Electricity Storage Health and Safety Gap Analysis

Final Report

May 2021

Prepared for: Department for Energy Security and Net Zero

SYSTEMS ● ENGINEERING ● TECHNOLOGY

Department for Energy Security & Net Zero

FRAZER-NASH CONSULTANCY
A KBR COMPANY

Authors

The primary authors of this report are Daniel O'Brien, Thomas Bransden and Steven Fletcher. For any inquiries regarding this work please contact s.fletcher@fnc.co.uk

Acknowledgements

Frazer-Nash worked with the Storage Health and Safety Governance Group in the development of this report and appreciated their expert input throughout the course of the project.

During the project, Frazer-Nash engaged a number of industry stakeholders. We would like to acknowledge all those who engaged and thank them for the input provided. We are also grateful for the support provided by Department for Energy Security and Net Zero (DESNZ) in delivering this work.

Please note

This publication and the advice contained within has been prepared by Frazer-Nash Consultancy Ltd with the specific needs of DESNZ in mind under their instruction. Frazer-Nash Consultancy Ltd cannot guarantee the applicability of the advice contained within this publication for the needs of any third party and will accept no liability for loss or damage suffered by any third party. Frazer-Nash Consultancy Ltd would therefore advise any third party to seek their own confirmation of the detail contained within for their specific requirements.

This publication was developed in May 2021 and as such does not reflect the various changes in the energy storage sector since this time.

Originating Office: FRAZER-NASH CONSULTANCY LIMITED
Hill Park South, KBR Campus, Springfield Drive, Leatherhead, Surrey, KT22 7LH

Executive Summary

To meet the UK government's legislated target of net zero carbon emissions by 2050, our electricity system is undergoing a transition. Changes in the deployment of technology, stakeholder interactions and novel governance and commercial arrangements have resulted in a number of trends, including: the electrification of heating and transportation; the increasing presence of distributed generation and demand side response; a high penetration of intermittent and non-dispatchable renewable generation sources; and novel roles for system operators, generators and customers.

Energy storage is a vital enabler of all of these trends, reducing the overall costs of the system whilst mitigating risks to customer supply and grid stability. Overall, Electrical Energy Storage Systems (EESS) enhance grid flexibility allowing the electricity system to cope with a wider range of demands and support a range of operating philosophies. The potential benefits of EESS technologies have led to a surge in development and deployment of storage assets – cumulative applications to the planning system for EESS installations were just 2 MW in 2012, rising to 6,900 MW by 2018 and 10,500 MW by 2019 [1] [2].

In response to the ongoing growth of installed and planned electricity storage capacity, there is a requirement to ensure that the current health and safety (H&S) standards framework for electricity storage is appropriate, robust and future proofed. The Department for Energy Security and Net Zero (DESNZ) have therefore commissioned Frazer-Nash Consultancy to conduct a review of the standards landscape, judge its accessibility and adequacy, identify potential gaps and provide proposals to close them.

This report is the final output of this review. It is intended to present the outcomes of all work conducted, gaps identified, and recommendations for mitigating these. Gaps in the standards landscape are broadly split across technologies: less mature technologies such as novel battery chemistries have limited hazard-specific standards, while rapidly commercialising technologies such as lithium-ion (Li-ion) have an evolving standards landscape reflecting a growing consensus among industry actors.

For novel technologies, we do not expect hazard-specific standards will be developed where individual technology manufacturers hold much of the technological expertise. Despite this, there is a lack of general guidance on H&S processes for these systems and we recommend that this guidance is developed.

For Li-ion storage, both our analysis of EESS hazards and engagement with stakeholders indicates that there are relatively minimal gaps in the standards themselves. However, the standards landscape is complex and somewhat challenging to navigate, with different requirements across lifecycle stages and development scales. Additionally, there are more prescriptive requirements in other nations' standards, including for spacing of modules in installations, that could be adopted in the UK to ensure consistency across the sector. To address these two points, we recommend providing concise navigability guidance for different development scales, and considering how international approaches could be incorporated.

In addition, the 'framework of practice' for Li-ion storage, including training, supporting processes and enforcement of standardisation practices, is in a state of flux. Therefore we have recommended a range of actions to improve training, auditing, certification, accreditation, and firefighting processes for Li-ion systems.

The study has found only one specific and potentially significant gap in hazard coverage. DC arc flash, as a comparatively new hazard at smaller deployment scales, appears to be a gap in the current content of the standards relating to battery storage systems. There is an international standard (AS/NZS 5139:2019) which provides an example methodology to form the basis of this effort. We have identified, and begun pursuing, mitigation of this gap via an update to the Institute of Engineering and Technology (IET) Code of Practice for Electrical Energy Storage Systems.

Aside from specific risks, we recommend engaging with international standards committees and national committees in countries with more mature EESS markets to update specific UK standards and ensuring international standards are mirrored in the UK. In order to provide better signposting to relevant standards, guidance and voluntary certification schemes, we also believe there is a need for additional resources within industry or government bodies to provide general storage H&S guidance. This would provide EESS developers, installers and customers with access to appropriate independent expertise; however, it is recognised that may be challenging as there is currently limited international precedent for such support.

Contents

1 Introduction 6
1.1 Background 6
1.2 Research Questions 7
1.3 Report Structure 7

2 Problem Context 8
2.1 Energy Storage Technologies 8
2.2 System Deployment Scales 13
2.3 System Lifecycle Stages 14

3 The H&S Standards Landscape 16
3.1 Overview of The Landscape 16
3.2 UK Standards and Guidance 19
3.3 International Standards 20
3.4 Supporting Framework of Practice 21
3.5 Options for Standards Creation 23

4 Hazard and at Risk Activity Analysis 25
4.1 H&S Assessment Framework 25
4.2 Battery Storage 27
4.3 Supercapacitor Storage 33
4.4 Flywheels 34
4.5 Liquid Air Energy Storage 35
4.6 Compressed Air Energy Storage 36
4.7 Superconducting magnetic energy storage 37

5 H&S Standards Gap Analysis 39
5.1 Approach for Gap Analysis 39
5.2 Gaps in Standards 39
5.3 GAP 1: Immature Technology Standards 42
5.4 GAP 2: LI-ION Product Certification 43
5.5 GAP 3: DC ARC Flash 43
5.6 GAP 4: Navigability of the Standards Landscape 44
5.7 GAP 5: LI-ION Testing and Installation Standards 45
5.8 GAP 6: Installer Competency Framework 45
5.9 GAP 7: Independent H&S Advice 46
5.10 GAP 8: EU-Exit and Standardisation 46
5.11 GAP 9: LI-ION Certification and Accreditation 47

5.12 GAP 10: LI-ION Audit and Verification 47
5.13 GAP 11: LI-ION Fire Services Processes 47

6 Conclusions and Recommendations 49
6.1 Conclusions 49
6.2 Recommendations 50
6.3 Acknowledgements 51

7 References 52

Annex A – Arc Flash .... Error! Bookmark not defined.

1 Introduction

1.1 Background

To meet the UK government's legislated target of net zero carbon emissions by 2050, the UK's electricity system is undergoing an increasingly complex transition. This transition is resulting in a number of key trends: the electrification of heating and transportation, the increasing presence of distributed generation and demand side response, high penetration of intermittent and non-dispatchable renewable generation sources and novel roles for system operators, generators and customers. Energy storage is a vital enabler of all of these trends, reducing the overall costs of the system whilst mitigating risks to customer supply and grid stability. Overall, storage enhances grid flexibility allowing the electricity system to cope with a wider range of demands and support a range of operating philosophies.

The potential benefits of energy storage technologies have led to a surge in development of storage assets – cumulative applications to the planning system for EESS installations were just 2 MW in 2012, rising to 6,900 MW in 2018 and 10,500 MW in 2019 [1] [2] (Figure 1 UK Battery Storage portfolio by status (reproduced from [1])). In conjunction with this growth in demand, the price of storage has dropped rapidly in conjunction with the growth of the electric vehicle supply chain. Bloomberg New Energy Finance estimates that the price for Li-ion battery packs have fallen by 87% between 2010 and 2019, and is expected to fall further in the coming years [3]. This fall in costs is a driver for proliferation of energy storage systems. In parallel, incentives for demand-side response (DSR) combined with other use cases such as generation time shifting, has led to more behind-the-meter installations of energy storage.

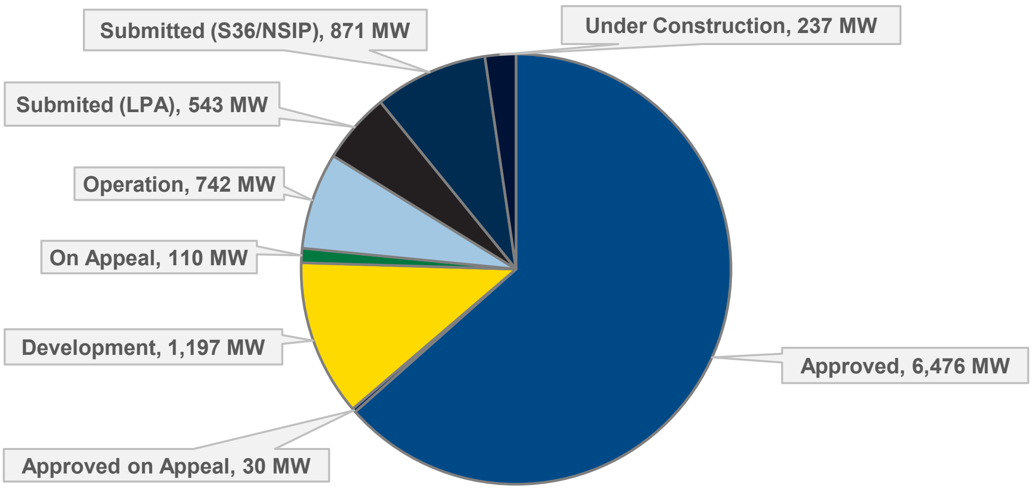

Figure 1 UK Battery Storage portfolio by status (reproduced from [1])

HM Government and Ofgem jointly published the Smart Systems & Flexibility plan in 2017, with a progress update published in 2018. These documents outlined 38 actions for the Government, Ofgem, and/or industry that will enable the transition to a smart and flexible system. Action 1.7 of the plan specifically commits the Government to work with industry on reviewing, consolidating and, where necessary, updating health and safety (H&S) standards for storage.

To address this task, DESNZ formed an independent, industry-led Storage Health and Safety Governance Group (SHS Group) in 2018 with the principal task of reviewing the H&S framework for storage. Following an initial analysis, this group recommended that DESNZ fund an external organisation to carry out a detailed gap analysis of these standards, including those in development or any other relevant standards or guidance/documents.

1.2 Research Questions

The work aims to answer the following research questions in a publicly available report, which will include recommendations for how to address any gaps identified:

Overall research question:

Is the current H&S standards framework for electricity storage appropriate, robust and future proofed for the expected increase in deployment and as technologies develop? If not, how should this be addressed?

Individual research sub-questions:

1. What are the H&S risks for electricity storage at each scale (grid, commercial, domestic), and at what part of a storage device's lifetime do they occur? How should these be prioritised?
2. How well do the current standards, and those in development, address the activities (and their risks) involved in the installation, use, maintenance and disposal of electricity storage systems?
3. How accessible and easy to navigate is the current standards framework?
4. To what extent do any gaps/issues identified under sub-questions two and three pose a health and safety risk?
5. What is the recommendation for how to solve any issues identified by this gap analysis? These recommendations should set out whether standards need to be revised or added, and what form they should take.

1.3 Report Structure

This report is intended to inform DESNZ, the SHS Governance Group, industry bodies and the wider public of our findings in the Electricity Storage Health and Safety Gap Analysis project. Our work is summarised as:

- The industry context in which this framework sits (Section 2);
- Standards and guidance we consider relevant in the UK and internationally (Section 3, research sub-questions 3 and 4);
- The risks we have assessed for various EESS technologies (Section 4, research sub-questions 1-2);
- Gaps in the H&S standards framework for EESS, and in the supporting framework that sits around them (Section 5, research sub-question 2); and
- Recommendations for mitigating these (Section 6, research sub-question 5).

2 Problem Context

Before seeking to identify gaps in the current standards framework, it is important to define the areas of coverage in which gaps may exist. We propose that there are three such areas:

1. Gaps in coverage of energy storage technologies;
2. Gaps in coverage of system deployment scales; and
3. Gaps in coverage of system lifecycle stages.

These areas, and our understanding of their current state and ongoing trends, are discussed below.

2.1 Energy Storage Technologies

2.1.1 Scope

There are a range of existing and developing technologies which have been proposed for deployment in energy storage systems. These technologies vary in principle of operation, constituent components, and types of energy present. To enable identification and prioritisation of the risks associated with these systems, it is necessary to define and order energy storage technologies according to their current and predicted relevance to the UK market.

This study aimed to cover all energy storage technologies with relevance to the UK market (Table 1). Exceptions to these were:

- **Non-electricity systems:** technologies which do not receive, store or output electrical energy were excluded. An example of this would be solar hot water storage, where thermal energy is received from a solar array, stored in a mass of water, and later distributed as heat. Technologies which use stored energy to generate electricity, such as high-temperature molten salt which can be used in conjunction with a steam turbine, are included.
- **Pumped hydroelectric storage:** this was excluded on the basis that it is a well-established technology whose H&S risks are adequately understood, and that there are only a small number of planned projects due to geographic and financial constraints [4] [5].
- **Hydrogen storage**: the H&S risks associated with conversion of grid electricity to hydrogen for storage are currently being examined by other initiatives, such as the University of Edinburgh's HyStorPor project funded by the Engineering and Physical Sciences Research Council (EPSRC) [6], recent Frazer-Nash work for DESNZ on the logistics of domestic hydrogen conversion [7] and on hydrogen storage for transport refuelling as a cryo-compressed liquid, as ammonia or underground [8].
- **Vehicle-to-grid (V2G):** the H&S risks of storage systems deployed in a V2G application are considered to be captured by assessment of conventional battery systems. Although some risks captured for conventional batteries could apply to V2G applications, this study does not make a formal assessment of this. Challenges unique to vehicle safety are being developed through specific vehicle standards and safety regimes, and by other works such as the Department for Transport's 2019 Electric Vehicle Smart Charging consultation [9].

Table 1: List of storage technologies considered.

Storage Type	Name	Principal of Operation
Mechanical	Compressed-Air Energy Storage (CAES)	Compresses air using electric motors, then releases it through a turbine to generate energy.
	Flywheel	Accelerates an inertial mass using an electric motor, storing rotational kinetic energy as the rotor spins. Recovers by decelerating the mass using a generator.
Electrochemical	Conventional batteries	Uses chemical composition to build up electrons at an anode, which flow to a cathode when a circuit is closed. Batteries in storage systems are commonly rechargeable.
	Flow Batteries	Similar chemical composition to conventional batteries, but using liquid electrolytes which are pumped around a circuit.
Thermal	Thermal Storage	Stores incoming thermal energy, e.g. from solar generation, as heat for later retrieval and conversion to electricity
	Liquid Air Energy Storage (LAES)	Uses electricity to cool purified air until liquefied, then stores it at low pressure. It is then is pumped to high pressure and vaporised, expanding and heating as it does so.
Electrostatic	Supercapacitors	Stores charge in an electric field between two conductors, separated by a dielectric medium.
Electromagnetic	Superconducting Magnetic Energy Storage	Uses the flow of direct current through a cryogenically cooled superconducting coil to generate a magnetic field that stores energy, which is released by discharging the coil

2.1.2 Discussion

Lithium-ion (Li-ion) batteries are the most significant contributor to current and future UK energy storage capacity, with cumulative planning applications for over 10,500 MW of capacity being made by November 2019 [1]. This was a significant increase from the previous year, which saw 6900 MW of applications. Li-ion batteries are also the technology of choice for domestic users, with consumer products becoming more affordable and desirable in conjunction with solar PV installations. It is difficult, however, to gauge actual installed capacity of this technology – as many systems are likely to be of smaller size they may have been installed without planning permission, and may not be captured on private registers of storage systems.

Flow batteries are an electrochemical storage technology which use liquid electrolytes, as opposed to the solid electrolytes found in conventional batteries. These liquids are pumped through a membrane, inducing current flow via ion exchange to absorb or release energy. This arrangement makes scaling up of the battery system simple, as higher capacity only requires larger electrolyte tanks [10]. Flow batteries are beginning to be deployed in some commercial- and grid-scale applications – US-based ESS secured a $30 million investment in 2019 to develop its iron flow battery technology to commercial scale [11].UK-based RedT has installed a 300 kWh vanadium-flow battery and 250 kW solar PV array in Dorset, and has also attained pre-qualification from National Grid to provide dynamic firm-frequency response (dFFR) services [12]. RedT has also partnered with US-based Avalon Battery Corp. in plans for a 2 MW vanadium-flow battery in Oxford, as part of the local council's Energy Superhub project launched in April 2020 [13].

Compressed Air Energy Storage (CAES) stores energy by using electric compressors to capture atmospheric air and store it at high pressure during times of low demand. Energy can later be extracted by expanding the air through a turbine to produce electricity. CAES has been successfully implemented as early as 1949, using an underground cavern as the pressure vessel for air storage. There are currently only two commercial-scale CAES plants – Huntorf, Germany (290 MW) and McIntosh, USA (110 MW, 2.7 GWh) both of which use salt caverns as their pressure vessels – gas reservoirs and coal mines can also be used [14]. A number of suitable locations have been identified in the UK, including offshore saline aquifers (up to 96 TWh), on-shore salt caverns in the Cheshire Basin (up to 2.5 TWh), [15] [16]. UK-based Storelectric are exploring the potential of CAES in combination with Combined Cycle Gas Turbine (CCGT) power generation, and has been awarded an EU Project of Common Interest (PCI) status for a planned site in Cheshire [17].

Liquid Air Energy Storage (LAES), also known as Cryogenic Energy Storage (CES), can be considered a variant of CAES as the components which comprise these systems – compressors, turbines, electric motor/generators and heat exchangers – are largely common with CAES plants. The differing factor in LAES systems is that in addition to compression, atmospheric air is cooled to cryogenic temperatures and stored as a liquid, permitting a higher energy density than CAES and avoiding the geographic restrictions associated with using existing natural pressure vessels [18]. There is currently only one operational LAES system in the world; a 15 MWh demonstration plant operated by Highview Power at Bury, near Manchester [19]. There are two commercial-scale LAES sites planned, both by Highview Power – a 400 MWh plant in Vermont, USA and a 250 MWh plant at a yet-unnamed site in Northern England [20].

Gravitational energy storage systems store gravitational potential energy by raising mass away from the Earth’s surface, which can later be lowered to recover energy on demand. The most mature form of gravitational energy storage is pumped hydroelectric, which has been excluded from this study (see 2.1.1). Gravitational systems using solid masses have also been explored – UK-based Gravitricity has designed a system which raises and lowers masses in a vertical shaft such as a disused mineshaft, and is currently planning a demonstration project at the Port of Leith in Edinburgh to become operational in December 2020 [21] [22]. The Swiss start-up Energy Vault has also published designs for a tower-style gravitational storage system, which uses cranes to raise and lower 35-ton composite bricks as required to store and recover energy [23]. Energy Vault are currently commissioning a demonstration plant in Switzerland, which will be the first such system in the world [24]. Although a promising technology in the coming years, gravitational storage is largely still at the concept stage and not yet mature enough to warrant standardisation and so has not been considered further in this study.

Flywheel energy storage systems store energy mechanically, using available intermittent energy to accelerate a spinning mass and recovering it by decelerating the mass. Flywheels have been used for energy storage for many decades, with applications in transport as early as the 1950s [25]. There are currently no domestic- or grid-scale flywheel installations in the UK – the only operational system at present is collocated with the Joint European Torus in Oxfordshire, where two flywheels can provide up to 400 MW each to provide large amounts of short-term power [26]. UK-based OXTO Energy have developed a flywheel design to prototype stage, and Norwegian Statkraft have proposed plans to install a flywheel system in Moray, Scotland to provide grid stability and frequency response services [27].

Superconducting Magnetic Energy Storage (SMES) systems store energy in the form of a magnetic field around a superconducting coil at cryogenic temperature. DC current is passed through the coil to generate the magnetic field, and energy is recovered by discharging the coil [28]. SMES systems have been installed at small scale in the USA (around 50 MW), as well as in Japan [29]. No current or proposed SMES installations are known, however the technology is considered to have potential applications in grid-scale voltage stabilisation, frequency regulation and electric vehicle charging stations [30].

Supercapacitors (also known as ultracapacitors, double layer capacitors or electrochemical capacitors) are high-capacity capacitors. Supercapacitors are constructed differently from normal capacitors to enable the storage of much larger amounts of energy. Key features of supercapacitors are their ability to rapidly charge and discharge (far faster than many batteries), their tolerance of a high number of charge/discharge cycles (hence long life) and their high specific power (although not energy) density. These features are particularly attractive for transportation applications (e.g. for acceleration or regenerative braking) where they are currently seeing the largest uptake. Practical examples include the use of large supercapacitor banks, with an output in the order of 2MW for 30 seconds, connected to the power supply of electric rail applications (e.g. to reduce peak power requirements or support voltage during train acceleration). A significant drawback of currently available supercapacitors is their low energy density which is around two orders of magnitude lower than that of the commercial lithium-ion batteries [31][1], limiting wider applicability. For stationary grid applications, potential use cases for supercapacitors include backup supply for critical equipment (e.g. through their use in uninterruptable power supplies) and short-term grid support such as fast frequency response. Given their fast response but limited energy, they may be used in a hybrid configuration with other energy storage technologies. Where supercapacitors whose primary function is not energy storage on the grid i.e. where used as circuit impedance components, they do not typically fall within the regulatory framework of electricity energy storage, however, they have been included within this study given their potential grid support applications.

Thermal storage comes in many forms. For electricity storage, a key example is in concentrating solar power (CSP) plants where solar heat can be stored for electricity production when sunlight is not available. A number of these types of plant exist worldwide, with thermal energy being captured through the use of phase change materials such as molten salt. Examples of this include the 19MW Gemasolar storage facility (near Seville, Spain), and the Crescent Dunes Tonopah, Nevada, and the 250MW Solana thermal energy storage system in Arizona [32]. There is also significant potential for these types of plant in developing nations [33]. Whilst there is technical experience with these storage systems (with a good safety track record [34] [35]) and a promising outlook worldwide, they require a hot and sunny climate to be effective and economical. This is a key limitation for their deployment in the UK, and at present they are not mature enough to warrant formal standardisation in this country and so has not been considered further in this study.

[1] Research is ongoing on the use of novel materials such as graphene which aim to substantially close this gaps in energy density.

Table 2: Technology Maturity Breakdown

	Research & Development	Demonstration & Deployment	Rapid Commercialisation	Maturity
Technology Readiness	Operational principles observed. Component-level testing Small-scale system demonstration	Scaled-up system demonstration. Proof of concept in operational environment	Standardisation of designs Growing volume of installations Competing products emerge	Iteration on existing designs Focus on end-of-life and re-use
Technical Expertise	Limited to academia and research, expertise from related industries / technologies	Pilot schemes provide some operational experience and testing of research assumptions	Strengthening – operational experience feeds better technical understanding	Strong – guidance and training available from experienced industry bodies
Community Consensus	None – very small number of developers	Little – small number of developers, technologies vary	Strengthening – best practice emerging, industry bodies forming	Strong – best practice widely adopted / standardised
Extent of Deployment	Technology demonstrations Research-scale only	Tens of installations Full-scale pilot schemes	Hundreds or thousands of installations Commercial deployments	Market saturation Established use-cases
Technologies	SMES Novel Battery Chemistries	Flywheel Thermal CAES / LAES Flow Battery	Li-ion Batteries	Lead-acid / NiCd Batteries
Purpose of Standards	Ensure safety in research environment	Address novel technical risks. Define interfaces with other systems	Product standardisation Consumer safety	Normative standards for industrial development

2.2 System Deployment Scales

The diversity of deployment scales and use-cases for energy storage systems is a key challenge for this project to address. We recognise that energy storage systems installed at domestic scale serve a different purpose and operate under a different regulatory and standards regime from those installed at grid scale. While a grid-scale stakeholder is likely to operate in a professional engineering environment, with established safety procedures and understanding of the risks associated with their equipment, a domestic-scale customer cannot, and should not, be expected to understand or account for the H&S risks of their energy storage system. The burden of safety assurance in this case must fall on product manufacturers and qualified installers/maintainers, who undertake all non-routine interactions with the system.

The third deployment scale – that of commercial/industrial energy storage systems – is less well-defined. Firstly, the range of use-cases for such systems is broader – they may be used to store energy from intermittent renewables for later use, to support short-term high-demand activities such as running powerful industrial equipment, or may simply be scaled-up versions of domestic storage systems intended to save their owners money on electricity consumption.

The level of expected customer competence and ownership of H&S risk also varies at this 'in-between' deployment scale: while some system owners may have the professional engineering expertise to safely configure, operate, maintain and decommission a large-scale energy storage system, this cannot be assumed for all cases. The impact of gaps or conflicting overlaps in the current standards framework may therefore be more severe in commercial/industrial scale deployments, as customers may be unsure of which standards to follow and of the level of responsibility they must assume for the H&S risks associated with their system.

Table 3: Deployment scale definitions

	Domestic	Commercial / Industrial	Grid
Typical Owner	Domestic households Low electrical expertise Expect purchase to 'work'	Large demand consumer Co-located with wind / solar PV. Increasing professionalization	Utility company / specialist storage developer Strong access to expertise; either in-house or contracted
Use Cases	**User defined:** Bill reduction Revenue from incentives Support decarbonisation	**Diverse & complex:** Backup power supply Time-shifting renewable generation Micro-grid support Grid support, e.g. demand-side response, peak shaving	**Grid support services:** Frequency response Synthetic inertia Wholesale energy storage Black start capability
Technical Specification	<~10 kW, <~ 50 kWh Delivered at local supply voltage and frequency	No 'typical' installation: voltage, power, capacity, current type can all be bespoke for on-site storage & distribution	Tens / hundreds of MW / MWh; transmission or distribution network connected, so compliant with grid code parameters
Dominant Technologies	Li-ion battery systems, with some lead-acid	Some diversity (e.g. flow batteries), but li-ion dominates	Li-ion dominates, but with more diversity e.g. CAES/LAES, gravitational

	Domestic	Commercial / Industrial	Grid
Market Potential	Hundreds of thousands of installations	Thousands of installations	Tens to Hundreds of installations
H&S Approach	**Product Engineering Safety:** CE (or equivalent) product markings Qualified installers and maintainers	**Mixed Approaches:** System and customer-dependent – some scaled-up consumer systems, some small bespoke installations	**Project Engineering Safety:** H&S assured through-life by asset management-type processes
Decommissioning / Recycling	Potential for refurbishment and resale of discrete units; recycling for batteries via current Waste Electrical and Electronic Equipment (WEEE) facilities. Second-life components an economical option if safety can be assured via appropriate testing / certification	Technology-dependent, but larger system sizes may require more stringent decommissioning practices. Important to highlight safety hazards to operators at this scale, e.g. batteries remain an energy source even when disconnected	Continuous maintenance and replacement of constituent parts throughout lifetime, followed by systematic decommissioning. Performance and safety requirements for critical use-cases may reduce suitability of second-life components

2.3 System Lifecycle Stages

To provide context to the examination of at-risk activities, and subsequent categorisation of risks and standards, it is pertinent to define the relevant stages in the life cycle of an energy storage system. This was done with reference to the IET's Code of Practice for Electrical Energy Storage Systems [36], described in more detail in **3.2**:

1. **Design & Planning:** Activities taking place before any equipment is moved to the installation site. May include design, manufacture and certification of equipment, site appraisal, and performance estimation.
2. **Installation:** Physical placement, mounting and fixing of system components at their intended location, and connection to their respective mechanical, electrical, thermal and other interfaces.
3. **Commissioning:** Inspection and testing of the system to assure conformance to applicable standards, including any witnessing, registration or notification requirements. Includes training and testing of suitably qualified and experienced operators, handover of the system from installer to operator, and post-handover tuning/bedding-in period.
4. **Operation & Maintenance:** Usage, inspection, testing and upkeep of the commissioned system by its operator or an appointed maintainer. May include periodic verification of system safety by a third party, e.g. a manufacturer or regulator.
5. **Decommissioning & Disposal:** Activities associated with the permanent shutdown and disconnection of the system and its components, their removal from the installation site, re-use and recycling or disposal in accordance with waste equipment regulations.

Re-use of energy storage systems and their constituent components is desirable, as it reduces demand both for supply of new components and for final disposal of existing ones. This lessens the environmental and ethical impacts of the industry as a whole, as fewer raw materials are needed and less waste is produced per unit of energy stored.

Activities relating to re-use include post-decommissioning inspection, refurbishment, testing and certification of previously-deployed components with the express purpose of their being deployed again in an identical or similar role. These activities will be captured under the Decommissioning & Disposal lifecycle stage. Design, assembly, installation, commissioning, operation and maintenance activities for re-used components are considered to be substantially similar to those for virgin components, as are the H&S risks associated with these activities.

Some activities, such as transport of equipment between sites, may fall across several life cycle stages.

3 The H&S Standards Landscape

3.1 Overview of The Landscape

In common with all safety-critical technical systems, a library of technical standards exists for EESS, which provide a framework for H&S compliance and risk mitigation. These standards provide a source of good practice, guidance on EESS implementation and clarifications on requirements for design, certification, testing, installation and more. Standards also allow stakeholders to understand their responsibilities, develop safe systems of work, and operate systems with the assurance that other stakeholders have fulfilled their duties.

For this study a, broad definition of “standard” has been used; we have considered not only formal approved technical standards but also guidance documents, associated technical volumes, and literature from regulators. This is because all of these documents have an influence on stakeholder practice, and thus are relevant to an assessment of the standards framework’s suitability for addressing EESS H&S risks. We have also considered future roadmaps and standards under production, to understand the future direction of the landscape.

Standards set out the minimum requirements a product or service needs to meet. In the case of a product standard, test methodologies along with pass/fail criteria are often what is defined. The development of standards can be a complex process and, particularly for products traded globally, are ideally developed at an international level to avoid cross-border technical barriers to trade. In the case of services that may only be delivered locally and where local codes or regulations apply it can be more appropriate for standards to be developed locally.

Standards are normally developed by working groups or technical committees populated by industry experts and other relevant stakeholders. In order for those standards to be meaningful, the process of development needs to be robust and transparent, often involving public consultation at one or more drafting stages. The final document should be publicly available to allow for compliance to be verified where necessary. All privately-developed, British, European and International standards are published.

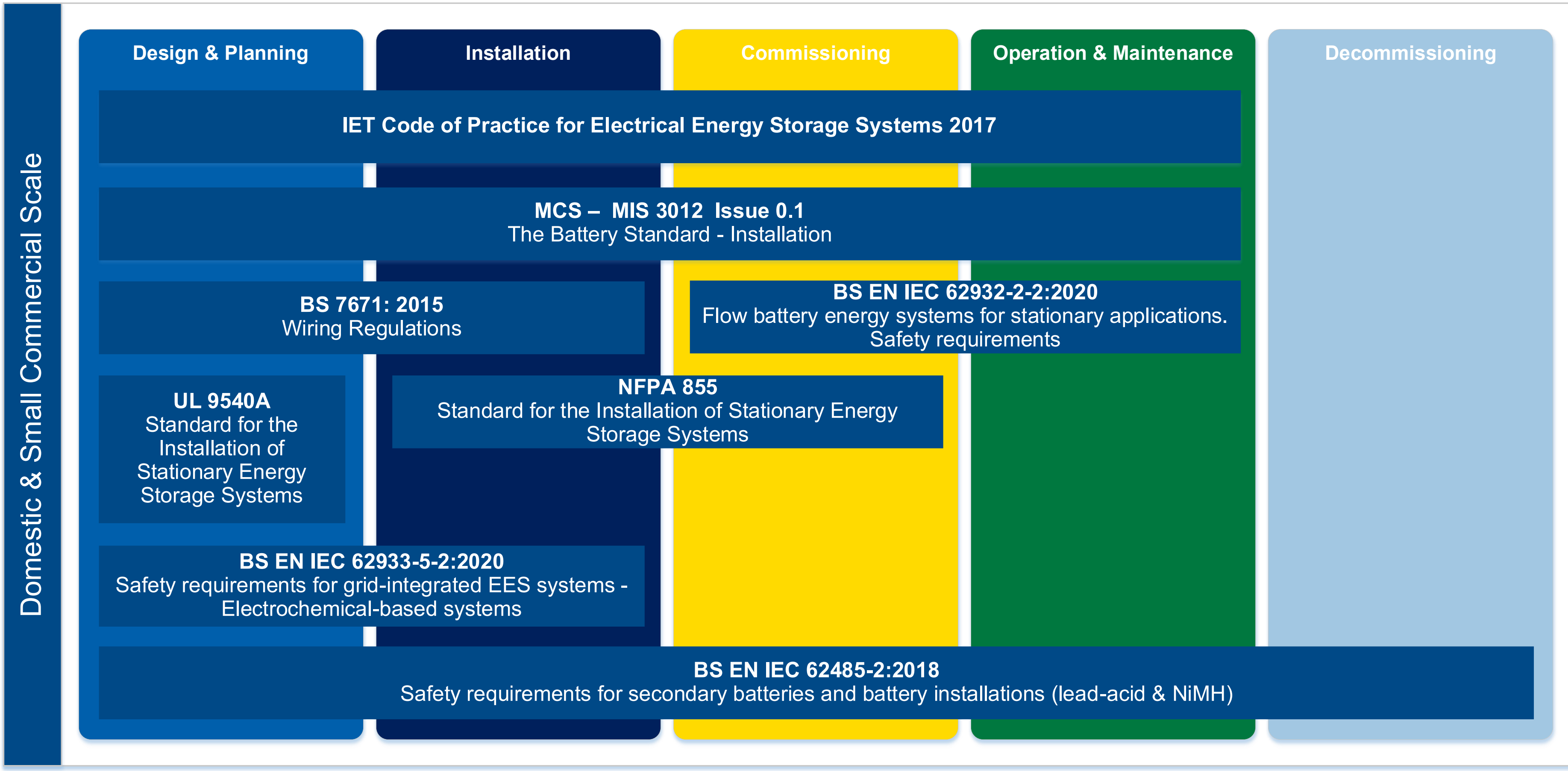

Figure 2 .Representative overview of the key standards for a domestic or small commercial EESS installation.

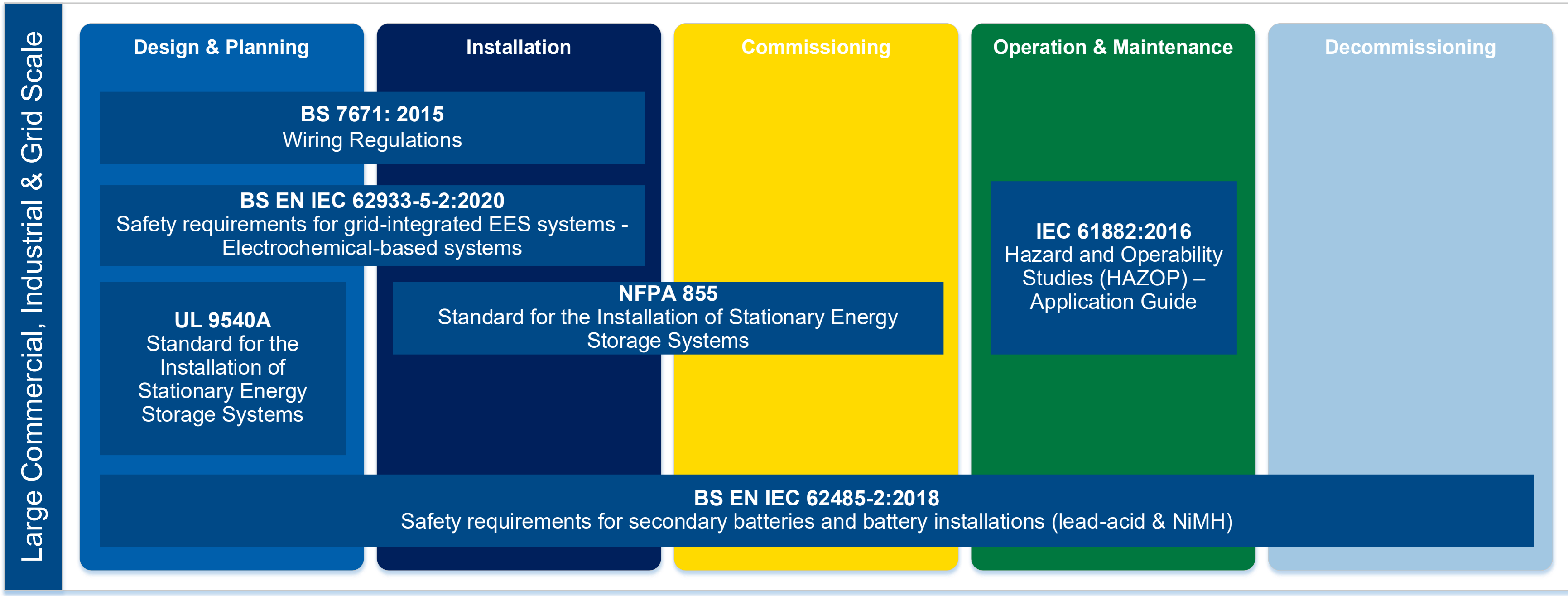

Figure 3 Representative overview of the key standards for a large commercial, industrial or grid scale EESS installation.

3.2 UK Standards and Guidance

The categories of documents reviewed, and the relationships between them, are summarised in Figure 4. The following subsections provide initial outline analysis against the categories. The analysis provides some detail on how each document addresses the lifecycle stages and deployment scales detailed in Sections 1 and 2 of this document.

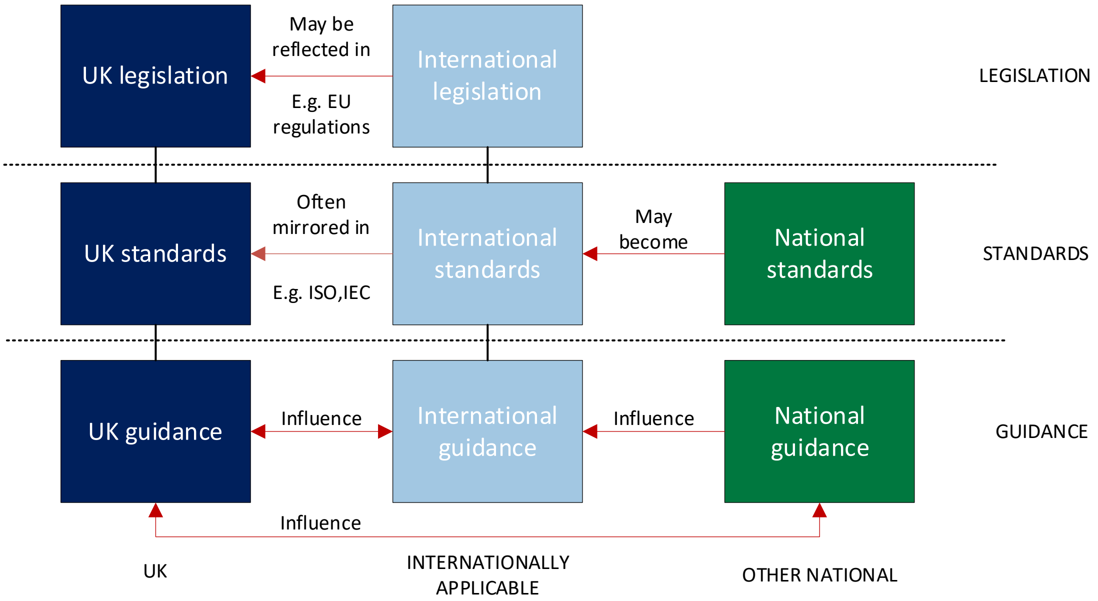

Figure 4 H&S Standards Framework

3.2.1 UK H&S Legislation

The UK Health and Safety at Work Act (1974) is the primary overarching legislation relevant to workplace H&S practices. The Act sets out the rights of workers to work in an environment where H&S risks are properly controlled. This includes properly controlling the H&S risks of an EESS, and is relevant to all development scales and lifecycle stages. For instance, storage system installation companies must ensure that their employees are not subjected to unnecessary risks during the installation of domestic or commercial & industrial battery systems. Similarly, grid scale EESS developers must ensure that their employees are not exposed to any H&S risk over the full lifecycle of an EESS.

The Electricity at Work Regulations (1989) describes requirements for maintaining safe practices in the workplace that relate to the installation, operation and maintenance of EESS.

The Building Regulations (England and Wales) address a number of pertinent H&S risks such as fire safety. The Regulations describe relevant measures that would partially or completely mitigate the risks due to an EESS fire in a building, such as escape routes, alarm systems, ventilation and sprinkler systems.

3.2.2 UK EESS-Specific Standards

A key source of UK-specific guidance on EESS is the IET Code of Practice for Electrical Energy Storage Systems 2017. The scope of this code gives practitioners a reference on the safe application and design of EESS across the system lifecycle and provides relevant content for systems of up to 50 kW – typically relevant to domestic and small commercial installations. This code is being updated to a 2nd edition in 2020, incorporating learnings (such as improved treatment of earthing requirements) from a process of continuous consultation with industry. This reflects a very rapid update cycle corresponding to large changes in the industry; in general the IET aim for a 5-year review lifecycle for Code of Practices, while a British Standard is typically 7 years.

MIS 3012 is a battery installation standard produced by the Microgeneration Certification Scheme (MCS). This standard covers design, installation and commissioning of EESS up to 50 kW, and defines requirements relating to ventilation and component location. It also provides informative requirements for installers, including signposting applicable regulations (e.g. Construction (Design and Management) Regulations 2015, Electrical Safety, Quality and Continuity Regulations 2002) that they must comply with. MIS 3012 uses the same competency requirements as MIS 3005, MCS' equivalent standard for solar PV systems. MIS 3012 does not address product certification requirements, although it is expected these may be developed in the future. This would reflect evolution towards a similar level of maturity to solar PV systems where there is an obligation to meet MCS' certification standard within MIS 3005. MCS also operate a database, the Microgeneration Installation Database, where certified installers register their systems – this database also includes non-EESS systems such as solar PV.

Certi-Fi, an oversight body for the renewable and flexible energy sectors, also operate a product and installer registration scheme. The Energy Performance Validation Scheme (EPVS) allows installers to register with Certi-Fi, and also requires that installers sign up to an industry code of conduct, such as the HIES Consumer Code or Renewable Energy Consumer Code (RECC). EPVS also provides a route for registration of installed EESS and other smart energy systems via Flexi-Orb, which operates a portal that assists in providing notification to Distribution Network Operators (DNOs) and fire services and in registering for manufacturer product guarantees. Certi-Fi plans to publish a standard for installation of EESS in 2021.

Non-technology-specific standards, which cover fundamental H&S issues associated with the safe installation of electrical systems (e.g. prevention of electric shock) and by extension EESS, also exist. One primary example is the electrical wiring configuration BS 7671, which describes the requirements for safe design of building wiring systems including fuse boxes (and associated residual current devices (RCDs) in modern systems). BS 7671 is the UK's core electrical safety standard, and is currently at its 18th edition. This standard applies in EESS at both domestic and commercial/industrial scale (up to 1000 V AC or 1500 V DC).

Another standard of significant importance to the safe deployment of EESS is BS 5839 "*Fire detection and fire alarm systems for buildings*". This covers fire risk assessment and the suitability of a chosen fire detection and alarm system, relevant to all lifecycle stages of EESS installed in buildings.

3.3 International Standards

3.3.1 Global / European Union

Figure 4 illustrates that internationally developed standards are often mirrored by the BSI in the UK and hence become UK standards. These standards form the bulk of the technical standards related to energy storage discussed here and in subsequent sections. These standards are developed through relevant working groups in organisations such as the IEC, the European Committee for Electrotechnical Standardization (CENELEC) or the ISO and present an international consensus on what standards should apply. UK membership of these organisations and working groups enables the UK to influence what becomes an international standard.

There are a number of IEC EESS standards currently under development under the TC 120 work programme, with publication dates extending to 2023. The IEC's TC 120 Work Programme has published seven standards, three of which have made it through to BSI publication via the UK's mirror ESL/120 committee.

The TC 120 work programme was introduced to focus on the system aspects of EESS as well as investigating the need for new standards. For example, IEC 62933-5-2:2020 Safety requirements for grid-integrated EESS - Electrochemical-based systems addresses the safety of people and environment for grid-connected electrochemical storage systems. IEC 62933-5-2 was based on a proposal from Japan and is currently at the approval stage.

3.3.2 United States

The United States has a mature national framework of EESS standards reflecting a significant focus on mitigating H&S risk of storage, particularly fire risks.

UL is an independent product safety certification organisation which, in conjunction with other organisations and industry experts, publishes consensus-based safety standards. They have recently developed battery storage standards which are in use both nationally and internationally. For lithium batteries, key standards are:

- **UL 1642: Standard for Safety of Lithium Batteries (2012).** Covers component-level testing of lithium cells. Battery-level tests are covered by UL 2054.
- **UL 2054: Standard for Household and Commercial Batteries (2004).** Covers measures relating to fire/explosion risk, including during transport and disposal.
- **UL 1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications (2018).** Applies to battery cells and modules used for domestic, commercial and grid-scale storage. Defines requirements for cells, batteries and battery systems for stationary systems (e.g. for use with solar PV), as well as EVs and LER. Non-technology specific but does include testing criteria for many battery chemistries, including Li-ion, Ni-Cd, lead-acid, sodium and flow batteries and ultracapacitors.
- **UL 1974: Standard for Evaluation for Repurposing Batteries (2018).** Covers the sorting and grading of battery packs, modules and cells that were originally configured and used for other purposes, such as EVs, and that are intended for a repurposed use application such as in an EESS. Defines a process for sorting and grading devices according to their state of health, and using this and other criteria to assess their suitability for continued use. Batteries incorporating re-used or second life components must meet the same ultimate standard as new components; in this case UL 1973.
- **UL 9540: Standard for Safety for Energy Storage Systems and Equipment (2020).** Far-reaching standard for energy storage safety, setting out a safety analysis approach to assess H&S risks and enable determination of separation distances, ventilation requirements and fire protection strategies. References other UL standards such as UL 1973, as well as ASME codes for piping (B31) and pressure vessels (B & PV).

The National Fire Protection Association (NFPA), a global self-funded non-profit organization, compiles research through the Fire Protection Research Foundation and collaborates with research institutions to gather evidence and data that helps shape their published standards:

- **NFPA 1: Fire Code (2018).** Addresses minimum requirements for building construction, operation and maintenance, fire department access, and hazardous materials necessary to establish a reasonable level of fire safety and property protection in new and existing buildings. Draws requirements from 57 other NFPA codes and standards, providing wide coverage when conducting reviews and inspections.
- **NFPA 855: Standard for the Installation of Stationary Energy Storage Systems (2020).** Addresses minimum requirements for mitigating hazards associated with EESS. Applies to many types of EESS – electrochemical (including li-ion, lead acid, ni-cad, sodium, flow), supercapacitor, SMES, flywheel, CAES. Applies to a range of lifecycle stages – design, construction, installation, commissioning, operation, maintenance, and decommissioning. Defines requirements for equipment specification, electrical installation, system location and separation, ventilation and smoke detection, fire control and suppression, and emergency planning (e.g. shutdown procedures, removal of damaged equipment).

3.3.3 Australia

Australia has seen a particularly rapid updated of EESS at all deployment scales and therefore its standard landscape has matured apace. For example, Standards Australia and Standards New Zealand have recently published AS/NZS 5139:2019, which sets out general installation and safety requirements for battery EESS with a storage capacity of greater than 1kWh. AS/NZS 5139 follows a risk-based process for installation based on hazards identified. Standards Australia acknowledges that AS 5139 will continue to be refined as the industry evolves2.

3.4 Supporting Framework of Practice

The purpose of this project is to identify gaps in the standards which address health and safety risks of electricity storage systems. However, ensuring risks are mitigated through a supporting framework of tools, products and

[2] https://www.pv-magazine-australia.com/2019/10/12/new-controversial-standard-for-battery-storage-sector/

installation services, training, certification and accreditation programmes. The supporting framework is a critical element of the standards landscape to achieve safe outcomes. This framework can be broadly split into:

- **Certification** – How is an installation adequately certified and who enforces action on shortcomings? How are products certified?
- **Accreditation -** How are certification bodies accredited?
- **Audit and verification** - How is safety of installations across the UK verified?
- **Training Provision** – What training is available to help manufacturers/ installers/ maintainers etc. comply with standards and guidance? What training is available for certifiers?
- **Oversight and Engagement -** What committees/ governing bodies have oversight of the standards framework, and what powers do they have?

3.4.1 Certification

Certification is verification by an impartial and competent third party (a Certification Body) that a product or service meets the requirements given in a particular standard. Certification normally involves sampling or audit of the product or service to verify compliance. In the case of product certification this may involve the witnessing of a product test.

Certification generally employs sampling because it is not cost effective to test and witness every product produced or every time a service is delivered. Therefore certification also often requires the manufacturer or service provider to employ quality procedures designed to ensure every product or service meets the particular standard and not just that witnessed or tested.

3.4.2 Accreditation

Accreditation in the UK is undertaken by the United Kingdom Accreditation Service (UKAS) which ensures that Certification Bodies undertake their certification activity in a competent, consistent and impartial manner. Certification bodies are assessed by UKAS in accordance with ISO 17065 and ISO 17067 (for product certification). It is important to note that ISO 17065 is not a standard against which a product or service can be certified, it is a standard that applies to Certification Bodies for their certification activity in general. ISO 17065 considers many aspects of Certification Bodies' operation to include:

- The legal form of the Certification Body;
- How it manages and ensures impartiality;
- How it finances itself and its liabilities;
- Confidentiality;
- Management structure and resources;
- Competence of the personnel involved in certification; and
- Independence of the certification decision from the evaluation audit.

3.4.3 Auditing

Audit and verification of installations is sometimes used in mature industries where there is a specific safety issue or desire to understand safety of installations across the sector. We understand that auditing of battery storage installations is at an early stage, for example MIS 30012 is in the pilot stage of certification by the certification bodies NAPIT and NICEIC. We are not aware of any audits of UK storage installations to date which focus on H&S aspects.

In the future, auditing activities similar to those conducted by BRE for Solar PV in 2017 could also be expected for EESS. This audit was conducted when the UK had approximately 11 GW of solar PV installations, with an increase of 24% in the previous year[3].

3.4.4 Training

Training is a crucial element of the standards landscape to ensure effective compliance with standards. This includes training of manufacturers and installers on compliance with standards and certification bodies for verifying compliance. Some manufacturers of Li-ion storage have their own training for installers, however there is a lack of a common approach to training across different EESS technologies and development scales.

3.4.5 Oversight

Appropriate oversight of standards development is key to creation and update of standards to meet the emerging needs of the sector. British standardisation is led by BSI as the national standards body with the support of standards committees. The interface between some of the key British committees and their international counterparts, such as IEC TC 120 and ESL/120, is shown in Figure 5 Interface between British and international standards committees.

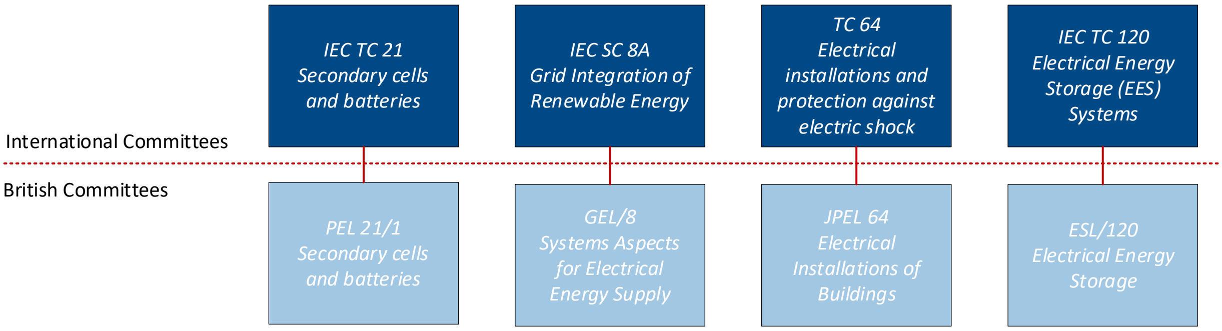

Figure 5 Interface between British and international standards committees

3.5 Options for Standards Creation

Standards bodies, such as BSI and the IET, offer a number of routes for the creation of new standards. The first stage in any such route is to determine the need for a standard, normally through consultation with industry stakeholders and subject matter experts – this task has formed part of our efforts during this project. This consultation stage must establish confidence that the relevant body understands the current landscape of stakeholder needs, market trends and currently available standards.

A standards development process can be time- and resource-intensive, and require close collaboration between industry, standards organisations and Government. Once a need for standardisation has been established a number of options are available, including:

- **Formal standardisation:** this may take the form of a British Standard, and provides the opportunity to feed into international standards e.g. ISO/IEC. This type of standard takes longer to develop – normally 18+ months – and normally involves the creation of an assessment or certification process to allow users to claim compliance with the standard. It can be difficult to reach consensus for standards creation in industry sectors which are rapidly developing, as is the case with some energy storage technologies, as knowledge and best practice are not yet established.

[3] BRE produced a report in 2017 on the fire safety of solar PV installations: https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/fireproject/P100874-1006-D6-Interim-Report---Recommendations-for-PV-Ind-Feb-2017-Issue-2.5.pdf

- **Code of practice:** these are guidance published for practitioners in a field, often published by technical bodies such as the IET. They intend to capture consensus on best practice in emerging and established fields.
- **Publically Available Specification (PAS):** this is a sponsored standardisation mechanism, intended to allow rapid publication for the purpose of addressing standardisation needs in developing markets. PASs can also be used as a means of exporting UK knowledge internationally. A current example of this mechanism is the three PASs BSI intend to publish from the Faraday Battery Challenge on research and innovation in production, use and recycling of electric vehicle batteries, of which two are now in public consultation [37].
- **Flex standard:** this option is similar to a PAS, but intended to be more iterative and faster to publish. It is a relatively new method, which has been piloted with government agencies but not yet widely deployed.

4 Hazard and at-Risk Activity Analysis

This section presents the relevant hazards associated with various energy storage technologies which could lead to a health and safety risk. For this project we have adopted a broad definition for an H&S risk related to an Electrical Energy Storage (EES) system. This is:

> *'Any hazard caused by the energy storage system which could lead to the risk of injury or loss of life to any stakeholder who is interacting with the system across its lifecycle'.*

The hazards identified within this section will form an input to later standards gap analysis.

The following section will outline the approach used to identify hazards, associated initiating events (IEs), and mechanisms for mitigating these hazards/IEs for the energy storage technologies within scope of this work.

4.1 H&S Assessment Framework

We have used a consistent framework for assessing H&S Hazards, associated causes and mitigation approaches. This framework separates out the following considerations:

- **H&S Consequence** – which is the ultimate consequence(s) that the H&S regime should be designed to minimise (as per the definition stated above)
- **H&S Hazard** – The effects that the EES may emit or cause, which could potentially lead to a H&S Consequence
- **Initiating Event** – understanding which events may lead to the creation of an H&S Hazard. These events may be external to the storage system (e.g. faults which the EES contributes to or which cause a fault within the EES) or internal to the EES (i.e. internal system failures which then lead to a hazard).
- **Control Actions** – The relevant controls that could be put in place to reduce the probability of a Hazard (or Initiating Event) occurring4.
- **Mitigation Actions** – The mitigations that could be put in place to mitigate the consequences of an H&S Hazard (e.g. an alarm or mechanical casing for fault containment).

[4] This could be a physical system or a process detailing installation best practice when installing an electrical installation in a domestic setting or at grid level, a particular standard that details how to install electrical systems safely in specific scenarios.

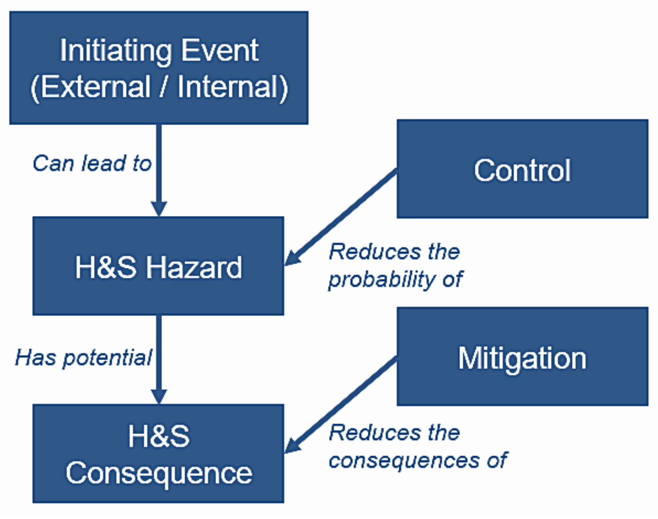

Figure 6 Framework for capturing H&S consequences of an external / internal event at a particular point in the lifecycle.

The various elements which make up this were identified through a review of appropriate literature and in-house analysis by Frazer-Nash. Through our analysis, we have focused on hazards likely to pose an H&S risk as defined above (i.e. those which could directly or indirectly lead to injury or loss of life). However it should be emphasised that with appropriate controls and mitigations in place, the probability of many of these hazards occurring may be significantly reduced.

A detailed analysis for each energy storage technology is presented in a tabular format. Whilst efforts have been made to conduct a thorough analysis, the list of potential hazards, initiating events and control and mitigation activities (in particular) should not be considered exhaustive. However based on our review, we believe these provide suitable coverage in order to test the comprehensiveness of standards and guide documentation.

To provide a relative measure of the coverage of the hazards across the standards landscape, each hazard is presented with an assigned Red-Amber-Green (RAG) categorisation. This is a subjective measure but based on the authors' judgement of the risk the hazard poses and the understanding of that hazard (and hence chance of mitigation) within the current standards framework. Table 4 outlines the rating criteria used for assignment of a RAG category. The following sections also provide further discussion on how relevant hazards are reflected in the standards landscape.

Table 4: Hazard RAG rating criteria

Hazard RAG rating	Rating criteria
Red	There is a clear gap within the current standards landscape related to this hazard.
Green-Amber	The hazard is recognised and mitigations exist within the current standards landscape however there is some residual risk and opportunity for improvement (e.g. more specific or prescriptive specification of controls/mitigations or testing and better navigability).
Green	Hazard adequately covered within current standards landscape[5].

[5] This is either because technology specific standards are mature and cover the hazard adequately or the hazard is well covered by more general guidance (as may be the case for less mature technologies).

4.2 Battery Storage

The hazards associated with battery systems at many deployment levels are generally well understood. There is long standing industry experience using conventional battery chemistries such as lead acid, with more recent research studies detailing the hazards and mitigations associated with chemistries such as Li Ion.

The key hazards and their potential causes are described within Table 5. It is recognised that some initiating events will be specific to different battery chemistries and also that manufacturer variants of these chemistries which will further shape their specific response. The section 4.2.1 through to 4.2.8 provide further detail of our review and supporting justification for the RAG rating.

The power converters which connect the batteries to the electrical system are not considered in detail within this report. However it is recognised that the failure of such equipment (for example through the shorting of a power converter switch or the failure of an electrolytic capacitor) may be the cause of the type of hazard described in Table 5.

Table 5: Identified hazards associated with battery storage technologies

H&S Hazard	Initiating Event	Hazard RAG rating
Electric shock[6]	▸ Electrical short circuit (e.g. loose connection to a casing) ▸ Rise of earth potential (e.g. due to ineffective system earthing) ▸ Accidental contact during installation, inspection, maintenance ▸ Network backfeeding (i.e. incorrectly supplying the electrical network during an outage)	Green Amber
Exposure to extreme heat, acoustic noise, pressure or light (e.g. hazards associated with an arc flash/blast)[7]	▸ Arc flash (primarily on the DC side) caused by accidental contact, corrosion, dropped tools, incorrect work procedures etc. A plasma arc is established from current flowing through ionised air and can rapidly lead to extreme temperatures (enough to explosively vaporise conductive metals) and light. ▸ Arc blast can follow the arc flash through the instantaneous expansion of gas at the point of fault.	Red
Injury caused by movement of cables/components through electro-mechanical stresses	▸ Electromagnetic forces are induced in conductors by the currents flowing through them. Where such electromagnetic forces interact on parallel conductors, they cause stresses which have to be taken into account. The force is proportional to current magnitude and is therefore largest during high current discharge events such as electrical faults.	Green
Hazards associated with manual	▸ Lifting, placement of battery systems	Green

[6] https://www.worksafe.qld.gov.au/injury-prevention-safety/electricity/installing-battery-energy-storage-systems-bess

[7] Rosewater, Williams, "Analyzing system safety in lithium-ion grid energy storage", Journal of Power Sources, http://dx.doi.org/10.1016/j.jpowsour.2015.09.068

H&S Hazard	Initiating Event	Hazard RAG rating
handling, movement of equipment etc.	▸ Failure of shelving/enclosure ▸ Seismic activity (limited issue in the UK)	
Fire[8,9,10,11]	▸ The thermal runaway of the batteries. ▸ A short-circuit event of the internal electrodes, which leads to thermal runaway. ▸ Overvoltage/overcharge, which builds internal pressure, eventually venting explosive gasses for some chemistries and housing types. ▸ External electrical short circuit potentially leading to high discharge current (e.g. due to degraded insulation, mechanical damage, incorrect wiring) ▸ Sustained electrical arc fault leading to ignition of cable or surrounding material ▸ Excessively high discharge demand on the battery system (e.g. during testing or use for fast discharge services beyond those which designed for) ▸ Build up and ignition of flammable gases through normal operation (e.g. continuous release of hydrogen from vented batteries) ▸ Inadequate management of operating environment (e.g. temperature, humidity, dust and particulate matter) ▸ Cascading failure/thermal effects from adjacent battery cells within pack ▸ Exposure to external flame/surrounding fire ▸ Emergency services unable to respond effectively if unaware of presence/size/type of system	Green-Amber
Explosive hazards (explosive gas or battery rupture hazard)	▸ Thermal runaway leading to the release of explosive gases (e.g. Li-ion releases hydrogen during faulted conditions) ▸ Build up and ignition of flammable gases through normal operation (e.g. continuous release of hydrogen from vented batteries)	Green-Amber

[8] FM Global, Flammability Characterisation of Lithium-ion Batteries in Bulk Storage, March 2013 https://www.fmglobal.com.au/research-and-resources/research-and-testing/~/media/E40FF1B5489341AB92DA8DFD818EF663.ashx
[9] Hazard Assessment of Lithium Ion Battery Energy Storage Systems, https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFFireHazardAssessmentLithiumIonBattery.ashx
[10] Sriramulu, Suresh, and Stringfellow, Richard. Internal Short Circuits in Lithium-Ion Cells for PHEVs. United States: N. p., 2013. Web. doi:10.2172/1124078.
[11] A Review on the Thermal Hazards of the Lithium-Ion Battery and the Corresponding Countermeasures, https://www.mdpi.com/2076-3417/9/12/2483/pdf-vor

H&S Hazard	Initiating Event	Hazard RAG rating
	▸ Release of flammable gases due to overcharging ▸ Cascading failure/thermal effects from adjacent battery cells within pack ▸ Exposure to external flame/surrounding fire ▸ Cascading failure/thermal effects from adjacent battery cells within pack ▸ Exposure to external flame/surrounding fire	
Exposure to harmful chemicals or substances[12]	▸ Maintenance, disposal or recycling of certain battery types (e.g. containing mercury, lead, cadmium, vanadium) ▸ Leakage or maintenance of electrolyte (e.g. acid electrolyte is caustic)	Green
Exposure to vented gases[13]	▸ Vented hydrogen gas from battery during charging could lead to oxygen-deficient environment ▸ Vented toxic gas due to battery overcharging or exposure to fault conditions	Green-Amber

4.2.1 Electric Shock

The wiring regulations BS 7671 provide comprehensive information on the electrical installation of battery systems in relation to aspects such as wiring, earthing arrangements and electrical protection. The measures outlined should prevent users from electric shock hazards and provide protection under fault conditions. Furthermore, other installation and design standards (e.g. IEC 60364-4-41 for installations in general and IEC 62485 for batteries in particular) make provisions to install insulating barriers to prevent accidental contact during inspection or maintenance activities. These measures are similarly reflected in installation standard MIS 3012 and the IET EESS COP.

It is noted that multiple electrical installation standards do exist. These are IEC 62933 and IEC 62485 in addition to the mandatory BS 7671. The overlap in scope of these standards may lead to divergence over time and navigability issues.

It was also noted that there is currently a lack of standardization around DC protection technologies beyond fuses for domestic installations (e.g. circuit breakers, residual current devices (RCDs))[14]. Further work may be required to determine the suitability of protection devices, particularly where employed in more extensive DC networks.

4.2.2 Arc Flash

AS/NZS 5139:2019 [38] defines arc flash as an "*electrical explosion or discharge, which occurs between electrified conductors during a fault or short circuit condition*". It further states that "*Arc flash occurs when electrical current*

[12] Functional and Safety Guide for Battery Management System (BMS) assessment and certification, http://bureauveritas-evenements.com/bms/GuideBMS2014pagessepareesv11.pdf

[13] Larsson, F., Andersson, P., Blomqvist, P. et al. Toxic fluoride gas emissions from lithium-ion battery fires. Sci Rep 7, 10018 (2017). https://doi.org/10.1038/s41598-017-09784-z

[14] It is noted that draft standard BS EN IEC 60755-2 does specify general safety requirements for RCDs however this has yet to be formally published.

passes through the air between electrified conductors when there is insufficient isolation or insulation to withstand the applied voltage."

Battery systems present a potential source of arc flash energy, particularly for electrical faults on the DC side (i.e. prior to conversion to the AC distribution grid). The associated risk increases proportionately to the installed capacity. Whilst the arc flash risk is relatively well understood for AC systems, in large industrial settings, the deployment of energy storage is creating the potential for this risk to occur in new smaller scale installation environments. Hence there is potential lack of experience for managing this at low voltage (LV) scales. This is coupled with a lack of standards, given there is no agreed UK standard for the assessment of DC arc flash risk.

A more detailed description of arc flash risk and the international standards landscape is provided within Annex A.

4.2.3 Electro-mechanical stresses on cables

This phenomena is not typically recognised as a hazard associated specifically with energy storage but it is relevant for all installations with potentially high discharge current.

It is noted that BS 7671 contains provisions for managing electromechanical stresses, with specification of cable cleats (used to restrain cables) covered by IEC 61914. For larger installations requiring detailed understanding of electromagnetic forces, standards such BS EN 61660-2:1997 describe methods for calculating the effects. Therefore it is considered that standards adequately cover this potential hazard.

4.2.4 Hazards associated with manual handling and movement equipment

It is considered that hazards associated with the weight and stability of a battery system are relatively predictable. Good installation practice should mitigate any severe consequences. To support this installation standards such as MCS MIS 3012 Issue 0.1 provide specific guidance.

4.2.5 Fire

Fire is a key hazard associated with battery systems if manufactured, installed, operated or maintained incorrectly (Li Ion in particular) and Table 5 identifies a range of possible initiating events.

The potential for a battery fire is well known and this is reflected in a range of research studies considering causes of fire, battery tolerance and potential mitigations. It is noted that there are various UK applicable IEC/ISO design standards that specify design practices and testing to minimise occurrence of failure modes such as thermal runaway which could lead to fire.

From the USA, various UL standards (discussed in section 3.3) and NFPA standards 855 and 850 standards provide detailed and prescriptive requirements around fire mitigation including details of the installation environment (e.g. distance from combustible materials), required testing (also referencing UL9540A). Australian standard AS/NZS 5139:2019 also provides specific requirements or constraints associated with the installation environment or the necessity for enclosures to provide fire containment (both internal and external). This specific guidance is not provided in UK standards highlighting a potential gap.

As part of the electrical installation, there are potential risks around sustained electrical arcing related to the fault current infeed from energy storage systems. This is an area which would benefit from further research outwith this project.

Discussions with UK fire service stakeholders have highlighted concerns around requirements for notification of energy storage system installations. There is currently no national guidance on the types or sizes of system which should be notified to fire services, which may result in increased risk to firefighters or other first responders at incidents where energy storage hazards are involved. This issue could potentially be mitigated through an update to the Building Regulations providing guidance on which types and sizes of system should be reported to local emergency services, the items of information required, and the method by which this should be accomplished.

There is also no widely-adopted policy on the methods or tools fire services should use to tackle storage system fires, presenting a risk that fire services may be unsure of the risks involved at incidents involving energy storage systems of which they are aware. This is also the case for some other emerging technologies, such as solar PV where there is also little guidance on firefighting methods. A potential mitigation for this issue could be an update to the National Fire Chiefs Council (NFCC) National Operation Guidance (NOG) – a wide-ranging resource which provides information for fire chiefs and incident commanders on dealing with incidents. This resource could be updated to provide information on potential energy storage hazards, such as lithium-ion battery fires, to provide firefighters greater flexibility to select the most suitable approach to a given incident.

4.2.6 Explosive Hazards

Explosive hazards are considered an extension of the fire hazard, with similar potential initiating events but leading to more extreme consequences. There are potential gaps on the necessity for enclosures to contain explosive battery events[15].

Potential causes of explosion due to vented gases are discussed in section 4.2.8.

4.2.7 Exposure to harmful chemicals or substances

This hazard mainly relates to contact with battery electrolyte, with this most likely to occur during maintenance of electrolyte (although only for certain chemistries) or through transport, recycling (e.g. for reuse) or disposal.

It is considered that these hazards are well reflected and mitigated within current standards. For example:

- BS EN IEC 62485 2 details risks protective measures associated with handling and maintaining electrolyte.
- BS EN 62281 covers transport risks for Li Ion, and UN38.3 specifies test which must be conducted to demonstrate safe storage during transportation.
- BS EN 61429:1997 covers marking of secondary cells and batteries for disposal purposes
- BS EN IEC 62932-2-2:2020 provides specific guidance around the hazards associated with flow batteries

It is noted that there is limited standardisation around battery reuse/second life (either being design for second life or the process for recycling a battery), and this represents one scenario for greater exposure to the battery electrolyte. The impact of second life battery use on the risk profile is discussed in greater detail within section 4.2.9.

4.2.8 Exposure to vented gases

For conventional battery chemistries, with the release of gas during normal operation, the management of vented hydrogen gas for flooded cell types (vented lead acid, VRLA, NiCd) is well specified in IEC 62485-2.

There are specific requirements internationally (e.g. from NFPA 855/International Fire Code) on ventilation for Li Ion which can vent gases under certain failure conditions such as thermal runaway. However current UK standards do not provide clear guidance on ventilation for Li Ion[16]. This will primarily impact allowed installation location for domestic installations.

[15] IEC 62485 (e.g. the draft part 5 for Li Ion) requires that protection from hazards generated by the battery (such as fire and explosion) and protection from external hazards be assessed as part of the overall accommodation of the battery system. It also highlights that the enclosure may provide these protections however it is not a requirement. There is also no guidance on how to assess the severity of these hazards and design accommodation/enclosures accordingly.

[16] For example, BS 7671, the IET EESS COP and the MCS installation guide only specify that 'appropriate ventilation' for a given battery chemistry is provided without further guidance.

4.2.9 Second life application of batteries

'Second life' batteries typically refers to the repurposing of electric vehicle batteries once they no longer meet EV performance standards[17]. This may see EV batteries being refurbished and used within stationary energy storage applications within an alternative configuration, alongside other batteries.

Given the increasing uptake in EVs, and hence the eventual surplus of batteries for this application, the potential market for second life batteries is substantial. Whilst they could be deployed in the same applications as new batteries, key use cases for second life batteries are at large industrial and grid scale for purposes such as maintaining grid stability or deferring transmission and distribution investments [39].

The use of repurposed batteries introduces a number of performance and safety considerations. Table 6 presents a sample of these based on our analysis. The table highlights that the primary risks are around understanding the age and condition of a battery when deployed in a new environment. These factors have a large impact on the probability of the key hazards (outlined previously) occurring.

From a standards perspective, the US standard UL 1974 (introduced in section 3.3.2) details methods of evaluating batteries which are intended for use in another application. This standard requires the repurposed battery to meet the safety requirements of its new application and as such may require the recertification of battery systems. It is noted that similar standards do not currently exist in the UK and this represents a potential gap in the standards landscape. PAS 7061, currently undergoing approval by BSI, will seek to address re-use and disposal of electric vehicle batteries, and could act as a starting point for standardisation of these activities in EESS.

The UN 38.3 global standard defines a set of tests for lithium based batteries in order for them to be transported. This standard may require testing of repurposed batteries (or a representative set of batteries) to ensure they can be safely transported.

Table 6: Potential H&S issues associated with the use of second life batteries

Potential Issues	Potential Effects
Battery has been damaged through prior use	Potential accelerator of multiple failure modes.
Installed batteries are older and hence installed in a degraded state compared to new batteries	Battery aging may increase probability of thermal hazards occurring (e.g. thermal runaway)[18]
Combined batteries may be different ages and hence have different levels of degradation.	Older batteries may form a 'weak link'. Their failure may lead to propagation of failure effects (e.g. fire).
	The level of degradation can affect a batteries peak voltage level and voltage through state of charge. This can make it more difficult to balance cells. This creates a potential risk of overcharging for older cell types, with the associated impacts of vented gases.
Combined batteries may be from different manufacturers or have different chemistries	Different chemistries will have different performance and safe operating limits and associated hazards. Combining chemistries makes this more difficult to manage.
	Different chemistries may pose control challenges.
	Opportunity for mixing of maintenance tools (particularly an issue for flooded cells)
The demands and safety requirements of the new	Issues depend on application.

[17] Often including maintaining 80% of the total usable capacity.

[18] For example, for Li Ion batteries aging issues include: a) Increased electrode Li plating, potentially leading to micro-shorting and eventually thermal runaway; and b) the solid electrolyte interface layer will gradually increase with the age of the battery, increasing battery resistance and heat generation [55].

Potential Issues	Potential Effects
application may be different.	Applications with a higher duty cycle could see accelerated aging of the battery, with associated acceleration of risk factors, need for increased cooling, ventilation etc.

4.3 Supercapacitor Storage

Many of the hazards introduced by supercapacitor systems are similar to those presented by battery systems, albeit with a potentially different risk profile. The electrical response(s) of a supercapacitor/s are similar to batteries given their ability to rapidly discharge their stored energy. Therefore hazards related to this electrical response (electric shock, arc flash, cable movement) have parallels to battery systems.

Supercapacitor systems also have the potential to pose hazards such as fire, explosion, exposure to harmful chemicals or substances or exposure to toxic gases. The potential causes of these hazards are described in Table 7.

Table 7: Identified hazards associated with supercapacitor storage technology

H&S Hazard	Initiating Event	Hazard RAG rating
Fire	‣ The internal components of a supercapacitor can be flammable and may be ignited if a rupture occurs and they are exposed to an ignition source or if subjected to direct flame.	Green-Amber
Explosion	‣ Sealed supercapacitor devices involved in a fire may rupture explosively if heated for a sufficiently long period of time. ‣ When incinerating the supercapacitor can explode unless it is crushed or punctured prior to incineration	Green-Amber
Exposure to harmful chemicals or substances	‣ Some electrolyte material can be hazardous. If the supercapacitor is ruptured or otherwise opened in a way that will release the internal components or produce fumes, exposure to these components is possible.	Green
Exposure to toxic gases	‣ Overcharging may cause a supercapacitor to vent which could then cause a release of these toxic fumes.	Green
	‣ The plastic (poly vinyl chloride) sleeving of supercapacitors can produce chlorine gas if incinerated at lower temperatures.	Green
	‣ If involved in a fire, the materials contained in supercapacitors may thermally decompose and produce toxic gases (e.g. nitrogen oxides, carbon oxides, hydrogen cyanide, hydrogen fluoride and other fluoride and boron compounds).	Green-Amber

Based on our review of standards related to supercapacitors, it is noted that general capacitor device level design and test standards exist detailing device requirements (the BS EN 62391), which should minimise the failure of designed components. Some application specific standards exist (hybrid electric vehicles (BS EN IEC 62576:2018) and railway applications (BS EN 61881-3)), but these do not cover grid applications. US standard UL 810A provides similar coverage and specifies design and testing requirements for supercapacitors used in electronic products, uninterruptible power supplies, emergency lighting, engine starting, and power equipment.

There is limited identification of specific hazards associated with supercapacitor systems within standards, however manufacturer guidance appears to cover these gaps[19,20].

Whilst there are a lack of specific supercapacitor standards for stationary applications, given that supercapacitors currently have limited use cases for large scale energy storage (although may form hybrid storage systems with alternative technologies), there appears to be limited demand for further standardisation currently.

4.4 Flywheels

Although relatively new for electrical grid energy storage, flywheel energy storage has existed in different forms for many years. Their construction involves the use of a heavy spinning mass (often steel or composite material) spinning at high speed, and consequences of failure can be severe if not appropriately mitigated through design and protection systems. SAND2015-10759 [40] describes a number of noteworthy failures over recent decades leading to the loss of life or injury of operators and severe building damage.

Given this previous experience, the associated hazards and controls and mitigations are relatively well understood. SAND2015-10759 provides an overview of hazards, initiating events and means of managing these events. These have been summarised in Table 8.

Table 8: Identified hazards associated with flywheels.

H&S Hazard	Initiating Event	Hazard RAG rating
Explosion risk (for flywheels with rotor made from composite material)	Vacuum leak and rotor burst in presence of oxygen. High temperatures caused by rotor rub (against housing), disintegration and cracking of the composite resin can lead to ignition of fire.	Green-Amber
Rotor break up and resulting flying debris	Stress due to centrifugal force at maximum operating speed, leading to rotor disintegration into multiple parts. This can subsequently lead to excess pressure and cracking of the flywheel housing. Overspeed may be due to a control system failure.	Green-Amber
Loose rotor event or entire rotor flying off	External load or seismic activity Internal mount and housing failure, bearing damage Overspeed condition (leading to internal housing failure)	Green-Amber
Fire	Flywheel systems use various flammable fluids/oils for lubrication and cooling etc. and there is the potential for these to leak. The flywheel itself under a failure condition (rotor contact with housing or breakup) or associated electrical equipment could spark and become an ignition source.	Green

There are relatively few specific flywheel systems standards which may guide a developer to mitigate these issues.

Within the USA, the SAND2015-10759 guide was developed in 2015 partly in response to the lack of associated standards. Flywheels now come under the broad remit of UL9540, with SAND2017-2352C [41] identifying that the

[19] Maxwell, Ultracapacitor Safety Data Sheet https://library.e.abb.com/public/5184a587e60d4f1ea541de4f4d3d676d/Maxwell%20Ultracap%20Safety_Datasheet_3000389_EN_2.pdf

[20] Eaton, Supercapacitor application guidelines, https://www.eaton.com/content/dam/eaton/products/electronic-components/resources/technical/eaton-supercapacitor-application-guidelines.pdf

SAND2015-10759 guide can be used in support of claiming the UL mark. The 2020 edition of NFPA 855 contains a placeholder chapter on flywheels, indicating an intention to develop of more specific standard in future. NFPA 850 does include a short section on flywheels, highlighting the aspects of its design and operation for which fire may be an issue.

Reference [42] outlines the codes and standards related to flywheel systems in the UK and EU. This source highlights that there is a lack of specific standards related to the deployment of flywheel storage systems, but various 'Safety of machinery' standards do cover aspects of the system design. Therefore a broad collection of standards need to be navigated to certify the flywheel system.

Whilst there appears to be limited demand for further standards in the UK currently, there is an opportunity to adopt practices from elsewhere and provide greater clarity on the installation requirements for flywheels.

4.5 Liquid Air Energy Storage

LAES systems are typically associated with grid scale storage deployment and as such it is expected that detailed hazard analysis would be conducted as part of a plants design and construction. Therefore our review has been limited to an assessment of broad industry guidance which could support the development of a plant specific safety case.

At a high level, LAES plants consist of three stages of design:

- The 'charge' stage, where air is liquefied through refrigeration;
- The storage stage, where liquefied air is stored as a cryogenic fluid (similar to liquid nitrogen); and,
- The discharge stage, where fluid is converted to high pressure and temperature gas and used to drive a turbine and associated electrical generator.

Such a design can be achieved through the integration of existing equipment used within other industry applications, as Highview Power highlight their use of as part of their LAES system description [43]. This in turn reduces design risk and provides existing H&S knowledge to draw upon.

The types of hazards presented by LAES systems will include those detailed in Table 9.

Table 9: Identified hazards associated with Liquid Air Energy Storage (LAES)

H&S Hazard	Initiating Event	Hazard RAG rating
Respiratory problems and asphyxiation	▸ Leakage of cryogenic fluid (only an issue in poorly ventilated areas)	Green
Cryogenic burns and Frostbite	▸ Leakage and contact with cryogenic fluid or contact with uninsulated piping, containers etc.	Green
Hypothermia	▸ Close proximity to liquefied gases	Green
Oxygen Enrichment and associated fire risks	▸ When transferring liquid nitrogen, oxygen in the air surrounding a cryogen containment system can dissolve and create an oxygen-enriched environment	Green
Pressure Build-up and Explosions	▸ Without adequate venting or pressure-relief devices on the containers or connecting pipes, large pressures can build upon cryogen evaporation.	Green
Rapid phase transition (RPT) explosion	▸ Explosive vaporisation of the cold liquid if it spills out and comes into contact with other hotter liquids (e.g. water)	Green

Whilst there are no specific LAES system H&S standards it is recognised that industry experience for similar applications provides a basis for H&S assessment of LAES systems. For example, the European Industrial Gases Association "Safe Practices Guide For Cryogenic Air Separation Plants" guidance document provides coverage of hazards related to air liquefaction and cryogenic fluid storage.

Furthermore, specific industry guidance around storage of cryogenic fluid is provided COP CP 36 by the British Compressed Gases Association[21], with more general requirements provided with the Pressure Systems Safety Regulations (PSSR) 2000.

Hazards associated with RPT explosion are recognised by HSE as a hazard for liquid hydrogen and has been observed with liquid natural gas (LNG) on water. However this hazard is considered relatively unlikely for an energy storage system.

These hazards are related to the potential risks associated with the storage of cryogenic fluids (which are the means of energy storage). The use and storage of cryogenic fluid, such as liquid nitrogen, is commonplace in industry, hospitals, laboratories etc. and so hazards are well understood and mitigated.

Reference [44] highlights that over a longer time period, there may be the opportunity to utilise liquid air for energy storage at a smaller scales. For example this could involve removal of the 'charge' phase described above, with cryogenic fluid instead being delivered to various premises for backup power. A smaller scale and more distributed model for LAES electricity storage and generation would require more robust standards than are currently defined.

4.6 Compressed Air Energy Storage

In a similar manner to LAES systems, CAES systems can be broken down into three main stages: charge (air compression), store (storage of compressed air) and discharge (release of compressed air to drive a turbine).

Whilst compressed air canisters are used within many applications, to get the gas volume required for bulk energy storage, CAES systems for electrical energy storage purposes are primarily underground. This variant of CAES system has formed the basis for our review.

As noted within section 2, there is industry experience for this type of application with plant in Germany [45] and the USA, storing compressed air with salt caverns. Both of these applications report strong H&S records. Reference [46] highlights that salt caverns have generally proven safe for natural gas storage (with over 141 facilities in Europe), however some accidents have been reported [47] (e.g. due to well failure).

Whilst salt caverns appear to represent the safest form of underground storage, the number of useable sites is limited. Potential alternatives include Depleted Natural Gas Reservoirs [48] and abandoned coal mines [46]. Each of these sites present unique hazards, key examples of which are summarised within Table 10. The table focuses on underground deployments such as salt caverns, coal mines or depleted gas reservoirs, and excludes hazards related to air compression and turbine operation as these are considered to be well understood in industry.

[21] https://www.thenbs.com/PublicationIndex/documents/details?Pub=BCGA&DocID=303653

Table 10: Identified hazards associated with Compressed Air Energy Storage (CAES)

H&S Hazard	Initiating Event	Hazard RAG rating
Underground fires (with potential for surface breach)	- Residual gas (including gas generated in salt caverns) or coal in cavern could ignite. - Ignition source include heat from compressed air, static or piezo electricity, or lightning.	Green-Amber
Impact on the integrity and stability of soil and rock	- Former mining operation at various depths causes cracks/fissures and fractures in the over and interlaying strata. These may be further impacted with storage of pressurised gas and can result in air leakage or infiltration of water.	Green-Amber
Coal mines flooding	- Water inflow may impact available volume and moisture content of air.	Green-Amber

Through our review, we did not identify any specific standards framework apparent to CAES applications beyond the more generally regulations such as PSSR 2000, its related code of practice "Safety of pressure systems"[22] and guidance notes on "Compressed air safety"[23]. It is noted that there is operational experience and associated standards related to the storage of gas underground (as described within [49]) which may have relevance for this application. However given the relative immaturity of this application, and the diversity of possible locations, there does not appear to be an immediate need for standards development in this areas.

4.7 Superconducting magnetic energy storage

As a novel technology, detailed information on hazards associated with SMES systems is relatively limited. From our review we identified one key reference investigating the potential safety considerations of SMES systems. Polk et al [50] explored the potential issue of the biological effects of long term and acute exposure to the strong magnetic fields associated with the SMES units but concluded that H&S issues were unlikely given the limited close interaction personnel would have with the system.

It is recognised that there are parallels between the operation of SMES systems and the H&S concerns of the medical sector in the use of MRI scanners (which utilise cryogenically cooled superconducting materials to create strong electromagnets). Hazards associated with such applications are described in [51]. Hazards and initiating events are summarised in Table 11.

Table 11: Identified hazards associated with Superconducting Magnetic Energy Storage (SMES)

H&S Hazard	Initiating Event	Hazard RAG rating
Attraction of ferromagnetic objects	- Small ferromagnetic objects could become projectiles and larger could objects move within a certain proximity to the SMES device.	- Green-Amber
- Interference with medical devices (e.g. pacemakers)	- A strong magnetic field can affect the operation of electronics. The field strength experienced is proportional to the distance from the SMES. Therefore a hazard could be triggered by personnel moving within a certain distance of the SMES storage unit.	Green

[22] https://www.hse.gov.uk/pubns/priced/l122.pdf
[23] https://www.hse.gov.uk/pubns/priced/hsg39.pdf

Exposure to cold venting gas to surrounding area	During spontaneous or emergency shutdown, the superconducting material to quench and result in the heating and expansion of cryogenic coolant into gas. This must be vented very rapidly.	Green
Impact of exposure to magnetic fields on personnel	Potential impacts on personnel from acute and long term exposure to magnetic fields. There are established biological effects from acute exposure at high levels (well above 100 µT).	Green
Hazards associated with storage and use of cryogen material	See LAES systems for cryogenic storage hazards (Table 9).	Green

Whilst the risks posed by the hazards in Table 11 will be application specific, we do not consider that these will pose specific concerns for SMES systems provided good safety practice is followed. Many SMES systems will be substantially smaller than current MRI scanners, lessening the severity of their associated hazards e.g. amount of cryogenic material involved.

Through our review we did not identify any specific standards on SMES applications, although note that NPFA 855 contains a reserved chapter for SMES applications, indicating it may provide further guidance in subsequent versions.

5 H&S Standards Gap Analysis

Gaps in the standards landscape could occur in a number of different forms and from several sources. The landscape review that we have conducted and the independent hazard analysis that we have undertaken provide the evidence base from which gaps can be identified. Subsequent to this the team have used stakeholder interviews, and a workshop session with the SHS Governance Group to obtain feedback and provide confirmation or challenge on the identified gaps.

In a varied and complex standards landscape it has been important to take a structured approach to gap analysis. We have applied a consistent approach for identifying, articulating and testing the gaps. The sections below describe our approach and provide the identified gaps in both the technical standards and the framework of practice (see Section 3.4) which enables their application.

5.1 Approach for Gap Analysis

We have conducted a gap analysis of existing and in-development standards against H&S risks and use cases. Our approach to identification of gaps has been to:

1. Identify any H&S risks that are not clearly mitigated by existing or planned standards (see Section 4).
2. Review the existing standards landscape described in Section 3 against possible use cases - covering all development scales and lifecycle stages identified in Section 2.
3. Challenge and update hypotheses formed in steps 1 and 2 based on consultation with relevant industry stakeholders.

5.2 Gaps in Standards

By following this process we have identified a set of key gaps in the standards presented in Section 3 of this document (**Table 12**). The "urgency of action" column is coloured red where the majority of mitigation options should be undertaken immediately or in the next year, yellow where the majority of actions should be completed within 3 years, and green where the majority of the actions are expected to be completed beyond 3 years.

Table 12: Standards gap analysis results.

	Gap Description	Ease of Mitigation	Mitigation Options	Urgency of action
1	There is a lack of standards for immature technologies such as novel battery chemistries to address technology specific hazards, due to lack of operating experience with these systems.	**Difficult** - very limited expertise and relatively small current market -publishing standards is not a suitable solution due to lack of industry maturity.	• Appoint an industry body to facilitate development of a short general H&S guidance document targeted at novel technology developers	**Medium-term -** general H&S guidance should be developed for novel technology developers within 3 years.

	Gap Description	Ease of Mitigation	Mitigation Options	Urgency of action
2	There is no widely agreed product certification standard for Li-ion storage systems at any development scale. This is due to different approaches between major nations (particularly US and EU), evolving sector.	**Difficult** - some candidates available although international coordination is required.	• Consult domestic/commercial scale working group convened under gap 4. • Support international standardisation through TC 120.	**Medium - long term -** consultation can occur as soon as the relevant working group is assembled - within 3 years. International product standardisation is likely to take longer than 3 years.
3	There is no widely available standards or guidance for addressing DC arc flash for storage systems, due to relative inexperience with this hazard.	**Easier** - guidance can be adapted from other nations.	• Develop appendix of existing standard e.g. IET Code of Practice for Electrical Energy Storage Systems and reflect in other relevant electrical installation standards as appropriate.	**Immediate -** this can and should be addressed now.
4	The standards landscape is difficult to navigate for many use cases and technology types, with a number of overlapping and conflicting standards.	**Moderate** - additional guidance can be published but the area will remain complex.	• Appoint industry bodies to facilitate production of separate guidance for Li-ion storage at domestic/small commercial and industrial/grid scales. Facilitator should arrange separate working groups for each development scale, utilising existing working groups where possible.	**Short-term -** industry facilitators should be appointed within 6 months to begin developing guidance
5	UK standards are not as prescriptive as standards from other nations on key technical aspects including installation spacing, and capacity limits for Li-ion storage.	**Moderate** - new standards may help but individual corporate approaches may persist.	• Consult both working groups convened under gap 4 on mandating compliance with international standards such as IEC 62933-5-2:2020 or NFPA 855.	**Short-term** - the working groups should be consulted as soon as industry facilitators are appointed, within 12 months.

	Gap Description	Ease of Mitigation	Mitigation Options	Urgency of action
6	It is difficult to assess competency of installers of residential and small commercial energy storage systems and there is no common training across different systems.	**Moderate** - a range of different competencies are required depending on the technology type.	• Appoint an industry group to develop an installer competency framework for energy storage. This could focus initially on technologies with sufficient market demand.	**Medium-term -** ideally this should consider input from the audit of installations conducted under gap 10, likely to be after 12 months but within 3 years.
7	There is a lack of independent advice and support on H&S relevant risks, particularly for novel technologies.	**Difficult** - very limited expertise and relatively small current market.	• Recruit specialist resources in government bodies. *OR* • Provide funding for an industry body to devote specific resources for storage H&S advice.	**Medium-term -** specialist resources should be recruited to an industry or government body within 3 years.
8	There is currently no clear plan to ensure continued collaboration with European standardisation committees such as CENELEC following EU-Exit.	**Moderate** - some uncertainty remains.	• Task industry and standardisation bodies to understand knock on effects on EESS standardisation including mitigation options in this report.	**Short-term -** this should be addressed by the end of 2021.
9	There are no robust installation certification and certifier accreditation processes for energy storage at the domestic and small commercial scales.	**Difficult** - this will require consensus on an appropriate product standard.	• Fund training for certification and accreditation bodies on IET CoP for EES • Appoint an industry body to develop a roadmap for certification and accreditation.	**Short-Medium term -** training should proceed within the next 6 months. The roadmap should be conducted after gap 10 is addressed, within 3 years.
10	There are no sector-wide audit or verification results to understand the safety of installations.	**Moderate** - this requires significant expertise	• Contract an industry organisation to undertake a programme of audits across Li-ion storage installations.	**Short-term -** a relevant organisation should be appointed in the next 12 months.

	Gap Description	Ease of Mitigation	Mitigation Options	Urgency of action
11	There is a lack of guidance on notification of energy storage system installations to fire services, or on fighting of li-ion system fires	**Difficult –** would require consensus across multiple groups on reporting methods, and updates to guidance / regulations	• Convene a working group of fire services experts and hold separate meetings with the domestic/small commercial and industrial/grid-scale working groups convened under gap 4. These meetings should discuss notification and fire-fighting requirements. • Incorporate notification requirements into building regulations • Update fire service guidance (e.g. UKFRS National Operational Guidance) to cover energy storage hazards	**Short to Medium term -** a working group can be convened in the next 6 months. Updated guidance and regulations will require engagement but should be completed within 3 years.

5.3 GAP 1: Immature Technology Standards

We have assessed that there is a gap in standards for some novel energy storage technologies based on a review of available energy storage standards, hazard analysis for each technology completed in Section 4 and engagement with manufacturers of novel storage technologies.

5.3.1 Evidence for the Gap

The current standards assessed are understandably focussed on technologies that are undergoing rapid commercialisation and that have reached maturity as described in Table 2. This is because the expertise and investment levels for these technologies support the ability to reach industry consensus and technology adoption levels have grown to levels where there is potentially significant risk to society. These trends result in standards that address Li-ion hazards in detail, e.g. NFPA 855 for Li-ion storage, and others that are focussed on hazards that relate to Li-ion storage - e.g. UL 9540A covering thermal runaway. More generic standards tend to focus on risks common to different storage types (e.g. electric shock) as well as specific risks for mature technologies. These standards include the IET code of practice for electrical energy storage systems and the recently released IEC-62933-5-2 which is specific to electrochemical storage systems.

Our analysis of the hazards of different storage systems shows that different technologies pose significantly different hazards. For example, flywheel storage can pose a rotor breakup risk and some battery storage technologies can result in risks of exposure to vented gases. This means that if a novel version of these technologies is proposed, these hazards will need to be carefully assessed.

The stakeholder engagement completed supports this desktop analysis. Specifically, manufacturers of novel mechanical and electrochemical storage have commented on the lack of standards for design, manufacture and installation relating to the novel elements of their technology. This might include the chemical hazards presented by a new battery storage technology or the mechanical hazards posed by a new gravitational or flywheel storage system. This gap is related to gap 7 described below.

5.3.2 Mitigation options and timeline

We recommend appointing a standardisation organisation or industry body to publish generic guidance for new technology developers, covering the conventional processes for designing, manufacturing and installing safe systems, for example HAZID and HAZOP processes. This guidance should indicate related useful standards such as IEC 62933-5-2:2020 or UL 9540 that could be used to assess safety of systems. Our stakeholder engagement has indicated that novel technologies are typically implemented at industrial scales in most cases initially. Therefore we suggest using the same facilitating body as for the industrial/grid-scale Li-ion storage navigability guidance (see Section 5.6.2) if possible. However, we suggest a separate industry working group is arranged by the facilitating body, to include primarily manufacturers of novel storage technologies and research & development (R&D) facilities who provide guidance and analysis on novel storage. This could be an existing working group as applicable. Proposed or updated standards should consider all life cycle stages, including disposal and (where applicable) re-use.

In the medium to long term, this gap could be addressed in conjunction with Gap 7 by providing funding for a government or industry body that maintains this guidance and provides specific advice as necessary. It is recognised that this may pose a challenge, as there is currently limited international precedent for such a body providing general H&S guidance for EESS.

5.4 GAP 2: LI-ION Product Certification

As Li-ion storage systems have been rapidly deployed, there is a growing demand for product certification standards among installers and developers. This is driven by the need to ensure safety of systems while deploying increasing numbers from a multitude of manufacturers. A product standard also supports robust auditing and verification of systems by installation certifying bodies.

5.4.1 Evidence for the Gap

Our review of the standards landscape has shown that there is no widely accepted product certification standard for Li-ion storage. This has been validated by engagement with manufacturers and developers, who often have their own internal processes for validating system safety. Some of these processes conduct testing of cells with reference international standards such as BS EN 62620:2015, however there is no widely agreed testing standard.

5.4.2 Mitigation options and timeline

Initially, the working group appointed to support development of guidance for domestic Li-ion storage could consider whether there is a suitable current or future standard for product certification purposes. This could be at any system level, for example cell, module, rack or system. A product certification standard is only likely to be viable if it is implemented in a significant number of nations globally. This is supported by our engagement with manufacturers who state a desire for a consistent standard internationally. Therefore, British efforts to support development of a product certification standard should focus on support to international standards committees such as TC 21 and TC 120. However, this consensus is likely a number of years away based on the complexity of storage systems and experience from other sectors such as Solar PV where design type approval standards such as BS EN 61215-1:2016 took 10-20 years to reach maturity.

5.5 GAP 3: DC ARC Flash

Our hazards analysis, review of standards from other nations and stakeholder engagement has revealed a gap in UK-specific standards relating to DC arc flash.

5.5.1 Evidence for the Gap

The phenomenon of DC arc flash is described in Section 4.2.2 and detailed in Annex A. The risk of DC arc flash increases with the installed capacity of systems. Our review of standards indicated that while there were standards internationally such as AS/NZS 5139:2019 that address DC arc flash, there are no UK-specific standards or guidance.

5.5.2 Mitigation options and timeline

Our stakeholder engagement investigated the opportunity to provide an annex to the IET code of practice for EESS. We have submitted a draft for this annex to the IET code of practice for EESS and it is currently under review. Relevant standardisation bodies and international standards committees (including the IET and TC120) should be consulted to investigate the need to formalise the same methodologies within other standards.

5.6 GAP 4: Navigability of the Standards Landscape

The standards landscape for EESS is complex and can be difficult to navigate, as shown in Section 3.

5.6.1 Evidence for the Gap

For rapidly commercialising technologies the standards landscape is naturally in a state of flux, with new standards emerging and existing standards regularly updated. This is supported by the release of new international standards that cover all development scales, for example IEC 62933-5-2, and local installation standards such as MIS 3012 in the past year. A second edition of the IET code of practice for EESS will also be published soon. On top of new and updated standards, there are also multiple available standards that address specific battery storage hazards, described in detail section 4.2. For example, there may be overlapping requirements between the four standards which cover electrical installation – IEC 62933, IEC 62485, IEC 60364 and BS 7671. This complexity has been validated through engagement with industry stakeholders including manufacturers, installers and standards organisations. The SHS Governance Group has also validated the difficulty of navigating the standards landscape for different technologies and use cases.

5.6.2 Mitigation options and timeline

While the landscape will continue to evolve, we believe it would be helpful to have supporting guidance for manufacturers and installers of storage systems. Due to the rapid commercialisation of Li-ion, we believe it would be most appropriate to develop guidance for this technology first, with one document for the domestic and small commercial scale, and a separate document for the industrial and grid scales. The rationale for having these two different documents is the grouping of standards and organisations at these scales. For example, the IET code of practice for EESS covers smaller systems with lower voltage levels (typical of domestic and small commercial systems), while MCS intends to accredit installers against these smaller installations. On the other hand, grid-scale developments typically follow safety processes defined by the project developer organisation, in some cases following standards from other nations such as NFPA 855 and UL 9540A.

We suggest that the domestic/small commercial guidance provides relevant signposting to key design and installation standards (at least the IET code of practice for EEES and MIS3012), relevant H&S legislation and key process steps and applicable organisations in an easily accessible format (1-5 pages). The primary audience of this document is intended to be installers of energy storage systems, with other interested parties include manufacturers, certifying bodies, accreditors and fire services.

For the industrial/grid-scale guidance, we recommend this covers a common set of principles for safe design, manufacture, installation, operation and disposal of grid-scale Li-ion systems. Where relevant, common standards should be signposted such as IEC 62933-5-2, UL 9540A and NFPA 855. The primary audience of this guidance is project developers, while other interested parties include manufacturers, safety consultants, H&S managers, the HSE and fire services.

For each guidance document we suggest a standards organisation or other industry body familiar with publishing similar guidance to facilitate the process. Supporting this facilitator should be separate working groups for domestic/small commercial and industrial/grid-scale systems. Where possible existing working groups should be used to build on previous work.

Due to the rapid development of the sector, we believe these mitigation options should be pursued as soon as possible in order to provide clarity, particularly to new entrants.

5.7 GAP 5: LI-ION Testing and Installation Standards

From our review of international standards and stakeholder engagement, we have found that there are more prescriptive standards for storage in other nations such as the U.S. Elements of these standards could be adopted in the UK for the full range of development scales.

5.7.1 Evidence for the Gap

The review of standards in Section3 highlights that particular nations have additional and more prescriptive national standards for storage safety. This includes NFPA 855 in the U.S. and AS 5139 in Australia. From engagement with manufacturers of Li-ion storage and developers of grid-scale projects, we have received feedback that NFPA 855 provides clearer requirements for technical parameters such as spacing of storage modules and capacity limits for systems in different environments than any international or British standards. Adoption of key elements of this standard in the UK may therefore be useful to encourage safe installation practices as the sector grows. Similarly for UL 9540A, which is referenced as a potential source (not a mandated standard) for large-scale fire testing methods in BS EN IEC 62933-5-2, provides clear requirements for testing of thermal runaway behaviour which is common in Li-ion systems. Wider compliance with this standard by manufacturers would provide a common set of key information to project developers on the potential fire risk and influence mitigation options.

We also received feedback from grid-scale storage developers that there is a lack of common principles between developers for safety processes. Some developers bring knowledge and expertise from safety-critical industries while smaller companies may not have these resources.

5.7.2 Mitigation options and timeline

We recommend that the same working groups appointed to produce domestic/small commercial and industrial/grid-scale navigability guidance as recommended in section 5.6.2 be consulted on mandated compliance with international and other national standards such as IEC 62933-5-2:2020, UL 9540A and NFPA 855. Based on the advice of the working groups, compliance could be then mandated through relevant mechanisms to each development scale. For example, building regulations could mandate a certain standard for systems of a certain size or future grant schemes could require this.

We understand from our standards review that the recently published IEC 62933-5-2:2020 refers to but does not require compliance with UL 9540A. The working groups should consider whether UL 9540A compliant testing for commissioning systems should be mandated.

We understand from engagement with storage manufacturers that AS/NZ 5139 has adopted key elements of the NFPA 855 standard. This means that creation of a British Standard to include elements of NFPA 855 is one available option. An alternative would be to engage with the NFPA to understand how the UK could mandate compliance with NFPA 855 directly. However, this would need to be carefully implemented such that the UK could have foresight of and input into future updates to NFPA 855.

5.8 GAP 6: Installer Competency Framework

We understand from our stakeholder engagement that with the rapid growth of the sector there are not yet clear requirements for competency of installers of storage systems.

5.8.1 Evidence for the Gap

From engagement with standardisation and trade bodies, we understand that installation of storage has not yet reached the maturity of other technologies such as solar PV. This means that requirements for competent installation of these systems is not yet clear. For example, MIS 3012 specifies the same installation competency requirements as for solar PV. Further engagement with manufacturers of Li-ion storage indicates that most manufacturers have their own training programs for installers. For larger manufacturers we engaged with, this includes an in person training day covering requirements for transportation and installation of storage systems. However, there is no common basis for this across the industry.

5.8.2 Mitigation options and timeline

We recommend that a competitive tender is undertaken to contract an industry organisation for development of the installer competency framework. The contractor will seek input from wider industry, particularly manufacturers and installers. This should include as a minimum the domestic Li-ion storage domestic/small commercial working group described in section 5.6.2.

5.9 GAP 7: Independent H&S Advice

Due to the fast pace of technological development and varying maturity of different storage technologies, there is a lack of independent advice for manufacturers, installers and project developers of storage systems, particularly for novel technologies.

5.9.1 Evidence for the Gap

From engagement with manufacturers of novel electrochemical and mechanical storage, we received feedback that there is a lack of independent advice on processes and standards to mitigate H&S risk of storage technologies. While standards are available for hazards and design elements that are common to different storage technologies, there is a lack of advice for addressing unique technological hazards. This typically reflects the lack of expertise for these unique hazards and the lack of investment in industry or government bodies to support technologies at low adoption levels.

5.9.2 Mitigation options and timeline

It is recommended that funding is provided to an industry or government body to support recruitment of additional resources to provide general H&S guidance to storage manufacturers, installers, and developers. Providing funding to a standards organisation or other industry body may be advisable to recruit technical staff with broad expertise across storage technology safety. Alternatively, similar funding could be provided to a government organisation to recruit relevant staff. These staff could then provide general advice on available standards and processes to manufacturers and installers of relevant systems. However, it is unlikely that advice could be given on very specific technical areas such as gas venting of new battery chemistries.

5.10 GAP 8: EU-Exit and Standardisation

From our assessment of the standards landscape and engagement with industry actors involved in standardisation it is clear that the UK's relationship with European standardisation committees such as CENELEC is an important element of British support to international standardisation initiatives. A plan should therefore be developed to ensure this collaboration continues following EU-Exit.

5.10.1 Evidence for the Gap

The UK left the EU on the 31 January 2020 and the transition period ended on 31 December 2020. BSI's membership of CEN and CENELEC is guaranteed beyond the end of transition period until the end of 2021 and BSI are working with the other CEN and CENELEC members to ensure the best outcome for the UK. They have been classed as a non-EEA member and will continue to provide UK influence over standards produced in CEN and CENELEC. The UK Government have asked that BSI as the UK's National Standards Body continue to pursue the interests of UK stakeholders within the standardisation bodies at both at the International and European levels.

5.10.2 Mitigation options and timeline

This gap can likely be addressed through engagement with BSI and other industry bodies to understand the impacts of these changes on storage H&S standardisation including the other mitigation options outlined in this document. Any outstanding challenges could then be mitigated through a clear plan of how to continue engagement with these committees following EU-Exit.

5.11 GAP 9: LI-ION Certification and Accreditation

We have assessed that there is a gap in processes for certification and accreditation of storage systems. The sector has now matured to a level where installation numbers have reached a critical mass that necessitates adoption of similar processes to more mature sectors such as solar PV.

5.11.1 Evidence for the Gap

Installation standards are currently at a low level of maturity reflecting the nascent nature of stationary storage technologies. For example, the MIS 3012 standard was only recently published. The experience within certification bodies for certifying storage technologies is similarly low: UKAS has not yet accredited certification bodies such as NAPIT or NICEIC to certify compliance with storage installation standards such as MIS 3012. Installation standards such as MIS 3012 also require compliance with sections of the IET code of practice for EESS and certification bodies and accreditors will need to have understanding of this code of practice.

5.11.2 Mitigation options and timeline

We recommend that a competitive tender is undertaken to contract an industry organisation for development of a roadmap for certification and accreditation of storage systems. This roadmap could propose milestones for certification and accreditation of storage systems. The procurement could occur in conjunction with that outlined in section 5.8.2.

Additionally we propose that training is provided to potential certification bodies and accreditors on the second edition of the IET code of practice for EESS, which could be arranged by the IET with inputs from authors of the IET code of practice. This training could be provided as soon as the second edition of the IET code of practice is finalised.

5.12 GAP 10: LI-ION Audit and Verification

Engagement with stakeholders with experience in the solar PV sector has indicated that there is an opportunity to conduct audit and verification of storage installations that may reveal the current status of installations in terms of compliance with standards and mitigation of H&S risks.

5.12.1 Evidence for the Gap

We have engaged with manufacturers and standardisation bodies with experience in both the solar PV and storage sectors. These stakeholders indicated that an audit report produced by BRE for fire safety of solar PV installations[24] was influential in updates to the IET code of practice for solar PV. Similar detailed audit results are not available for storage systems.

5.12.2 Mitigation and Timeline

We recommend that a competitive tender is undertaken to contract an industry organisation for an audit of Li-ion storage systems initially, focussing on key hazards such as fire due to thermal runaway. This initial audit could also verify compliance with key standards such as the IET code of practice for EESS. Further work could then be sought to address outcomes of the audit.

5.13 GAP 11: LI-ION Fire Services Processes

From our engagement with project developers and fire services, it appears that there is a lack of detailed guidance on notification of projects to fire services and firefighting procedures for Li-ion systems.

[24] https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/fireproject/P100874-1006-D6-Interim-Report---Recommendations-for-PV-Ind-Feb-2017-Issue-2.5.pdf

5.13.1 Evidence for the Gap

We have spoken to several project developers and representatives from fire services regarding this issue. There is no mandatory notification for new Li-ion systems to fire services and this results in varying levels of engagement from fire services in the design and installation stages. It is also not clear to fire services what firefighting approach should be taken due to limited engagement between fire services, manufacturers, and project developers. In some cases this has led to local fire services taking a stance that they will not fight Li-ion fires where there is no risk to loss of life.

5.13.2 Mitigation options and timeline

We recommend that a fire services working group is convened with representatives from the national fire chiefs and relevant local fire services. This working group should then conduct separate meetings with the domestic/commercial scale and industrial/grid-scale working groups described in Section 5.6.2. Outcomes of these meetings could then feed into updates to the National Operational Guidance for fire services or specific industry guidance to be shared more widely. It could also feed into requirements for mandatory notification to fire services, which could be put in place through building regulations or other appropriate avenues.

6 Conclusions and Recommendations

Section 2 of this document introduces the different areas of application of EESS within a UK context. It provides a framework, in terms of development scale, lifecycle and use cases, of the technologies and approaches that EESS industry participants currently use. Sections 3 and 4 of this report then provide a detailed review of the set of technical standards currently applied by the EESS industry and their correspondence to the H&S risks and hazards present in EESS. We have reviewed and tested the information provided in these sections through discussion and review with subject matter experts drawn from across the UK industry.

6.1 Conclusions

Our findings reflect that the H&S standards landscape for energy storage systems is complex and somewhat challenging to navigate, with differing requirements across lifecycle stages and development scales. A number of interviewees have acknowledged that additional guidance about the applicability of different standards would be helpful in allowing them to deliver their roles. In addition the 'framework of practice', including appropriate training, supporting processes and enforcement of standardisation practices, is essential to mitigate H&S risk. In general, gaps in the H&S standards framework are also reflected in the supporting guidance.

Within the standards themselves, standardisation levels vary significantly by technology type reflecting the differing levels of maturity and adoption. Areas of ongoing effort in standardisation and guidance development reflect the dominant technology-specific requirements of industry; Li-ion battery storage has seen significant volumes of standard and guidance development reflecting its prevalence across a range of use cases. For less mature technologies specific guidance is less well developed: H&S risk is primarily mitigated by overarching H&S legislation, product certification requirements, and project engineering practice.

The study has found one specific potentially significant gap in hazard coverage. DC arc flash, as a comparatively new hazard at smaller deployment scales, appears to be a gap in the current content of the standards. There are significant hazards associated with arc flash, including blast, exposure to extreme heat, acoustic noise, pressure and light. The standards do not currently include guidance on approaches for assessing the severity of DC arc flash. Given the lack of experience managing these hazards at lower voltages, this gap should be closed promptly. There is a draft international standard (AS/NZS 5139:2019) which provides an example methodology which could form the basis of this effort. We have begun to engage with the authors of the IET Code of Practice for Electrical Energy Storage Systems to explore options for mitigating this risk via an update to that publication.

There are also minor gaps in the coverage of containment of explosion hazards. The relevant standards require that protection from hazards generated by the battery (such as fire and explosion) and protection from external hazards are assessed as part of the overall accommodation of the battery system. Whilst not mandated by the standards, an enclosure may provide these protections in many cases. However, there is no guidance on how to assess the severity of these hazards and design accommodation/enclosures accordingly.

6.2 Recommendations

The gaps identified in Section 5, and the mitigation options provided in Table 12, provide the core of the recommendations resulting from this project. A summary of these is provided below.

In the short term:

1. Contract an industry organisation to conduct an audit of Li-ion storage installations;
2. Develop a robust plan for the impact of EU-Exit on storage H&S standardisation;
3. Address DC arc flash risk via an update to the IET Code of Practice for EESS;
4. Appoint industry facilitators for developing domestic/small commercial scale and industrial/grid scale Li-ion storage guidance. The facilitator should appoint separate working groups for domestic/small commercial scale and industrial/grid scale Li-ion storage;
5. Appoint a fire services working group to develop notification and firefighting requirements in conjunction with the working groups assembled under 4.;
6. Appoint an industry facilitator to produce general H&S guidance for novel technology developers; and
7. Provide "train the expert" courses for certification bodies and accreditors on the 2nd edition of the IET Code of Practice for EESS.

In the medium term:

8. Investigate funding a national body for providing independent advice on storage H&S risks and available standards. This body could then work with industry stakeholders to develop more specific guidance for the sector, particularly for manufacturers and installers of novel technologies;
9. Consider updates to regulations and fire services guidance based on outputs from the relevant working groups and the audit of installations mentioned above. Engage with national standards bodies (such as NFPA and UL in the U.S.) to understand how elements of standards in other countries could be adopted in the U.K., seeking advice from the working groups; and
10. Support international standardisation initiatives through U.K. support to international standards committees.

In the long term:

11. Support manufacturers to reach consensus on international product certification standard(s) for Li-ion storage and any other rapidly developing technologies. Once this standard is agreed, support compliance through incentivising via government schemes.

6.3 Acknowledgements

This report incorporates contributions from industry stakeholders, who have been interviewed to gather feedback and experiences of applying H&S best practice to EESS. We are grateful for all such contributions, in particular from:

Health & Safety Executive (HSE)	**Institution of Engineering and Technology (IET)**
Microgeneration Certification Scheme (MCS)	**Certi-Fi & Flexi-Orb**
British Standards Institution (BSI)	**London Fire Brigade**
Renewable Energy Systems (RES)	**National Physical Laboratory (NPL)**
Low Carbon	**Electrical Contractors Association**
Tesla	**Sonnen**
Oxto Energy	**PS Integrity**
Andy Geddes	**G Kenyon Technologies**
Cumulus Energy Storage	**EDF Renewables UK**

7 References

Body citations

[1] RenewableUK, “Energy Storage Project Intelligence: December 2019,” 2019.

[2] P. Gordon, “Research shows massive growth in UK energy storage projects,” Smart Energy International, 2019.

[3] S. Henbest, “The First Phase of the Transition is About Electricity, Not Primary Energy,” Bloomberg New Energy Finance, 28 Jan 2020. [Online]. Available: https://about.bnef.com/blog/the-first-phase-of-the-transition-is-about-electricity-not-primary-energy/.

[4] T. Hoy, “The Role of Additional Pumped Hydro Storage in a Low Carbon UK Grid,” University of Strathclyde, Glasgow, UK, 2015.

[5] International Hydropower Association, “2018 Hydropower Status Report,” London, UK, 2018.

[6] University of Edinburgh, “HyStorPor,” [Online]. Available: https://blogs.ed.ac.uk/hystorpor/.

[7] S. Livermore, “Logistics of Domestic Hydrogen Conversion,” Frazer-Nash Consultancy, Glasgow, UK, 2019.

[8] S. Livermore, “Hydrogen Storage for Transport Refuelling,” Frazer-Nash Consultancy, Glasgow, UK, 2019.

[9] Department for Transport, “Electric Vehicle Smart Charging,” HM Government, London, UK, 2019.

[10] R. F. Service, “New generation of ‘flow batteries’ could eventually sustain a grid powered by the sun and wind,” 31 Oct 2018. [Online]. Available: https://www.sciencemag.org/news/2018/10/new-generation-flow-batteries-could-eventually-sustain-grid-powered-sun-and-wind.

[11] J. Spector, “Iron Flow Battery Startup ESS Raises $30M From SoftBank and Breakthrough,” 29 October 2019. [Online]. Available: https://www.greentechmedia.com/articles/read/ess-raises-30-million-to-scale-iron-flow-batteries.

[12] M. Willuhn, “National Grid pre-qualifies first vanadium-flow battery for frequency response in UK,” 26 Jul 2019. [Online]. Available: https://www.pv-magazine.com/2019/07/26/national-grid-pre-qualifies-first-vanadium-flow-battery-for-frequency-response-in-uk/.

[13] M. Hall, “UK deals for vanadium redox flow merger and electric vehicles announced,” 17 Mar 2020. [Online]. Available: https://www.pv-magazine.com/2020/03/17/uk-deals-for-vanadium-redox-flow-merger-and-electric-vehicles-announced/.

[14] S. Succar and R. H. Williams, “Compressed Air Energy Storage: Theory, Resources, And Applications for Nuclear Power,” Princeton Environmental Institute, Princeton, New Jersey, USA, 2008.

[15] M. Dooner and J. Wang, “Potential Exergy Storage Capacity of Salt Caverns in the Cheshire Basin Using Adiabatic Compressed Air Energy Storage,” Entropy, Coventry, UK, 2019.

[16] J. Mouli-Castillo, M. Wilkinson, D. Mignard, C. McDermott, S. Haszeldine and Z. K. Shipton, “Inter-seasonal compressed air energy storage using saline aquifers,” Grant Institute, University of Edinburgh, Edinburgh, UK, 2019.

[17] Eureeca Blog, “Storelectric aims to transform the global energy market,” 12 Sept 2019. [Online]. Available: http://blog.eureeca.com/crowdfunding/storelectric-aims-to-transform-the-global-energy-market/.

[18] A. Sciacovelli, Y. Ding and A. Vecchi, “Liquid air energy storage (LAES) with packed bed cold thermal storage - From component to system level performance through dynamic modelling,” University of Birmingham, Birmingham, UK, 2016.

[19] Highview Power, “Highview Power launches world's first grid-scale liquid air energy storage plant,” Highview Power, London, UK, 2018.

[20] L. Collins, “First commercial liquid-air energy storage facility to be built in the US,” Recharge News, London, UK, 2019.

[21] Gravitricity Ltd, “Technology,” [Online]. Available: https://www.gravitricity.com/#technology.

[22] G. Cameron, “Gravity-powered batteries generate electricity when the wind dies down,” 11 May 2020. [Online]. Available: https://www.thetimes.co.uk/article/gravity-powered-batteries-generate-electricity-when-the-wind-dies-down-r98l0mjtt.

[23] A. Fyke, “The Fall and Rise of Gravity Storage Technologies,” *Joule,* vol. 3, no. 3, pp. 625-630, 2019.

[24] Business Wire, "Energy Vault Named Technology Pioneer by World Economic Forum as It Offers an Economic Way to Store Clean Energy and Deliver Dispatchable Power," 16 June 2020. [Online]. Available: https://www.businesswire.com/news/home/20200616005363/en/Energy-Vault-Named-Technology-Pioneer-World-Economic.

[25] CDV - Transport Research Centre, Czech Republic, "Transactions on Transport Sciences," CDV, Brno, Czech Republic, 2013.

[26] EUROfusion, "JET's flywheels," EUROfusion Consortium, Abingdon, Oxfordshire, 2010.

[27] FR24 News, "Giant flywheel project in Scotland could prevent UK power outages," 6 July 2020. [Online]. Available: https://www.fr24news.com/a/2020/07/giant-flywheel-project-in-scotland-could-prevent-uk-power-outages-business.html.

[28] A. M. Gee, F. Robinson and W. Yuan, "A Superconducting Magnetic Energy Storage-Emulator/Battery Supported Dynamic Voltage Reducer," *IEEE Transactions on Energy Conversion,* vol. 32, no. 1, pp. 55-64, 2019.

[29] N. Kumar, "Superconducting Magnetic Energy Storage (SMES) System," National University of Singapore, Singapore, 2015.

[30] A. W. Zimmerman, "Review of the State of the Art Superconducting Magnetic Energy Storage (SMES) in Renewable/Distributed Energy Systems," 2017.

[31] J. R. Rani, R. Thangavel, S.-I. Oh, Y. S. Lee and J.-H. Jang, "An Ultra-High-Energy Density Supercapacitor; Fabrication Based on Thiol-functionalized Graphene Oxide Scrolls," *Nanomaterials (Basel),* vol. 9, no. 2, p. 148, 2019.

[32] Solana, "SOLANA | Loan Programs Office," United States Department of Energy, [Online]. Available: https://www.energy.gov/lpo/solana.

[33] Rawlins, James, Ashcroft, Michael, "Small-scale Concentrated Solar Power," Carbon Trust, London, UK, 2013.

[34] C. K. Ho, "Safety of Thermal Energy Storage Systems for Concentrating Solar Power Plants," in *2017 ESS Safety Forum: Meeting the Challenge*, Santa Fe, NM, 2017.

[35] J. Deign, "Molten salt: too hot to handle?," Reuters Events, 23 May 2014. [Online]. Available: https://analysis.newenergyupdate.com/csp-today/technology/molten-salt-too-hot-handle.

[36] The Institution of Engineering and Technology, "Code of Practice for Electrical Energy Systems - 2nd Edition - Draft for Comment," The Institution of Engineering and Technology, Stevenage, UK, 2020.

[37] British Standards Institution, "Faraday Battery Challenge: Standards, guidelines, research and viewpoints," British Standards Institution, 2019. [Online]. Available: https://www.bsigroup.com/en-GB/industries-and-sectors/energy-and-utilities/faraday-battery-challenge/.

[38] Standards Australia Limited/Standards New Zealand, "DR2 AS/NZS 5139:2019, Electrical installations — Safety of battery systems for use with power conversion equipment," [Online]. Available: https://infostore.saiglobal.com/en-au/standards/as-nzs-5139-2019-1166297_saig_as_as_2775044/.

[39] H. Engel, P. Hertzke and G. Siccardo, "Second-life EV batteries: The newest value pool in energy storage," 30 Apr 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage.

[40] Donald Bender, "Recommended Practices for the Safe Design and Operation of Flywheels," Sandia National Laboratories, Albuquerque, New Mexico, 2015.

[41] D. A. Bender, "Recommended Practices for the Safe Design and Operation of Flywheels," in *Meeting the Challenge: 2017 Energy Storage System Safety Forum*, Santa Fe, New Mexico, 2017.

[42] Rainer vor dem Esche (Stornetic GmbH), "Safety of Flywheel Storage Systems," White paper, 2016.

[43] Highview Power, "Technology | Highview Power," [Online]. Available: https://highviewpower.com/technology/.

[44] Centre for Cryogenic Energy Storage, University of Birmingham, Liquid Air Technologies - a guide to the potential, Birmingham, UK: Centre for Low Carbon Futures and Liquid Air Energy Network, 2013.

[45] F. Crotogino, Huntorf CAES: More than 20 Years of Successful Operation, Orlando, Florida: KBB GmbH, 2001.

[46] M. Lutyński, "An overview of potential benefits and limitations of Compressed Air Energy Storage in abandoned coal mines," in *IOP Conference Series: Materials Science and Engineering*, Gliwice, Poland, 2006.

[47] P. Bérest, B. Brouard, "Safety of Salt Caverns Used for Underground Storage Blow Out; Mechanical Instability; Seepage; Cavern Abandonment," in *Oil & Gas Science and Technology*, 2003.

[48] Mark C. Grubelich, Stephen J. Bauer, & Paul W. Cooper, "Potential Hazards of Compressed Air Energy Storage in Depleted Natural Gas Reservoirs (SAND2011-5930)," September 2011. [Online]. Available: https://prod.sandia.gov/techlib/access-control.cgi/2011/115930.pdf.

[49] Health & Safety Laboratory, "Failure rates for underground gas storage," Health & Safety Executive, Buxton, UK, 2008.

[50] Polk, Boom and Eyssa, "Superconductive Magnetic Energy Storage (SMES) External Fields and Safety Consideration," *IEEE Transactions on Magnetics,* vol. 28, no. 1, 1992.

[51] U. Reddy, M. J. White and S. R. Wilson, "Anaesthesia for magnetic resonance imaging," *Continuing Education in Anathesia Critical Care & Pain,* vol. 12, no. 3, pp. 140-144, 2012.

[52] US National Fire Protection Association, "NFPA 70E Standard for Electrical Safety in the Workplace (Annex D)," 2018.

[53] Daniel R. Doan, "Arc Flash Calculations for Exposures to DC Systems," *IEEE Transactions on Industry Applications,* vol. 46, no. 6, pp. 2299-2302, 2010.

[54] Ammerman, R.F. & Gammon, Tammy & Sen, P.K. & Nelson, J.P., "DC-Arc Models and Incident-Energy Calculations," *IEEE Transactions on Industry Applications,* vol. 46, no. 5, pp. 1810-1819, 2010.

[55] Dongxu Ouyang, Mingyi Chen et al, "A Review on the Thermal Hazards of the Lithium-Ion Battery and the Corresponding Countermeasures," Applied Sciences - MPDI, 2019.

Installation Standards (UK &EU)

IET *Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings,* 2015.

BS EN 50549-1:2019. *Requirements for generating plants to be connected in parallel with distribution networks. Connection to a LV distribution network. Generating plants up to and including Type B*

BS HD 60364-8-2:2011+A11:2019. *Low voltage electrical installations. Prosumer's low voltage electrical installations.*

BS EN 61140:2016 *Protection against electric shock — Common aspects for installation and equipment*

BS EN 61508-7:2010 *Functional safety of electrical/ electronic/ programmable electronic safety related systems Part 7: Overview of techniques and measures*

BS EN 62305-1:2011. *Protection against lightning. General principles*

BS EN 62305-2:2012. *Protection against lightning. Risk management*

BS EN 62305-3:2011. *Protection against lightning. Physical damage to structures and life hazard*

BS EN 62305-4:2011. *Protection against lightning. Electrical and electronic systems within structures*

BS EN IEC 62485-1. *Safety requirements for secondary batteries and battery installations. General safety information*

BS EN IEC 62485-2. *Safety requirements for secondary batteries and battery installations. Stationary batteries*

BS EN IEC 62933-1:2018. *Electrical Energy Storage (EES) systems. Terminology*

BS EN IEC 62933-2-1:2018. *Electrical Energy Storage (EES) systems. Unit parameters and testing methods*

PD IEC/TS 62933-4-1:2017. *Electrical energy storage (EES) systems. Guidance on environmental issues. General specification*

BS 7273-6:2019 *Code of practice for the operation of fire protection measures. Part 6: Fire detection and fire alarm systems – Interface with ancillary systems and equipment*

BS 7430:2011+A1:2015. *Code of practice for protective earthing of electrical installations*

BS 7671 *IET Wiring Regulations 18th Edition*, 2018.

Construction Industry Research and Information Association CDM 2015 – *Construction work sector guidance for designers, fourth edition (C755)*

Construction Industry Research and Information Association CDM 2015 – *Workplace 'in-use' guidance for designers, second edition (C756)*

MCS, MIS 3012: *The Battery Standard: Installation*, 2020

EESS Standards (UK & EU)

IET *Code of Practice for Electrical Energy Storage Systems*, 2017.

BS EN 60079-14:2014. *Explosive atmospheres. Electrical installations design, selection and erection*

BS EN 61427-1:2013 *Secondary cells and batteries for renewable energy storage— General requirements and methods of test Part 1: Photovoltaic off-grid application*

BS EN 61427-2:2015 *Secondary cells and batteries for renewable energy storage — General requirements and methods of test*

BS EN IEC 62281:2019 *Safety of primary and secondary lithium cells and batteries during transport*

BS EN IEC 62485-1:2018 *Safety requirements for secondary batteries and battery installations Part 1: General safety information*

BS EN IEC 62485-2:2018 *Safety requirements for secondary batteries and battery installations Part 2: Stationary Batteries*

BS EN IEC 62485-4:2018 *Safety requirements for secondary batteries and battery installations (Part 4: Valve-regulated lead-acid batteries for use in portable appliances*

BS EN IEC 62932-2-2:2020 *Flow battery energy systems for stationary applications. Part 2-2: Safety requirements*

PD IEC/TS 62933-4-1:2017 *Electrical Energy Storage (EES) systems Part 4-1: Guidance on environmental issues - General specification*

Industry Specific Standards (UK & EU)

BS EN 62271-202:2014 High-voltage switchgear and controlgear. Part 202: High-voltage/low-voltage prefabricated substation

BS EN 62619:2017 Secondary cells and batteries containing alkaline or other non-acid electrolytes — Safety requirements for secondary lithium cells and batteries, for use in industrial applications

BS EN 62620:2015 Secondary cells and batteries containing alkaline or other non-acid electrolytes — Secondary lithium cells and batteries for use in industrial applications

ENA Engineering Recommendation G98 – *Recommendations for the Connection of Type Tested Small-scale Embedded Generators (Up to 16A per Phase)*

ENA Engineering Recommendation G99 - *Recommendations for the Connection Of Generating Plant to The Distribution Systems of Licensed Distribution Network Operators*

ENA Engineering Recommendation G100 – Issue 1 (2016) – Technical Requirements for Customer Export Limiting Schemes

Relevant Standards (UK & EU)

BS EN 50171:2001. *Central power supply systems*

BS EN IEC 62040-1:2019. *Uninterruptible power systems (UPS). General and safety requirements for UPS*

BS EN 62040-2:2018. Uninterruptible power systems (UPS). Electromagnetic compatibility (EMC) requirements

BS EN 62040-3:2011. *Uninterruptible power systems (UPS). Method of specifying the performance and test requirements*

BS EN 62040-4:2013. *Uninterruptible power systems (UPS). Environmental aspects. Requirements and reporting*

BS EN 62040-5-3:2017. *Uninterruptible power systems (UPS). DC output UPS. Performance and test requirements*

Guidance Documents (UK & EU)

Energy Institute, *Battery storage guidance note 1: Battery storage planning*, 2019

ESOF, *A Good Practice Guide on Electrical Energy Storage,* 2014

BRE, Batteries and Solar Power: *Guidance for domestic and small commercial consumers,* 2016

Guidance documents (US)

Pacific Northwest Laboratory, Inventory of Safety-related Codes and Standards for Energy Storage Systems, 2014

U.S. Department of Energy, Codes and Standards Update, published seasonally (e.g. Spring 2020)

International Standards

AS/NZS 5139:2019 *Electrical installations - Safety of battery systems for use with power conversion equipment* (Australia)

AS 2676.1:2020 *Installation, maintenance, testing and replacement of secondary batteries in buildings Vented cells* (Australia)

AS 2676.2:2020 *Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings Sealed cells* (Australia)

NFPA 70E, *Standard for Electrical Safety in the Workplace*, 2018

NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*, 2020

NFPA 1: Fire Code

UL 1642: Standard for Safety of Lithium Batteries

UL 2054: Standard for Household and Commercial Batteries

UL 1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications

UL 1974: Standard for Evaluation for Repurposing Batteries

UL 9540: Standard for Safety for Energy Storage Systems and Equipment

UL 9540A: Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

A.1 Arc Flash

A.1.1 Hazards Associated with Arc Flash

AS/NZS 5139:2019 [38] defines arc flash as an "*electrical explosion or discharge, which occurs between electrified conductors during a fault or short circuit condition*". It further states that "*Arc flash occurs when electrical current passes through the air between electrified conductors when there is insufficient isolation or insulation to withstand the applied voltage*."

An arc flash event can quickly evolve from an arc fault[25] caused by events such as accidental contact, corrosion, dropped tools or incorrect work procedures. During an arcing fault, a plasma arc is established from current flowing through ionised air. When substantial energy is discharged into this arc it can rapidly lead to extreme temperatures (enough to explosively vaporise conductive metals) and light. Arc blast can follow the arc flash through the instantaneous expansion of gas at the point of fault. Depending on the magnitude of the arc flash, it can pose a serious threat to nearby personnel.

The hazards posed by arc flash are well recognised for large electrical installations. For example, in the UK, there are an estimated 400 Arc Flash incidents, resulting in two fatalities, an average of 36 burn injuries and more than 230 7-day injuries annually[26].

Whilst traditionally an only consideration for large electrical installations, energy storage also introduces a potential means of generating an arc flash event in new and smaller scale application areas (i.e. commercial or domestic). Given it is not typically a concern for these applications; it creates a risk that this potential hazard is overlooked.

This is of particular significance to battery systems. The electrical characteristics of batteries is such that their energy is readily discharged. When coupled to suitable high voltage and capacity levels they can supply high magnitude and high rate of change of fault current[27]. This rapidly developing fault current can quickly contribute energy to a fault, risking an arc flash event.

Based on some indicative calculations carried out by Frazer-Nash in the support of our review work using the above methodology we have established that:

- The possible hazard posed by arc flash increases with deployment size due to the higher fault current available (a function of voltage and capacity);
- The hazard level at the domestic level is relatively low but not negligible and will increase as the installed capacity at the domestic level increases. This suggests that guidance on arc flash assessment and mitigation is required at this level; and
- The potential hazard level for use cases associated with larger commercial and industrial applications and grid scale applications can be high (extremely high in some cases) and arc flash assessment and mitigation is critical in these applications.

[25] Short circuits may also evolve into an arc fault if there is sufficient fault current.
[26] https://centurionsafety.eu/wp-content/uploads/2018/11/Arc-White-Paper-Page-by-Page.pdf, and originally sourced from HSE 2014/2015 accident report data
[27] This is due to the typically low internal impedance. Fault current characteristics will change based on battery voltage and internal impedance. These parameters are affected by the specific battery design and the series-parallel combination of battery cells (where multiple cells are used to increase battery voltage or capacity). BS EN 61660-1:1997 provides an example of how to establish the short circuit current from a lead acid battery.

A.1.2 Standards on DC Arc Flash

There are currently two international standards which cover DC arc flash. These are the NFPA 70E [52] and the AS/NZS 5139:2019 [38]. The possible incident energy[28] of an arc flash event is used within these standards to quantify its severity.

Within NFPA 70E (Annex D), two methods for calculating incident energy are recognised. These are the:

- Maximum power method (Doan method) [53]; and
- Detailed arcing current and energy calculation method (Ammerman method) [54].

AS/NZS 5139:2019 adopts the former of the two methodologies, recognising that whilst both methodologies are acceptable to industry and that the Ammerman method may be more accurate, the Doan method is the easier to calculate and apply in practice. This is of particular importance for smaller scale applications.

Both NFPA 70E and AS/NZS 5139:2019 also acknowledge that the Doan method provides a conservative estimate of incident energy. The method is designed to be relevant for DC systems rated up to 1000V and hence is applicable to a range of application types[29]. Larger and more complex installations may choose to apply more detailed arc flash assessment models (e.g. the Ammerman method) as appropriate.

It is noted that there is limited guidance within UK applicable standards on DC arc flash, and the consideration of arc flash in general at the domestic/small commercial scale is limited. For example the IET EESS COP [36] and IEC 62933-5-2 highlight the potential arc flash risk but require an associated prescribed methodology to enable assessment of arc flash risk severity and potential mitigations[30].

[28] A measurement of energy, usually heat, striking a surface.
[29] 1000VDC on the battery side will supply a relatively large capacity application.
[30] Through this work, Frazer-Nash have submitted details of a DC arc flash assessment methodology, consistent with international practice, for inclusion in the IET EESS COP.

180 West George Street
Glasgow
G2 2NR

Tel: +44 (0)141 3415400

fnc.co.uk

Offices at:
Bristol, Burton-on-Trent, Dorchester, Dorking, Glasgow, Gloucester, Leatherhead, Middlesbrough, Plymouth and Warrington