Consideration of loss of control scenario for Kells Battery Storage Facility

Author: D. Haigh

Institution: Golder Associates (UK) Ltd, Stanton-on-the-Wolds, Notts. NG12 5BL

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GOLDER

TECHNICAL MEMORANDUM

DATE 22 October 2020 **Reference No.** 170820-400/01

TO John Dundee, SYNERGY

CC

FROM Dale Haigh [redacted]

CONSIDERATION OF LOSS OF CONTROL SCENARIO FOR KELLS BATTERY STORAGE FACILITY

Kells BES Limited has been granted Planning Permission for a battery storage facility in proximity to an existing electricity network substation at Kells, Co. Antrim. A review of the proposed development in relation to the Planning (Hazardous Substances) (No. 2) Regulations (Northern Ireland) 2015 (hereafter, referred to as Regulations), was completed by SYNERGY in August 2019. This note develops the work performed by SYNERGY and so should be read in association with the SYNERGY report.

The list of relevant chemicals within the batteries and their associated quantities of chemical substances, as set out in Parts A and B of the Regulations, has been provided by SYNERGY (2019/027 PAC, August 2020) concluding that these were beneath the thresholds set out in the Regulations. This note considers further the Regulations related to a potential loss of control scenario considering the contents of the batteries proposed to be stored at the facility as set out on Part C of the Regulations. The scope of work considers what might occur under a loss of control scenario at the facility and what chemical reactions might take place. The resultant "new" chemicals are then considered relative to the thresholds in the Regulations. The most likely loss of control scenario associated with battery storage facilities is a fire and additional results from fire-fighting activities that might follow. This is considered further below.

The work has been completed by Dale Haigh, who is a chemist by training and an EHS consultant and senior partner with Golder Associates, with over 30 years' experience. He has considerable experience of providing consultancy support related to COMAH (Seveso), Planning and Hazardous Substances Consent and related regulations across Europe.

Scope of Work

In order to consider what might occur during a loss of control incident involving fire, the following activities have been performed:

- Consider chemicals (and quantities) provided and consider reactions (at an overview level) in the event of a fire and identify what chemicals might be produced.
- Consider implications in event that a fire might require firefighting with water (this is considered further below as each container has a self-contained solid CO2 firefighting system in place).
- Identify components produced (and expected quantities) and determine if listed in CLP (European Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures) to

Golder Associates (UK) Ltd
Attenborough House, Browns Lane Business Park, Stanton-on-the-Wolds,
Nottingham, NG12 5BL, UK
Company Registered in England No. 1125149
At Attenborough House, Browns Lane Business Park, Stanton-on-the-Wolds, Nottinghamshire NG12 5BL
VAT No. 209 0084 92
T: +44 0 115 937 1111 F: +44 0 115 937 1100

identify Globally Harmonized System of Classification and Labelling of Chemicals (GHS) Hazard (H) phrases where relevant and Regulation threshold quantities.

- Compare with relevant Regulation criteria but consider any mitigation measures planned at the facility.

Background

The Site itself will comprise 22 cells located in each module and 6 modules are located within each rack. 28 racks are located in each container and 25 containers on Site in total. A CO2 firefighting system is present within each container. The Site has a total of 26,300 kWh energy capacity at the Site (equivalent to a maximum power of 50 MW).

The Site has hardstanding but is not sealed.

The batteries are Lithium ion batteries and the whole Site contents (from all 25 containers) includes:

- Cobalt Oxide - 19.1 tonnes present on site.
- Manganese Dioxide - 19.1 tonnes on site in total.
- Nickel Oxide - 19.1 tonnes held in total.
- Carbon - 38.1 tonnes of carbon on site.
- Electrolyte (includes Lithium hexafluorophosphate (LiPF6) and Organic Carbonates) - 28.6 tonnes of electrolyte in total on site.
- PVdF (Polyvinylidene fluoride or polyvinylidene difluoride) (C2H2F2)n - 9.5 tonnes of PVdF on site.
- Aluminium foil - 19.1 tonnes of aluminium foil on site.
- Aluminium and inert materials – 21 tonnes of aluminium on site.
- Copper foil - 17.2 tonnes held on site.

Fire Risk Management

The installation is proposed to consist of the Sungrow-Samsung SDI system which incorporates a series of safety features at each stage of operation to minimise the potential for a fire to start, including safety features within each part of the system (battery cells, switch gear, battery management system and storage unit).

In the unlikely event that a fire starts within a cell, then inherent in the design is a separator which provides a protective space to adjacent cells. Cells are also incorporated into separate racks with Battery Management Systems (BMS) which monitor a variety of operational parameters, allowing shut down when any of these exceed standard operating tolerances. Further, each rack is separated from other racks. Racks are assembled within steel container units which have a ventilation system to reduce the risk of overheating and an automated Fire Fighting Suppression (dry CO2 powder) with a variety of input parameters to respond immediately to an outbreak of fire within the unit ensuring that it does not propagate.

Beyond the individual containers themselves, each container is separated by a minimum of 2.3m so that in the unlikely event that all of the above fail safes and systems do not extinguish the fire, it will be unable to spread to neighbouring units for a considerable period of time. There is also an automatic alarm system in place, and this is monitored to ensure a response from the local Fire and Rescue Service.

A Fire Risk Assessment (FRA) report completed by Jensen Hughes (BB/841/R1, July 2020) stated that the proposed extinguisher system reached extinguishing capacity within 10 seconds. A fire growth calculation was also undertaken and the report indicated (using conservative inputs) that the fire spread was considered medium but that the critical heat flux from one battery rack would not exceed the levels that give rise to a second rack within the same container catching fire. The fire growth calculations did not include the fire protection measures including the extinguisher system noted above.

Given the above fire management system, the potential for a loss of control scenario to exist that includes all containers at the Site is considered to be very limited indeed. We have therefore considered two scenarios below; the most reasonable worst-case scenario involving the loss of one container; a further scenario considering all containers on Site are captured by fire. This is considered further in the evaluation below.

Fate of Chemicals in a Fire

Many of the chemicals used within the batteries are metals (cobalt, nickel, manganese, copper and aluminium) or metal oxides and these will largely convert to metal oxides or remain in the same state in the event of a fire depending on the temperature attained (we note for cobalt oxide the form of the oxide may vary depending on temperature attained).

Other key chemicals include the following:

- Fluorophosphate and PVDF – these are likely to produce HF and POF3 in the event of a fire.
- Carbon – likely to produce CO2 and CO in the event of a fire. Both CO2 and CO will be produced and the literature suggest that the CO2 content will dominate. This is discussed further below.
- Organic carbonates – these would be expected to convert to CO2, CO, O2 and water in the event of a fire. As noted above, both CO2 and CO will be produced and the literature suggest that the CO2 content will dominate. This is discussed further below.

The quantities of the above materials produced have been estimated, and the relevant Hazard phrases identified and compared with the Regulation threshold criteria. None of the "new" chemicals formed are specifically named within the Regulations, but are considered for other properties which fall under the Regulations, such as being flammable, explosive or toxic. The results are summarised in the tables below.

<u>Fluorophosphate and PVDF</u>

The electrolyte contains Lithium hexafluorophosphate, additionally Polyvinylidene fluoride (or polyvinylidene difluoride) is present within the batteries. A study by Larsson et al, 2017 (Toxic Fluoride gas emissions from lithium ion battery fires, Nature Scientific Reports, 30 August 2017), stated that HF and POF3 were produced during a battery fire and also estimated the amount produced based on the nominal battery energy capacity in Wh with 20 to 200 mg (mean 110 mg) of HF produced per Wh of nominal battery energy capacity being produced and between 15 to 22 mg (mean 18.5 mg) of PFO3 produced per Wh of nominal battery energy capacity. Estimates of HF and POF3 gas production rates have been made using the mean of the estimated range by Larsson et al. The volume of HF gas produced is 0.1T and below the 5T threshold in the Regulations (H310) (Toxic) for a single container loss of control scenario. The total mass of HF gas produced (from Lithium hexafluorophosphate and Polyvinylidene fluoride) is calculated at 2.93T (average of range 0.53 to 5.3 tonnes) for the whole site loss of control scenario. To exceed the 5T threshold, a value in the upper 6% of the range would have to be assumed but this is an extreme value, as would be an assumption close to the 0.53T lower limit, and hence the average is seen as a reasonable professional determination.

Carbon and Organic Carbonates

Carbon and Organic carbonates may be converted in a fire to CO and CO2. The threshold for CO in the Regulations is 10T (due to its flammability (Physical) and 50T due to STOT RE Category 1 (Toxic). It is recognised that the actual extent of conversion of carbon to CO and CO2 in a fire would depend on a number of considerations including temperature reached and amount of available oxygen.

Research into the impact of fire on lithium ion batteries has been performed and have identified the potential for carbon dioxide (CO2) and carbon monoxide (CO) release during a fire. Andersson and FM Global have performed tests on lithium ion batteries and confirmed CO2/CO peak concentration release ratios of 65-99 and 43 to 71 respectively. Wang has performed similar release experiments on the larger format batteries and identified peak concentration release ratios for CO2/CO of 17 to 19 for the 148 LIB which is most similar to the battery cells in use at the site (from comment below). A further paper by Wang identified peak concentration release ratios for CO2/CO of 3.75 to 200. Taking the mean of these values gives a CO2/CO ratio of 64.7.

Only one of the studies provided relative masses of CO2 and CO produced and this is most directly relatable to the thresholds for the Planning and Hazardous Substances Consent. The FM global study estimated masses of CO2 and CO released in fires and identified (CO2/CO) ratios of relevant release masses of 43 and 71 (which are in the same order of magnitude as for the peak concentration ratios).

By assuming the worst case scenario from the FM Global study which presented released CO2 and CO masses, (i.e. CO2/CO ratio of 43), we would assume that any fire would result in the 38.1 tonnes of carbon reacting to create 135 tonnes of CO2 and 3.1 tonnes of CO. This is below the 10T threshold for the requirement for HSC.

The above estimates assume that all of the carbon would react to produce CO2 and CO which is considered to be conservative. Loss of total mass has been measured in several experiments and show arounds 25% total mass loss. Therefore, the mass of CO produced is considered to be a worst case estimate.

Potential Impact of Firefighting Water

In the event of a fire occurring within a container there is a carbon dioxide based dry powder fire extinguisher that self-actuates. It is assumed that this should be effective in most cases thus limiting the potential for a loss of control scenario to exist. Further it also reduces the potential for water to be used during firefighting and so would limit the potential for water-based chemicals to be produced and for further reactions to take place. However, we have considered the low probability occurrence that the CO2 system is not effective, and that water would be used to fight a fire. We have further considered that this could occur over the two scenarios identified above (one container as a reasonable worst case and a second scenario involving all containers across the Site). Should this be the case there is the potential for mobilising some of the chemicals stored within batteries within the container. This note assesses the chemicals that might be formed from those chemicals within the battery makeup (as listed above).

The main issue associated with chemicals produced in connection with firefighting water is the environmental impact. As noted above the site has hardstanding but does not include sealed surfaces that could contain fire water in the event of a fire.

We have estimated what chemicals might be produced in the event of fire water being used. We have considered the likely most environmentally sensitive materials produced which are metal chlorides, sulphates and nitrates and identified the likely greatest mass produced (usually the sulphate). In order for these reactions to take place they require sufficient chloride, sulphate, or nitrate to be present (ideally as acids). The chemical inventory provided for the Site does not indicate that these species are present at all. We therefore do not see the potential for all the metals available to be converted to these species. However, we have set a conservative maximum value of 50% conversion to the relevant chloride, sulphate or nitrate.

Based on the assumed scenario, no individual metal (as its resulting compound) will lead to production of quantities above the threshold value individually. In addition, the aggregate result is also below the aggregate threshold value.

Summary

This note has focused on further developing the work by SYNERGY in considering at an overview level, potential loss of control scenarios in relation to the Planning (Hazardous Substances) (No 2) Regulations (Northern Ireland) 2015. Two impacts are considered and relate to a fire (where “new” chemicals may be formed) and subsequent firefighting using water which may mobilise chemicals causing further reaction and creation of additional “new” chemicals.

A fire scenario which includes the whole Site is considered to have an extremely low probability of occurrence due to the overall fire management system in place which is considered to be effective to the extent that it is unlikely that a fire beyond one container will occur. This latter scenario is considered to represent a reasonable worst case for the loss of control condition but both scenarios have been considered.

Within the fire scenario, the loss of control for one container would not lead to the production of any substance in excess of the applicable thresholds. If the whole site of 25 containers is considered, then within the fire scenario the potential CO gas produced (3.1T) would be below the threshold for CO as a flammable substance (10T limit) and STOT RE Category 1 (50T limit). For HF the total estimated mass produced (from Lithium hexafluorophosphate and Polyvinylidene fluoride) is 2.93T based on the reasonable professional assumption of the HF produced in a battery fire by Larssen.

Within the water use during firefighting scenario environmentally sensitive materials may be produced which may give cause for concern. However, no individual metal (as its resulting substance produced through reaction) will lead to production of quantities above the threshold value individually under single container or whole site loss of control scenarios. In addition, the aggregate result is also below the threshold value. These results are based on our assumptions above.

Results are provided in the summary tables below.

This note sets out the consideration of Part C of the Regulations relating to loss of control and the conclusion is that the potential quantities of substances generated in the unlikely scenario of all 25 containers suffering a loss of control and fire are below the thresholds set out within the Regulations.

References

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Table 1 - Loss of Control Scenario - One Container

Chemical and Mass	New Chemical formed on Loss of Control due to fire (and mass)	Regulation Threshold (tonnes)	New Chemical formed on Loss of Control during water use in firefighting (and mass for compound of greatest mass only)	Regulation Threshold (tonnes)	Summary
Cobalt Oxide (CoO) 19.1 tonnes present on site.	CoO or Co3O4 (0.82 tonnes)	100 T (H400/H410)	Cobalt dichloride and Cobalt Sulphate (1 tonne)	100 T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Manganese Dioxide 19.1 tonnes on site in total.	Manganese Dioxide (0.764 tonnes)	Not Applicable	Manganese Sulphate (1 tonne)	200T (H411)	< threshold for both loss of control under fire and use of fire water
Nickel Oxide 19.1 tonnes held in total.	Nickel Oxide (not combustible)	Not Applicable	Nickel Hydroxides, Nickel Sulphate (1 tonne), Nickel dichloride and Nickel dinitrate	100T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Carbon 38.1T of carbon on site.	CO (3.56 tonnes) and CO2 gas produced.	For CO only 10T (H220), 50T (H372)	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Electrolyte (includes Lithium hexafluorophosphate (LiPF6) and organic carbonates (see below for organic carbonates) 28.6 tonnes in total on Site.	HF 0.02 to 0.21T POF3 <0.02T	5T (H310)	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
PVdF (Polyvinylidene fluoride or polyvinylidene difluoride) (C2H2F2)n 9.5T of PVdF on site.	HF 0.02 to 0.21T POF3 <0.02T	5T (H310)	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Aluminium foil 19.1T of aluminium foil on site.	Not Applicable	Not Applicable	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Aluminium and inert materials 21T of aluminium on site.	Not Applicable	Not Applicable	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Copper foil 17.2 tonnes held on site.	Not Applicable	Not Applicable	Copper Sulphate (0.9 tonne)	100T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Organic carbonates	CO (0.90T), CO2 and water	For CO only 10T (H220), 50T (H372)	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water

Table 2 - Loss of Control Scenario - Whole Site

Chemical and Mass	New Chemical formed on Loss of Control (fire) and Mass	Regulation Threshold (tonnes)	New Chemical formed on Loss of Control (water use in firefighting) and Mass (for compound of greatest mass only)*	Regulation Threshold (tonnes)	Summary
Cobalt Oxide (CoO) 19.1 tonnes present on site.	CoO or Co_3O_4 (20.5 tonnes)	100 T (H400/H410)	Cobalt dichloride and Cobalt Sulphate (25 tonnes)	100 T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Manganese Dioxide 19.1 tonnes on site in total.	Manganese Dioxide (19.1 tonnes)	Not Applicable	Manganese Sulphate (26 tonnes)	200T (H411)	< threshold for both loss of control under fire and use of fire water
Nickel Oxide 19.1 tonnes held in total.	Nickel Oxide (not combustible)	Not Applicable	Nickel Hydroxides, Nickel Sulphate (25 tonnes), Nickel dichloride and Nickel dinitrate	100T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Carbon 38.1T of carbon on site.	CO (3.1 tonnes) and CO_2 gas produced.	For CO only 10T (H220), 50T (H372)	Not Applicable	Not Applicable	< threshold for both loss of control under fire (CO)
Electrolyte (includes Lithium hexafluorophosphate ($LiPF_6$) and organic carbonates (see below for organic carbonates) 28.6 tonnes in total on Site.	HF 2.93T (range 0.53 to 5.33T) POF_3 <0.5T	5T (H310)	Not Applicable	Not Applicable	< threshold for loss of control under fire for mean estimate, but exceeds threshold for higher estimate
PVdF (Polyvinylidene fluoride or polyvinylidene difluoride) $(C_2H_2F_2)_n$ 9.5T of PVdF on site.	Included in above total for Electrolyte	5T (H310)	Not Applicable	Not Applicable	< threshold for loss of control under fire for mean estimate, but exceeds threshold for higher estimate
Aluminium foil 19.1T of aluminium foil on site.	Not Applicable	Not Applicable	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Aluminium and inert materials 21T of aluminium on site.	Not Applicable	Not Applicable	Not Applicable	Not Applicable	< threshold for both loss of control under fire and use of fire water
Copper foil 17.2 tonnes held on site.	Not Applicable	Not Applicable	Copper Sulphate (22 tonnes)	100T (H400/H410)	< threshold for both loss of control under fire and use of fire water
Organic carbonates **#**	CO (22.5T), CO_2 and water	For CO only 10T (H220), 50T (H372)	Not Applicable	Not Applicable	> threshold for loss of control under fire (CO)

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Dale Haigh
Principal

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