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LITHIUM ION SAFETY

Report on the revised Sunnica Energy Farm Application

By Dr. Paul Christensen, Lithiumionsafety Ltd, 3 December 2022

1. Introduction

I am an academic electrochemist with over 35 years experience in research. I have over 180 papers in international, peer reviewed journals and an H-index of 53. I am an Editorial Board member of Nature Special Reports. I am Senior Advisor to the National Fire Chiefs Council (NFCC), Special advisor to Tyne and Wear Fire and Rescue Service and I am a Subject Matter Expert to DSTL. I serve on the Cross-government Technical Steering Group for EV fire safety, the Department of Business Energy and Industrial Strategy (BEIS) Energy Storage Health and Safety Governance Group, the BEIS Storage Safety - Fire Service Working Group, the British Standards Institute (BSI) PAS 63100 (domestic energy storage systems) Steering Group, the BSI Review Group in the development of the BSI base document for Lithium-ion battery cells, modules and packs – Physical storage – Guide and the BSI FSH/2/-/20 – Working Group (lithium-ion battery extinguishers), the Australian Building Codes Board working group on EV safety and the Tyne & Wear FRS and Envision-AESC Gigafactory fire safety working group. I am the recipient of the 2022 Motorola Foundation-funded AFAC Knowledge Event Series lecture tour of Australia, New Zealand and Tasmania (Oct 2022, presenting to first responders, government officials etc).

I advised Nissan for 3 years on all aspects of lithium-ion battery safety during the construction and commissioning of the battery plant in Tyne & Wear. I am routinely asked for input and advice by OZEV and the Department for Transport. I have conducted tests and experiments to research thermal runaway at module, pack and vehicle levels. I have assessed a number of LiBESS planning applications in the UK and abroad.

2. Executive Summary

I have reviewed 7.6 Outline Battery Fire Safety Management Plan [REP2-033], Chapter 16: Other Environmental Topics [REP2-025] and Appendix 16D: Unplanned Atmospheric Emissions from Battery Energy Storage Systems (BESS) [REP2-265]. I have not reviewed sections not relevant to safety or outside my expertise.

I have already reviewed the initial Outline Battery Fire Safety Management Plan and my comments from this, where unchanged in this latest revision, still stand. This report should be considered along with my previous report.

The revised Outline Battery Fire Safety Management Plan (OBFSMP) is an improvement over the original OBFSMP and includes some examples of Good Practice. However, some significant areas of concern remain.

There is still a lack of essential detail including: the vapour cloud explosion hazard is not considered. This is a major omission. Neither is cyber security, and no indication is given of the formulation of the Emergency Response Plan despite there now being many templates and examples available from reputable sources.

The c.a. 65 fires and explosions to date involving lithium-ion BESS are not discussed or analysed for lessons learned. The choice of cell chemistry, cabinet or container is still not made: these have a direct impact on the energy density of the units and the free volume- both of which determine the detection and suppression systems required, or indeed if suppression is possible. These also have a direct impact on appropriate safety features and on realistic fire and emergency service operational procedures.

Mention is also not made of assembly areas for first responders including Fire and Rescue Services (FRS).

It is encouraging to note that the applicants intend to be guided by internationally-recognised standards including UL 9540A & NFPA 855: however no mention is made of retaining an independent expert to assess the test results from UL 9540A as required under NFPA 855 (2023) section 9.1.5.2.2. This is important to prevent “game playing” e.g. showing only the “best” test result out of e.g. 4 tests, and claiming compliance when in reality only UL 9540A tests have been carried out BUT improvements to the design on the basis of the test results have not been made. In addition, no mention is made of testing the Ingress Protection (IP) of the containers/cabinets which is also required under UL 9540A.

The sections on fire detection, suppression and deflagration prevention/amelioration are particularly confusing and make it impossible to review to any suitable extent.

Finally, given the wealth of data routinely logged in BESS and the potential to employ data analytics to provide advance warning of maintenance or even failure, it is disappointing to note that the applicants do not seem to have considered this as an option.

Overall, given that the eventual Battery Fire Safety Management Plan must be "substantially in accordance with the OBFSMP" (as indicated in the draft Development Consent Order) I do not consider that this OBFSMP can be used as a basis for this.

Detailed review

3. Outline Battery Fire Safety Management Plan

<u>Section 2.5.2 - 2.5.4</u>

The indicative layout designs for the two different technology types under consideration (Appendices A & B) do not make reference to an assembly area for fire and rescue services (FRS) which should ideally be placed near the entrance to the site to ensure that FRS do not have to drive through toxic and/or explosive fumes, or near to flames or containers liable to explode (see, for example, [1][2]).

<u>Table 3: BESS Design Parameters</u>
Module.
Mention is made of a liquid cooling system, but there is no mention of leak detection capability, an important consideration arising from learning from previous events. Coolant leaks can cause short circuit.

Such systems have been responsible for fires involving EVs (see, for example, the Chevy Volt fire[3][4]) and BESS (see, for example, the Moorabool fire[5]).

Cell.
The chemistry to be employed remains under discussion and this renders assessment of the safety aspects impossible. The two chemistries under consideration, LFP (Lithium iron phosphate) and NMC (Nickel Manganese Cobalt), present markedly different hazards. I would expect to see safety considerations and data for both options. Thus NMC cells are likely to have a higher fire hazard whilst LFP poses more of an explosion hazard [6] (the only fatal BESS explosion to date involved LFP cells[7]). This is an important consideration due to the potential risks of explosion and the hazards these present to first responders as well as to nearby homes etc.

One of the key reactions that occur before thermal run away is the exothermic structural collapse of the cathode which produces oxygen and is believed to initiate ignition: this collapse occurs at a much higher temperature in LFP cells (310°C [D. Ren et al., "Investigating the relationship between internal short circuit and thermal runaway of lithium-ion batteries under thermal abuse condition", Energy Storage Mat., 34 (2021) 563 – 573]) hence LFP cells are considered "safer" than for example NMC.

However, this can just delay ignition and hence LFP cells are perceived to have a higher risk of vapour cloud explosion. Further, recent work has shown that the vapour cloud from LFP cells has a lower explosion limit, larger explosion overpressure, higher explosion index and the ignited vent gas has a higher laminar flame speed [H. Wang et al., eTransportation 13 (2022) 100190.]

BESS container/enclosure.
The applicant states that, **"**The construction will be in the form of modified 20-foot / 40-foot ISO shipping containers OR factory built modular cabinets / units"

Cabinets have a far higher energy density than containers and little free volume: this renders any form of suppression extremely challenging as water (which is still the best of the bad options when it comes to dealing with thermal runaway) will not be able to reach the cells in thermal runaway to prevent thermal propagation.
Recognising this, Tesla recommends that their cabinets be allowed to burn out [5].

Hence, safety measures, the FRS operational procedure, impact on those in close proximity, etc will all depend upon the container topography in addition to the cell chemistry.

The cell chemistry and the container topography need to be disclosed at this stage in order to build in suitable safety measures.

BESS compound.
It is noted that the examples shown here are of considerably smaller BESS compounds compared to those being proposed.

Section 2.6.4
Consultation
The consultation with local FRS should be in the spirit of Dame Maria Miller's draft Bill for lithium ion battery storage: *"The Bill would ensure that industrial lithium-ion battery storage facilities are correctly categorised as hazardous, so that the Environment Agency, the Health and Safety Executive and the fire and rescue services would be statutory consultees when planning applications are considered"*

Given the significant size and scale of the proposed BESS I consider it essential that the HSE, EA and the FRS are all fully consulted during the DCO application.

Section 2.9 – Safety Standards

Table 4:
Automatic Fire Protection
This section is not relevant if the high energy-density cabinet design is chosen.

3rd party fire and explosion testing is mentioned in Table 4, subsection Automatic Fire Protection.
No mention is made of the *independent validation* of the test results as stipulated in NFPA 855 9.1.5.2.2. This is important for the reasons set out in the Executive Summary (with regard to "game playing").

It is noted that cyber security is not covered at all in the plan despite, for example, the 2021 DarkSide ransomware attack on the Colonial Pipeline and the warnings of similar threats to BESS[8][9]. This is a serious omission. For example, scientists in TŰV Rheinland have shown that BESS are vulnerable to hacking and could be used to dump energy onto the Grid or turn the BESS into a "bomb" [9].

Serious concerns over the lack of cybersecurity in BESS were recently raised by DNV[8]. Given the size of the BESS being proposed in this application, a cyber attack could have significant consequences.

Section 2.10 – Guidelines and Recommendations

2.10.1. It is stated that "Experience from other projects of a similar nature for property protection purposes":

The applicant should provide details about the analyses undertaken and any changes that have been made to their proposal to address the learning points from investigations into previous incidents. This would help to inform and assist the overall assessment of the OBFSMP.

Table 5.
The Australian Country Fire Authority guidelines have not been included, which are a useful resource [2].

Section 2.11- Contributors and consultees
It is correct to state that "Effective stakeholder engagement and consultation is a key requirement of the PA 2008"

The comments made by the FRS and HSE should be given in detail at this stage as it is currently unclear what suggestions have been made and how these have been acted upon.

<u>Section 3 – Purpose and Scope</u>

3.1.1 It is stated that "The scope of this Outline Battery Fire Safety Management Plan covers the life safety, welfare and property protection fire safety requirements of the BESS at Sunnica East Site A, Sunnica East Site B and Sunnica West Site A."

I do not agree that this is the case.

3.1.2 It is stated that
"The purpose of the Outline Battery Fire Safety Management Plan is to demonstrate that the location of BESS within the Scheme does not give rise to a significant increase in fire risk and that any risk that does exist can be addressed by ensuring that the Scheme is constructed, operated and decommissioned in accordance with the approved Outline Battery Fire Safety Management Plan."

I do not consider that this purpose has been achieved with this OBFSMP.

<u>Table 6</u>

Item 2. Emergency Response Plan (ERP).
There are a wealth of templates and guidelines for ERPs available, for example from the NFPA and CFA[2], so it is disappointing that an outline ERP has not been included in the OBFSMP plan. It is essential to protect those attending/ in close proximity to the site that an outline ERP is prepared alongside the OBFSMP. These documents would support each other and ensure that appropriate safety features are designed into the BESS compounds.

Item 3. Location away from residential areas.
There is insufficient evidence presented by the applicants to justify the statement regarding the Unplanned Atmospheric Emissions report that:

"…in the unlikely event that a fire were to break out in a single cell or module, it is considered very unlikely given the control measures that the fire would spread to the rest of the BESS".

Nor that

"the resultant hydrogen fluoride concentration at the closest receptors would be below the level that Public Health England has identified as resulting in notable discomfort to members of the general population" (see later notes on the applicants Unplanned Emissions chapter.

More evidence is required in order to justify the suitability of the BESS location, ideally including the results of actual UL 9540A tests

Regarding the UL 9540A testing, independent review of the results of UL 9540A tests is essential for reasons set out previously (regarding interpretation of test results and the consequent actions that arise from them).

Item 7. Fire detection and suppression.
This will critically depend upon the topography of the battery enclosure, whether container or cabinet. This has not been declared. The FRS response will also be affected by this choice. Cabinets are not explicitly dealt with, which is a major oversight at this planning stage, given that this will determine appropriate safety measures, including water requirements etc.

Items 12 & 13. These sections are confusing. It is not clear if the applicant will employ both gas and smoke detection. No allowance is made for vapour cloud production in the absence of fire as per the McMicken BESS thermal runaway incident in Surprise, Arizona (2019) and Carnegie Road, Liverpool BESS explosion (2020), or of the fact that both heavier than air and lighter than air vapour clouds could be produced[10-12].

This requires clarification before any assessment of the proposals can be made.

Item 15. Water resources.
As with the previous version of the OBFSMP, the significant volumes of water required to deal with a thermal runaway incident have not been given sufficient consideration and this has clearly not been addressed in this latest version. The applicants do not appear to have carried out research into past incidents and in particular about the water requirements used in these situations. This is essential to factor in at the planning stage as it will have consequences on the design and equipment needed for the BESS compounds.

Item 18. Inclusion of Hazard Identification Study (HazID) and Hazard and Operability Study (HAZOP) are examples of Good Practice.

Item 19. Details of the BESS technology.
It is stated "Details of the BESS technology has been provided in Table 3 for each element of the Scheme including cell, module, rack, BESS container enclosure and BESS compound"

This is not correct. The essential details of cell chemistry and form factor, container type (ISO container, cabinet etc), gas sensing system, location of sensors, type of suppression system and the layout of suppression systems etc are not given. These are all essential to know when considering suitable safety measures.

There are no *details* in Table 3 – options only are presented. For this OBFSMP plan to have any validity it should address ALL issues for ALL the options provided in Table 3. In other words, all issues for the two cell chemistries proposed, all issues for container versus cabinet, etc. Only then can an accurate assessment of the suitability of the OBFSMP be made.

Item 25. The removal of contaminated water is an example of Good Practice. It remains the case that the applicant has underestimated the possible water volumes needed.

Item 26. In addition to comments in my initial report I also note that water releasing coatings on containers are suggested.

The Ingress Protection , IP, of containers is not detailed and should be provided. (This is standard nomenclature - IP65 means dust prevention to level 6, water to level 5, as per industry specifications: [redacted]

Item 30. Residual charge. The applicant has not explained how cells would be discharged and how long this would take (and thus how soon a site could be made safe).

It is stated that "there will be a requirement for first/second responders to analyse the system data".

I consider it unlikely that first/second responders will have the knowledge and experience to analyse system data. This would require a subject matter expert.

Section 4.6.1. Decommissioning.

There is limited information regarding decommissioning. It is not clear on what basis the cells/modules would be assigned for decommissioning. For example, whether this is decided by State-of-Health (SoH i.e. how much maximum capacity remains compared to maximum capacity at the beginning of life) or State-of-Safety.

This is an important consideration as the same risks are present during decommissioning and during installation. Further, the Sunnica scheme would operate for at least 40 years, during which time decommissioning of batteries would be necessary since the batteries do not have such long lifetimes. Decommissioning during the operational lifetime of the scheme also needs to be considered.

It is also surprising that data analytics are not considered at all in the plan.

Section 5.1.2 Mitigation and Control

Table 13

RMM10. It is not clear what trigger temperature(s) would be employed and on what basis. Breaking connection to the external circuit will not stop thermal runaway.

RMM11. Insufficient detail is provided here. The level of cell monitoring, the cell configuration (XS, YP), how this provides effective monitoring, etc., needs to be presented to be able to assess the suitability of the proposals. There are important lessons that can be learned from the 2019 McMicken BESS explosion [10][11].

RMM17. As indicted in my report of the initial OBFSMP, this section is confusing. The term "coincidence detection" requires explanation.
If this refers to the detection of smoke and carbon monoxide to activate an alarm, this needs further consideration.
The positioning of the detectors will be critical given the production of heavier and lighter than air vapour clouds.
In addition, on activation of the alarm: *"The EMS for the BESS container enclosure will engage the first stage alarm and will close access doors, louvres, shut down ventilation system and BESS electrical installation."*
This would allow the build-up of a potentially explosive vapour cloud should ignition not have occurred and is in conflict with the principles of NFPA 855 (2023).
The vapour cloud hazard does not appear to have been considered in the OBFSMP plan, which is a serious omission (especially considering that such occurrences have resulted in death and serious injury to first responders).

RMM20. The IP rating needs to be specified (see previous comment about this in item 26).

RMM21. Further details about the parameters that will be monitored is required here before any assessments of the suitability of these systems can be made. This is essential to allow early warning of failure.

RMM22 & 23. Further to previous comments (such as those relating to RMM17) this section needs clarification before any assessment can be made

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Review of Revised Chapter 16: Other Environmental Topics

Section 16.7.19
Landfill of BESS equipment including batteries.

The applicant has not duly considered waste disposal arising out of the batteries either during the operational lifetime or during decommissioning Landfill of lithium-ion batteries is prohibited in the UK[13].

Review of Revised Appendix 16D: Unplanned Atmospheric Emissions from Battery Energy Storage Systems (BESS)

Overall the applicant's assessment of Unplanned Emissions fails to provide any assurances regarding the potential hazards arising from a likely thermal runaway incident. It fails to consider explosion risk, as a result of the formation vapour clouds. It fails to assess potential emissions arising from the different cell types (NMC and LFP). It fails to account for other toxic emissions that are likely to arise out of thermal runaway events.

Section 2.1.2
The application in general focusses only on the emissions from fire: the documents do not consider the large volumes of vapour cloud that can, and have been, produced. In the Arizona 2019 incident, a heavier-than-air vapour cloud rolling across the prairie in Surprise Arizona an hour after the alarm and deployment of Novec 1230 caused locals to alert the fire service to a prairie fire[10][11].

Despite the fact that only the cells in a single rack went into thermal runaway (c.a. 90 kWh), the vapour cloud was produced for 3 hours and leaked from the container, but sufficient remained to cause a major deflagration with a 75 foot long, 20 foot high fireball when the door was opened. This explosion potential must be factored into the safety features.

Whilst the academic literature also focusses primarily on the fumes from lithium-ion batteries on fire, there are some papers on incidents where ignition has been prevented or simply did not occur, and these provide data on the volume and composition of the vapour cloud.

In addition, Hydrogen Fluoride is not the only hazardous chemical: for example, Hydrogen Cyanide has been detected in vapour clouds. This will burn in fire but is a potential additional hazard regarding the vapour cloud, as are other toxic and combustible compounds.

Section 3.2.1
It is unclear on what basis the emission rate of 1 ug m^{-3} s^{-1} was selected for the modelling calculations. This needs to be explained in order to assess the validity of this.

Section 3.2.2
The emission of vapour cloud rather than smoke has not been considered, which is a major oversight (as per my previous comments).

Section 4.1.4
As stated above – there are too many unknowns at present for this modelling to provide any degree of assurance. For example, this assessment would likely change with a high energy-density cabinet. It would also change as a function of the cell chemistry. All of this needs to be considered to provide valid emission assessments.

Signed: [redacted]

Dated: 7 Dec 2022

References

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