Written Representation of Dr Edmund Fordham

Dated: 11th November 2022

Annexes EF12 through to EF33 uploaded separately

THE PLANNING INSPECTORATE

EN010106 – Sunnica Energy Farm

APPLICATION BY SUNNICA Ltd for an Order Granting Development Consent for the Sunnica Energy Farm Project pursuant to The Planning Act 2008

To the Examining Authority (ExA)

WRITTEN REPRESENTATION of

EurIng Dr Edmund John Fordham MA PhD CPhys CEng FInstP

Interested Party – Unique Reference: 20030698

Please note:

1. This Written Representation (WR) is being submitted as required by Deadline 2 (11 November 2022) covering *inter alia* the technical reasons why Hazardous Substances Consent (HSC) is almost certainly required for the BESS elements of the Application. This WR is therefore complementary to the accompanying PHS subsequent to the ISH1 on the structure of the dDCO. This WR also raises other policy and battery safety issues.

2. A separate Post-Hearing Submission subsequent to contributions made orally at the ISH1 on the dDCO on 1 November 2022 is also being submitted as required by Deadline 2 (11 November 2022) and is confined so far as possible to the legal issues raised by the structure of the dDCO. Policy issues not directly arising from the structure of the dDCO are brought forward in this WR.

3. Footnotes are used to make citations to literature elsewhere. Links to verifiable sites such as www.legislation.gov.uk are stated to be acceptable and have not been removed. Other domains presumed to be acceptable are European Commission domains ending .europa.eu and the United Nations Economic Commission for Europe domain unece.org. The DOI (Digital Object Identifier) system is not explicitly mentioned in the Guidance but such references are now a standard part of citations to scientific journals of record and are included, without the https://doi.org/ prefix. Citations to literature central to the case are included as Annexes to obviate any need to consult external documents.

SUMMARY

(per Guidance, being 10% of the main submission)

[*Please refer to the Glossary following, for a list of abbreviations.*]

1. Li-ion BESS suffer a failure called "thermal runaway" leading to "loss of control" accidents popularly but incorrectly called "battery fires", which require no oxygen, and may proceed without flame until a final "deflagration".

These are matters of record and not alarmist speculation.

They occur in both NMC and LFP cells although behaviour may be qualitatively different and result in different leading concerns.

The likely extent of a major accident involving grid-scale BESS remains an open question. Most incidents so far investigated have been "fires" or VCEs in BESS that were much smaller than those projected for Sunnica.

Even a single-cabin accident could be significantly larger than those on record because of the large cabin size.

2. This WR presents evidence that HSC is almost certainly a legal requirement. The P(HS)A 1990 regulates aggregate total of HS across the establishment.

Under the "loss of control" provisions of Schedule 1 Part 3 P(HS)Regs 2015 substances "S" integral to the battery cells are Hazardous Substances.

The CQs should ideally be determined by actual fire tests, verified and documented, on representative samples of the actual cells proposed. I contend that this a duty of the Applicant.

Absent such tests, scoping estimates of the likely thresholds for HSC are shown in Annex EF16, co-authored with Professor Sir David Melville CBE.

3. The principal technical considerations are:

(i) Physical Hazards (Flammable Gases, Flammable Aerosols);
(ii) BESS cells in a high SoC as Explosive Articles;
(iii) Health Hazards (Acute Toxic Gases);
(iv) Nickel Oxides in Inhalable Powder Form, a Named Hazardous Substance originating in fires from Li-ion cells with nickel-based cathodes (including NMC).
(v) Environmental Hazards from contaminated fire-water.

The Aggregation Rule of Part 4 Note 5 P(HS)Regs 2015 is applied.

(*continued*)

4. The leading reasons requiring HSC are:

(a) NMC cells: the likely generation of CQs of inhalable Nickel Oxides from BESS as low as 2.75 MWh.

NMC cells are also likely to exceed CQs of Physical Hazards at a storage capacity around 28.3 MWh. A limitation is lack of data on quantities of Flammable Aerosols, to include in the Aggregation Rule. However the relevance is moot if the CQ of Inhalable Nickel Oxides is exceeded at much lower capacity.

(b) LFP cells: the likely generation of CQs of Health Hazards, dominated by Hydrogen Fluoride and other Acute Toxic gases, from BESS of around 22.1 MWh.

These CQs are respectively 873 times and 108 times smaller than the “design target” capacity of 2400 MWh now declared for Sunnica.

5. Environmental Hazards presented by contaminated fire-water are complex. Further investigation on likely contaminants and their eco-toxicology is warranted.

The example of copper oxides shows however that CQs of E1 Environmental Hazards are readily conceivable.

6. Li-ion cells in a high SoC can fail explosively, from video evidence, meeting the qualitative description of a Division 1.3 Explosive Article. Verified tests prescribed in the CLP Regulation have not to my knowledge been done, so BESS cells are not thus-qualified formally.

However, were such tests to be done and show that cells at high SoC do qualify as Explosive Articles, the CQ would be exceeded at around 15.5 MWh.

7. A Swedish government report detected in fire phosphonofluoridates which are analogues of the outlawed chemical warfare agent Sarin-GB. If confirmed this would present a significant concern to public, wildlife, livestock and bloodstock.

8. I conclude that it is virtually certain that the BESS will require HSC, irrespective of cell type.

The estimates would have to be in error by over 800-fold (NMC cells) or over 100-fold (LFP cells) before it could be argued that HSC is not required.

This provides the technical grounds for the assertion made in my PHS on ISH1 that “HSC is almost certainly required”.

(*continued*)

9. The Schedules to the P(HS)Regs 2015 and the COMAH Regs 2015 are closely aligned, both containing "loss of control" provisions, so an HSC obligation implies *prima facie* that the BESS should be regulated as a COMAH site. With NMC cells, even a single cabin could constitute an "upper tier" COMAH site.

Yet there appears no consultation with the COMAH Competent Authority (CA), though required by Policy in Sect. 4.11.4 of NPS EN-1. The CA have not done any "safety assessment" of a full design.

Scoping Opinions (without full specification) have been recorded from HSE, but the CA comprises the HSE acting jointly with the EA.

Policy requires the SoS to "be satisfied that an assessment has been done where required and that the Competent Authority has assessed that it meets the safety objectives". It is also a legal duty on the SoS to maintain this policy.

10. The Application should be **Refused**, reasons including:

(a) Though HSC is not absolutely required within the DCO, the obligation implies *prima facie* that a formal safety assessment should have been done by the CA. Hence neither Policy guidance in Sect 4.11 NPS EN-1, nor the duty on the SoS in R.24 P(HS)Regs 2015, have been satisfied.

Failure to satisfy this overarching safety policy is an irreparable defect.

(b) Article 13(3) of *Seveso* (implemented in UK law) requires in land-use Planning that "operators provide sufficient information on the risks … and that technical advice … is available … when decisions are taken".

The lack of a full specification fails to provide "sufficient" information on the BESS hazards, which cannot be adequately assessed without it.

(c) The requirement in P(HS)Regs 2015 to evaluate *"the matters referred to in Article 13(2) of the Directive"* , (*viz.* appropriate safety distances from other development, and areas of natural sensitivity), cannot be properly evaluated except by reference to a full safety appraisal by the CA.

11. The duty of the ExA to consider whether the Application represents an acceptable use of land should not result in approval where significant doubt over major safety issues remains.

That would pre-judge whether giant BESS of the size proposed can be operated with acceptable safety, at all, where sited so close to (i) population centres, (ii) areas of natural sensitivity, (iii) remaining farmland, and (iv) a major bloodstock industry.

(Summary 982 words)

EJF, 11/11/22

GLOSSARY

Abbreviations used in the interests of brevity.

Legislation and statutory permissions:

CLP	– the Classification, Labelling and Packaging Regulation
COMAH Regs 2015	– the Control of Major Accident Hazards Regulations 2015
CQ	– Controlled Quantity (of a HS as defined in P(HS)Regs 2015)
DCO	– Development Consent Order
dDCO	– draft Development Consent Order
HS	– Hazardous Substance (as defined in the Schedule to P(HS)Regs 2015)
HSC	– Hazardous Substances Consent
PA 2008	– The Planning Act 2008
P(HS)A 1990	– The Planning (Hazardous Substances) Act 1990
P(HS)Regs 2015	– The Planning (Hazardous Substances) Regulations 2015
QQ	– Qualifying Quantity (of a "dangerous" substance) in the COMAH Regs 2015; similar to CQ in the P(HS)Reg 2015
S or "S"	– any "substance used in processes" which on its own or in combination with others may generate HS defined in Parts 1 or 2 of the Schedule to the P(HS)Regs 2015
Seveso	– the "Seveso III Directive" 2012/18/EU of 4 July 2012
UN MTC	– United Nations Manual of Tests and Criteria

Direct quotations from legislation are shown in blue

Policy documents:

NPPF	– National Planning Policy Framework
NPS	– National Policy Statement
EN-1	– Overarching National Policy Statement for Energy (EN-1)

Direct quotations from policy documents are shown in magenta

Competent authorities:

CA	– COMAH Competent Authority	
DHCLG	– Department for Housing Communities and Local Government	
EA	– Environment Agency	
ECDC	– East Cambridgeshire District Council	(LPA)
ExA	– Examining Authority	
FRS	– Fire and Rescue Service	
HSA	– Hazardous Substances Authority	
HSE	– Health and Safety Executive	
HSE(NI)	– Health and Safety Executive for Northern Ireland	
LPA	– Local Planning Authority	
SoS	– Secretary of State	
WSC	– West Suffolk Council	(LPA)

GLOSSARY (cont.)

Parties:

Sunnica – the Applicant, or the proposal under Examination
SNTSAG – Say No To Sunnica Action Group Ltd (continued)

Technical:

BESS – Battery Energy Storage System(s)
Li-ion – Lithium-ion
M-factor – Multiplying Factor used for certain substances Toxic to the Aquatic Environment in eco-toxicity classifications
SoC – State Of Charge of cells, usually given as percentage, between fully charged (100%) and completely discharged (0%)
STEL – Short Term Exposure Limit, i.e. limiting allowed concentration for short-term exposures (typically 15 minutes)
VCE – Vapour Cloud Explosion
IUPAC – International Union of Pure and Applied Chemistry
GCMS – Gas Chromatography Mass Spectrometry
CAS – Chemical Abstracts Service, maintains a catalogue of unique chemical substances with reference numbers

Chemical substances:

CH_4 – Methane
C_2H_4 – Ethylene
C_2H_6 – Ethane
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
Co – Cobalt (as metal) (not to be confused with CO)
CoO – Cobalt (II) Oxide
Cu – Copper (as metal)
CuO – Cupric (or Copper (II)) Oxide
Cu_2O – Cuprous (or Copper (I)) Oxide
H_2 – Hydrogen
HCN – Hydrogen Cyanide
HF – Hydrogen Fluoride
Mn – Manganese (as metal)
MnO – Manganese (II) Oxide
Ni – Nickel (as metal)
NiO – Nickel Monoxide
ONiO – Nickel Dioxide
Ni_2O_3 – diNickel triOxide
POF_3 – Phosphoryl Fluoride

GLOSSARY (cont.)

Li-ion cell types:

NMC – Nickel – Manganese – Cobalt; a popular Li-ion cell type, with cathodes based on complex oxides of those elements

LFP – Lithium – Iron [chemical symbol Fe, hence “F”] – Phosphate; another type of Li-ion cathode chemistry

LCO, NCA, LATP – other cell cathode chemistries mentioned in text

Measurement units:

MW – megawatt, or one million watts, a unit of *power*, i.e. *rate* of transfer of *energy*

MWh – megawatt-*hour*, or one million watt-hours, a unit of *energy* e.g. the *energy* transferred by a *power* of 1 MW acting for 1 *hour*

m^2 – square metre (area)

ha – 1 hectare = 10,000 m^2

MWh ha ^{1} – energy storage density (on the land) in the BESS compounds, as MWh energy storage capacity, per hectare of land allocated

MWh / tonne or MWh tonne ^{1} – energy density of the BESS cells themselves, as MWh energy storage capacity, per tonne of cells

Wh / kg or Wh kg ^{1} – energy density of the BESS cells themselves, as Wh energy storage capacity, per kg of cells

1 MWh / tonne = 1000 Wh / kg

mg / Wh or mg (Wh) ^{1} – gas generation from cells in failure, in milligrams gas per watt-hours of energy storage capacity

tonne – 1 metric tonne or 1000 kg or 1 Mg

μg m ^{3} – trace concentrations of highly toxic gases, in micrograms of toxic contaminant per cubic metre of air

Personal

1. I reside in the village of Fordham, close to land affected by Sunnica. I am a Chartered Physicist, Chartered Engineer, European Engineer and a Fellow of the Institute of Physics. I have 45 years experience in the energy industries, largely in the oil industry, but also in nuclear reactor safety (for HM Inspectorate of Nuclear Installations) and wrote my doctoral thesis on wind energy in 1984. I retired in 2018 as Scientific Advisor to a major international company in the oil and gas sector[1].

2. I make this WR both as a local resident and as a technical expert. My family are affected immediately by the impact of Sunnica locally, and face hazards to life, health and property in the event of a major accident involving the BESS components. Having researched BESS technology and safety issues for the SNTSAG since mid-2020[2], I have grave concerns over the operational hazards presented by the BESS components of the scheme, and I do not consider that the safety of Li-ion BESS has been adequately considered by Sunnica.

Scope of this Written Representation

3. My Post-Hearing Submission subsequent to ISH1 on the dDCO contains much detail on the legal issues concerning Hazardous Substances Consent (HSC) and should be read in conjunction with this WR. To avoid repetition only outline summaries of the legal issues are rehearsed here. The PHS also discusses our estimates of the likely energy storage in Sunnica as requested by the ExA.

4. This WR supplies an outline of the principal hazards presented by grid-scale Li-ion BESS, supplemented by Annexed papers in the public domain by myself and others. The probable requirement for HSC in Sunnica is outlined in a technical paper whose main implications are summarised herein.

5. Certain policy implications are also discussed, because a requirement for HSC would usually define an establishment as a COMAH site regulated by the COMAH Competent Authority.

Failure modes in Li-ion BESS

3. A failure mode known as "thermal runaway" is well-known in Li-ion BESS. Failure of a single cell can propagate to neighbouring cells, causing further release of stored energy, further overheating, etc[3]. The cascade causes a "battery fire" though the popular terminology is misleading, because such "fires" require <u>no oxygen to proceed</u>. There may be no flame, as in the 2019 explosion in Arizona[4], until the final "deflagration" (i.e. explosion). Thermal runaway is a self-sustaining chemical reaction essentially uncontrollable once started.

4. It is uncontrollable by electrical means. Affected units can be disconnected, but that does not control the "fire", which propagates by heat.

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[1] Further personal details in Annex EF1 uploaded separately.
[2] Annex EF2 uploaded separately is a general paper on BESS safety co-authored with Professor Wade Allison DPhil and Professor Sir David Melville CBE CPhys FInstP.
[3] Further discussion in Annex EF2.
[4] Discussed in Annex EF2 and Annex EF11

5. Fire suppression systems based on “smothering” (restriction of air supply to the fire using dry powders, inert aerosols or aerosol forming composites or AFCs) will be useless, because their mode of action is to stop air reaching the fire. In a “fire” that requires no air, this is futile.

Such systems arguably make matters worse, allowing combustible gases and aerosols to build up in large volumes *before* combustion happens, leading to “vapour cloud explosions” or VCEs.

6. The only means for stopping thermal runaway is extravagant water cooling; if the “fire” can be cooled below the threshold temperature for thermal runaway, the cascade should stop. However prodigious quantities may be needed.

7. “Battery fires” in grid-scale BESS are not exceptional, nor alarmist speculation. They are matters of record. Some are listed in the paper in Annex EF2 but this is not exhaustive. A large catalogue[5] maintained by the Electric Power Research Institute (EPRI[6]) lists reports of BESS “fires” continuing to accumulate from all parts of the world. A partial review is also made by Atkins (Consulting Engineers) in a safety review[7] for HSE(NI).

8. Three important examples are (i) the heavily-analysed 2019 explosion at McMicken, Arizona[8] (ii) the 2021 fire and explosion in central Beijing, involving 47 fire trucks, 235 crew, with 2 fatalities[9] (iii) the explosion and fire in urban Liverpool in September 2020, which destroyed one cabin and engaged Merseyside FRS for several days in efforts to prevent spread to neighbouring cabins[10].

Major Accident Potential with Sunnica BESS

9. All these examples were significantly *smaller* in energy storage capacity than the likely extent of Sunnica. All stored energy has the potential to do damage if released uncontrollably; the greater the stored energy, the greater the damage potential. Until the ISH1 on 1 November 2022, Sunnica had not stated a maximum stored energy, but estimates based on the land allocated for BESS compounds[11] implied a storage capacity up to 3000 MWh[12] even without explicit disclosure from Sunnica. The “target projection” of 2400 MWh stated at the ISH1 requires only a further 25% “upgrade” to be aligned with our independent estimates.

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[5] BESS Failure Event Database. (2022, August 17). *EPRI, Program 94*. Retrieved 16:46, November 5, 2022 from [redacted]

NB: Access is confirmed to be “Public” on the main page [redacted]

[6] The EPRI is “an independent non-profit energy research, development and deployment organisation” based in Palo Alto, California.

[7] Annexed as Annex EF28.

[8] The Arizona explosion is covered in Annex EF2 (outline) and Annex EF11 (detailed forensic analysis) but full reports on the other incidents post-date that paper. Annex EF12 contains an independent incident analysis on the Arizona explosion.

[9] Five reports included in Annex EF13

[10] Two reports included in Annex EF14

[11] See Appendix 1 of Annex EF2

[12] Extensive discussion in my PHS on ISH1 on the dDCO, submitted separately.

10. This represents a very large amount of stored energy. The Dinorwig Pumped Storage Scheme in Snowdonia, the largest energy storage scheme in the UK, stores about 9000 MWh[13], based on "pumped hydroelectricity" with tunnels through a slate mountainside. At 3000 MWh, the Sunnica BESS would represent around one third of Dinorwig. The energy released in the Port of Beirut explosion of August 2020 has been estimated at about 580 MWh.

11. Because of the existence of a well-known failure mode, the potential for a major industrial accident should be obvious. Moreover, the energy storage capacity does not represent an upper limit on energy release in fires once started. BESS cells contain considerable quantities of organic chemicals which are combustible in conventional fires (i.e. those limited by supply of air) and which may be several multiples of the stored electrochemical energy[14].

12. The open question remains how serious a major BESS accident could be. Loss of even a single rack within one cabin in a relatively small BESS (2 MWh) resulted in a major explosion in the McMicken incident.

The 2019 Arizona explosion was in a single cabin installation but firefighter witnesses from outside the "hot zone" reported during the final deflagration "*a jet of flame that extended at least 75 ft* [22.9 metres *] outward and an estimated 20 ft* [6.1 metres] *vertically from the southeast-facing door*"[15].

It has to be remembered this represented just 1/27 of the system total energy from a single rack within the cabin, hence about 0.075 MWh. This is clearly minute compared to the likely size of Sunnica.

A prior Arizona incident in 2012 also reported "*fires with 10 – 15 ft* [3.0 – 4.6 metres] *flame lengths that grew into flame lengths of 50 – 75 ft* [15.2 – 22.9 metres]*, with the fire appearing to be fed by flammable liquids coming from the cabinets*".[16]

13. Complete destruction of a single cabin fire and/or explosion is certainly possible and has happened in multiple incidents, not least the Liverpool fire and explosion of September 2020[17].

14. Cabin-to-cabin propagation has been noted in the "Big Battery" fire at Moorabool, Geelong, Australia[18], and remote propagation of major failure has occurred in the Beijing incident, where the 2 fatalities occurred in an explosion from a cabin spatially remote from the original "fire" to a location where accident propagation had not been expected[19].

15. I am aware of no serious Process Safety Engineering of the prevention and mitigation of major BESS accidents. Whilst the technology is clearly evolving continuously, very few engineering standards exist designed to prevent, control and

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[13] See the book of the late Prof Sir David MacKay (2009), *Sustainable Energy – Without the Hot Air* UIT Cambridge Ltd p 239

[14] See for example, Figure 2(b) of Larsson *et al.* included as Annex EF15

[15] See Annex EF12, page 25, last paragraph.

[16] See Annex EF21 for official Letter and Fire Department report from Arizona Public Service.

[17] See Liverpool reports in Annex EF14

[18] Report Attached as Annex EF20

[19] See Beijing reports in Annex EF13

mitigate thermal runaway failures, and (to my knowledge) none at all address the question of cabin-to-cabin propagation, which is the route with the potential to escalate fire or explosion in a single cabin into a major disaster.

16. In addition to fire and explosion, BESS "fires" release large quantities of highly toxic gases or smokes, presenting significant danger to life, health, property and the environment. If water used in fire-fighting is contaminated with toxic substances, there is hazard to the aquatic environment in addition to air quality.

Regulatory control of Major Accidents

17. The regulatory regime for controlling major accident hazards involving hazardous substances is represented by the COMAH Regs 2015, and in Planning decisions by the P(HS)Regs 2015. The P(HS)A 1990 requires Hazardous Substances Consent to be obtained before introducing hazardous substances in quantities above those specified in the Schedule to the Regulations. Failure to obtain HSC where required constitutes an offence under S.23 of the Act. Further details on these regulatory regimes, the policy purposes, and the Schedules of HS, are given below, and in my accompanying PHS after ISH1 on the dDCO.

18. What are the "hazardous substances" in BESS ? In normal operation the batteries are innocuous. It is in thermal runaway accidents that hazardous substances arise. Controls on hazardous substances "generated during loss of control of the processes" are fundamental to the regulatory regime derived from *Seveso*. The 1976 disaster in the eponymous Italian town was itself a "loss of control" accident.

19. As implemented in the P(HS)Regs 2015, the "loss of control" provisions are in Part 3 to the Schedule, "Substances used in processes", whereby if it is "reasonable to foresee" that substances "HS" listed in Parts 1 or 2 "may be generated during loss of control of the processes", then any substance "S" used in that process is a Hazardous Substance under Part 3.

20. Thermal runaway accidents in BESS are plainly a "loss of control of the processes". Moreover the technical literature shows that the generation of "HS" listed in Parts 1 or 2 is more than "reasonable to foresee"; it is certain. Therefore, any and all of the many complex chemicals comprised in the BESS cells may be considered "hazardous substances" under Part 3.

21. What are the Controlled Quantities of hazardous substances under Part 3 ? Column 2 of Part 3 defines the CQ as "the amount of "S" which it is believed may generate (on its own or in combination with other substances used in the relevant process) an amount equal to or exceeding the CQ of the HS in question". Therefore, deciding whether the CQ has been exceeded requires a knowledge of the behaviour of the battery cells in failure, thermal runaway or other "fire". This depends on the electrochemical type of the cells chosen, and for regulatory purposes could only be shown satisfactorily by actual fire tests on representative cells.

22. In the absence of such tests, one is limited to estimates of the CQ based on technical literature and the cell types proposed. Sunnica have stated[20]: Battery cells will be either NMC (Nickel Manganese Cobalt) or Lithium Iron Phosphate (LiFePO4) chemistry. It was also stated at the ISH1 that future flexibility was the reason for not fixing either chemistry or capacity at the Planning stage.

23. Yet the HS, and quantities, "generated in loss of control" depend on the cell type. No clear assessment is possible until the choice is made.

24. Moreover until ISH1 Sunnica had not stated what energy storage capacity is proposed. The figure of 2400 MWh is now disclosed as a design target, but I contend that further upgrades are credible based on the land area allocated. Hence the inventory of cells, and thus quantities of chemicals regarded as hazardous under Part 3, remain undetermined.

25. Even the obvious "reference case" for safety assessments, namely an accident confined to a single BESS cabin, cannot be appraised because a maximum stored energy per cabin has not been disclosed.

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[20] Sunnica Environmental Statement Appendix 16D "Unplanned Atmospheric Emissions from BESS", Para. 1.2.2 item a., page 16D-1 Document Reference EN010106/APP/6.2 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010106/EN010106-001872-SEF_ES_6.2_Appendix_16D_Unplanned%20Atmospheric%20Emissions%20from%20BESS.pdf

Requirement for Hazardous Substances Consent for Sunnica BESS

26. Sunnica obtained a Scoping Opinion from the HSE[21] that the presence of hazardous substances "*will probably require HSC*", advising further consultation with the relevant HSAs.

27. My contention, after careful study of both technical and legal aspects, is that HSC is almost certainly required. A detailed technical paper co-authored with Professor Sir David Melville CBE CPhys FInstP is Annexed[22] and will be summarised below.

28. The obligation could only be avoided if the energy storage were ineffectually low, or if verified fire tests showed that exceeding the CQs of HS generated in accidents is impossible. I am aware of no such tests. Various tests are cited in the Applicant's Appendix 16D, but these do not relate to the actual BESS cells proposed which have not yet been defined.

29. A low *energy* storage capacity is inconceivable given the land allocated, and a stated *power* rating "exceeding 50 MW". This was further amplified at the ISH1 to be designed to match the rated power of the solar PV arrays at 500 MW, with a "design target" storage capacity of 2400 MWh disclosed at ISH1. Thresholds estimated in our annexed technical paper are very significantly below this system capacity.

Routes to HSC and Applicant's current position

30. Routes to obtaining HSC are detailed in my PSH after ISH1 on the dDCO.

31. The Applicant confirmed at ISH1 that they are not seeking HSC within the DCO and would revert to the HSAs if HSC proves to be required.

[21] Sunnica Volume 6, Environmental Statement Chapter 16 "Other Environmental Topics", 18 November 2021, Document Reference EN010106/APP/6.1 Table 16-8 Page 16-24 last entry.
[22] See Annex EF16 for a comprehensive analysis, co-authored with Professor Sir David Melville CBE CPhys FInstP

Technical paper with Professor Sir David Melville CBE CPhys FInstP

32. The detailed technical paper in Annex EF16 was written to address exhaustively the likely generation of hazardous substances in BESS accidents and to estimate from the technical literature the BESS energy storage capacity at which the CQs of the various HS might be exceeded. A summary of the governing law is also given, and the operation of the Schedule to the P(HS)Regs 2015 is closely detailed, including explanation of the operation of the Aggregation Rule contained in Note 5 of Part 4 of the Schedule.

The current version has been available in the public domain since 11 July 2022[23].

33. I acknowledge Sir David's contributions as a matter of normal scientific and professional courtesy. However as Sir David is not a party at this Examination, I take full responsibility for the content.

34. The approach taken in this paper is to observe that (i) the tonnage of substances "S" integral to the battery cells, and (ii) the energy storage capacity in MWh, are *both* proportional to the number of cells. Hence the tonnage of substances "S" in the cells is proportional to the energy storage capacity in MWh. The "energy density" (in MWh/tonne or more usually quoted in Wh/kg) may vary according to cell type, but the proportionality would remain.

Evolution of hazardous substances is sometimes given in the technical literature in terms of milligrams of hazardous substance per watt-hour of energy storage (mg/Wh) for this reason.

35. This approach avoids needing to specify directly the tonnages of individual chemical components of the cells (the substances "S"), which are frequently a closely-guarded trade secret. We estimate instead the energy storage capacity in MWh (irrespective of cell type) at which the Controlled Quantities (always reckoned in tonnes in the Schedule) are exceeded.

36. Section 1 of the paper outlines the definitions of HS and the CQs under the "loss of control" provisions in Part 3 of Schedule 1 to the P(HS)Regs 2015. These are also discussed in my PHS following ISH1 on the dDCO. The definition of a HS is given in Column 1 of Part 3 ("Substances used in Processes") to Schedule 1:

> Where it is reasonable to foresee that a substance falling within Part 1 or Part 2 ("HS") may be generated during loss of control of the processes, including storage activities in any installation within an establishment, any substance which is used in that process ("S").

The corresponding Controlled Quantity CQ is:

> The amount of S which it is believed may generate (on its own or in combination with other substances used in the relevant process) an amount equal to or exceeding the controlled quantity of the HS in question.

37. The importance of this is that any "substance S" whatever that is "used in that process" is to be reckoned "hazardous" for the purposes of the P(HS)A 1990,

[23] On the *Research Gate* preprint server, DOI reference: 10.13140/RG.2.2.35893.76005

provided only that it is "reasonable to foresee that a substance falling within Part 1 or Part 2 ("HS") may be generated during loss of control of the processes".

38. Li-ion BESS technology is plainly an electro-*chemical* process, as with any battery technology. Many sophisticated substances "S", integral to the battery cells, are "used in that process" as the cell converts the substances "S" from one chemical state to another, during the "process" of charging or discharging the cell. Thermal runaway accidents in Li-ion BESS are plainly a "loss of control of the processes".

39. The Part 3 definition of a hazardous substance does not require any consideration of how likely or probable it is that control of the process in question is in fact lost. We are instead required to ask what is reasonable to foresee being generated *during* that loss of control. In other words, the loss of control is a given; we must ask what *then* is "reasonable to foresee".

40. Nor does this definition have any regard to safety features, bunding against spillages, secondary containments, or the likelihood of actual *release* of the hazardous substances "generated during loss of control". It is sufficient that the HS listed in Part 1 or Part 2 be *generated*.

41. This is because the P(HS)A 1990 controls HS by mere *presence*, by S. 4(1) P(HS)A 1990. S.4(2)(a, aa) make clear that it is the "aggregate quantity of the substance" that is present in the entire establishment which must be less than the CQs, for HSC *not* to be an obligation.

42. Hence to determine whether an establishment has exceeded the Controlled Quantity requires the total inventory of hazardous substances in the establishment to be considered, i.e. the total inventory of BESS cells across the Sunnica project.

43. The definition of the CQ in Part 3 requires consideration of the amounts of substance(s) "S" which it is believed may generate (on its own or in combination with other substances …) an amount equal to or exceeding the controlled quantity of the HS in question.

44. Application of the definition of CQ should ideally be made by reference to actual tests in failure situations on representative samples of the actual cells proposed to be used in the system. None have been provided by Sunnica not least because the final choice has not been declared.

45. In any application for HSC to the HSA(s), under P(HS)Regs 2015 the Applicant would be required to state, *inter alia*:

R.5(1)(d)(iii) *each hazardous substance for which consent is sought ("relevant substance"), including the maximum quantity of each relevant substance proposed to be present;*

R.5(1)(d)(v) *how and where each relevant substance is to be kept and used;*

R.5(1)(d)(viii) *the measures taken or proposed to be taken to limit the consequences of a major accident;*

Under Part 3, the "Substances S" integral to the BESS cells would need to be specified and their maximum tonnages given. However whether they exceeded the CQs defined in Part 3, and if so the amount by which they exceeded the CQs, could not be determined by the HSA unless sufficient information was also provided to define the CQ from the definition given in Column 2 of Part 3.

The objective engineering determination of such information would be by actual “fire tests” of cell failure, on representative samples of the actual BESS cells proposed for installation. Otherwise both Applicant and HSA would be reliant on technical information from elsewhere, not necessarily directly applicable to the actual cells proposed.

I contend that providing such representative test data is a duty of the Applicant implied by R.5(1)(d)(iii).

46. Absent such tests, our paper was written to estimate from the technical literature scoping figures for the amounts of HS listed in Parts 1 and 2 of the Schedule that may be generated “during loss of control of the processes” i.e. during “thermal runaway” accidents in the BESS, taking account different behaviours in failure reported for cells of the “LFP” type and cells of the “mixed oxide” types, of which the “NMC” type is one.

47. Several other Li-ion cathode chemistries are available and reported in the technical literature, including e.g. LCO = Lithium Cobalt Oxide, mixed LCO-NMC cathodes, NCA = Nickel Cobalt Alumina, LATP = Lithium Aluminium Titanium Phosphate, mixed NCA-LATP and so on. Most are oxide materials unless specifically designated “phosphate” but clearly a wide range of chemistries are under continuous development and details are usually a well-guarded trade secret among manufacturers for powerful commercial reasons. Exact behaviours in failure will of course vary between these cell types.

Both NMC and LFP chemistries are widely available so it is understandable that Sunnica have stated “one or the other”.

Behaviour in thermal runaway or fire does appear qualitatively different between these two cell types[24]. Hence our paper distinguishes between LFP cells and the “mixed oxide” chemistries, with special attention to Nickel-containing chemistries of which NMC is one.

[24] An example comparative study is annexed as Annex EF27

Routes to generation of HS listed in Parts 1 or 2 of the Regulations

48. Section 3.0 of our technical paper Annex EF16 considers various routes to generation of HS listed in Parts 1 or 2 of the Regulations and states the leading hazardous substances to be expected in "loss of control". We consider separately:

(i) generation of P2 Flammable Gases, as in Schedule 1, Part 1, Column 1, Section "P" – Physical Hazards, of P(HS)Regs 2015

(ii) possible classification of BESS cells as P1a or P1b Explosive Articles (part of the Physical Hazards class)

(iii) generation of H1 or H2 Acute Toxic gases, as in Schedule 1, Part 1, Column 1, Section "H" – Health Hazards, of P(HS)Regs 2015

(iv) generation of "Nickel compounds in inhalable powder form", a "Named Hazardous Substance" in Part 2 of the Schedule, Column 1, entry no. 11.

Physical Hazards

49. From the technical literature, the leading P2 Flammable Gases of concern were identified as

(i) Hydrogen H_2 (also a Named Hazardous Substance under Part 2)

(ii) Carbon Monoxide CO (also classified as a H2 Health Hazard)

(iii) Methane CH_4

(iv) Ethylene or ethene C_2H_4

(v) Ethane C_2H_6

Sufficient technical information on these Flammable Gases is available to form scoping estimates of the quantities that it is reasonable to foresee being generated[25].

50. One limitation of the assessment of Flammable Gases is that actual experimentation reported by experts such as Professor Paul Christensen of Newcastle University routinely observes evolution of a "white smoke" believed to constitute an aerosol of the organic solvents used in the cell electrolytes. Example images are included[26] in Annex EF16.

These aerosols may need to be included under the P3a or P3b (Flammable Aerosols) or under P5b (Flammable Liquids) for a complete determination of HSC obligations, because they plainly form part of the "Physical Hazards" class in Part 1. In Part 4, Note 6 makes clear that "substances …not covered by the CLP Regulation …likely to possess … equivalent properties … must be provisionally assigned to the most analogous category or named hazardous substance falling within the scope of these Regulations".

Such Flammable Aerosols should also be included in application of the Aggregation Rule given in Part 4, Note 5.

[25] The leading source for this assessment is Golubkov *et al.* included in Annex EF17

[26] See Figures 5 (a) to (d) in Annex EF16 from Professor Christensen's tests and Figure 6 (p 43) showing CCTV images of the Liverpool incident

51. Consideration of the possible classification of BESS cells as P1a or P2b Explosive Articles is also made. Such classification would cover the BESS cells directly in Section P of Part 1 (as functioning cells) and not under Part 3 (cells in failure). Under Part 4, Note 9, Explosive Articles are explicitly included in the hazard class "Explosives".

Li-ion cells in a high State of Charge (SoC) can certainly fail explosively, whether initiated by heat, overcharging or mechanical penetration, as illustrated by images from publicly available videos abstracted[27] in Annex EF16. Behaviour does depend on the cells' State of Charge, but it is likely that in normal operation cells would pass through a high SoC several times per day.

Visually the behaviour meets the qualitative description of a "Division 1.3 Explosive" in Annex I Reg. 2.1.1.1(c) of the CLP Regulation[28], viz.

Division 1.3: Substances, mixtures and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard:
(i) combustion of which gives rise to considerable radiant heat; or
(ii) which burn one after another, producing minor blast or projection effects or both;

Such formal classification would require tests under conditions prescribed in the UN Manual of Tests and Criteria[29] but to my knowledge no such tests have been carried out.

A policy to carry out such tests to determine a possible Explosive Articles classification could greatly simplify the regulatory control of Li-ion BESS.

Health Hazards

52. From the technical literature, the leading H1 and H2 Acute Toxic gases of concern were identified as

(i) Hydrogen Cyanide HCN

(ii) Hydrogen Fluoride HF

(iii) Phosphoryl Fluoride POF_3

(iv) Carbon Monoxide CO

Sufficient technical information on these Flammable Gases is available to form scoping estimates of the quantities that it is reasonable to foresee being generated.

53. Hydrogen Cyanide (HCN) is not likely to be generated from the functional chemicals of BESS cells (which do not contain significant quantities of Nitrogen compounds) but from ancillary plastics and polymers used in packaging, electrical

[27] See Figure 3(a) to (f) in Annex EF16
[28] Relevant section of CLP Regulation is here: https://www.legislation.gov.uk/eur/2008/1272/annex/I/division/2/division/2.1/division/2.1.2/division/2.1.2.2
[29] United Nations (2019). Manual of Tests and Criteria, 7th revised edition, ST/SG/AC.10/11/Rev.7 UN Publication Sales No. E.20.VIII.1 ISBN 978-92-1-130394-0. Available from United Nations Economic Commission for Europe: https://unece.org/fileadmin/DAM/trans/danger/publi/manual/Rev7/Manual_Rev7_E.pdf

insulation and so on. Nevertheless it is a common hazard in firefighting and was an operational concern at the McMicken, Arizona explosion in a 2 MWh BESS; rough estimates of concentrations are available from the incident reports[30].

54. Hydrogen Fluoride (HF) is the leading Acute Toxic Gas foreseeably generated in BESS accidents. On contact with water it forms one of the most notoriously corrosive acids known. As a gas it has a dual classification as H2 Acute Toxic by the oral and inhalation routes, but H1 Acute Toxic by the dermal (skin attack) route. By Part 4 Note 7, for substances with more than one classification, the lowest Controlled Quantities apply, so the governing CQ for HF is as an H1 Acute Toxic.

Significant quantities are reported as being generated in fire tests, particularly from cells of the “LFP” class[31].

55. Phosphoryl Fluoride POF_3 is a very unstable fluoride gas likely to hydrolyse to form further quantities of HF. It is not listed in the European Chemical Agency database nor in the Mandatory Classification and Labelling List now maintained by the HSE after EU exit[32]. It is however reported in some literature and by Part 4 Note 6 should probably be assigned the same classification as HF on grounds of similar toxicity. The literature reports evolution from some types of Li-ion cell.

56. Carbon Monoxide CO is also classified as a P2 Flammable Gas but is also a H2 Acute Toxic Health Hazard. In application of the Aggregation Rule (Part 4 Note 5) it has to be considered both in Physical Hazards class and in the Health Hazards class.

The principal uncertainty in evaluating CO generation is that amounts and concentrations will depend upon the availability of air to a fire. CO may form either from the organic solvents in the BESS cell electrolytes or from the graphite that is routinely used for the Li-cell anodes (the principal variation in cell chemistry lies in the cathodes).

Complete combustion will generate Carbon Dioxide CO_2 which is non-toxic. Incomplete combustion typically generates the monoxide CO which is toxic. Sources with CO_2/CO ratios in Li-ion cell fires are cited in the paper Annex EF16[33] but this has to be reckoned a limitation of the Acute Toxics assessment.

Chemical analogues of outlawed Chemical Weapons

57. One report from a Swedish government agency[34] compares evolution of gases and particulates from LFP and NMC batteries and detects many organic compounds by the GCMS (Gas Chromatography Mass Spectrometry) method.

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[30] See report by Underwriters Laboratories in Annex EF12

[31] The largest generation of HF in Larsson *et al.* Annex EF15 was from pouch cells of the LFP type

[32] “All existing EU harmonised classification and labelling in force on 31 December 2020 are retained in GB as the GB Mandatory Classification and Labelling List” https://www.hse.gov.uk/chemical-classification/legal/clp-regulation.htm

[33] The FM Global technical report Annexed as EF18 provides measurements of CO_2/CO ratios

[34] U. Bergstrom et al, “Vented gases and aerosol of automotive Li-ion LFP and NMC batteries in humidified nitrogen under thermal load”. Report of MSB Civil Contingencies Agency, the Swedish “competent authority for transport of dangerous goods by road and rail”. Annexed as Annex EF19

Disturbingly, these included ethyl- and methyl-phosphonofluoridates, which are chemically similar to the “Sarin-GB” organophosphorus compound having the IUPAC systematic name Propan-2-yl methylphosphonofluoridate.

These compounds all have the O=PF-O active group with potentially severe neurotoxicity, acting as acetylcholine blockers paralysing neuromuscular junctions. For this reason Sarin-GB is popularly called “Nerve Gas” and its production is outlawed under the Chemical Weapons Convention of 1993 under Schedule 1.

At least one of the detected phosphonofluoridates (ethyl methyl phosphonofluoridate, CAS number 673-97-2) is reported at a concentration of 0.5 micrograms per cubic metre (0.5 $\mu g\ m^{3}$) which is well in excess of the Short Term Exposure Limit (STEL) for Sarin which is 0.1 $\mu g\ m^{3}$.

It is not known whether further information on the neurotoxicity of these compounds is available nor whether evolution of these compounds in fire tests of NMC cells has been followed up.

Lacking sufficient technical data they do not feature in our paper but are plainly a ground of legitimate public concern, both for people and for livestock and bloodstock.

Nickel compounds in inhalable powder form

58. The generation of “Nickel compounds in inhalable powder form”, a “Named Hazardous Substance” in Part 2 of the Schedule, Column 1, is also evaluated. This is of particular importance because the Controlled Quantity CQ of this Named Hazardous Substances is particularly low, only 1 tonne.

The corresponding entry in Column 2 of Schedule 1 to the COMAH Regs 2015 is blank; the Qualifying Quantity (QQ) of 1 tonne appears in Column 3 which would make such establishments “upper tier” COMAH establishments subject to more stringent controls than “lower tier”.

59. Moreover the inventory of Nickel Oxides in BESS cells of the NMC type is of the order of 0.7 tonne per MWh[35], so a 5 MWh BESS cabin would contain potentially 3.5 tonnes of Nickel Oxide, and more in proportion to the energy storage capacity if the BESS contains more cells. A single 10 MWh BESS cabin would contain around 7 tonnes of nickel oxide equivalent, well in excess of the Controlled Quantity of 1 tonne. If released in “inhalable powder form”, a single cabin would breach the CQ for HSC and at the same time the QQ for “upper tier” COMAH.

60. Li-ion cathodes of the NMC type contain complex nickel (Ni) cobalt (Co) and manganese (Mn) oxides in nanoporous form on (typically) an aluminium foil support[36]. In cell failure, Professor Christensen’s experiments routinely show a “black smoke” emitted immediately after cell failure which is believed to comprise nanoparticles of the heavy metal oxides NiO, MnO and CoO[37].

[35] See Table 7 of Annex EF16 for an actual BESS chemical composition. Source document (report prepared for a BESS Application in Northern Ireland) also Annexed as Annex EF22.
[36] See, e.g. Ouyang *et al* annexed as Annex EF23 for discussion of NMC electrode chemistry
[37] See Figures 5(a) and 5(b) of Annex EF16, page 42. The composition as oxides of Ni, Mn and Co is confirmed by Held *et al.* annexed as Annex EF26.

Other literature[38] confirms the generation of NiO powders of inhalable particle sizes, from tests carried out in model parking garages[39]. The same sources[40] confirm that collected particulates can comprise up to 35% of the original cell mass.

Further details are in our paper in Annex EF16 but it is clear that evolution of significant quantities of nickel oxides meeting the description in Part 2, Item 11 are likely to be generated in BESS failure, and that an accident confined to a single BESS cabin could credibly generate in excess of the Controlled Quantities of this Named Hazardous Substance.

Hazards to the Aquatic Environment

61. The final Hazard Class evaluated was that of Part 1, Section E, Environmental Hazards. These hazard classes concern hazards to the aquatic environment in categories Acute 1, Chronic 1 or Chronic 2. The Controlled Quantities of such substances are 100 to 200 tonnes, but the principal route to generation of such hazards "during loss of control of the processes" would be contamination of water used in fire-fighting. Many potentially toxic contaminants could easily enter waste-water during fire-fighting operations, and such contaminated water can easily be reckoned toxic to the aquatic environment in various classes.

The provision of water tanks for firefighting purposes includes tanks of capacity 242.5 m^3 per BESS compound[41] which is clearly capable of generating "during loss of control of the processes" in excess of 200 tonnes of waste "fire water", the density of water being 1 tonne per m^3.

62. Hence Controlled Quantities of the E1 or E2 hazard classes are readily conceivable from fire sprinkler operation if water is contaminated with eco-toxic substances in the designated classes.

63. Evaluation of eco-toxicity and appropriate classification is a complex subject and moreover we have not located sufficient technical information regarding quantities of known eco-toxic substances being generated in BESS fires from sprinkler water.

Further evaluation is warranted to establish the eco-toxicology of likely contaminants generated in BESS "fires" subject to sprinkler action.

64. A list of potentially eco-toxic contaminants was nevertheless given in our paper (Table 2) Annex EF14 including eco-toxicity classifications reported and also "M-factors"[42] where listed. Substances of concern include:

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[38] See, e.g. Chen *et al.* citation in Annex EF25. The article is copyright, but public domain.
[39] See Essl *et al*, annexed as Annex EF24, which also confirms distant transport of particles.
[40] The mass loss figure is documented in Essl *et al*, annexed as Annex EF24
[41] E.g. para. 3.4.46 of document EN010106/APP/6.1 Environmental Statement, Ch 3: Scheme Description at https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010106/EN010106-001797-SEF_ES_6.1_Chapter_3_Scheme%20Description.pdf
[42] "M-factors" are Multiplying Factors used in determinations of eco-toxicity. They are listed where determined in the European Chemicals Agency database, and elsewhere, and appear in formulae mandated by the CLP Regulation.

(i) Cobalt oxides CoO and Co_3O_4 and Cobalt Lithium Nickel Oxide (an actual Li-ion cathode material) and

(ii) Copper compounds, the oxides Cu_2O and CuO, the hydroxide $Cu(OH)_2$ and the fluoride CuF_2

Cobalt compounds are obviously a hazard only where cobalt-containing cell chemistries are used. This would include NMC types however.

Copper compounds are however a potential hazard from all cell chemistries, because anodes comprising nanoporous graphite on a copper foil support are ubiquitous in most Li-ion cell types. Copper foil will burn at sufficiently high temperatures to form oxides.

65. Both the cuprous Cu_2O and cupric CuO oxides are classified as Acute and Chronic Toxic to the Aquatic Environment in Category 1. Moreover both of these oxides have a large M-factor (100) for acute toxicity in the aquatic environment.

Solutions or dispersions are classified as “E1 Hazardous to the Aquatic Environment in Category Acute 1” if the sum of concentrations of Acute Toxic components, multiplied their “M-factors” exceeds 25%. Thus, for Acute Toxic substances with a M-factor of 100 (e.g. the copper oxides), the solution or dispersion becomes an E1 Environmental Hazard at a concentration of only 0.25% by weight.

Fire-water contaminated with copper oxides at a concentration of only 0.25% by weight would therefore represent a “E1 Environmental Hazard” with a Controlled Quantity of 100 tonnes, readily exceeded by the 242.5 m^3 (or 242.5 tonnes) per BESS compound in Sunnica.

A concentration of 0.25% by weight requires just 250 kg of copper oxides dispersed in 100 tonnes of water to form a Controlled Quantity of an E1 Environmental Hazard.

66. It bears repetition that the provision of bunding or other containment measures is irrelevant to requirements to seek HSC. By S.4(1) P(HS)A 1990, it is the mere *presence* (or reasonably foreseeable generation in loss of control) that creates the obligation for HSC.

67. A typical BESS chemical composition[43] is given in Table 7 of Annex EF16. About 650 kg of copper foil per MWh of energy storage is listed; this could burn to create about 730 kg of copper (II) oxide. This (arising from the copper inventory of just 1 MWh of energy storage) is well in excess of the quantity needed (250 kg) to generate a Controlled Quantity of a E1 Environmental Hazard.

[43] The primary source document is annexed as Annex EF22

Application of the Aggregation Rule of Part 4 Note 5

68. A frequently misunderstood and overlooked aspect of the Schedule to the P(HS)Regs 2015 is the so-called Aggregation Rule[44] of Part 4, Note 5.

It is not necessary for any individual hazardous substance HS to exceed its scheduled CQ on its own. Where "two or more below-threshold substances in the same hazard group are present, the rule in paragraph (3) applies to those substances". This is the Aggregation Rule, which is required to be applied in turn to the Hazard Groups "Health Hazards" (i.e. toxics), "Physical Hazards" (typically flammables and explosives) and "Environmental Hazards".

Therefore, it is not necessary for any individual substance in Part 1 or Part 2 to exceed its CQ on its own. If, for example, one has Substance A at 10% of its CQ, Substance B at 30% of its CQ, and Substance C at 60% of its CQ, where all Substances A, B and C are in the same Hazard Group, then the summation given in Note 5(4) equals unity, and the Controlled Quantity of each substance used in the formula is deemed to have been exceeded (Part 4 Note 5(3) P(HS)Regs 2015).

69. The Aggregation Rule has been applied in Annex EF16 to each of the Hazard Groups "Health Hazards" and "Physical Hazards". Application to the "Environmental Hazards" group was not necessary because of the likely excess of the CQ for E1 hazards alone, and the lack of data to make more rigorous appraisals.

[44] The parallel provision in the Schedule to the COMAH Regs 2015 is thus-named in the Guidance Notes published by the HSE, L111, Guidance Note 384 page 92 of 132 and elsewhere https://www.hse.gov.uk/pubns/priced/l111.pdf

Thresholds in MWh likely to trigger HSC obligations for Li-ion BESS

70. The conclusions of our technical paper Annex EF16 are summarised on page 49 with a summary Table 13 on page 50. The most stringent limiting reasons likely to trigger an obligation for HSC are abstracted below, with further detail in the technical paper:

Storage capacity estimated at threshold	cell cathode type and conditions	governing reason for HSC
1 MWh	*any, fire with water extinguishant > 100 m^3*	*CuO-contaminated fire water exceeds CQ of E1 Environmental Hazard*
2.75 MWh	Nickel oxide cathodes (including NMC), in fire, generating smoke or dust	NiO in “inhalable powder form” exceeds CQ of Named HS
15.5 MWh	Any, at high SoC	Active materials exceed CQ for P1a Explosive Articles
16.7 – 22.1 MWh	LFP, depending on CO	Aggregation Rule > 1 for Health Hazards (H1 or H2 Acute Toxic Gases)
25 MWh	LFP, HF alone	HF exceeds CQ as H1 Acute Toxic
28.3 MWh	LCO-NMC, anoxic conditions	Aggregation Rule > 1 for Physical Hazards (P2 Flammable Gases)
34.5 MWh	LCO-NMC, high CO	Aggregation Rule > 1 for Health Hazards (H1 or H2 Acute Toxic Gases)
45.7 MWh	LCO-NMC, anoxic conditions	CO exceeds CQ as P2 Flammable Gas

71. Limitations include:

(i) data on likely contaminants of fire-water and their eco-toxicology are insufficient to form a rigorous assessment so the E1 Environmental entry is italicised. Nevertheless the very low threshold for the example of Copper Oxide contaminated fire water (leading to the Table entry) suggests that this issue requires further examination.

(ii) BESS cells have not (to my knowledge) been tested according to the UN Manual of Tests and Criteria (UN MTC) so classification as Explosive Articles cannot currently be claimed. However the qualitative behaviour seen in many publicly available videos suggests a behaviour consistent with the qualitative description of a Division 1.3 Explosive, at least for cells in a high SoC. This suggests that were such tests to be carried out, a classification as a Division 1.3 Explosive Article could result.

In this event, the inventory of Explosive Articles at Sunnica (using the “design target” of 2400 MWh disclosed) would be about 155 times the Controlled Quantity.

(iii) Quantities of CO generated during battery “fires” are dependent on air supply which will determine completeness of combustion of graphite or organic components. Hence the range given for the LFP cell type based on the Aggregation Rule. HF gas is the dominant hazard but rigorous application of the Rule requires estimation of CO in addition.

(iv) Application of the Aggregation Rule for Physical Hazards requires technical data on quantities of the aerosolised organic solvents believed to comprise the “white smoke” seen in Professor Christnesen’s experiments, and also observed directly from CCTV footage abstracted in the accident report on the Liverpool BESS fire and explosion.

We have not found such data so omitted the “white smoke” from our application of the Aggregation Rule for Physical Hazards. However a rigorous application of the Rule requires potential P3a or P3b flammable aerosols or P5b flammable liquids to be included.

(v) the results for “mixed oxide” cell types are drawn from data for mixed LCO-NMC electrodes. Data directly applicable to NMC cells is available and the calculations could be repeated for such data. However the relevance of such an exercise is moot, because

(a) the very low threshold implied the generation of inhalable nickel oxides is the governing hazard implying HSC obligations for NMC cells;

(b) the inclusion of aerosolised organic solvents in the Aggregation Rule as in item (iv) would still remain to be done;

(c) the results would still not be from representative samples of the actual cells proposed.

Amounts by which the Sunnica BESS breach the CQs for HSC

72. The major observation from this Table is that all implied thresholds are well below 50 MWh storage capacity. The "design target" energy storage of the Sunnica BESS is now stated to be 2400 MWh, many times larger.

This is the principal justification for my contention that HSC is "almost certainly required" for the Sunnica BESS, irrespective of cell type.

These estimates would have to be over-stated by at least a factor of 48 for any doubt to be credible.

NMC cells

73. Disregarding the open question of E1 Environmental Hazards from fire-water, potentially applicable to any cell type, the most stringent threshold for NMC cells is undoubtedly the generation of "black smoke" believed to constitute "nickel oxides in inhalable powder form" with a very low CQ of only 1 tonne. This threshold is implied even for a single BESS cabin, and would imply that even a single cabin constitutes an "upper tier" COMAH site where NMC (or other nickel-based electrode chemistries) are used.

The "design target" capacity of 2400 MWh for Sunnica is 873 times the threshold implied for HSC, using NMC cell types.

The estimate would have to be in error by a factor of at least 800-fold for "inhalable nickel oxides" not to be the governing issue requiring HSC.

LFP cells

74. Disregarding E1 hazards similarly, the most stringent threshold for LFP cell types is that determined by generation of HF gas, combined with other toxic gases of which CO generation is the most uncertain being determined by air supply. Taking the conservative end of the range given, the CQ in the Aggregation Rule for Health Hazards is exceeded at a capacity of 22.1 MWh.

The "design target" capacity of 2400 MWh for Sunnica is 108 times the threshold implied for HSC, for the LFP cell types.

The estimate would have to be in error by over 100-fold for Health Hazards from toxic gases not to be the governing issue requiring HSC.

Conclusion on requirements for HSC

75. All these estimates are in the nature of "scoping estimates" based on the technical literature in the absence of actual test data provided by the Applicant.

They are quite likely to be non-representative of the actual cells proposed, but until those are specified more closely than "NMC or LFP" then obtaining more representative data is not possible.

They are also likely not to be representative of actual evolution of BESS cell failures and subsequent behaviour which will be highly dependent on design details, location of failures, detailed cell chemistries, fire suppression systems deployed and so on. Such evaluation would require much more in the way of detailed process safety tests than so far disclosed by the Applicant or indeed available publicly, even in this rapidly growing competitive industry.

As remarked in Para. 45 above, I contend that R.5(1)(d)(iii) of the P(HS)Regs 2015 implies that it is the responsibility of the Applicant to perform such tests.

76. Nevertheless, these estimates have been made on the available technical literature with a systematic exploration of the probable governing hazards leading to HSC requirements, with application of neglected aspects of the Regulations such as the Aggregation Rule.

It is most unlikely that these estimates would be in error by as much as 873-fold (NMC cells) or as much as 108-fold (LFP cells).

Hence I conclude, as stated orally at ISH1, that HSC is “almost certainly” required for the BESS systems proposed for Sunnica.

Requirement for Major Accident Prevention in policies

77. It is a duty upon the SoS to ensure that any designated national policy under S. 5(1) PA 2008 must consider the prevention of major accidents and limiting their consequences, and specifically the matters in Article 13(2) of *Seveso* (viz. appropriate safety distances between BESS compounds and other land use, and areas of natural sensitivity). This duty is affirmed by R. 24 of the P(HS)Regs 2015. Sunnica cannot be compliant with any designated policy unless major accident prevention and mitigation is considered.

78. Existing National Policy Statements (though pre-dating the P(HS)Regs 2015) contain explicit guidance on (i) Safety[45] and (ii) Hazardous Substances control[46] which are largely consistent with these obligations.

79. The regulatory regime inherited from *Seveso* comprises two aspects: on-site controls emphasising the *prevention* of major accidents, implemented in the COMAH Regs 2015, and land-use Planning controls of the off-site risks, implemented in the P(HS)Regs 2015[47]. These govern the consenting regime for Hazardous Substances Consent (HSC) introduced in the P(HS)A 1990; this Act predates the *Seveso* obligations and in some respects goes beyond them.

80. Though requirements for HSC are a Planning control, enforced by Planning authorities, and requirements in the COMAH Regs 2015 are an operational control, enforced by the COMAH Competent Authority[48], the two aspects are strongly coupled because the Schedule of substances designated “hazardous substances” HS in the P(HS)Regs 2015 is now aligned with that for “dangerous substances” in “lower-tier” COMAH[49] in the COMAH Regs 2015[50], and both derive directly from Annex I of *Seveso*.

81. Thus, a requirement for HSC under the P(HS)Regs 2015 will usually imply obligations under the COMAH Regs 2015.

[45] Section 4.11 of NPS EN-1, Annex EF8 uploaded separately

[46] Section 4.12 of NPS EN-1, Annex EF8

[47] This policy is outlined in the DHCLG document “Hazardous Substances – Common Framework” included as Annex EF3 uploaded separately.

[48] The COMAH Competent Authority comprises (in England) the Health and Safety Executive (HSE) and the Environment agency (EA), acting jointly.

[49] With 3 exceptions, Liquified Petroleum Gas, Hydrogen, and Natural Gas, for which more stringent CQs pre-date *Seveso* and were retained in the P(HS)Regs 2015; see Para 7.5 of the EM, Annex EF6.

[50] The language of the COMAH Regs 2015 refers to “dangerous” substances; that of P(HS)Regs 2015 and the P(HS)A 1990 to “hazardous” substances. Comparing the Schedules makes evident that the identical library of substances is referred to.

Safety requirements in National Policy Statements

82. NPS EN-1[51] contains explicit policy on Safety in Sect. 4.11:

4.11.3 Some energy infrastructure will be subject to the Control of Major Accident Hazards (COMAH) Regulations 1999. These Regulations aim to prevent major accidents involving dangerous substances and limit the consequences to people and the environment of any that do occur. COMAH regulations apply throughout the life cycle of the facility, i.e. from the design and build stage through to decommissioning. They are enforced by the Competent Authority comprising HSE and the EA acting jointly in England and Wales (and by the HSE and Scottish Environment Protection Agency acting jointly in Scotland). The same principles apply here as for those set out in the previous section on pollution control and other environmental permitting regimes.

4.11.4 Applicants seeking to develop infrastructure subject to the COMAH regulations should make early contact with the Competent Authority. If a safety report is required it is important to discuss with the Competent Authority the type of information that should be provided at the design and development stage, and what form this should take. This will enable the Competent Authority to review as much information as possible before construction begins, in order to assess whether the inherent features of the design are sufficient to prevent, control and mitigate major accidents. The IPC should be satisfied that an assessment has been done where required and that the Competent Authority has assessed that it meets the safety objectives described above.

These policies essentially assert the regulatory regime for the "control of major accident hazards involving dangerous substances" inherited from *Seveso*. The COMAH Regulations 1999 have been superseded by the 2015 Regulations, and the responsibility of the IPC has been superseded by the Secretary of State (advised by the ExA). Taken together however, Sect. 4.12 and Sect. 4.11 remain broadly consistent with the obligations on the SoS affirmed in R.24 P(HS)Regs 2015 for all valid policies to consider *"the objectives of preventing major accidents and limiting the consequences of such accidents for human health and the environment".*

83. As explained in the "Common Framework" document[52], the policy basis was that on-site controls covered by the COMAH Regs 2015 dealt with minimising risk of a major accident (prevention), but that off-site risks *due to the proximity of hazardous substances to other development or sensitive environments … was considered to be a spatial planning matter to be addressed through planning controls.*

R.25 P(HS)Regs 2015 is specific regarding the Planning issues to be considered, in particular proximity to other development or areas of natural sensitivity.[53]

84. Because the Schedule of dangerous/hazardous substances in both the P(HS)Regs 2015 and the COMAH Regs 2015 are now aligned (see Para. 80 above) then if HSC is a legal requirement it is likely that operational controls under the COMAH Regs 2015 are required also. Hence, *prima facie,* Sect. 4.11 should apply.

This WR has presented evidence that HSC is almost certainly a requirement.

86. Hence the Policy principles in Sect. 4.11.4 of NPS EN-1 in particular should apply (see Para. 82 above).

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[51] "Overarching NPS for Energy (EN-1)" July 2011. Linked on Inspectorate website, "Legislation and advice tab", leading to https://www.gov.uk/government/publications/national-policy-statements-for-energy-infrastructure, downloaded 26 October 2022 and included as Annex EF8 uploaded separately
[52] Annex EF3
[53] See paras. 12 and 13 of my PHS subsequent to ISH1 on the dDCO

Failure to comply with Policy requirements under Sect. 4.11.4 of NPS EN-1

87. Although the Applicant has obtained a Scoping Opinion from HSE indicating that HSC is probably required (see below), this does not appear to have been followed up. The COMAH Competent Authority comprises the EA in addition to the HSE as they are required to act jointly[54]. It is not clear that the EA has been involved in the safety issues, so the COMAH Competent Authority as such does not appear to have been consulted.

88. The policy requirement on the Secretary of State (advised by the ExA) is that the SoS "should be satisfied that an assessment has been done where required and that the Competent Authority has assessed that it meets the safety objectives described above".

89. No safety report has been obtained from the Competent Authority, the "information to be provided at the design … stage" has not been determined, and no assessment (by the CA) of whether the "inherent features … are sufficient to prevent, control and mitigate major accidents" has been provided.

90. Hence it is hard to see how the ExA can be satisfied that the Policy requirement of Sect. 4.11.4 "that the Competent Authority has assessed that it meets the safety objectives described above" has been complied with.

91. I conclude that the Application is fundamentally defective because the Policy requirement in Sect. 4.11.4 of NPS EN-1 has not been complied with.

(a) A proper appraisal by the Applicant of the potential need for HSC would have involved early consultations with the relevant HSAs (as advised by HSE in their Scoping Opinion) who should have advised of the "loss of control" provisions of Part 3 of the P(HS)Regs 2015.

(b) an appraisal on the lines set out in our Annex EF16 would have indicated the likely need for HSC. This would have alerted the Applicant of an early need to consult with the COMAH Competent Authority.

(c) Whilst outline consultation with HSE has taken place, I am not aware of any consultation with the COMAH Competent Authority (i.e. the HSE and the Environment Agency acting jointly).

(d) A consultation with the COMAH Competent Authority with the loss of control provisions in P(HS)Regs 2015 exposed, and the "reasonably foreseeable" generation of Part 1 or Part 2 hazardous substances, would have informed the likely need for the "safety report" specified in Sect. 4.11.4 of NPS EN-1

(e) I am not aware of any consultations with the COMAH Competent Authority and no such safety report has been offered by the Applicant.

(f) without a full specification it would anyway be impossible for the CA to make a thorough report or give a responsible opinion.

[54] See, e.g., R.2(1)(b) of the P(HS)Regs 2015

Current practice in Northern Ireland

92. Thus far HSE (for Great Britain) does not appear to have been involved extensively with the Sunnica project, and the COMAH CA not at all.

Nevertheless examples of the approach taken in Northern Ireland provide illustrations of the application of essentially identical law in another UK jurisdiction.

The HSE for Northern Ireland is a different statutory body from the HSE in Great Britain. Nevertheless it is the enforcing authority for the COMAH Regs 2015 in Northern Ireland and likewise a statutory consultee for Planning applications for HSC in Northern Ireland.

Though the Regulations for COMAH and for HSC are made under different Statutory Instruments[55], the substantive content of the Northern Irish Regulations is identical[56] to those applicable in England, both deriving similarly from *Seveso* and required to be uniform in effect across the EU at the time they were made. Though the "Common Framework" document[57] acknowledges the possibility of regional divergence, no material changes have been made since EU exit.

93. Examples are annexed in the form of Notification Letters from HSE(NI) to local Planning Authorities. Specifically, HSE(NI) states:

> "Large scale battery facilities, also known as BESS (Battery Energy Storage Systems) have the potential to require a Hazardous substance Consent and be subject to the COMAH Regulations"
>
> "HSENI advises that the applicant should provide details (type and mass) of any dangerous substance:
> 1. stored or produced during normal operation
> 2. That can result from a fire, explosion or other event if there is a loss of control of the process." [58]
>
> "HSENI advise the applicant to clarify, in the scenario of a fire in a single module:
> 1. Will the fire spread to adjacent modules ?
> 2. What is the rate of propagation to adjacent modules?
>
> This information will allow the Council and the COMAH CA to determine if it is reasonable to foresee a fire will generate dangerous substances above their thresholds for HSC and COMAH" [59]
>
> "HSENI, in a previous response, advised that the applicant should provide information on the type and mass of dangerous substance stored or produced during normal operation or associated with a fire/explosion" [60]

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[55] The Northern Irish Regulations are The Control of Major Accident Hazards Regulations (Northern Ireland) 2015 at https://www.legislation.gov.uk/nisr/2015/325/regulation/1 and the Planning (Hazardous Substances) (No. 2) Regulations (Northern Ireland) 2015 at https://www.legislation.gov.uk/nisr/2015/344/schedule/2/part/3

[56] Numbering may be different. For instance the Hazardous Substances are listed in Schedule 2 instead of Schedule 1 (England).

[57] Annex EF3

[58] Annex EF29

[59] Annex EF30

[60] Annex EF31

"HSENI advises that the applicant should provide information on the type and mass of dangerous substance for the following:
1. Produced from a fire or explosion
2. stored or produced in normal operation" [61]

94. HSE(NI) also recognises that

"HSENI recognises that certain battery technologies may reduce the risk of thermal runaway but they do not eliminate the risk of fire or explosion.

HSENI advises the planning officer that UL 9540A is a test method and not a standard and to take a precautionary approach when considering the results of one test method." [62]

The status of the UL9540A test method is widely misunderstood and wrongly treated as a "certification". It is only a standard for the conduct of tests, but has no pass/fail concept. HSE(NI) advises the LPA correctly.

Further discussion on the paucity of engineering standards for grid-scale BESS is made in our Annex EF2[63].

95. HSE(NI) has also commissioned a report from Atkins (consulting engineers) annexed as Annex EF28 and refers to it routinely. The "reference case" accident is one in a single-cabin 5 MWh BESS.

96. These examples show that HSE(NI) is currently addressing actively the safety issues of large scale BESS, advising LPAs that (i) potentially HSC is required and the facility may be subject to COMAH, and that (ii) applicants must consider the dangerous/hazardous substances generated in loss of control of the process.

They further advise that applicants must (iii) provide information both on type and mass, and information on likely rates of fire spread, to enable the LPA and COMAH CA (for Northern Ireland) to determine if HSC and COMAH apply.

They correctly recognise that UL 9540A is a test specification and not a certifying standard.

97. All these cited examples show the Northern Ireland regulator acting consistently with the understanding of the law set out in this WR.

[61] Annex EF33
[62] Annex EF32
[63] Section 7, page 18 of Annex EF2

Synopsis

98. Li-ion BESS are well-known to suffer a failure mode called "thermal runaway" leading to "loss of control" accidents popularly but incorrectly known as "battery fires", incorrectly because they require no oxygen to proceed.

Such accidents are matters of record worldwide and are not alarmist speculation.

They occur in both the NMC and LFP battery cell types although the behaviour may be qualitatively different and the toxic substances generated in accidents may result in different leading concerns.

The likely extent of a major accident involving grid-scale BESS remains an open question in the present state of the technology. Most of the examples so far investigated have been of major fires or explosions in BESS that were much smaller in terms of stored energy than projected for Sunnica. Even an accident confined to a single cabin could be significantly larger than those on record because of the size of the Sunnica cabins which do not appear to have a maximum energy storage capacity declared.

99. This WR has presented evidence that Hazardous Substances Consent is almost certainly a legal requirement, under P(HS)A 1990, which regulates aggregate total inventory of hazardous substances across the establishment.

Under the "loss of control" provisions of Schedule 1 Part 3 of the P(HS)Regs 2015 substances "S" integral to the battery cells should be considered Hazardous Substances.

100. The Controlled Quantities should ideally be determined by actual fire tests, verified and documented, on representative samples of the BESS cells proposed. R.5(1)(d)(iii) of the P(HS)Regs 2015 implies that this a duty of the Applicant.

Absent such tests, we have made scoping estimates of the likely thresholds for HSC in our Annex EF16.

101. We conclude that it is virtually certain that Sunnica BESS will require HSC, regardless of whether NMC or LFP cells are eventually chosen.

Because the Schedules to the P(HS)Regs 2015 and the COMAH Regs 2015 are closely aligned, and both contain "loss of control" provisions, this implies that *prima facie* the Sunnica BESS should be regulated as a COMAH site. If NMC cells were selected, even a single cabin is likely to constitute an "upper tier" COMAH site.

102. No consultation with the COMAH Competent Authority appears to have taken place, as required by Policy in Sect. 4.11.4 of NPS EN-1.

The COMAH Competent Authority comprises the HSE and the EA acting jointly. Scoping Opinions (without full specification) have been obtained from HSE alone but HSE alone does not constitute the COMAH Competent Authority which requires the EA acting jointly with the HSE.

103. Had the Applicant observed the advice of HSE to consult the relevant HSAs, the "loss of control" provisions of Part 3 of the P(HS)Regs 2015 should have been alerted. A full technical appraisal on the lines of our Annex EF14 would have led to

the conclusion that HSC was almost certainly required, and that COMAH regulation was likely a requirement also.

104. In consequence Policy in NPS EN-1 regarding design information and safety assessments for establishments likely to be subject to the COMAH regulations has not been complied with.

105. Policy requires the Secretary of State to "be satisfied that an assessment has been done where required and that the Competent Authority has assessed that it meets the safety objectives described above".

This is more than a Policy obligation to which the ExA must have regard; it is a legal obligation on the SoS under R.24 P(HS)Regs 2015 to maintain it.

Reasons to Refuse the Application

106. No such assessment has been done and therefore neither the Policy guidance nor the legal requirement upon the SoS have been satisfied.

Failure to satisfy this overarching safety policy requirement is a fundamental defect of the Application.

The Application should therefore be Refused –

– on the grounds that the SoS cannot be satisfied that fundamental safety objectives are met, without a formal assessment by the COMAH Competent Authority, and that his duty under R.24 P(HS)Regs 2015 has been thus discharged.

107. Not only is the COMAH Competent Authority entitled to a full specification; so is the public.

Article 13(3) of *Seveso*[64] (from which the current UK regulatory regimes derive) makes clear that Planning procedures and consultations must ensure that "operators provide sufficient information on the risks arising from the establishment, and that technical advice … is available … when decisions are taken".

Thus far Sunnica have entirely failed to provide "sufficient" information on the BESS hazards which I have contributed[65] to this Examination.

This provides additional reason to Refuse the Application.

108. There is an explicit requirement of R.24(1)(b) to evaluate *"the matters referred to in Article 13(2) of the Directive"* , including appropriate safety distances from other development, and the protection of areas of natural sensitivity.

This cannot be properly evaluated except by reference to a full safety appraisal, whether from the COMAH Competent Authority or other equivalently expert bodies, which in turn cannot be done without a full specification.

This constitutes an additional reason to Refuse the Application.

[64] See Annex EF4. Transposed into UK law by Regulations 5, 9, 10, 26, and 32 of the P(HS)Regs 2015 according to the Explanatory Memorandum to those Regulations S.I. 627 of 2015
[65] Annex EF2 and Annex EF16 in particular.

109. The duty of the ExA to consider whether the Application represents an acceptable use of land should not, I contend, result in approval of a scheme where significant doubt over major safety issues remains.

That would be to pre-judge the issue of whether giant BESS of the capacity proposed by Sunnica can be operated with an acceptable degree of safety, at all, where sited so close to (i) population centres, (ii) areas of natural sensitivity, (iii) remaining farmland, and (iv) a major bloodstock industry, as they plainly are in this Application.

Without significant advances in the Process Safety Engineering of large BESS systems, my personal and professional opinion is that BESS at this scale should not be sited in close proximity to population centres, areas of natural sensitivity, or farmland, at all.

In any event the public is entitled to the protection of the regulatory regimes provided by the consenting regime for Hazardous Substances, and the operational controls provided by the COMAH Regulations. The latter, and the Planning policy in NPS EN-1, require the scrutiny the COMAH Competent Authority on a full design specification, which has not so far happened.

(10,091 words) EJF 11/11/22

List of Annexes referred to follows; Annexes uploaded separately

List of Annexes referred to: – Written Representation of Dr Edmund Fordham
(dated 11th November 2022)

EF1 – Personal details

EF2 – "Safety of Grid Scale Lithium-ion Battery Energy Storage Systems"
by E J Fordham (Interested Party), with
Professor Wade Allison DPhil and
Professor Sir David Melville CBE CPhys FInstP

EF3 – "Hazardous substances (Planning) Common Framework"
CP 508 Presented to Parliament by the SoS for DHCLG August 2021

EF4 – Directive 2012/18/EU of the European Parliament and of the Council
on the Control of Major-Accident Hazards involving dangerous substances
commonly known as the "Seveso III Directive"

EF5 – The Planning (Hazardous Substances) Regulations 2015

EF6 – Explanatory Memorandum to the P(HS)Regs 2015

EF7 – The Planning (Hazardous Substances) Act 1990

EF8 – Overarching National Policy Statement for Energy (NPS EN-1)

EF9 – Speech of Dame Maria Miller MP, House of Commons, 7 September 2022
Hansard, (House of Commons) Volume 719, Columns 275-277

EF10 – Battery Storage Guidance Note 1: Battery Storage Planning. Energy
Institute, August 2019, ISBN 978 1 78725 122 9

EF11 – D. Hill (2020).
"McMicken BESS event: Technical Analysis and Recommendations"
Technical support for APS related to McMicken thermal runaway and
explosion.
Arizona Public Service. Document 10209302-HOU-R-01
Report by DNV-GL to Arizona Public Service, 18 July 2020.

EF12 – Underwriters Laboratories incident report into McMicken explosion

EF13 – (5 items) News items and English translation from Chinese of official
accident investigation into April 2021 BESS fire and explosion in Beijing

EF14 – (3 items) Reports from Merseyside Fire and Rescue Service into September
2020 BESS fire and explosion in urban Liverpool

EF15 – Larsson *et al.* (2017), *Scientific Reports*, **7**, 10018,
DOI 10.1038/s41598-017-09784-z

EF16 – Paper with Professor Sir David Melville CBE: “Hazardous Substances potentially generated in “loss of control” accidents in Li-ion Battery Energy Storage systems (BESS): storage capacities implying Hazardous Substances Consent obligations.

In public domain on *Research Gate* preprint server
DOI 10.13140/RG.2.2.35893.76005

EF17 – Golubkov *et al* (2014) *RSC Advances* DOI 10.1039/c3ra4578f

EF18 – Research Technical Report by *FM Global:* Flammability characterization of Li-ion batteries in bulk storage”

EF19 – Bergström *et al* (2015) Vented Gases and Aerosol of Automotive Li-ion LFP and NMC Batteries in Humidified Nitrogen under Thermal Load

EF20 – (2 items) Victorian Big Battery Fire, July 2021. Report of technical findings. Also compendium of news items with aerial photography.

EF21 – (2 items) Letter from Commissioner Sandra D. Kennedy, Arizona Public Service Company, August 2019, regarding McMicken explosion.

Also letter with Fire Department report into earlier 2012 BESS fire with eye-witness reports on flame length.

EF22 – Technical Memorandum from Golder Associates re composition of BESS at Kells, Northern Ireland

EF23 – Ouyang *et al.* (2018), *J. Thermal Analysis and Calorimetry,*
DOI: 10.1007/s10973-018-7891-6

EF24 – Essl *et al.* (2020), *Batteries*, **6**, 30 DOI: 10.3390/batteries6020030

EF25 – Chen *et al.* (2020), *J. Hazardous Materials*, **400,** 123169
DOI: 10.1016/j.jhazmat.2020.123169 (Citation only: article copyright)

EF26 – Held *et al.* (2022) *Renewable and Sustainable Energy Reviews,* **165***,* 112474
DOI: 10.1016/j.rser.2022.112474

EF27 – Wang *et al.* (2019) *Energy Science and Engineering*, **7**, 411-419
DOI: 10.1002/ese3.283

EF28 – Hazard Assessment of BESS, Technical Report by Atkins (Consulting Engineers) for Health and Safety Executive for Northern Ireland HSE(NI)

EF29 – Letter 13/05/2022 from HSE(NI) to Ards and North Down Borough Council

EF30 – Letter 22/09/2022 from HSE(NI) to Derry City and Strabane District Council

EF31 – Letter 10/09/2021 from HSE(NI) to Armagh City, Banbridge & Craigavon Local Planning Office

EF32 – Letter 18/07/2022 from HSE(NI) to Derry City and Strabane District Council

EF33 – Letter 20/05/2021 from HSE(NI) to to Armagh City, Banbridge & Craigavon Local Planning Office