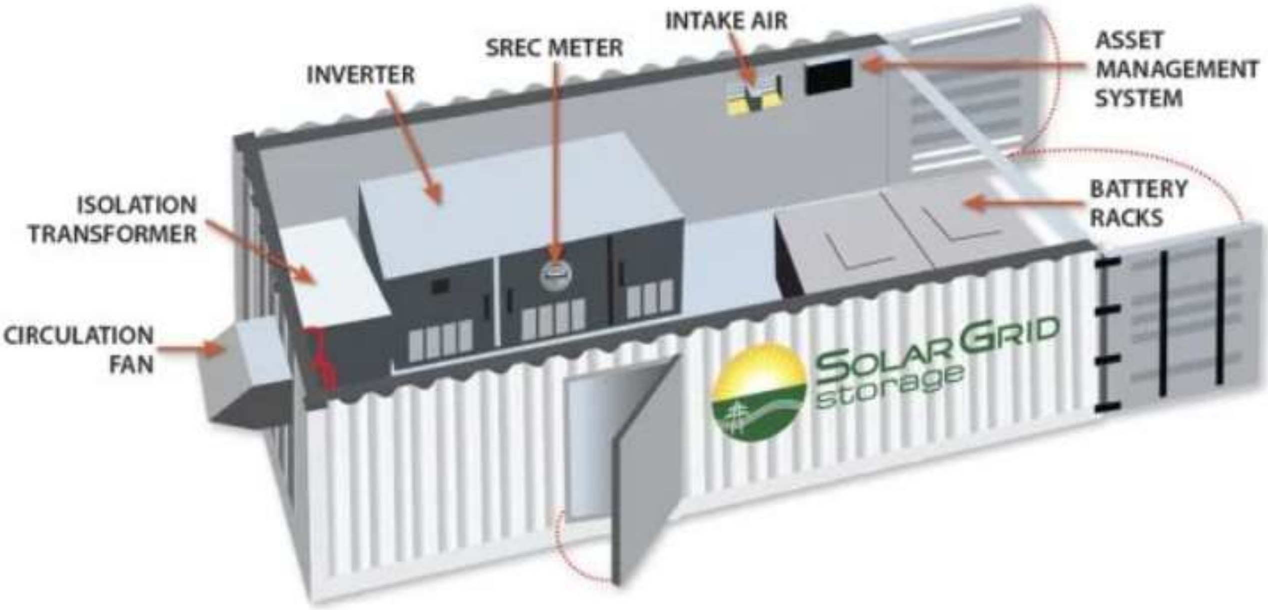
A Solid-State Battery system consists of multiple battery cells that are assembled together to form modules. Each cell contains a positive electrode, a negative electrode and an electrolyte. The BESS will comprise of multiple battery units or modules housed in shipping containers and/or an applicable housing structure which is delivered pre-assembled to the project site. Containers are usually raised slightly off the ground and laid out in 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 or Sodium-ion systems. The pictures in Figure 2.3.1.1 are typical BESS installations servicing solar power farms. Figures 2.3.1.2&3 show typical battery modules in the BESS facility.

FIGURE 2.3.1.1 – Images of Typical Centralized AC Coupled BESS Systems Servicing Solar Power Farms

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

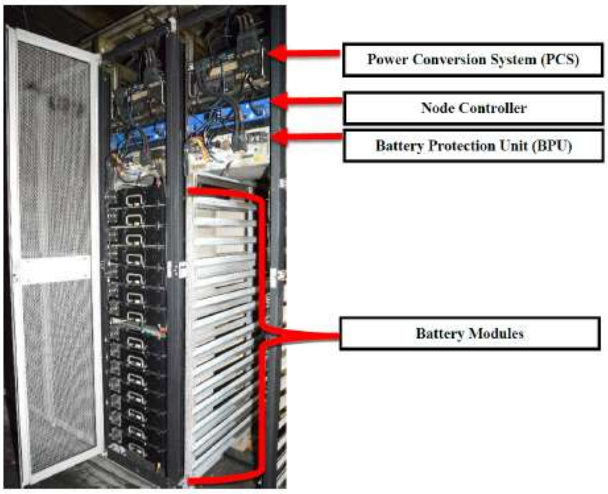


Source – Tesla MegaPack – Safety Overview



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

2.3.4 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 systems 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 could be approximately 10 persons on over the whole area (i.e., all five BESS installations) during the day depending on the activities taking place and possibly one or two operators as well as security personnel at night.

As the facilities are not located in isolated areas, but in the midst of agricultural lands, there could also be farm workers in the adjacent fields during the day.

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 follows together with some details:

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

No	PHASE	MAIN PROCESSES	DETAILS
1.1	Construction	Construction machines e.g., cranes, graders, cement trucks, diesel and oil storage	Graders to clear ground make roads, diggers for trenches foundations, cement mixers for civil works, cranes to place containers, diesel bowser for fuel for machines, oil for machines
1.2		Materials for the construction of any buildings, e.g. at the substation Equipment items for installations within the supporting infrastructure	Building materials such as bricks, cement, re-bar, I-beams, roof sheeting etc. Electrical equipment such as transformers, pylons, cabling.
		Equipment items for containerized installation e.g., lithium battery containers	Battery containers Electrical equipment such as transformers, pylons, cabling.
1.3		Waste e.g., packaging materials, paint	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
1.4		Construction camp	Temporary offices, accommodation, ablutions
2.1	Lithium-ion or Sodium-Ion Solid State Operation	Chemical electrolyte and electrode materials in the battery cell	Will most likely be solid state lithium-ion batteries but could be sodium-sulphur solid state batteries.
2.2		Battery cells, modules and racks typically in shipping containers	The facilities are designed for up to 120MW and eight hours storage (960 MWh) having typically ~ 100 containers (For example, each Tesla Megapack has up to 3 megawatt hours (MWhs) of storage and 1.5 MW of inverter capacity)
2.3		Electronic equipment in container	Battery management system for monitoring of the batteries and control of the loading and unloading cycles
2.4		Electrical equipment in container or separate container	Power conversion system, connections, switches, cabling
2.5		Mechanical equipment in container(s)	Air conditioners, fans, filters, coolant
2.6		Electrical equipment outside the containers	Network interconnection equipment, switchgear, transformers
2.7		Site office and workshop	Including potable water, 220V power, kitchen, sewage, tools and parts store etc
2.8		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
2.9		Waste	Broken parts, storm water run-off, hot air from battery and PCS cooling systems

No	PHASE	MAIN PROCESSES	DETAILS
3.1	Decommissioning	Solid State Lithium-ion or Sodium-Ion (Sodium-Sulphur) chemical waste	Batteries, air filters, transformer oils, coolants, contaminated soil
3.2		Electronic waste	Circuit boards, HMI screens
3.3		Building rubble - non-hazardous waste	Steel, copper, cement, equipment and structures
3.4		Battery Containers	Shipping containers

3. HAZARD IDENTIFICATION

3.1 SOLID STATE BATTERY CHEMICAL HAZARDS

3.1.1 BATTERIES IN GENERAL

The battery type being considered by the project is solid state lithium-ion or sodium-ion 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 Mercury BESS facilities. Should sodium-based batteries be used, the hazards are likely to be similar at a high level but different in their details and therefore the risk assessment may need to be reviewed once a type has been chosen. The discussion below focusses on lithium but where the solidum-sulphur issues are different they will be highlighted, for example the toxic smoke from a fire may contain sulphur dioxide as opposed to hydrogen fluoride

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 battery energy storage systems, 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 BATTERY CHEMISTRY

The lithium in the batteries is usually in the form of lithium salts dissolved in an electrolyte solution that is absorbed within the electrodes and/or lithium plated onto the surface of the electrode. These are referred to as solid state batteries because electrolyte liquid is not freely available in a form that can easily leak or be extracted. 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). Some of the lithium compound in the electrolyte include lithium hexafluorophosphate, lithium perchlorate, lithium cobalt oxide etc.

Some sodium ion batteries such as sodium-sulphur batteries operate at high temperature, 300 – 350 deg C as they have a molten sulphur component. These high temperature systems are common in Japanese utility applications with over 300 installations in Japan. Other low temperature sodium-ion batteries may be a relatively new technology and there is limited information about sodium-based batteries.

3.1.3 HAZARD - THERMAL DECOMPOSITION

Upon heating of the contents of a battery due to shorting, contaminants, external heat or exposure to water and reaction heat, the lithium salts in batteries 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) 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 vented, usually via the weakest point in the system. These vented fumes can be flammable due to vaporization of the electrolyte 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:

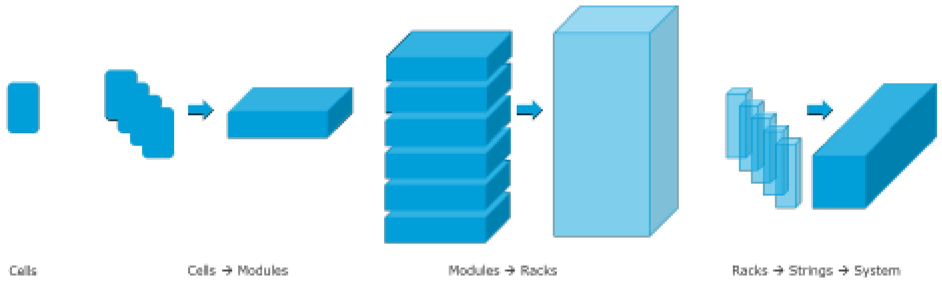
- the products of combustion such as carbon dioxide/monoxide, hydrogen cyanide
- VOCs like benzene and ethylene,
- decomposition products such as hydrogen fluoride, hydrogen chloride, phosphorous pentafluoride, phosphoryl fluoride and oxides of aluminium, cobalt, copper etc.

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 result.

3.1.4 HAZARD - PROPAGATION

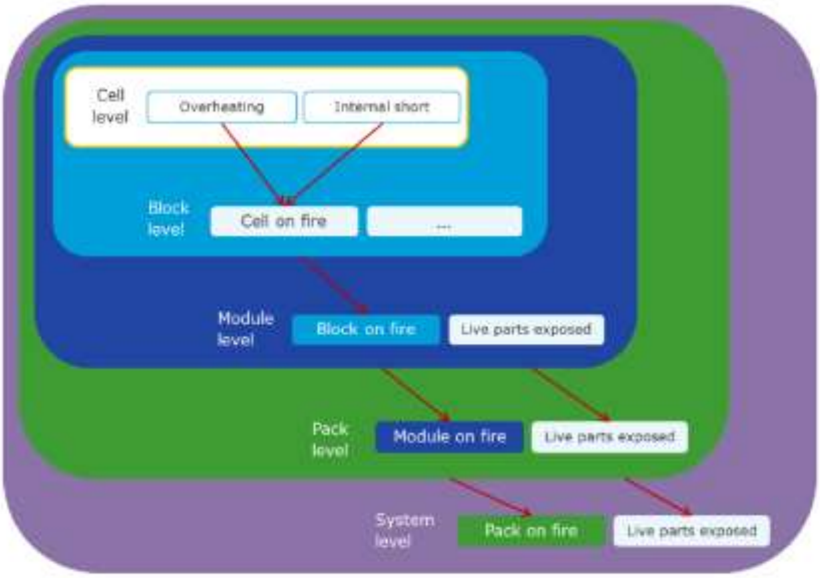
A BESS is composed of individual batteries which are combined into different size packs such as modules, racks, as illustrated on the diagram below.



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.

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



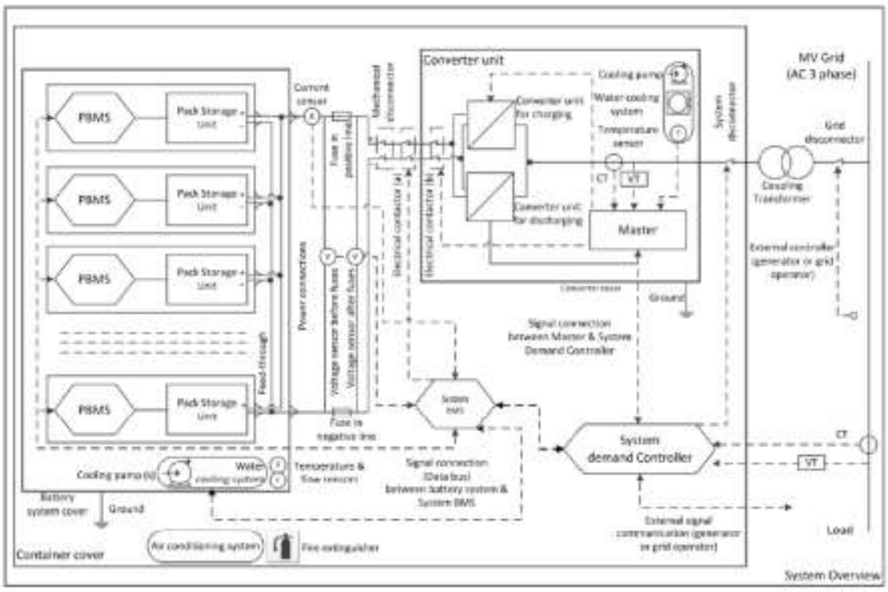
Source – STALLION Report

3.1.5 HAZARD - ELECTROLYTE LEAKS

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.

3.2 OTHER CHEMICALS OR HAZARDS

The BESS is composed not only of the batteries. There are electrical connections, switches, power converters, cooling systems etc. The diagram below shows a typical complex system for lithium solid state facility.



Source – STALLION reports

3.2.1 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 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.

3.2.2 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.

VRF batteries do not present a high fire risk. However, on any chemical plant there is always the risk of fires with electrical equipment and other materials used on site. Fire systems would typically consist of local strategically placed extinguishers as well as a fire water hose/hydrant system.

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.

3.2.3 GENERAL ELECTRICAL AND ELECTRONIC EQUIPMENT

Whatever the configuration of the battery containers there will be electrical and electronic equipment in the battery compartment 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.

3.3 PAST ACCIDENTS AND INCIDENTS RELEVANT TO BESS

There are no records of large-scale accidents involving VRF batteries, i.e., no fires, explosions, toxic gas releases or major chemical spills. A contributing factor in this lack of incidents could be that it is a relatively recent technology that is not yet widely used.

The following events occurred with other types of batteries, e.g., solid state, and are included only 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 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 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 2 fires per billion driven kilometers.

Source STALLION Report

4. 2010 a UPS Airlines cargo plane from Dubai crashed after a fire started in a large undeclared lithium battery shipment. 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 cargos. 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 solar 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. 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 were called and rapidly extinguished the fire preventing spreading to adjacent containers.

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

Photo Credit: Mr Joostvanj / YouTube

10. 19 April 2019 explosion at utility company Arizona Public Service's (APS) solar 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 battery energy storage system (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.

Posted Tuesday, April 30, 2019 9:44 am

By **Jason Stone & Matt Roy**, Independent Newsmedia

Arizona utility APS has grounded its energy storage operations while the investigation continues.

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 battery ESS 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 are reported to be with the incorrect installation of battery management systems, 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.

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.

iSHEcon CHEMICAL PROCESS SAFETY ENGINEERS

4.1 SOLID STATE BATTERY ENERGY STORAGE SYSTEMS (including associated electrical equipment)

TABLE 4.1.1 - CONSTRUCTION PHASE (Excluding commissioning)

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
							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	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 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 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 small, isolated 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 despite the relatively isolated location all the necessary equipment is available (and well maintained) during construction. Otherwise, employees may revert to unsafe practices. Isolated location, maintenance of construction equipment to ensure safe operation is critical. Ensure this is in place prior to project beginning. Development of local service providers. 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, 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 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 - Solid state battery containers damaged on route e.g., dropped in port (drops do happen about 1/2000 containers) and importing possibly approximately 100 containers for each BESS 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. 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).	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 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 applicants should ensure suitably competent transport companies are appointed. The company responsible for transportation should ensure: - Compliance with National Road Traffic 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 of the typical suppliers (Tesla) indications, the containers are classified as 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. Data indicates installed facility events are 0.001/year. Transport of 100 units per installation assumed to take 4 weeks each so f= 0.008 once in 125 years so likelihood is very low. Prior to bringing any containers into the country a full Emergency response plan should be in place for the full route from the ship to the site. Drivers trained in the hazards of containerized batteries. Emergency plan to determine and address: - 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? - Are there any secondary gases or residues from use of extinguishers? - If water is appropriate, may need outside connections to inside sprinklers? - First responders need to know what media to use, especially if water totally unsuitable and if there are no connection points for water etc.	Complex	5	2	5	5	2	**34**	5	2	5	5	1	**17**

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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 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. Cape Town port and up the N1 and N10 or Port of Saldanha and along the N14 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 Du Toitskloof tunnel.	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. 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. Due to isolated locations some distance from town, the ability to treat with anti-venom and extreme allergic reactions on site is critical to mitigate the impacts	Complex	4	2	3	2	3	**33**	3	2	3	2	2	**20**
						Significance	N3 - Moderate						N2 - Low					

Impact 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	Causes - Damaged solid-state batteries release fumes, leak electrolyte, are completely broken exposing hazardous chemicals. Thermal runaway and hazardous fumes released. Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive burns or lung damage.	Construction	Negative	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. Transport in sealed packages that are kept upright, protected from movement damage etc. Also packaged to ensure no short-circuiting during transport. 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. These will be fitted with the necessary protective measures by the supplier considering marine and road transport as well as lifting, setting down etc. Route selection to consider possible incidents along the way and suitable response, e.g. satellite tracking, mobile communication, 24/7 helpline response. Standard dangerous goods requirements for Hazmat labels, Trem cards, driver trained in the hazards of the load. Likelihood similar to fire above.	Complex	4	3	3	5	3	**45**	4	3	3	5	2	**30**
						Significance	**N3 - Moderate**						**N2 - Low**					

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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	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 moderately high. Outside work must be stopped during thunderstorms. Lighting conductors may be required for the final installation, to be confirmed during design phase.	Complex	5	2	5	5	2	**34**	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 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	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	2	2	3	4	4	**44**	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. 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. Isolated location both helps and hinders security. Night lighting to be provided both indoors and outdoors where necessary.	Complex	4	1	3	2	4	**40**	3	1	3	2	3	**27**
						Significance	**N3 - Moderate**						**N2 - Low**					

Impact 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	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. 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 runway 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 latest state of the art battery system are used.	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					
						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.

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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, diesel fuel, transformers oils, lubricating oils and greases etc. Consequences - Occupational illness.	Operation	Negative	The operation and maintenance phase will be managed according to all the requirements of the Occupational Health and Safety Act 85 of 1993. SHEQ policy in place. A detailed risk assessment of all normal operating and maintenance activities on site to be compiled, and form the basis of operating instructions, prior to commencing commissioning. SHE procedure in place, e.g., PPE specified, management of change, integrity monitoring. SHE appointees in place. Training of staff in general hazards on site. All necessary health controls/ practices to be in place, e.g. ventilation of confined areas, occupational health monitoring if required and reporting programs in place. Emergency response plan for full operation and maintenance phase to be in place prior to beginning commissioning and to include aspects such as: - appointment of emergency controller, - emergency isolation systems for electricity, - -emergency isolation and containment systems for electrolyte, - provision of PPE for hazardous materials response, - provision of emergency facilities for staff at the main office building, - provision of first aid facilities, - first responder contact numbers etc.	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	Solids state batteries sealed, individual batteries in modules which are also sealed, pre-packed in the container. 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. Possible detectors with local alarms if regulated occupational exposure limits are exceeded etc prior to entry for inspection of battery containers. Labelling of all equipment. Confined space entry procedures if entering tanks and possibly battery containers? There needs to be careful thought given to procedures to be adopted before entering into the plant or a container under normal circumstances (confined space) but particularly after a BMS shut down where there may be flammable or toxic gases present, a fire etc. Any situation could await those entering. 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	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, diesel generators etc. Consequences -	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**

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					
		Adverse impact on hearing of workers. Nuisance factor at 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. Battery life optimal at temperature also optimal for humans. Lighting to be provided inside the building, 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 - Isolated workstation and monotonous repetitive work. Consequences - Low performance, system productivity suffers.	Operation	Negative	Staff rotation to other activities within the site may be necessary. Performance monitoring of inspections / maintenance tasks in particular will be necessary.	Easy	2	3	3	2	2	**20**	1	3	3	2	1	**9**
						Significance	N2 - Low						N1 - Very Low					

Impact 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, 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, diesel generator 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 unlikely to be severe	Operation	Negative	Grass cutting and fire breaks around the BESS installations to prevent veld fires, i.e., ensure suitable separation between BEES and any crops grown in the area. No combustible materials to be stored in or near the batteries or electrical infrastructure. Separation of site diesel tank, gen-set, transformers from BESS and vice versa. 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. Abuse tests conducted by supplier. BMS should be checking individual cell voltage as well as stack, module, container, system voltages/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 plant trips actually work. Fire resistant barrier between the batteries and the PCS side if in the same container, or separate containers. Suitable ingress protection level provided for electrical equipment, e.g., IP55 - 66. If air cooling into container, suitable dust filters to be provided. Smoke detectors linked to BMS and alerts in the main control room. 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 run away starting at 65-70 deg C. BMS trips system at 50 deg C. Temperature monitoring to be in place. Regular infrared scanning. Data needs to be stored for trend analysis. Data indicates an event frequency of 0.001 per installation and with 100 units this would mean an event once 10 years. Low probability. Most events will be small not resulting in injuries, but this is possible if the event is not controlled. 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 solid state container fires - extinguishing, ventilating, entering as appropriate or not. PPE for container firefighting include fire retardant, chemically resistant, nitrile gloves	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**					
						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. 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	4	**68**	5	2	5	5	1	**17**
						Significance	**N4 - High**						**N2 - Low**					
Impact 7:	Human and Equipment Safety - exposure to explosion over pressures	Cause 1 - Transformer shorting / overheating / explosion. Cause 2 - Flammable gases generated by thermal run away reach explosive limits. Ignition on hot surfaces, static. Lithium Cobalt Oxide generates O2 during decomposition – escalation. Consequences - Potential fatalities amongst first responders. Damage to container or other nearby items, e.g., another container.	Operation	Negative	Electrical equipment will be specified to suit application. Emergency response plan and employee training referred to above is critical. This is only really likely do happen due to possible inappropriate emergency response, e.g. opening containers when they may be the type that should be left to burn out. Modern state of the art containers have ventilation systems for vapours. Undertake a hazardous area classification of the inside of the container to confirm the rating of electrical equipment. Might be zone 2 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 Suitable training of selected emergency responders who may be called out to the facilities is critical. NOTE. Refer to Appendix A for an initial approximation of worst-case possible explosion impact zones	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. Due to isolated locations some distance from town, the ability to treat with anti-venom and extreme allergic reactions on site is critical to mitigate the impacts	Moderate	4	1	3	2	3	**30**	3	1	2	2	2	**16**
						Significance	**N2 - Low**						**N2 - Low**					
Impact 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. Hazardous fumes released on thermal run away see fire above. Consequences - Impacts can vary from mild skin irritation from exposure to small leaks to serious corrosive burns for large exposure.	Operation	Negative	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. All operators/maintenance staff trained in the hazards of chemicals on site. Batteries contained, modules contained and all inside a container that acts as bund. Refer to fire above as all the protective measures apply to prevent toxic smoke. Fumes tend to be directed upwards by the structure of the container. Refer to fire above as all the measures apply to mitigate toxic smoke. 24/7 helpline response. Standard dangerous goods requirements for Hazmat labels.	Moderate	4	3	3	5	3	**45**	3	3	3	5	2	**28**

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**					
		In the case of toxic fumes / smoke, serious lung damage.			All operators/maintenance staff trained in the hazards. NOTE Refer to Appendix A for an initial approximation of worst case possible noxious smoke impact zones.													
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 9:	Human and Equipment Safety - exposure to violent release of kinetic or potential energy	Causes - Moving equipment, pumps, heavy equipment at elevation, nip points, working at heights. Traffic accidents. Earthquake / tremor. Consequences - Injury. Fatality in unlikely worst case, e.g., traffic accidents or fall from heights. Damage to equipment, spills, environment pollution	Operation	Negative	Apart from pumps, 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. Civil design to take seismic activity into account.	Moderate	5	1	5	5	3	**48**	5	1	5	5	1	**16**
							N3 - Moderate						**N2 - Low**					

Impact number	Receptor	Description	Stage	Character	Preventative and Mitigative Measures	Ease of Mitigation	(M+	E+	R+	D)x	P=	S	(M+	E+	R+	D)x	P=	S
							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). 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 moderately high. All outside work must be stopped during thunder storms. Lighting conductors may be required for the installation, to be confirmed during design	Complex	5	1	5	5	2	**32**	5	1	5	5	1	**16**
						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 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					
						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. Reportable Quantities NEMA	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	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 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	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.	Easy	2	2	4	4	4	**48**	1	2	4	4	2	**22**
						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 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. Isolated location both helps and hinders security. Night lighting to be provided both indoors and outdoors where necessary.	Moderate	3	1	3	2	4	**36**	3	1	3	2	2	**18**
						Significance	**N3 - Moderate**						**N2 - Low**					
Impact 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. 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. Storage of spare batteries (e.g., in stores on site or elsewhere) also needs to consider possible thermal	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.			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 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 4.1.3 - DECOMMISSIONING PHASE

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

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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	**#N/A**						**#N/A**					
Impact 5:	Human Health - exposure to ergonomic stress	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		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 6:	Human and Equipment Safety - exposure to fire radiation	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
							#N/A						#N/A					
Impact 10:	Human and Equipment Safety - exposure to electromagnetic waves	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		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 11:	Environment - emissions to air	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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. 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 can be predefined, and the monitoring can be in place to determine if it has been reached. Affected by temperature and time, cycles.	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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 De-commission and operational phases - no new hazards.	De-commission	Negative		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 17:	Employees and investors - Security	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		Easy	1	1	1	1	1	**4**	1	1	1	1	1	**4**
						Significance	#N/A						#N/A					
Impact 18:	Emergencies	Similar to the De-commission and operational phases - no new hazards.	De-commission	Negative		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

GENERAL

- This risk assessment has found that with suitable preventative and mitigative measures in place, none of the identified potential risks are excessively high, i.e., from a SHE perspective no fatal flaws were found with the proposed Solid-state BESS installations at the Mercury Solar PV Cluster near Viljoenskroon.

- 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 as it presents higher risks.

- The design should be subject to a full Hazard and Operability Study (HAZOP) prior to commencement of procurement. A HAZOP is s 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.

SOLID STATE CONTAINERIZED BATTERIES

- With 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 batteries at all scales and modern technology providers include many preventative and mitigative features in their designs. 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 installation.

- If the flammable gases accumulate within the container before they ignite, they may eventually ignite with explosive force. This type of event is unusual 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 are not expected.

- 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 are not expected.

- 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, 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. All the alternative BESS installation's locations are over 500m from any occupied farmhouse. Therefore, the risks posed by BESS to the closest isolated farmhouses are negligible.

- The Ratpan Solar PV1 BESS location is immediately adjacent the R76 access road which is also located downwind in the dominant wind direction from Hormah Solar PV1 BESS. Therefore, if these locations are, plans should be in place to limit public traffic on the R76 road in the event of a fire situation at any of the BESS facilities.

5.2 RECOMMENDATIONS

The following recommendations have been made:

- There are numerous different battery technologies but using one consistent battery technology system for all the BESS installations associated with the Mercury Solar PV facilities at would allow for easy of training, maintenance, emergency response and could significantly reduce risks in a remote location.

- 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.

- The use of solid-state battery technology of either lithium-ion or sodium-ion does not present any safety or health fatal flaws.

- 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.

- Prior to bringing any solid-state battery containers into the country:

  - An Emergency Response Plan should be 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 should be in place for the handling, repurposing or disposal of dysfunctional, severely damaged batteries, module and containers.

- The site layout and spacing between 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 solid-state 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.

  - All the current proposed BESS locations are over 500m from isolated farmhouses.
  - Mercury South Ratpan Solar PV1 substation / BESS facilities are immediately adjacent a public road (R76) and the R76 is down wind in the dominant wind direction from the Hormah Solar PV1 substation / BESS. If these locations are chosen, there should be plans in place to stop traffic on this road in the event of a BESS fire and toxic smoke possibly extending over the road.

- Where there is a choice of alternative locations for the BESS, those that are further from water courses would be preferred. 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. However, the current separation of over 300m seems reasonable.

- Any bulk diesel storage for generators / vehicles should be fully bunded and the generators designed with the OHS Act noise limitations in mind.

- Finally, it is suggested once the technology has been chosen and more details of the actual design are available, that this risk assessment could be updated.

6 REFERENCES

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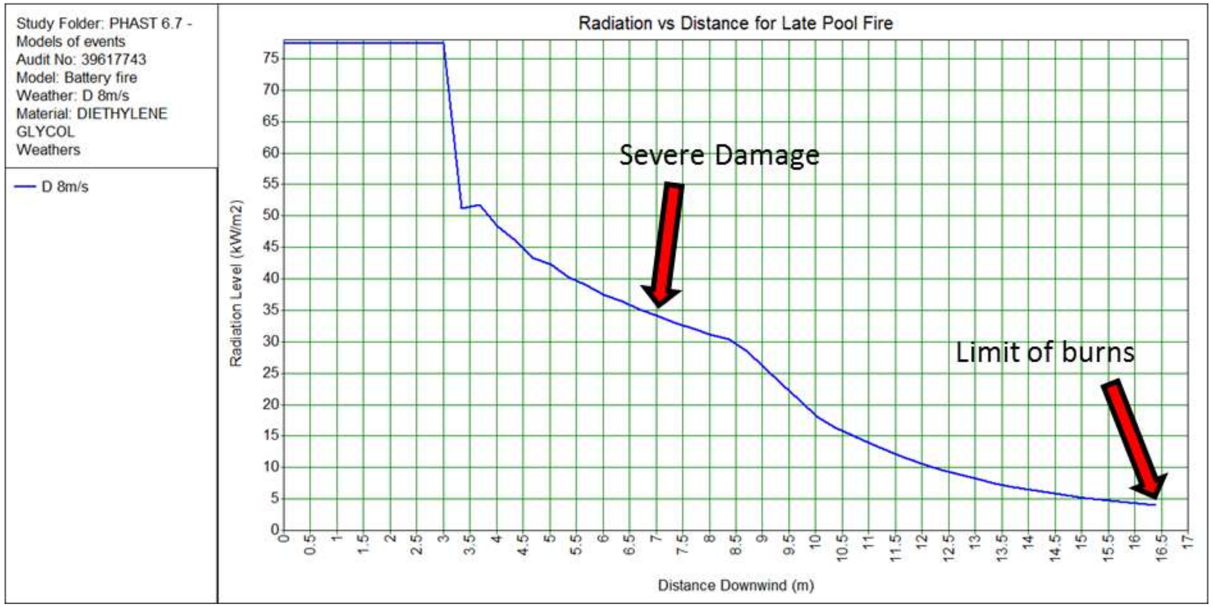
APPENDIX A

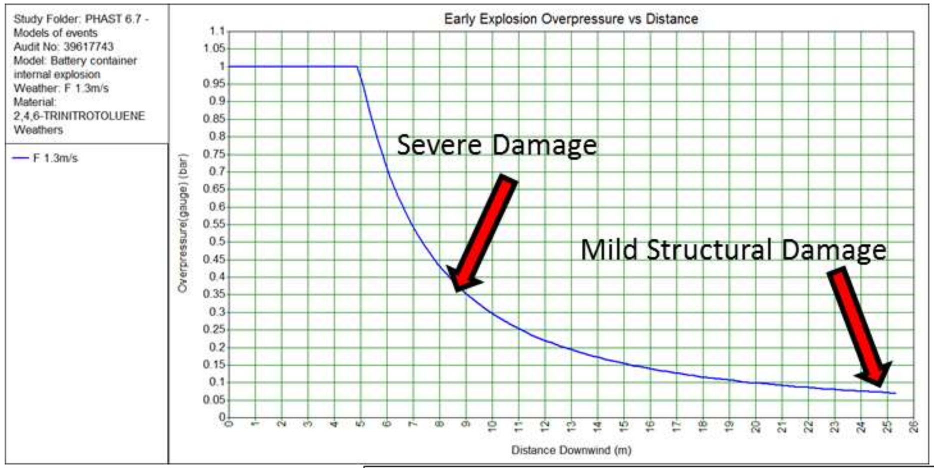
Preliminary <u>Approximations</u> of Absolute WORST-CASE Consequence and Risk Modelling (Modelling done using DNV-GL software PHAST RISK 6.7)

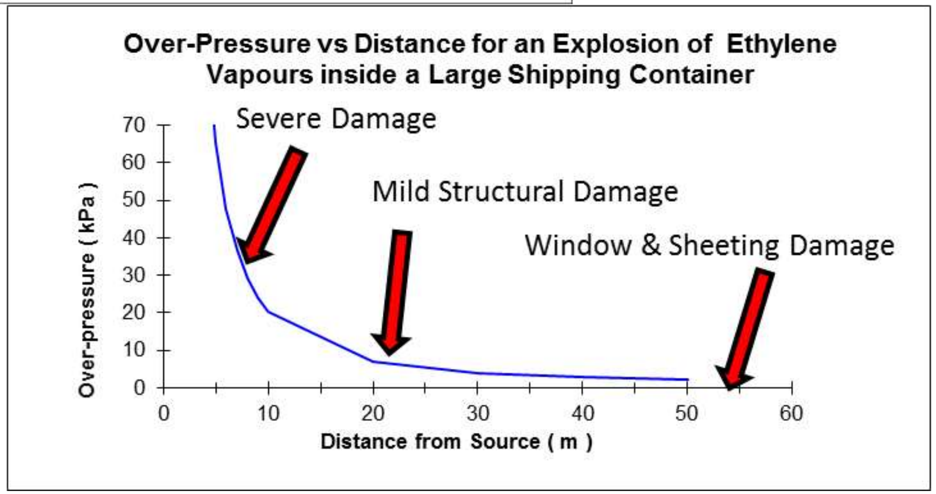
PLEASE NOTE – the modelling, especially the noxious smoke modelling, is an approximation.

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