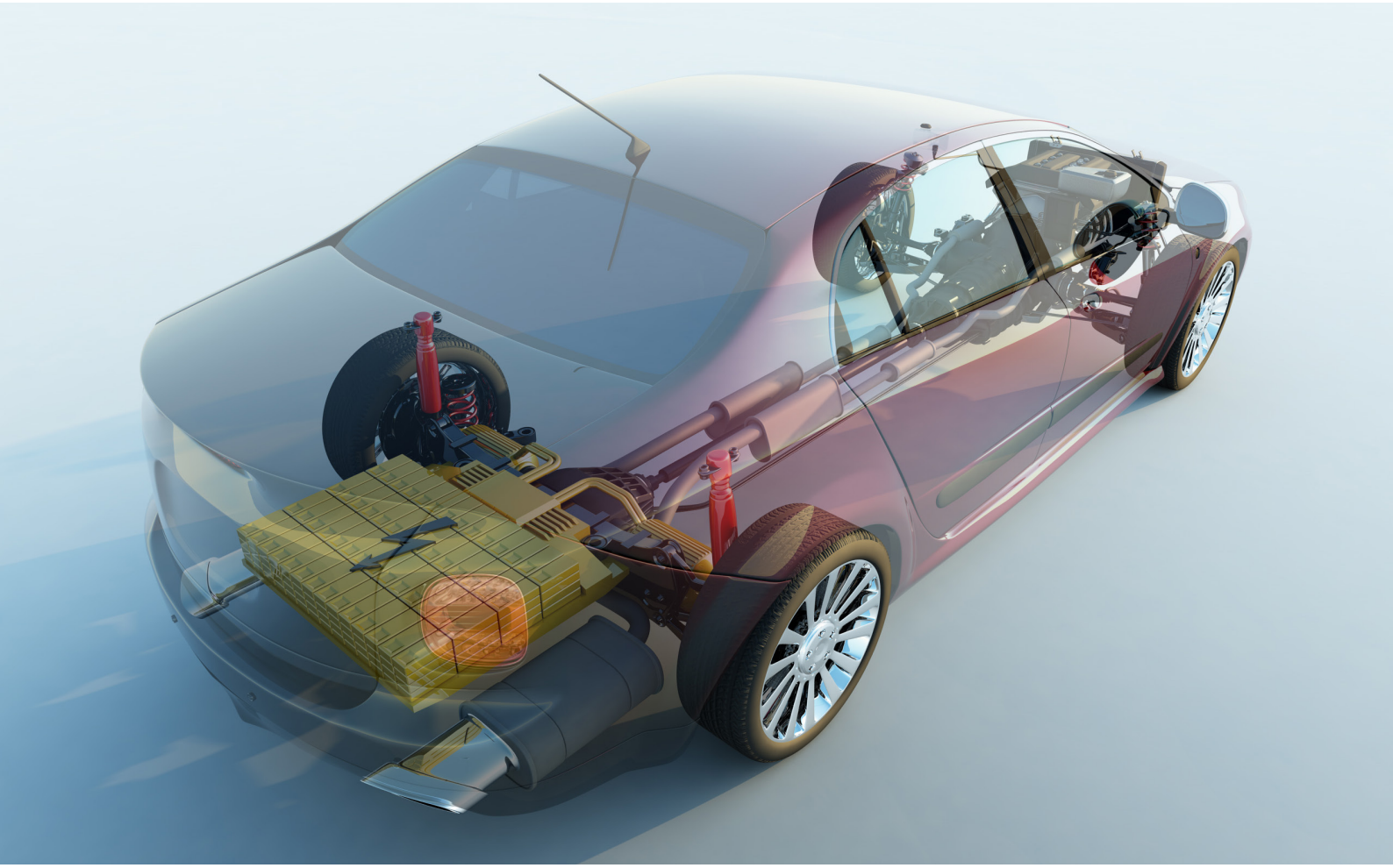
Battery manufacturing and technology standards roadmap

Enhancing the UK's battery manufacturing capabilities and enabling battery technology innovation

Developed by BSI as part of the
BSI Faraday Battery Challenge Programme

July 2021



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Foreword

This standards roadmap has been developed as part of a programme of work for the Faraday Battery Challenge (FBC) and is funded by Innovate UK (IUK). It considers existing battery manufacturing standards, identifies key knowledge gaps, and makes wider standardization recommendations to support the growth of the UK's battery manufacturing capabilities and enable battery technology innovation.

Whilst most recommendations fall within the scope of the FBC, the roadmap extends beyond this remit and it is anticipated that other funding mechanisms may be required if all the recommendations are taken forward.

The roadmap is intended to highlight key areas and themes to support the ongoing growth of batteries and provide recommendations for future standards development and supporting activities. All recommendations on future standards development and wider standardization activity have been identified and validated through feedback received from UK stakeholders working in the field of batteries, but will require further engagement with key stakeholders and subject matter experts to scope out and establish the most appropriate mechanisms for taking these forward.

Information contained within the standards roadmap is not exhaustive and is based upon available data, current assumptions and opinions of the consulted stakeholders.

More information on the BSI Faraday Battery Challenge Programme can be found here: https://www.bsigroup.com/en-GB/industries-and-sectors/energy-and-utilities/faraday-battery-challenge/.

Comments are welcome at Faradaybatterychallenge@bsigroup.com.

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Executive Summary

Introduction

In June 2019, the UK became the first major economy in the world to legally commit to end its contribution to global warming by 2050. The Faraday Battery Challenge (FBC) was set up to ensure that the research and innovation conditions required to deliver this ambitious net zero target are in place, enabling the deployment of battery technology to decarbonize the UK's transport sector.

BSI's FBC Programme, sponsored by Innovate UK (IUK) and supported by a number of other key strategic partners, including National Physical Laboratory (NPL), Health and Safety Executive (HSE), UK Battery Industrialisation Centre (UKBIC) and the Faraday Institution, was launched following extensive discussions about the role of standards, alongside regulation, in supporting the overarching objectives of the FBC.[1] BSI's FBC Programme is focused on:

- developing and codifying good practice to fill in key knowledge gaps and respond to pressing challenges;
- identifying further gaps and challenges and devising appropriate responses;
- growing the Faraday battery network; and
- building public confidence in batteries and electric vehicles (EVs).

BSI's FBC Programme has relied on extensive stakeholder engagement with industry, academia, regulators, UK's research and development community, policy makers, and legislators to shape the programme deliverables, and subsequently, the recommendations in this roadmap.

Urgent gaps identified at the start of BSI's work were addressed with the publication of three fast-track Publicly Available Specifications (PAS), the PAS 706X series. This roadmap builds on this effort and highlights other FBC-related challenges and topics that could be addressed through standardization activity, based on the premise that development of standards in parallel with technological advances in batteries would help drive UK competitiveness in this area of strategic value.

Key issues and challenges for the battery industry, corresponding knowledge gaps and recommendations

Our research and stakeholder engagement revealed that the most pressing challenges in battery manufacture are around:

- fire risk safety and management;
- design considerations (especially end-of-life and second life design); and
- recyclability/circularity requirements for current and future battery technology.

Alongside performance of the batteries themselves, safety in manufacture and full consideration of environmental impacts were considered two key differentiators for the UK battery industry. Coherence of

1 Further information on the FBC and its objectives can be found here: www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/future-of-mobility/faraday-battery-challenge/

the supply chain, alignment with the transition towards clean economic growth and net zero, and harnessing of smart technologies to support manufacturing growth are also key elements for the UK's penetration of the battery industry.

In response to these identified challenges and gaps, a codification framework of standards interventions has been developed, that prioritizes interventions on a short-, medium-, and long-term timeframe (refer to Section 3.2). In addition to codification, the framework also includes recommendations for supporting activities that vary from the development of implementation guidance and training, through the establishment and roll out of relevant certification, training and accreditation regimes, to dissemination and uptake measures.

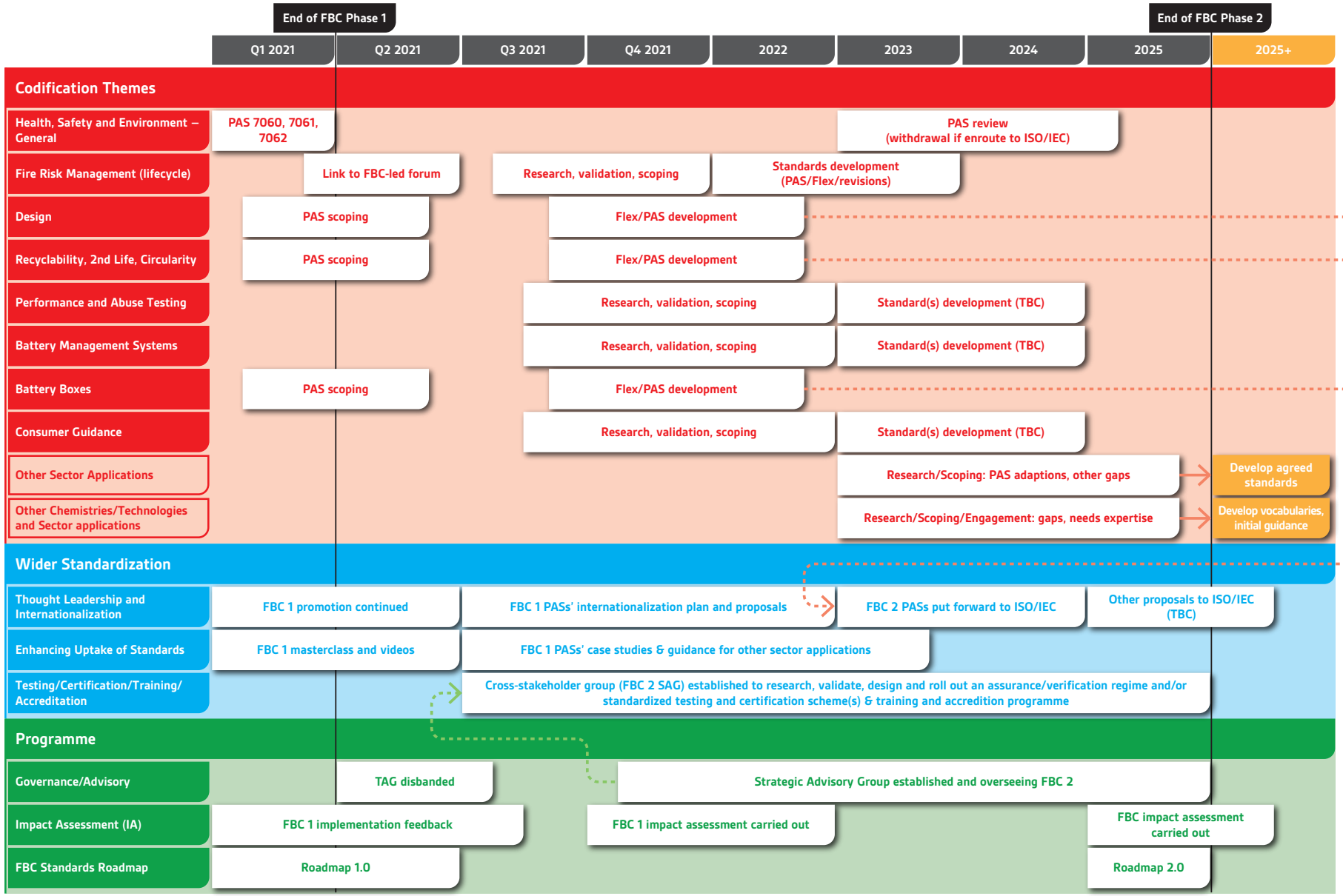
Provision of standards-related information and awareness raising is also recommended, as is the consideration of the impact that newly developed standards, as well as wider programmes/activities have on the growth of the industry, individual businesses, and international trade.

Strategic battery manufacturing and technology standards roadmap

With a mind on the overarching goal behind the roadmap recommendations to continue building an integrated, UK-wide, comprehensive battery standards infrastructure, supported by certification, testing and training regimes, and aligned with legislation/regulatory requirements; it is proposed that a Phase 2 of BSI's programme is developed. Phase 2 would encompass the key elements described in Section 4 and would look to take forward the key recommendations within this roadmap.

A high-level outline of BSI's roadmap developed in support of the long-term objectives of the ISCF FBC is shown in Figure 1. Whilst several of the recommendations fall within the scope of the FBC, it extends beyond the FBC's remit and it is anticipated that other funding mechanisms may be required if all of the recommendations within the roadmap are taken forward. All of the roadmap's recommendations will need to be further validated with a wider stakeholder community and may be adjusted as the battery manufacture and technology landscape develops.

Figure 1 – Battery manufacturing and technology standards roadmap



FBC Phase 1 (FBC1) – Phase 1 of the BSI FBC programme of work

FBC Phase 2 (FBC 2) – Suggested activities to be delivered for phase 2 of the BSI FBC programme

TAG – Technical Advisory Group supporting FBC 1

PAS – Publicly Available Specification https://www.bsigroup.com/en-GB/our-services/developing-new-standards/Develop-a-PAS/what-is-a-pas/

Flex – BSI Flex standard https://www.bsigroup.com/en-GB/our-services/standards-services/flex/

1 Context

1.1 The Faraday Battery Challenge and standards

In June 2019, the UK became the first major economy in the world to pass laws to end its contribution to global warming by 2050. The target will require the UK to bring all greenhouse gas emissions to net zero by 2050, compared with the previous target of at least 80% reduction from 1990 levels.

The Faraday Battery Challenge (FBC) is part of the Industrial Strategy Challenge Fund (ISCF), designed to ensure that research and innovation take centre stage in the government's Industrial Strategy.[2] With an investment of £330 million between 2017-2021, the challenge aims to support a world class scientific, technology development and manufacturing scale-up capability for batteries in the UK. The challenge is focused on developing cost-effective, high-performance, durable, safe and recyclable batteries to capture a growing market.

The challenge will allow the UK to realize its commitment to move to full electrification and zero-emissions vehicles, thus contributing to the UK's cross-economy net zero ambition. The challenge is expected to translate into other sectors including aerospace and rail.

All innovators in this space can save time, effort and resources by tapping into a consistent knowledge base (i.e. consensus-based, industry-relevant standards). This can reduce risks; help establish consistent practices and accelerate innovation within this emerging sector. It will also allow the UK (and its innovation community) to provide international thought leadership and influence international standards development.

BSI's FBC Programme (hereafter FBC Programme) was launched following the creation of a customer journey map (CJM) across the battery manufacturing process exploring existing standards, regulation and key knowledge gaps with a specific focus on issues of health, safety and environmental protection. The CJM identified a number of urgent standards gaps, which BSI proposed to address via its fast-track Publicly Available Specification (PAS) development mechanism.

1.2 FBC Programme - process and objectives

The key objectives of the FBC Programme are to:

- develop and codify good practice to fill in key knowledge gaps and respond to pressing challenges;
- identify further knowledge gaps and challenges, and devise appropriate responses;
- grow the Faraday battery network; and
- build public confidence in batteries and EVs.

Standards development is an industry-led, collaborative process. The FBC Programme has undertaken extensive stakeholder engagement with industry, academia, regulators, UK's research and development community, policy makers and legislators, etc. to identify the essential knowledge gaps and immediate standards development priorities for battery manufacture. This has been achieved over a series of workshops, individual technical discussions and input, surveys and interviews, which have all shaped the earlier programme deliverables, and subsequently, the recommendations in this roadmap.

2 Industrial Strategy available from: www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

1.3 FBC Programme - deliverables

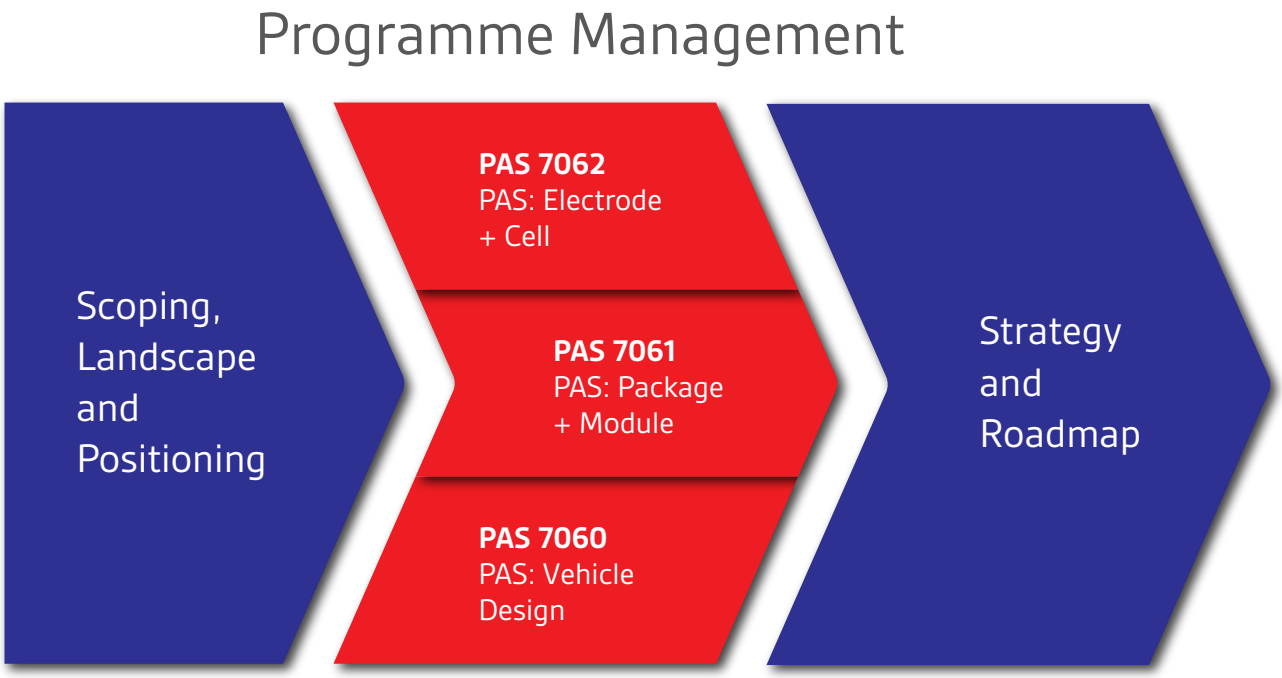
At the core of the FBC Programme and in response to the most immediate and pressing challenges that industry has been facing in battery manufacture, the PAS 706X series has been developed and published:

- PAS 7060:2021 *Electric vehicles – Safe and environmentally-conscious design and use of batteries – Guide*
- PAS 7061:2020, *Batteries for vehicle propulsion electrification – Safe and environmentally-conscious handling of battery packs and modules – Code of Practice*
- PAS 7062:2021, *Electric vehicle battery cells – Health and safety, environmental and quality management considerations in cell manufacturing and finished cell – Code of Practice*

With these important initial codification steps completed, this roadmap aims to identify other issues and FBC-related challenges and topics yet to be addressed through standards development and wider standardization activity.

Figure 2 illustrates all the deliverables within Phase 1 of the FBC Programme. The final deliverable, strategy and roadmap is intended to highlight areas for future development in the standardization of batteries, and to outline the key activities that would need to be undertaken to support such development, and the objectives of the FBC.

Figure 2 – FBC Programme: Phase 1



1.4 Roadmap - methodology

This roadmap has been developed through a combination of resource, information and stakeholder views obtained from the following:

- Stakeholder workshops:
  - Output from two validation workshops where key stakeholders and experts from across industry, government, trade associations and academia discussed and prioritized the key themes, categories, recommendations and proposed activities forming the core of the roadmap;
  - Output from a BSI-led cross-government workshop where the role of standards across sectors and battery applications, and related standardization needs, were discussed with representatives from key government departments, regulators and executive agencies; and
  - Internal BSI workshop across sectors and standards/committee portfolios where existing, ongoing or proposed work of relevance to the FBC Programme was highlighted.
- A short survey to key stakeholders to help define and understand additional gaps and wider opportunities in the codification and standardization of batteries (see Annex **A**).
- One-to-one interviews and exchanges with technical experts and partners (including the technical authors of the PAS 706x series, members of the PAS Steering Groups, other industry experts and standards contributors).
- External resources and standardization-relevant research, including the APC's *Electrical Energy Storage Roadmap* (2020 update)[3], WMG's *From Research and Manufacturing to Application and End of Life – Enabling Electrification Across Sectors, Battery Targets and priorities across sectors, 2020 to 2035*[4].

For the purposes of this roadmap, the information from the Standards Landscape Report[5] developed at the start of the FBC Programme, and the IUK CJM, have also been taken into account.

3 APC's Electrical Energy Storage Roadmap is available from: https://www.apcuk.co.uk/technology-roadmaps/
4 WMG's report is available from: www.ukbatteriesnetwork.org/resources/reports/43
5 A copy of the Standards Landscape Report is available from: www.bsigroup.com/en-GB/industries-and-sectors/energy-and-utilities/faraday-battery-challenge/download-standards-landscape/

2 Findings

2.1 Existing work of relevance

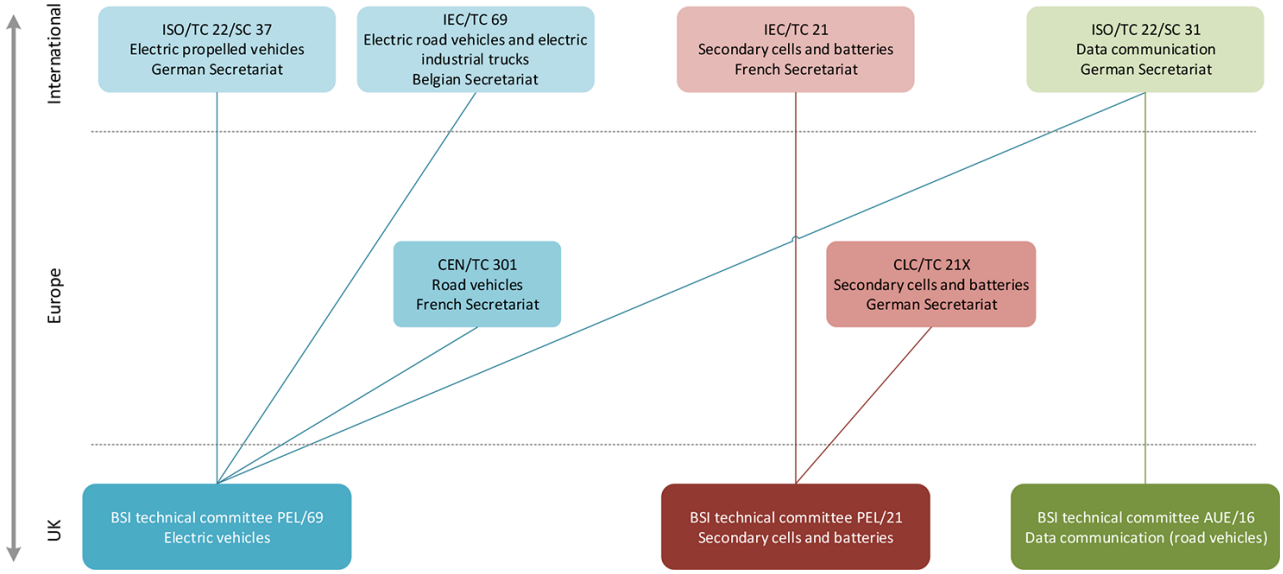
BSI participates fully in the standards creation process for EVs and battery manufacture at the European and International level (CEN, CENELEC, ISO and IEC) through numerous UK national committees, the most relevant being those working in the broader areas of Energy and Transport/Mobility.

2.1.1 National and international committees

Standards at BSI are developed by technical committees of experts from a broad set of organizations. Approximately 15 committees are responsible for about 60 standards relating to batteries, EVs and charging infrastructure. There are around 127 organizations involved in creating and maintaining the standards within these committees' portfolios.

Figure 3 shows the relationships between the three-key national, European and international technical committees and the secretariats that lead them. The secretariats alongside the technical leads establish priority areas and scopes for standards development through the formal process.

Figure 3 – International committees and UK input



Other BSI technical committees and subcommittees working on standards related to EVs and batteries include:

- PEL/23/1 Circuit breakers and similar equipment for household use;
- PEL/23/4 Protected type plugs and sockets;
- GEL/20/17 Electric cables – Low voltage;
- JPEL/64 Electrical installations of buildings, working on electric vehicle-related wiring regulations;

- AUE/32 Electrical and electronic components and general system aspects for road vehicles; and
- EPL/278 Intelligent transport systems.

There are also technical committees which work on standards indirectly relevant to EVs and batteries including:

- FSH/0 Fire and built environment sector policy and strategy committee;
- ACE/6 Aerospace avionic electrical and fibre optic technology;
- GEL/111 Electrotechnical environment committee;
- L/13 Smart Energy systems coordination group;
- ESL/120 Electrical energy storage; and
- SDS/2 Smart and sustainable cities and communities.

The above list is not exhaustive and there are other committees with links to this industry, however for the purpose of this roadmap, only the most relevant committees have been included.[6]

2.1.2 Key standards and guidance

The research carried out at the start of the FBC Programme looked at the level of standards provision and knowledge gaps across key themes, issues and challenges associated with the manufacture and use of EV batteries (see Figure 4). The research demonstrated the need to prioritize codification on the topics now covered by the PAS 706x series, while also indicating additional aspects that might benefit from standards development beyond the scope of these PASs.

6 The work programmes of the mentioned committees can be found at: https://standardsdevelopment.bsigroup.com/.

Figure 4 – Standards landscape profile indicating areas of activity and areas of potential gaps

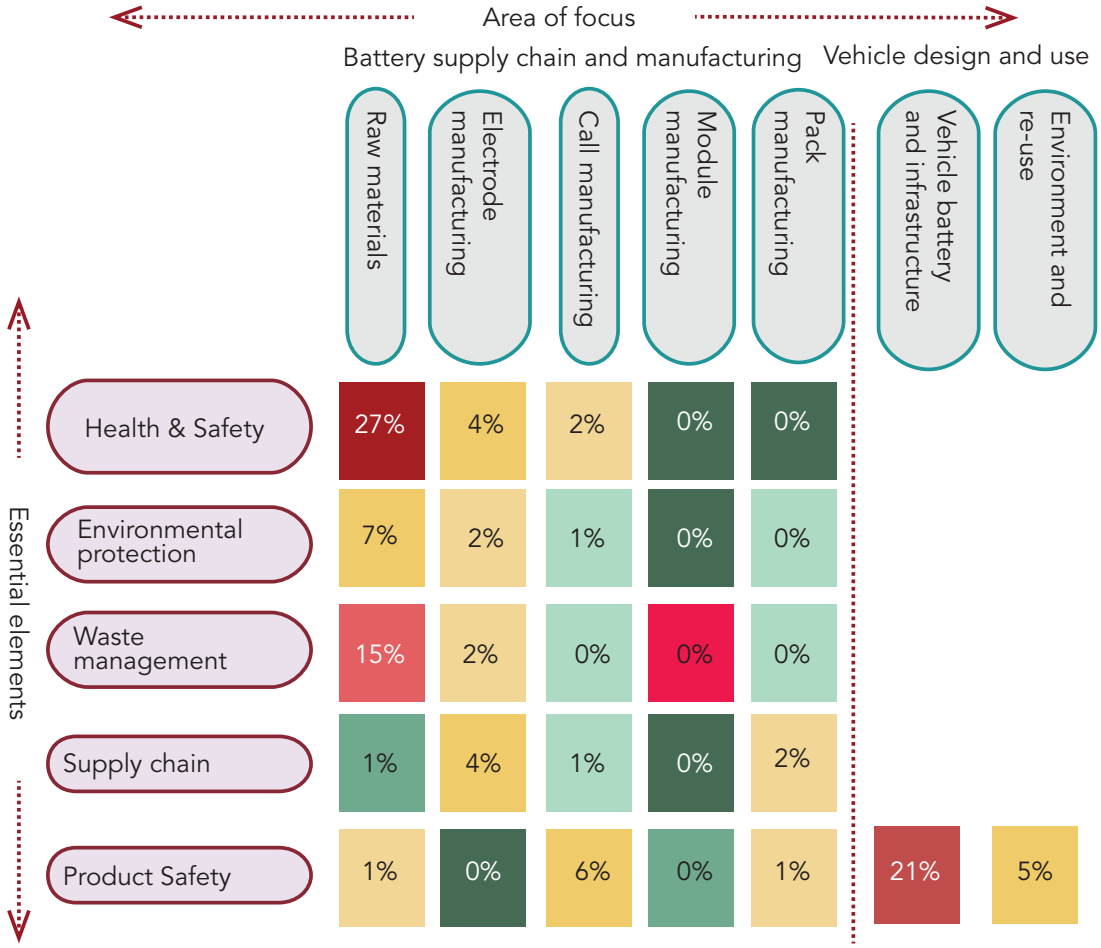


Table 1 lists the key standards of relevance to the knowledge gaps and additional codification activity outlined in this roadmap (see Section 2.2).

One further standard of relevance has been identified that is at the early development stages – IEC 63338 General guidance for reuse of secondary cells and batteries.

Table 1 – Current standards of relevance for battery manufacture

Standard	Status	Scope/Issue covered	Out of scope	Relevance to the gaps/needs identified in this roadmap
IEC 63218 – *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium, nickel cadmium and nickel-metal hydride cells and batteries for portable applications – Guidance on environmental aspects*	Under development	Provides requirements and recommendations on environmental aspects of secondary lithium, nickel cadmium and nickel-metal hydride cells and batteries for portable applications (hereafter referred to as "relevant secondary cells and batteries").	Batteries embedded in end-use products.	
IEC 62619 *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications*	Under development	Tests and requirements for the safe operation of secondary lithium cells and batteries used in industrial applications including stationary applications.	Road vehicles.	
BS ISO 26262 (series), *Road vehicles functional safety*	Published	Hazards caused by malfunctioning behaviour of safety-related electrical and/or electronic (E/E) systems.	Hazards related to electric shock, **fire**, **smoke**, heat, radiation, **toxicity**, **flammability**, reactivity, corrosion, release of energy and similar hazards, unless directly caused by malfunctioning behaviour of safety-related E/E systems.	Applies to hazards caused by malfunctioning behaviour of systems but does not cover hazards related to fire, smoke, flammability, etc.
BS ISO 12405-4:2018 *Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems -Performance testing*	Published	Specifies test procedures for the basic characteristics of performance, reliability and electrical functionality for the battery packs and systems for either high-power or high-energy application.	Does not cover specifications for battery cells, which are given in BS EN IEC 62660 (Parts 1 to 3), general safety relevant tests and requirements which are given in BS ISO 6469-1, nor environmental conditions and testing which are specified in BS ISO 19453-6.	Relevant to calls for detailed performance testing standard(s). Needs to be assessed for applicability to specific/other battery components and lithium-ion battery types used in EVs, also for other performance/reliability criteria (e.g. fire safety performance).
BS ISO 19453-6:2020 *Road vehicles - Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles - Traction battery packs and systems*	Published	Specifies requirements for lithium-ion traction battery packs or systems used in battery electric, hybrid electric and fuel cell electric road vehicles. It describes the most relevant environmental stresses and specifies tests and test boundary conditions. This document establishes a classification of battery packs or systems and defines different stress levels for testing when a classification is applicable and required. The objective of this document is to specify standard test procedures and conditions to enable the observation of the reliability of the lithium-ion traction battery in the vehicle.		Defines stress levels for testing and standard test procedures and conditions on the reliability of the lithium-ion traction battery in a vehicle.

		This document specifies tests for a battery pack or system of voltage class A and B. This document provides the necessary information to set up a dedicated test plan for a battery pack or system subject to agreement between the customer and supplier. If required, the relevant test procedures and/or test conditions can also be selected from this document.		
BS ISO 6469-4:2015 *Electrically propelled road vehicles - Safety specifications - Post-crash electrical safety*	Published	Specifies safety requirements for the electric propulsion systems and conductively connected auxiliary electric systems of electrically propelled road vehicles for the protection of persons inside and outside the vehicle. It specifies electrical safety requirements for vehicle post-crash conditions. It applies to electrically propelled road vehicles with voltage class B electric circuits. Applicable vehicles are those vehicles which are explicitly specified in these crash test procedures.	It does not apply to motorcycles and mopeds. It does not specify any crash test procedure. **It does not provide comprehensive safety information for first responders, emergency services, maintenance, and repair personnel.**	Does not provide comprehensive safety information for first responders, emergency services, maintenance, and repair personnel.
BS ISO 6469-1 *Part 1: Electrically propelled road vehicles - Safety specifications - Rechargeable energy storage system (RESS) - Amendment 1*	Under review	Provides safety requirements for rechargeable energy storage systems. *New inclusion (to be confirmed): Specifically, for lithium-ion based RESS, this document specifies demonstration methods for thermal runaway risk mitigation in case of a cell internal failure, including the collection of associated data. It also specifies a selection of different test methods for thermal propagation. The selected tests could be carried out at vehicle level or for RESS and RESS subsystem if appropriate.*	2019 edition does not provide comprehensive safety information for the manufacturing, maintenance and repair personnel.	Looks at test methods for thermal propagation; does not provide comprehensive safety information for certain personnel.
PD ISO/TS 23625 *Small craft - Lithium-ion batteries*	Under development, imminent publication	Includes elements the manufacturer/installer should consider in the selection and installation of lithium-ion batteries for boats. It applies to lithium-ion batteries, and battery systems with a capacity of greater than 600 W hours installed on small craft for providing power for general electrical loads, and/or electric propulsion systems. Elements include system design requirements, safe operating limits, general lithium-ion battery installations, fire protection and cell venting, battery management system and testing, manufacturer's safety information and operator's manual.		Covers elements to be considered by manufacturer in installation of batteries on boats.

(*Continues*)

Table 1 – (Continued)

Standard	Status	Scope/Issue covered	Out of scope	Relevance to the gaps/needs identified in this roadmap
UL 9540 ANSI/CAN/UL *Standard for energy storage systems and equipment*	Published	Covers energy storage systems that are intended to receive and store energy in some form so that the energy storage system can provide electrical energy to loads or to the local/area electric power system (EPS) when needed. The types of energy storage covered under this standard include electrochemical, chemical, mechanical and thermal. The energy storage system shall be constructed either as one unitary complete piece of equipment or as matched assemblies, that when connected, form the system. This standard is a system standard, where an energy storage system consists of an energy storage mechanism, power conversion equipment and balance of plant equipment Energy storage systems may include equipment for charging, discharging, control, protection, power conversion, communication, controlling the system environment, air, fire detection and suppression system, fuel or other fluid movement and containment. This standard covers energy storage systems for stationary indoor and outdoor installations. This standard also covers mobile energy storage systems. The standard includes requirements for energy storage systems used in residential installations, non-residential installations and wall-mounted applications.	Individual parts (e.g. power conversion system, battery system, etc.) of an energy storage system are not considered an energy storage system on their own. This standard evaluates the compatibility and safety of these various components integrated into a system. Systems using lead acid or Ni-cad batteries that only serve an uninterruptible power system (UPS) application are outside the scope of this standard. Requirements for installation, with the exception of installation manuals and documents for installation provided with the system are outside the scope of this standard.	Applies to the safety energy storage installations and electrical systems, not battery per se. Does not provide comprehensive safety information applicable at the battery or battery component level. Developed by ANSI, so largely driven by national requirements in North America and energy system/storage specifics.
UL 9540A ANSI/CAN/UL *Standard for test method for evaluating thermal runaway fire propagation in battery energy storage systems*	Published	The test methodology in this document evaluates the fire characteristics of a battery energy storage system that undergoes thermal runaway. The data generated will be used to determine the fire and explosion protection required for an installation of a battery energy storage system intended for installation, operation and maintenance in accordance with the International Fire Code (IFC), the Fire Code, NFPA 1, the National Electrical Code, NFPA 70, the National Electrical Safety Code (NESC), IEEE C2, other energy storage system codes, and the manufacturer's installation instructions.	Fire protection requirements not related to battery energy storage system equipment. These are represented by installation codes.	Fire protection requirements not related to battery energy storage system equipment. Developed by ANSI, so largely driven by North American requirements and specifics/needs. Can be used to inform UK-specific, battery specific fire safety and propagation codification.

2.2 Issues and challenges, corresponding knowledge needs and gaps

This section summarizes the knowledge gaps that require further guidance, best practice development or other supporting activity to enable the further safe, environmentally conscious and resource efficient development and deployment of battery technology, thus overcoming the most pressing market challenges. The observations presented here are based on feedback gathered from across representatives from industry, government, academia, insurers, regulators and other relevant stakeholders throughout the various stages of the FBC Programme. These in turn informs the framework of recommendations presented in this roadmap.

2.2.1 Knowledge gaps and further activity identified in Phase 1 of the FBC Programme

The initial research, scoping and stakeholder engagement work carried out by BSI confirmed the knowledge gaps in the crucial areas below, and validated the need to develop the PAS 706x series to address these gaps: cell manufacturing; module manufacturing; pack manufacturing; waste management beyond the raw materials phase of the supply chain; environmental protections, including end-of-life aspects.

The initial research, scoping and stakeholder engagement carried out by BSI highlighted the following gaps and needs for supporting measures (additional to the PAS 706x series) that cover a broad range of documents and activities:

- **Low consumer safety and public awareness** – There is limited public information available, which leads to low confidence. Creating consumer education guides/standard for consumer safety would be valuable. Codes of practice for manufacturers supplying a car and the information they need to provide to customers could also be considered.
- **Provision of standards-related information and awareness raising** – There is a need to build awareness of the existing standards (including PASs, British and international standards) that manufacturers can use and understand the benefits they deliver. Guidance on the implementation of these standards within individual organizations might also be useful.
- **Standardization, testing and certification** – Cooperation between the UK and other countries (target markets for UK manufacturers) needs to be established (e.g. with China, Korea, USA, etc.).
- **UK leadership in international standardization** – Measures to increase UK's influence in the international standardization arena, for example by providing better support for UK experts participation in international standards development, and by internationalizing standards and knowledge that originated in the UK (such as the PAS 706x series developed within the FBC Programme). Balanced stakeholder representation on relevant national committees will continue to be a BSI priority.
- **Consistent testing and certification market** – Enabling access to other markets and expanding the trading potential of UK manufacturers could also be considered.

More widely, creating standards as battery technology and battery technology applications develop further would give the UK an opportunity to put these forward as future international standards, ultimately helping to drive UK competitiveness in this area of strategic value.

In addition, previous BSI work and resulting reports include references to further related needs (as in the following example taken from the August 2019 research report *Developing a UK Standards Strategy for the Uptake of Light-weight Materials by the Transport Industry*[7]).

7 Report available from: www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/about-standards/Innovation/advanced-materials/developing-a-uk-standards-strategy-for-the-uptake-of-light-weight-materials-by-the-transport-industry/

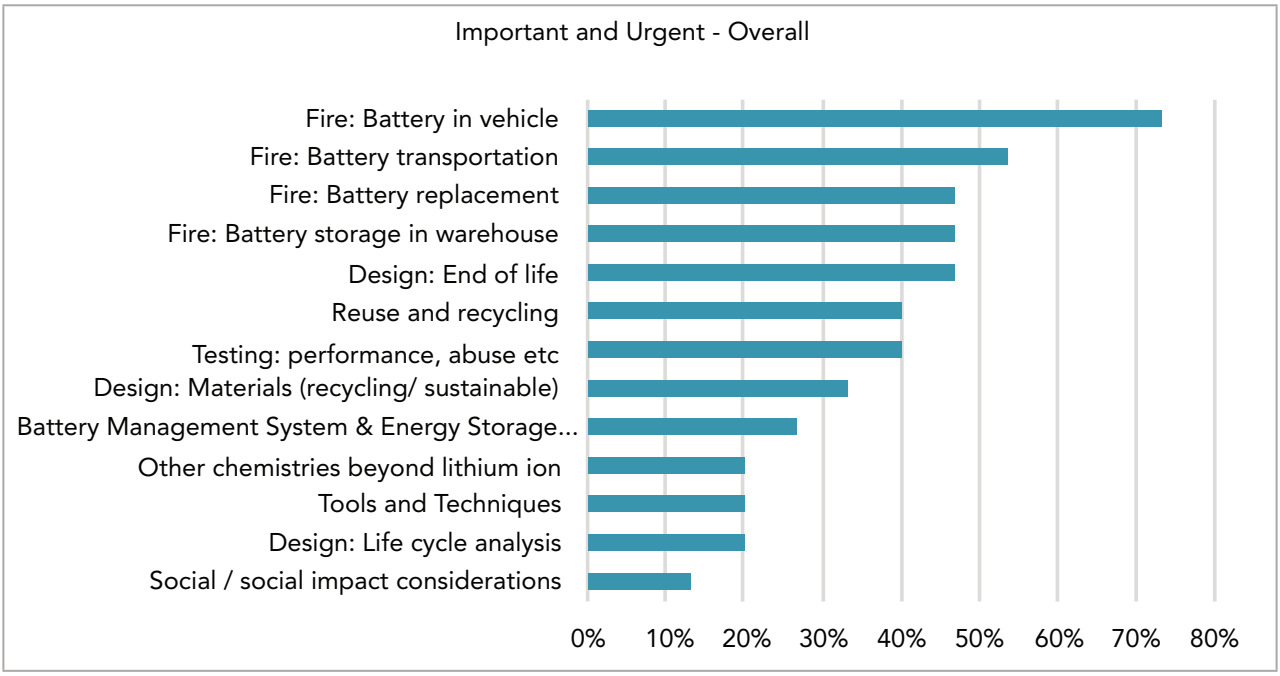
"The only available guidance on common requirements for battery boxes that companies have found are standards from China. Several companies in the UK are developing lightweight, composite battery boxes and would appreciate general guidelines on requirements for properties such as fire, electro-magnetic compatibility and penetration."

2.2.2 Highlights from the roadmap-specific stakeholder engagement and validation activities

2.2.2.1 Online survey

The survey responses confirmed the most urgent codification needs are around *fire risk safety requirements and guidance* (see Figure 5), whether it be for the battery in the vehicle, the battery being transported, the battery when stored or during battery replacement in the vehicle, and in secondary use/reuse (see Annex **A**).

Figure 5 – Immediate industry needs



Another urgent priority highlighted is *design*. This includes design considerations in materials use and selection, at the end-of-life, design for reuse and recycling or second life, and wider sustainability considerations throughout the battery's life cycle. As an example, there is no standard definition for "state of health" of a battery at end-of-life or for second use purposes. Suitability of cells for second life needs clear evaluation criteria/procedure, including 1st life use and performance trends. Longevity and safety can be affected by 1st life performance. As EV batteries become easier to dismantle, test and reuse definitions will be needed in terms of 2nd life, 3rd life etc. 2nd life testing is a gap and should be addressed separately to new batteries.

Similarly, several companies in the UK are developing lightweight, composite *battery boxes* and could benefit from general *guidelines on requirements for properties such as fire, electro-magnetic compatibility and penetration* (the only available guidance on common requirements for battery boxes are standards from China).

Respondents also highlighted a *need for standards detailing safety, health and environmental considerations of batteries and battery components for use in freight (73% of respondents), aerospace (87%), rail (80%) and marine transport (73%)*. This has been further validated by comments and discussions held during BSI hosted workshops and webinars. HGVs/freight have been highlighted as requiring guidance and standards.

Guidance around health, safety and environmental/sustainability considerations for battery design, manufacture, transport, storage and use is also lacking for non-passenger vehicles such as motorbikes/off-road/on-road/motor-sport/construction machinery/agricultural machinery/mobile equipment/fire engines/trucks and safe and efficient retrofitting of vintage cars.

Other areas highlighted as needing urgent codification include:

- recharging large groups of batteries – protection, fire safety, safe distances;
- inconsistencies within existing testing practice in standards;
- design requirements for specific applications;
- cleanliness and control requirements in the cell manufacturing process;
- fireproof battery bags to prevent harm if a battery leaks/sets fire in someone's backpack/pocket etc.;
- vented battery gasses in confined spaces – fire safety aspects;
- EV design standards for safety of emergency personnel – standardization around identification of electrical risk by personnel, risk management, how to recover/dismantle vehicle for passenger extraction;
- remanufactured packs - safety testing, grading, certification, asset tracking (links to the wider needs/gaps around recycling, reuse, second life and product circularity);
- thermal runaway detection and prediction (links to wider fire risk management needs/gaps); and
- battery management system (BMS) requirements – diagnostics for BMS, particularly state of health (SOH) diagnostic metrics.

2.2.2.2 Stakeholder workshops

BSI held two validation workshops, attended by 26 industry, government and standards experts and stakeholders.

The agenda covered:

- immediate standards needs and standards development gaps / FBC Programme related;
- cross-sector applications;
- other battery technology and its sector applications; and
- other standardization measures, supporting and dissemination activity.

Polling was carried out during the workshops to facilitate the discussion and to gather stakeholder views and responses are shown in Tables 2, 3 and 4. See Annex **B** for full polling results.

Attendees were asked to rank the codification recommendations in priority order taking into consideration:

- timeframe (how urgently a solution is needed);
- impact and effectiveness;
- availability of resource (cost) and expertise to develop the solution; and
- impact on public confidence.

Table 2 – Prioritization of immediate standards needs, and gaps identified

Workshop priority ranking	
1	Fire risk management (throughout the battery lifecycle; in use, transport, storage, repair specifically) – specification, management system, test method?
2	General recyclability, second life, circularity requirements/guidance – guidance, code of practice, specification
3	Performance and abuse testing requirements – specification, test method(s)
4	Design considerations (design for performance, recyclability, 2nd life) – guidance, code of practice, possibly specification
5	Battery boxes (health, safety, environmental considerations) – guidance, specification(s), code(s) of practice
6	Battery management system – general (management system or specification) + • explore/consider link with grid battery systems and electrical energy storage standards; • smart and connected systems
7	Code(s) of practice/guidance for manufacturers supplying a car and the information they need to provide to customers

Table 3 – Prioritization of cross-sector applications

Workshop priority ranking	
1	Health, safety and environmental considerations for: defence, aerospace, rail, marine, freight
2	Safety considerations (detailed) of battery use in hybrid rail, marine, all electric aero, eVTOL
3	Recyclability and second life
4	Predictability/modelling for all electric aero and eVTOL

Table 4 – Concerns and wider knowledge gaps relating to battery applications (other than batteries for EVs) and non-lithium-ion technologies

Other (sector) applications	• **e-Scooters, personal mobility** – currently only allowed to use a trial scooter in a controlled area. Need for standards and regulation.
	• **Drones** (consumer level to larger forms) - guidance required for mass charging.
	• Proliferation of **personal electrical devices in rail, aerospace**. There are fire safety concerns resulting from the rise in personal electronics on a plane. Aerospace – general safety case requirements, drones, battery management system requirements. Aerospace is driven by regulation with special conditions required for vertical take-off and landing technology. They need safety air-worthiness within 2-3 years and the challenge will be coordinating the work. Consequently, it may be necessary to design for the extra safety requirements that aerospace needs.
	• **Military/defence** - recharging large groups of batteries – protection, fire safety, safe distances required; energy density.
	• **Battery for rail** - codification of risk management is needed, how to deal with emergencies.
	• **Space** – testing against failure as well as safety.
	• **H&S** aspect of stationary storage, e.g. grid, microgrid and home/residential and particularly fire prevention and tackling. • **Off-highway applications** are often more niche and could be counted as an area in their own right. • **Grid balancing**, energy storage systems. • **Medical devices** and wearables are an emerging market - safety of testing issues. • **Charging standardization**, widen scope of existing standards from EVs to other applications.
Other battery chemistries and materials	Chemistries that increase the energy density are the ones industry are most interested in. Changing a fundamental technology requires all who use/supply/maintain/transport/replace it to have training and understand capabilities. Standard test methods for materials, components and cells (mainly for the UK, in R&D) are missing for emerging lithium-ion chemistries and other types of batteries.

2.2.3 Other sources and external research of relevance

Review of other key battery (technology) research, road mapping material, and engagement with organizations involved in the FBC Programme, reiterates the key issues and challenges facing the battery (technology) market, as well as the key areas where (urgent) standardization intervention is needed and would be most beneficial.

APC's updated *Electrical Energy Storage Roadmap*[8] (see Figure 6) broadly emphasizes the need for:

- advanced (packs and battery management systems) *design for performance* needs;
- *battery management systems*, smart and connected systems specifically; and
- *recycling and life cycle management* (end-of-life material recovery processes and 2nd life design).

8 APC's Electrical Energy Storage Roadmap is available from: https://www.apcuk.co.uk/technology-roadmaps/

Figure 6 – Electrical Energy Storage Roadmap

Roadmap 2020

Electrical Energy Storage

Cell Materials and Manufacturing Roadmap

Technology indicators for 2020-2035 can be seen on page 2

automotive council UK

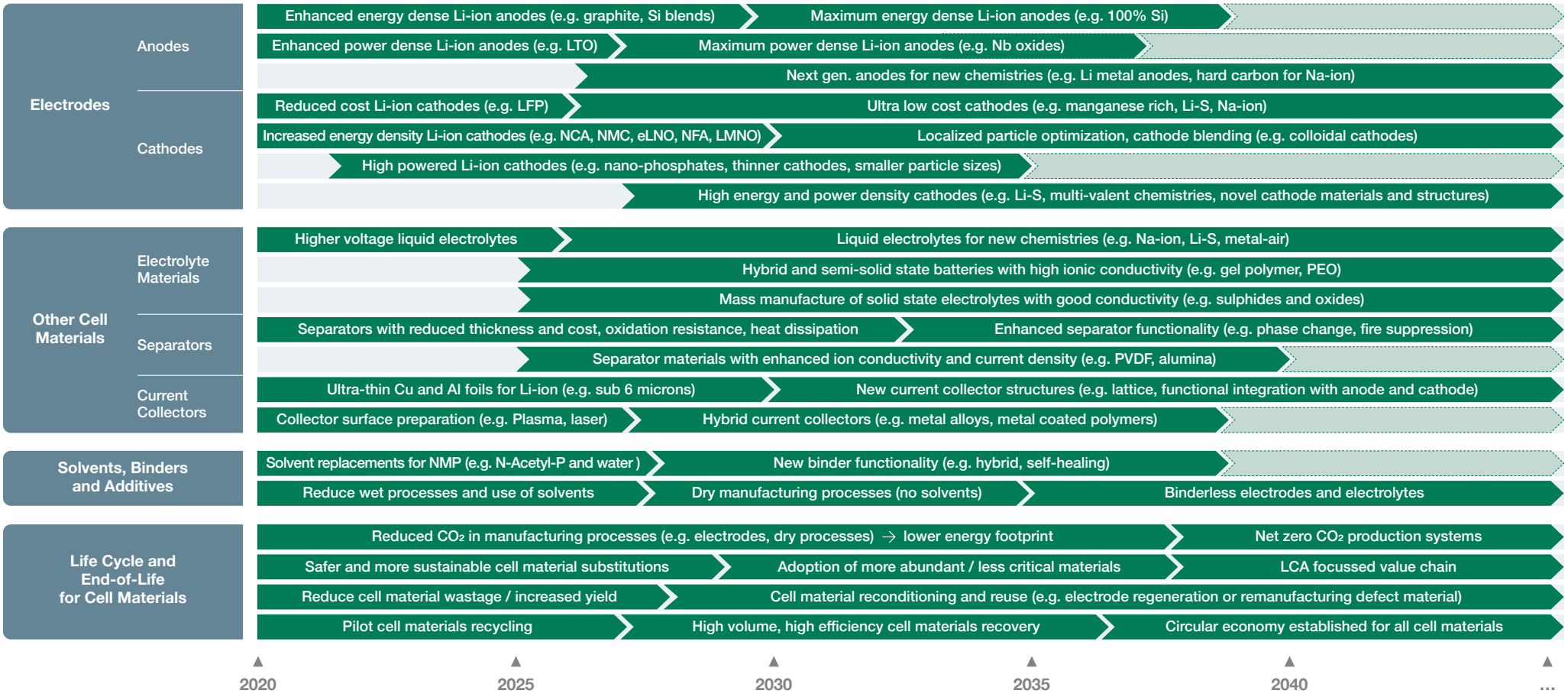
ADVANCED PROPULSION CENTRE UK

This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

Dark bar: *Technology is in a mass market application. Significant innovation is expected in this time frame*

Transition: *Transitions do not mean a phase out from market but a change of R&D emphasis*

Dotted line bar: *Market Mature – technology has reached maturity. Likely to remain in mass market until it fades out where it's superseded*



Roadmap 2020

Electrical Energy Storage

Modules and Pack Roadmap

Technology indicators for 2020-2035 can be seen on page 2

automotive council UK

ADVANCED PROPULSION CENTRE UK

This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

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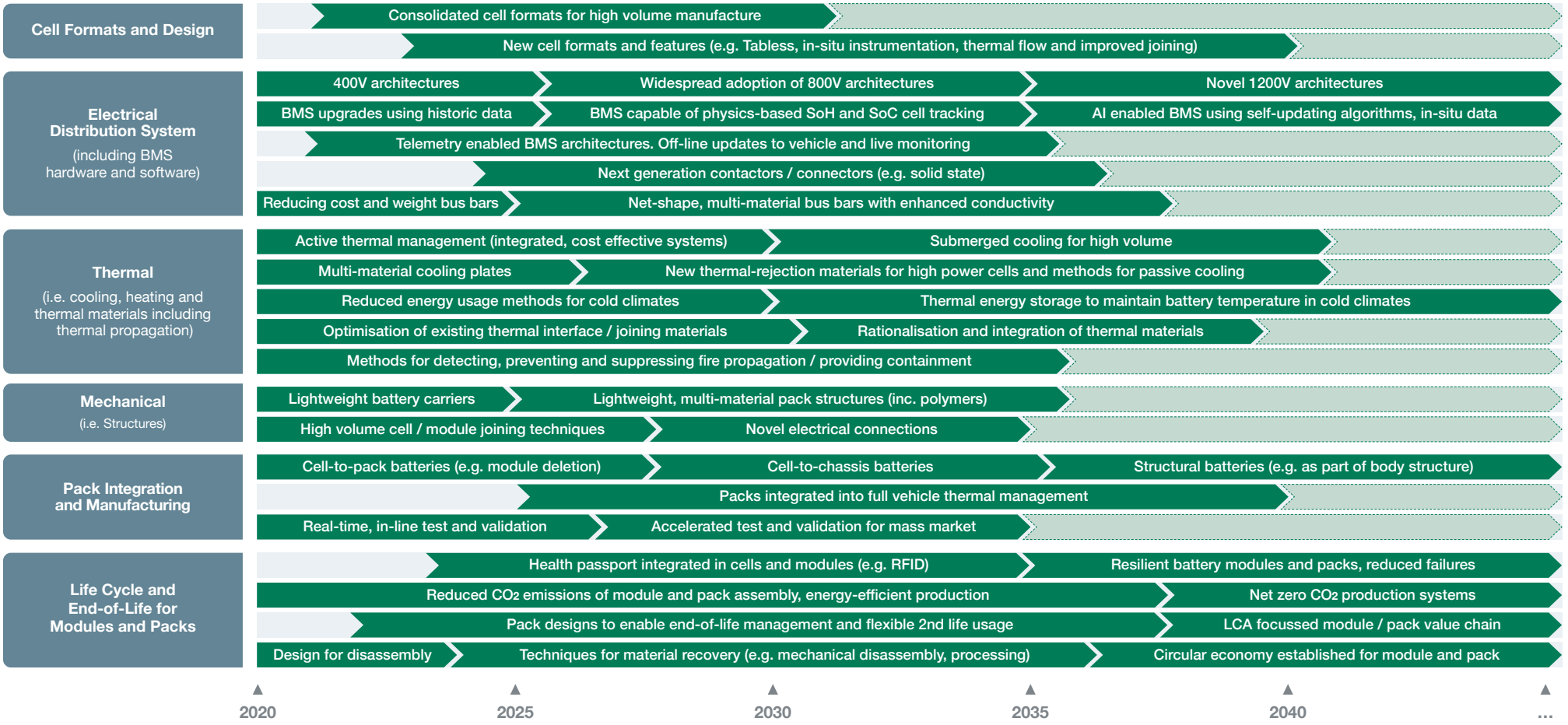


Source: APC UK and AC UK, Electrical Energy Storage Roadmap (2020 update)

When exploring other battery applications (beyond EVs) and conditions for future technology readiness, WMG's 2020 *From Research and Manufacturing to Application and End of Life – Enabling Electrification Across Sectors, Battery Targets and priorities across sectors, 2020 to 2035* report, captures the following issues and priorities (also identified in BSI's standardization work and roadmap engagement) (see Figure 7):

- safety of batteries for use in hybrid rail, marine, all electric aero, eVTOL;
- predictability/modelling (e.g. including via design) in all electric aero and eVTOL; and
- recyclability - highlighted as of high importance across all non-EV sectors and battery applications.

In terms of safety-related consideration of battery (technology) applications, WMG's work emphasizes the need to develop standards and certification methodologies for emerging sectors within the 2020-2025 time horizon (see Figure 8).

Figure 7 – Critical research priorities to meet future requirements

Critical Research Priorities to Meet Future Requirements

The viability of the sector to grow is dependent on these targets.

Improvements to current technology may be beneficial to the sector but not at the expense of higher priorities.

		Power Density	Energy Density	Cost	1st Life	Safety	Temperature	Predictability / Modeling	Recyclability
Energy Focused Cost Sensitive	Energy Storage	Low	Low	Critical (whole life cost)	High	Medium	Low	Medium	High
	Volume Automotive	Medium	Medium	Critical	Low	Medium	Low	Medium	High
	Low Cost, Efficient Mobility	Low	Low	Critical	Low	Medium	Low	Medium	High
	e-Motorbikes	High	High	High	Low	Medium	Low	Medium	High
	Light Goods Vehicle	Low	Medium	Critical	Medium	Medium	Low	Medium	High
	Heavy Goods Vehicle	Low	Medium	Critical	High	Medium	Low	Medium	High
	Hybrid Rail	High	Medium	Medium	High	Critial	Low	Medium	High
	Marine	High	Medium	Critical	Low	High	Low	Medium	High
Energy Focused Weight and Power Sensitive	Performance Auto	High	High	Medium	Low	Medium	Low	Medium	High
	All Electric Aero	High	Critical	Low	Medium	Critical	Medium	Critical	High
	eVTOL	High	Critical	Medium	Low	Critical	Medium	Critical	High
Power Focused Weight Sensitive	Very High Performance Hybrids	High	Medium	Medium	Low	Medium	Low	Medium	High
	Range Extender Hybrids	High	Medium	High	Low	Medium	Low	Medium	High
Power Focused Cost Sensitive	Hybrid-Rail	Medium	Low	Medium	High	High	Low	Medium	High
	Full Hybrid & Mild Hybrid	High	Medium	Critical	Low	Medium	Low	Medium	High

Source: From Research and Manufacturing to Application and End of Life – Enabling Electrification Across Sectors, Battery Targets and priorities across sectors, 2020 to 2035, WMG and Advanced Propulsion Centre UK

Figure 8 – Safety targets

Safety Targets

2020	2025	2030	2035
• Functional SoX monitoring (state of charge, health, power). • 5 minutes containment (no visible smoke or flames in vehicle). • Development of standards & certification methodologies for emerging sectors.	• Physics based SoX monitoring (state of charge, health, power). • Detection of degradation mechanisms leading to thermal event. • 5 minutes containment (no visible smoke or flames in vehicle). • Development of standards & certification methodologies for emerging sectors.	• Safety critical capable SoX monitoring (state of charge, health, power). • Detection & mitigation of thermal event onset phase at subsystem level. • Full containment at pack level for extended duration.	• Safety critical capable SoX monitoring (state of charge, health, power). • Detection & mitigation of thermal event onset phase at subsystem level. • Full containment at pack level.

Source: From Research and Manufacturing to Application and End of Life – Enabling Electrification Across Sectors, Battery Targets and priorities across sectors, 2020 to 2035 WMG and *Advanced Propulsion Centre UK*

3 Roadmap – knowledge framework

This section outlines the set of recommendations to address the issues and challenges and the corresponding knowledge gaps/needs identified in Section 2. The recommendations are presented in accordance with the initial urgency, significance and potential market impact that can be achieved through their implementation, as prioritized through stakeholder engagement.

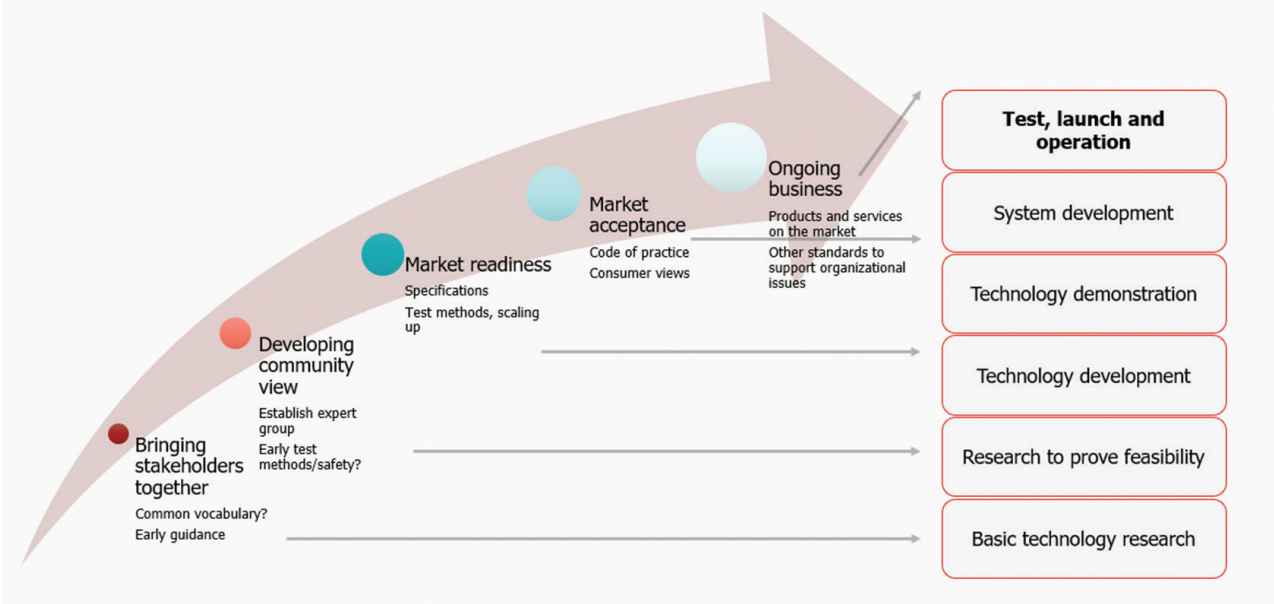
They consider national and international standards development capabilities and influence BSI could deploy and exert in its role as the UK's national standards body (NSB). While resource and expertise availability to take these recommendations forward have been taken into account and broadly discussed with stakeholders in the creation of this roadmap, no detailed resource requirements have been included, nor expectations laid out that the recommendations would be solely funded from the ISCF FBC. As with most standardization work in support of innovation, cross-sector collaboration, scoping of specific needs and resourcing would be needed to implement the activity outlined in this roadmap over the 2021 – 2035+ time horizon.

Many of the recommendations outlined would, in the first instance, require further research, scoping and validation of the individual solution and the appropriate corresponding delivery mechanism (including the resourcing requirements associated with that solution and its delivery mechanism).

3.1 'The right standard at the right time'

The type of standards needed varies according to maturity of technology, nature of technology and industry sector. Standards need to be considered in the early stages of technology road mapping and procurement to deliver maximum market impact (see Figure 9).

Figure 9 – The right standard at the right time



Source: O'Sullivan and Brévignon-Dodin, Role of Standardisation in support of Emerging Technologies, Institute for Manufacturing, University of Cambridge

3.2 Codification framework

The thinking behind, and the approach, outlined in Figure 9 is used to prioritize and plot the proposed standards interventions per category and on a short-, medium-, and long-term timeframe as outlined in Table 5.

The text in italics refers to the recommended form of standards development intervention, or the specific activity that should be carried out to determine and validate suitable interventions and formats. Further stakeholder validation, scoping and detailed planning (including resource considerations) of individual interventions selected for implementation would be required prior to rolling these out.

Table 5 – Codification framework

		2021 – 2025	2025 – 2030	2030 – 2035	2035+
1	**Immediate/FBC Programme Phase 1 related** • to address the gap/need for detailed, systematic guidance on fire risk management across the battery lifecycle, and in specific battery lifecycle stages • to build upon existing fire codification effort and draw attention to existing standards • to address waste and environmental issues, encourage recyclability, second life and product circularity	**Fire risk management** (throughout the battery lifecycle: in use, transport, storage, repair & replacement, etc.) – *specification(s), management system(s), test method(s), or signposting guidance document(s)*			
		Design considerations (design for performance, recyclability, 2nd life) – *guidance document(s), code(s) of practice, possibly specification(s)*			
		General recyclability, second life, circularity requirements/guidance – *guidance, code of practice, specification*			
		Performance and abuse testing requirements, e.g. 2nd life testing specifically – *specification(s), test method(s)*[1]. *Validate if these are sufficiently addressed, or not.*			
		Battery management system – general *(management system or specification)* + • commonality of module interface • battery systems and energy storage (format and No tbc) • smart and connected systems (format tbc)			
		Battery boxes (health, safety, environmental considerations) – *guidance, specification(s), code(s) of practice*			
		Code(s) of practice/guidance for manufacturers supplying a car and the information they need to provide to customers			
2	**Other (sector) applications of lithium-ion** • To address health, safety challenges which are sector specific such as off highway, HGV, in remote areas, etc. • to build upon the FBC 1 PASs effort, ensuring continuity, consistent practices, and higher levels of consumer confidence	**Health, safety and environmental considerations** *(PAS 706x series application/adaption or additional guidance)* for: • Defence, aerospace[2]; rail, marine, freight • mining (underground) • off-highway and agriculture machinery/vehicles • consumer batteries (drones, hoverboards), medical devices • space?			
		Safety considerations of battery use in (e.g. detailed guidance, specification(s), test methods): • Hybrid rail, marine, all electric aero, eVTOL • Stationary storage (residential); fast-charging infrastructure			
		Recyclability and second life *(assessment/further research of the applicability and adaptation of standards/ guidance developed under 1 for application to other sectors)*			
		Predictability/modelling for all electric aero and eVTOL *(research and assess the need for, scope out and develop standards and/or guidance)*			
3	**Other battery technology and its sector applications (e.g. solid-state batteries, sodium, lithium sulfur, carbon ion, cobalt, nickel, hydrogen fuel cell etc.)** • To address standardization needs in evolving technologies which are developing in parallel with Li+ batteries. • to build upon the previous/ongoing codification effort, ensuring continuity, consistent practices, and higher levels of consumer confidence in emerging battery technologies • to attract expertise and form a community of experts to enable a timely codification response (as/when required)	*Community established / expertise identified* *Agreement on key concepts, terms and definitions – vocabularies, initial guidance*	Energy density vs cost is a major consideration – is there a role for standardization? *(requires further research and assessment of issues needed; assessment of standards gaps needed; scoping and development of additional standards confirmed as needed)* Application/adaption of health, safety and environmental performance standards for lithium-ion batteries to other chemistries, technologies and their sector applications *(requires assessment of standards needs, scoping of validated standards, and development of safety and performance standards for other battery chemistries and technologies)* Standard test methods for materials, components and cells (mainly for the UK, in R&D) for emerging lithium-ion chemistries and other types of batteries *(requires assessment of standards needs, scoping of validated standards, and development).* *Other/evolving codification needs assessed and met in line with technology development cycles.*		

[1] Or could be an aspect of the standard(s) for design considerations, or the standard(s) for general recyclability, second life, circularity requirements/guidance.

[2] For defence and aerospace further research and assessment of current standards provision is needed to determine when new standards are to be developed (due to the high-level of standards provision and the existence of civilian and military standards).

3.3 Dissemination and uptake

The successful uptake of new standards and guidance involves an element of dissemination and engagement. We have set out some recommendations as to next steps once the PASs are published. This includes international cooperation to develop globally recognized standards based on the PASs, training and masterclasses, as well as wider promotion and marketing, development of certification and training tools, and impact assessment.

3.3.1 UK thought leadership and knowledge export - internationalization of PASs and other measures

BSI is the UK's NSB and provides the UK position and comments on standards developed at the European and international level through its national committees. It also works with committee experts to propose new standards at an international level (see Figure 3).

Standardization, testing and certification cooperation between the UK and other countries (target markets for UK manufacturers) has also been established (e.g. with China, Korea, USA, etc.). BSI is currently collaborating with SAC, the national standards body of China, to develop standards proposals in five key areas, one of which is batteries. The joint proposals would go some way to ensuring common ground is found between the two countries before a standardization proposal is submitted to bodies such as ISO and IEC.

The UK's influence in the international standards arena is enhanced by diversifying the expertise and representation on existing committees and providing support for UK experts' participation in international standards development. Committee diversification and support has increased because of the stakeholder engagement that BSI has carried out throughout the FBC Programme, specifically during the PAS development and roadmap creation process. Further research and discussion is proposed to identify additional expertise for the existing technical committees, and to establish sources of additional funding needed to enhance the UK's participation and leadership in international standards development work of relevance. A conversation between BSI's Committees, BSI Policy, Department for Business, Energy & Industrial Strategy (BEIS) (as BSI's sponsoring department) and the FBC innovation community is a first step in establishing the best way forward.

A crucial step in ensuring thought leadership and UK influence in the international battery and battery technology development space would be the internationalization of standards and knowledge that originated in the UK, starting with the PAS 706x series developed as part of the FBC programme . BSI has significant experience and considerable success in putting forward standards of UK origin to be developed and adopted as international standards (ISOs). The process of proposing a UK-based standard to ISO is formally managed by BSI in its NSB and ISO member capacity, it is quite complex, and the outcome is not guaranteed. However, in collaboration with the vast FBC stakeholder base, building upon BSI committees expertise and reputation, and working closely with partner NSBs, BSI will make every effort to put forward a solid business case around the value that the adoption of the PAS 706x series as ISOs would create. Where confirmed that the internationalization of the PAS 706x series is of interest to the UK's FBC community, a detailed plan would be put together and presented to Innovate UK, UK government and other key stakeholders, outlining the most effective internationalization routes and levers.

3.3.2 Enhancing uptake of existing and future standards

The following activities and supporting content creation are recommended for consideration:

- Guidance on the implementation of key standards in the FBC space within individual organizations. Specific emphasis needs to be put on providing implementation guidance around the PAS 706x series.
- PAS (and other key standards) implementation case studies by a variety of users.
- In addition to some of the knowledge gaps and codification solutions identified, guidance material and case studies could be developed to inform and 'translate' key standards and the PAS 706x series for use in other sectors.
- Promotion at BSI-led and external events, forums, focus group discussions; cross-stakeholder dissemination campaigns and events; BSI-UKRI-led events and dissemination activities across the wider FBC work and community.

Specific activities are in progress following the publications of the PAS 706x series, to support and implement some of these recommendations, including:

- A series of masterclasses aiming to give users a good understanding of the approaches in each PAS, including key takeaways, challenges and implementation guidance, that will help attendees adopt learnings into their organization.
- A suite of videos bringing the PAS 706x series, and the overall programme, to life. The aim is to reach a wider audience, explaining the potential uses and benefits of the standards.

3.3.3 Testing and certification

A consistent testing and certification market, enabling access to other markets and expanding the trading potential of UK manufacturers could also be considered. Such a certification regime could be developed to cover specific aspects and requirements associated with batteries and battery components or could cover the entire battery life cycle or the battery management system. The options for a (testing and) certification regime, the governance structure of a certification and enforcement system, etc. will need to be assessed in the context of any new standards developed and previous or ongoing initiatives to create a compliance and enforcement regime for batteries and battery systems.

3.3.4 Training and accreditation

Training and certification of engineers to use high-voltage equipment has been raised by industry on multiple occasions as a key ask.

To address the skills gap perceived as a barrier to further market growth, the design and development of a UK-wide training and accreditation scheme might need to be considered. The scope and components of such a scheme will need to be determined in a conversation with industry associations, training scheme/assurance providers, etc. A set of specific standards could be developed to enable and inform training components at various levels (e.g. in manufacturing process, in use, replacement and 2nd life, handling in storage and transport)

3.3.5 Impact

Provision of standards-related information and awareness raising is recommended as part of any standardization programme. This requires consideration of the impact that newly developed standards, as well as wider programmes/activities have on the growth of the industry, individual businesses, and international trade, etc.

An impact assessment exercise as part of the FBC Programme could be carried out with regards to its specific deliverables to determine the levels of interest. For example, a longitudinal study looking at levels of interest, engagement and advocacy of the programme or its specific deliverables (e.g. PAS 706x series, any additional standards developed and published within the FBC Programme). The assessment can be tailored to:

- provide evidence of the utility and impact of standards and standards strategies to the sponsor, wider stakeholders, sponsors and users;
- demonstrate the outcomes and impact of standards in relation to supporting innovation; and
- provide evidence of the value & and impact of standards more widely.

The FBC Programme would scope the activities best suited to demonstrate the impact the deliverables are making to support UK industry and battery manufacture.

3.3.6 Summary of supporting standardization measures, supporting and dissemination activity

Table 6 provides a summary of the activities to support the roadmap recommendations.

Table 6 – Other standardization measures, supporting and dissemination activity

Other standardization measures, supporting and dissemination activity			
Measure/Target outcome	**Recommendations**	**Suggested activities**	**Timeframe**
UK thought leadership and knowledge export – internationalization of PASs and other measures	**1. Design and initiate 3 PASs internationalization process upon publication**	• Confirm interest/support with Government and industry • Develop NSB-led internationalization strategy, plan and secure resource • Initiate internationalization process	**2021 – 2025**
	2. Continue collaboration with China/SAC and establish collaboration with other countries/ NSBs in the battery space – joint ISP proposal	• As per project scope agreed with China/SAC • Monitoring activity, identify and developcollaborations with other countries and NSBs	**Ongoing**
	3. Support/resource existing committee (additional expertise, funding)	• Identify resource and expertise needs within existing committees • Identify funding sources and secure funding for key activities, (new) committees, etc. / link up with PAS internationalization activity	**2021 onwards**
Enhancing uptake of existing and future standards	**1. Develop/disseminate implementation guidance for the PAS 706x series/masterclasses**	In progress	**2021**
	2. Develop/disseminate case studies for the PAS 706x series across user groups	• Identify sources/organisations based on implementation experience • Allocate resource for case study development • Develop and disseminate case studies	**2021 – 2022**
	3. Develop guidance for the use/application of the PAS 706x series in other sectors (where/ if new, specific standards are not needed)	• Consider related codification recommendations • Agree key sectors/applications and types of guidance needed • Secure resource (funding and expertise) to develop informal guidance • Develop guidance and disseminate (alongside any new sector application standards or instead of such standards)	**2021 onwards**
	4. Promote FBC programme and its outcomes at BSI-led and external events, forums, focus group discussions; develop cross-stakeholder dissemination campaigns and events; identify and design BSI-UKRI-led events and dissemination activities across the wider FBC work and community	• Develop and capture opportunities in marketing and engagement strategies • Agree and detail opportunities, allocate resource • Carry out activities, collect and analyse feedback (e.g. as part of an Impact Assessment activity)	**2021 onwards**
Testing and certification	**Consider the development and roll-out of an assurance/verification regime and/or standardized testing and certification scheme(s) – set out a cross-stakeholder group to take forward**	• Set up a multi-stakeholder group to discuss the issues, needs, opportunities and options • IUK/BEIS/regulators/assurance and certification bodies take agreed decisions forward (if/where the scheme is at the national level and requires an independent scheme operator; if certification by subject/standard is preferred – leave to the certification market with possible HMG support to create accredited certification)	**2021 onward**
Training and accreditation	**Consider the development and roll-out of a training and assurance programme. Establish a cross-stakeholder group to take forward.[1]**	• Set up a multi-stakeholder group (including industry associations, training scheme/ assurance providers, etc.) to discuss the issues, needs, opportunities and options • Agree parameters and scope of training and accreditation scheme(s) and programme(s), resource and roll out	**2021 onward**
Impact assessment	**Develop a scope of activities to assess the impact of the FBC Programme deliverables**	• Scope activities that can demonstrate impact standardization activities are having on battery manufacture in the UK • Carry out assessment and analyse outputs	**2021 onward**

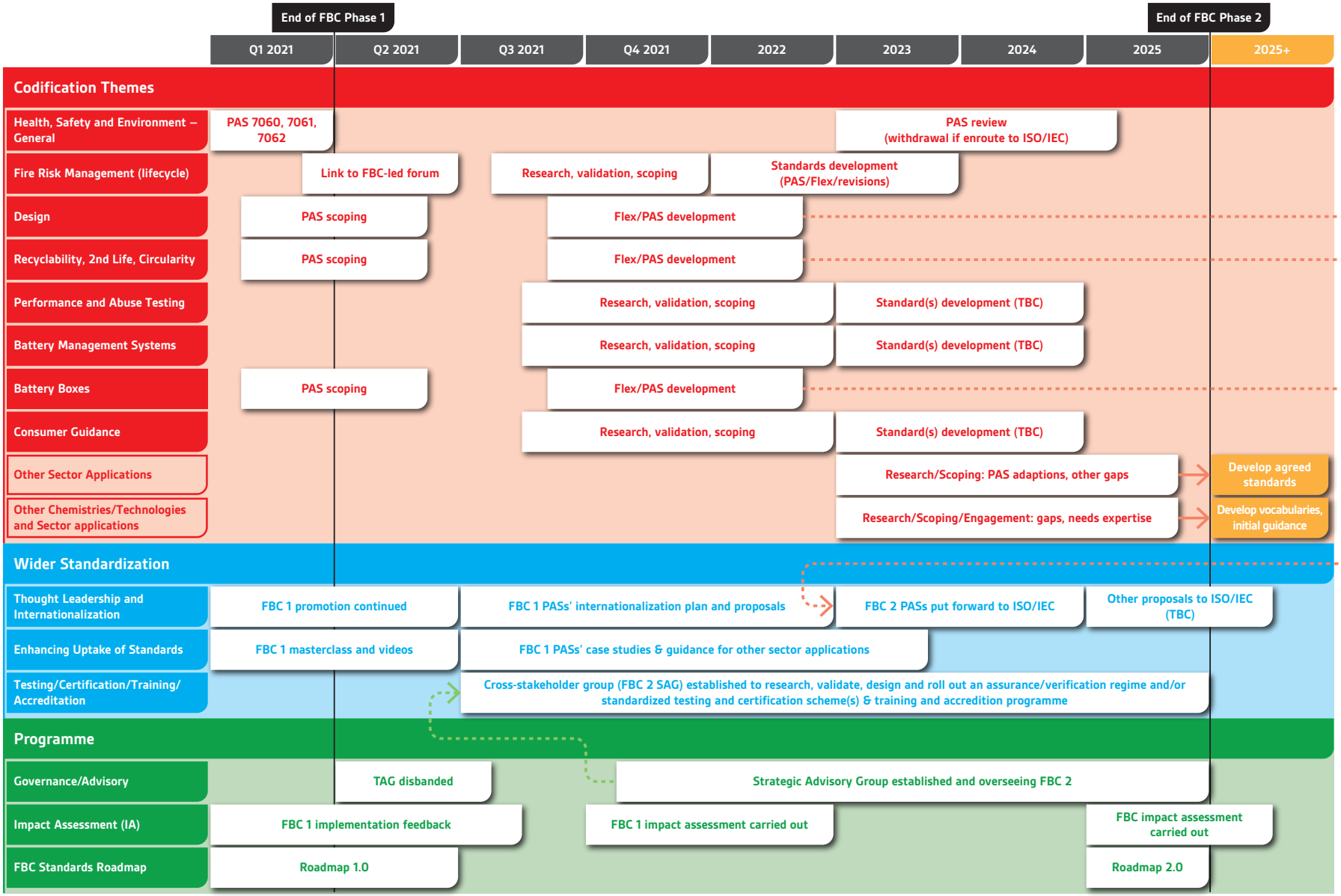
[1] The same group/task force can consider the development and roll out of both a testing and certification, and training and accreditation regimes.

3.4 FBC Programme – Roadmap

Figure 1 is a high-level outline of BSI's roadmap developed in support of the long-term objectives of the ISCF FBC, and exploring longer-term battery manufacturing and technology development needs which can be supported by standardization. The roadmap reflects the codification and engagement activities from FBC Programme Phase 1 and builds upon these. It is structured around the key challenges, knowledge needs and gaps (see Section 3) and the most impactful codification solutions, wider measures and dissemination activities that could be taken forward. The proposed solutions and activities, discussed and validated with stakeholders and experts, are designed to:

1. Enable the UK battery manufacturing sector to overcome pressing issues and barriers.
2. Increase the sectors manufacturing capacity.
3. Underpin long-term R&D effort and the UK's leadership in battery technology innovation.
4. More widely, support the achievement of the UK's ambitious cross-economy net zero target.

Figure 1 – Battery manufacturing and technology standards roadmap



FBC Phase 1 (FBC1) – Phase 1 of the BSI FBC programme of work

FBC Phase 2 (FBC 2) – Suggested activities to be delivered for phase 2 of the BSI FBC programme

TAG – Technical Advisory Group supporting FBC 1

PAS – Publicly Available Specification https://www.bsigroup.com/en-GB/our-services/developing-new-standards/Develop-a-PAS/what-is-a-pas/

Flex – BSI Flex standard https://www.bsigroup.com/en-GB/our-services/standards-services/flex/

4 Conclusions and next steps

Stakeholder feedback has revealed that several areas require urgent guidance, especially in relation to fire risk safety and management, design considerations (especially end-of-life and second life design), and recyclability/circularity requirements for current and future battery technology and battery sector applications, in particular freight, aerospace, rail, defence and marine applications, safety and recyclability issues should also be taken into account and addressed in the short to medium term. A further recommendation is to consider codification of the battery management system.

Additionally, supporting activities, are recommended - these vary from implementation guidance and training (so that engineers, fire services and other key personnel are able to handle batteries in various scenarios), through the establishment and roll out of relevant certification, training and accreditation regimes (where these are deemed relevant), to standards dissemination and uptake measures (such as internationalization of UK-led standards, increased resource for participation in international battery standards development, case study and educational material development, profile and awareness building events, etc.).

As highlighted at the beginning of this roadmap report, it must be reiterated that some of the recommendations go wider than the FBC funding remit and will require further discussion with relevant bodies if they are to be actioned.

Many of the recommendations outlined in Section 3.4 would require further research, scoping and validation of the individual solution and the appropriate corresponding delivery mechanisms (including the resourcing requirements associated with that solution and its delivery mechanism). Not all recommendations will fall under the scope of the FBC and will require discussions with relevant bodies such as IUK, BEIS, Office for Product Safety and Standards, Office for Zero Emission Vehicles, Department for Transport and the Ministry of Defence.

The overarching goal behind the roadmap recommendations is to continue building an integrated, UK-wide, comprehensive battery standards infrastructure, supported by certification, testing and training regimes, and aligned with legislation/regulatory requirements. The following approach is therefore proposed, and its key elements summarized below.

1. The (immediate – 2021-2025) standards development recommendations and priorities (see Table 5), are: further research to ensure duplication of activity is avoided and existing standards are taken into account and/or signposted; validate with a wider audience; and scope out individually. Scoping and engagement activity such as workshops (for individual standards/PAS or around prioritized themes, such as fire risk management) would enable this.
2. The development/delivery of scoped out priority areas starts at the required level (PAS, BS, Flex standards). These will take different formats to execute and timeframes to deliver/publish, and could be developed in parallel, or in short succession.
3. Supporting activity, including dissemination and uptake measures as outlined in Section 3, are set in motion. Each group of activities will require a detailed plan, agreed by the relevant parties (such as the PAS internationalization activity for which a delivery and engagement plan needs to be put in place).
4. Scoping out of additional gaps and needs, not considered immediate priorities and falling within the 2023 – 2030 time horizon; identification of delivery and resource options and timeframes for these. Scoping workshops (for individual standards/PASs or around prioritized themes, such as those highlighted under other sector applications in Table 5) would enable this. Community building and validation of long-term needs (such as those under other battery chemistries and technologies).

5. The development/delivery of scoped out priority areas from within the 2023 – 2030 time horizon starts at the required level (PAS, BS, Flex standards).
6. Create a Strategic Advisory Group to:
    - monitor the standards creation process, consider and advise on the expected market impact and compliance implications of the standards in development;
    - advise on unmet standards gaps and needs, help qualify these and consider possible resource avenues;
    - discuss the need, scope and elements of a future certification and testing regime relating to the standards in development, and align with any certification, testing and training initiatives and conversations that take place outside the programme;
    - support the dissemination and promotion of the outputs and related activities; and
    - advise on the interaction between standards and future regulations.
7. A methodology for assessing the on the ground impact of the initial set of standards is developed and launched (including actual compliance costs), an impact assessment piece is disseminated.

5 Annex A - Stakeholder survey and results

BSI invited key stakeholders to complete a short survey to help define and understand additional gaps and wider opportunities in the codification and standardization of batteries.

The roadmap has been developed using the information and stakeholder views obtained from the survey.

Survey questions

1. Please select which of the following best describes you or your organization (*Please select one only):* Battery manufacturer Testbed operator Vehicle manufacturer Insurance industry Legal/Regulator Public/Consumer Health and Safety Research Other (please specify)

2. In the FBC standardization programme to date, the following areas have been identified as the next set of immediate priorities for battery standardization. Please look at each area and score it by how important and urgent you see it. By important we mean where standardization is critical for battery development and by urgent, we mean where there is an immediate need, gap or opportunity for standardization. Note: rating 1 = highest priority; 4 = lowest priority *Please select one answer per gap* Options to select 1) Important and Urgent 2) Important but Not Urgent 3) Not Important but Urgent 4) Not Important and Not Urgent
Design: End of life Design: Materials (recycling/sustainable) Design: Life cycle analysis
Tools and Techniques (e.g. computer aided engineering (CAE)models, data structure and system development)
Testing - performance, abuse etc
Fire: Battery storage in warehouse Fire: Battery transportation Fire: Battery in vehicle Fire: Battery replacement
Reuse and recycling, remanufacturing, product circularity (broader environmental impact considerations)

Battery Management System &Energy Storage Systems
Other chemistries beyond lithium ion. (e.g. solid-state batteries, sodium, lithium sulphur, carbon ion, cobalt, nickel, hydrogen fuel cell etc.)
Social/social impact considerations (e.g. impact of material extraction and sourcing on local communities)

3. What other standards gaps/needs are you aware of/can add to this initial list? *Free text*
4. Of the areas you selected as important and urgent (highlighted below) Please tell us what are the key points that future standards would need to consider? Please consider what the standard should cover; how quickly it is needed in the marketplace; why the standard should be developed; who the standard is aimed at and who needs to be involved in its development. *Free text*

5. Which application areas could potentially benefit from standardisation (in relation to electric batteries)? Please look at the following application areas and select whether you think there is a need for standardisation?
Freight
Aerospace
Rail
Marine
Agriculture
Military/defence
Other – please specify

6. What other standardization activity will support the FBC ambitions and battery technology development? a. Internationalization of PASs b. Testing, certification c. Training and accreditation d. Guidance, implementation case studies, material (training) e. Research of dependencies with regulation – mandated standards or voluntary
f. Other, please specify

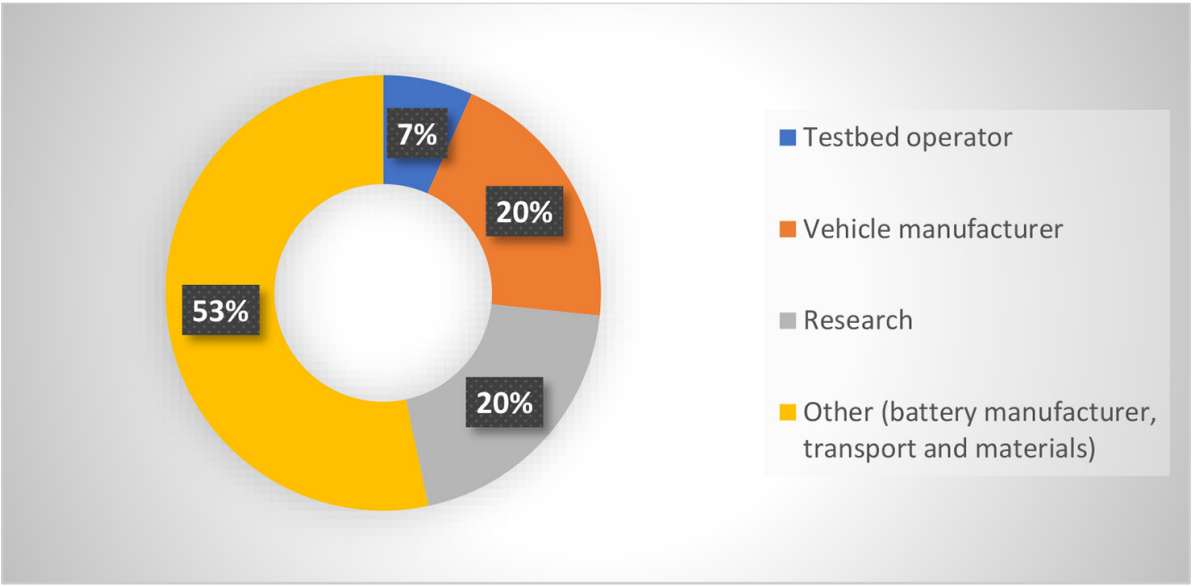
7. Do you foresee any newly developed standards having an impact on the growth of this industry/on your business? Please elaborate on what the benefits might be. *Free text*

8. We will be holding a workshop to validate the roadmap findings and start to prioritise the next steps. Would you be interested in participating in this workshop? If yes, please provide contact details in the box below. *Free text*

Survey results

We received 15 responses to the survey from across a number of stakeholder groups. Figure **A.1** shows the profile of those asked to complete the survey.

Figure A.1 – Participant profile



Figures **A.2** and **A.3** summarize the results broken down by what was the most important and urgent and by participant profile.

Figure A.2 – Immediate industry needs

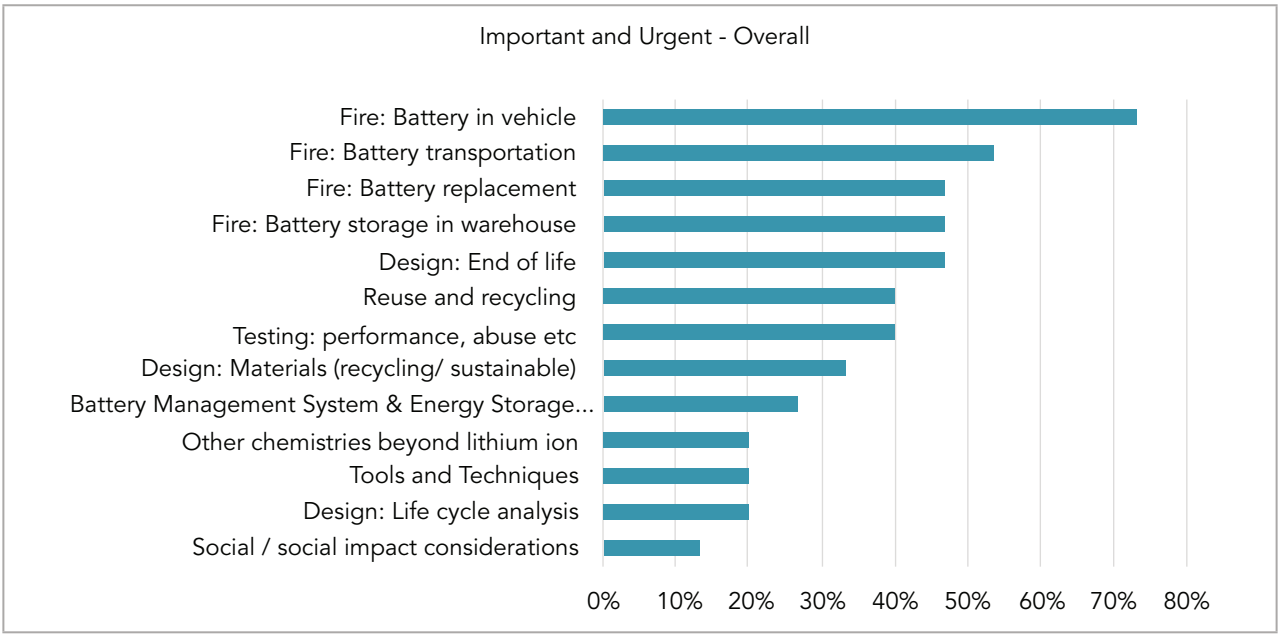
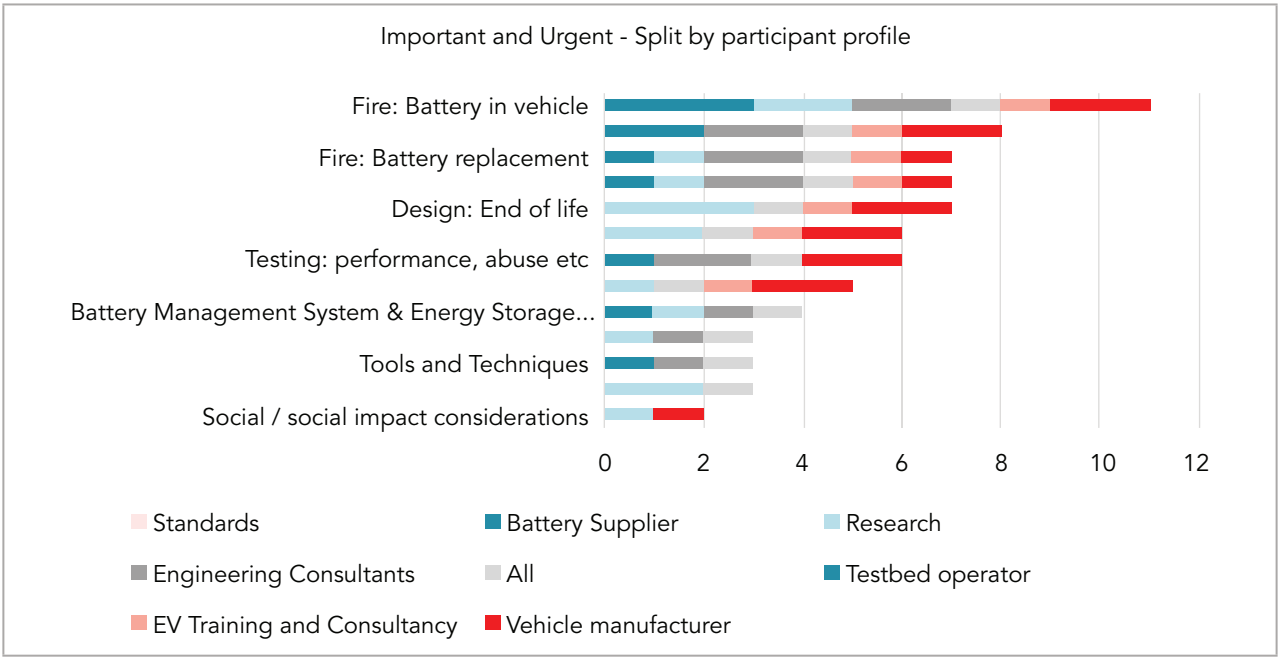


Figure A.3 – Immediate industry needs by profile



6 Annex B – Workshop polling results

BSI held two validation workshops, attended by 26 industry, government and standards experts and stakeholders.

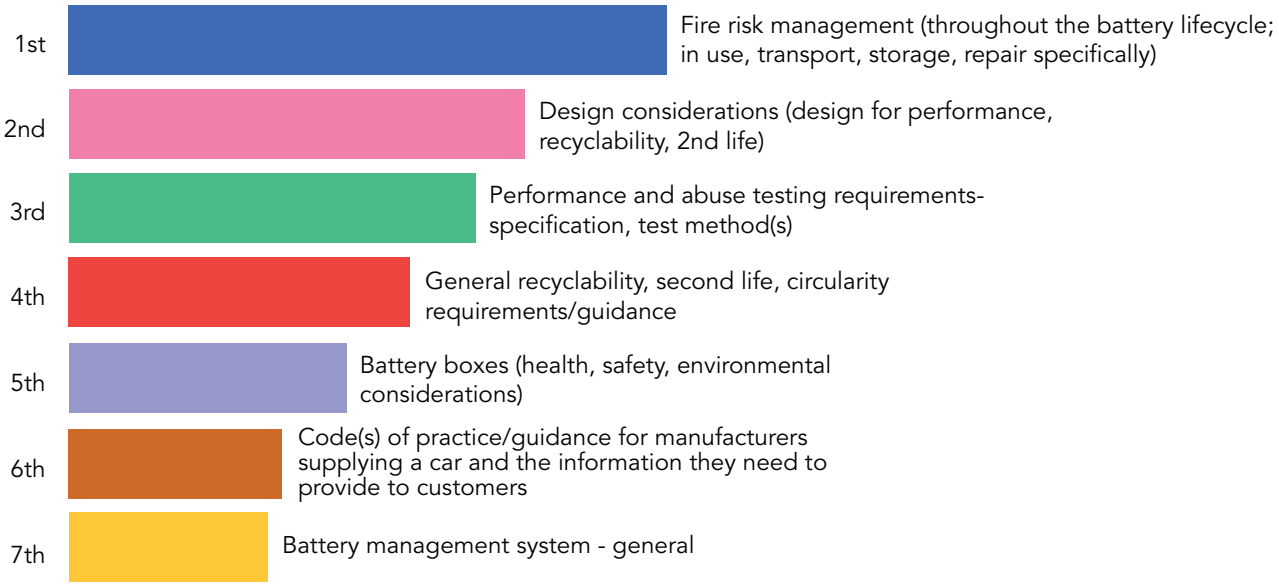
The agenda covered:

- immediate standards needs and standards development gaps / FBC1 programme related;
- other sector applications;
- other battery technology and its sector applications; and
- other standardization measures, supporting and dissemination activity.

Polling was carried out during the workshops to facilitate the discussion and to gather stakeholder views. The full engagement results are outlined below

Workshop 1 – Polling results

Please rank the roadmap recommendations in priority order?
Rank 1 – 7 (1 being top priority)



Is there anything missing from this list of solutions/measures? Please add as free text

Marine EV Design Guide

Recertification or refurbish qualification
Gas emissions/venting

Standardisation for Automotive base (Electrical and Mechanical) should be revised into that of Battery structure base (Electrochemical/Thermal/Dimensional)

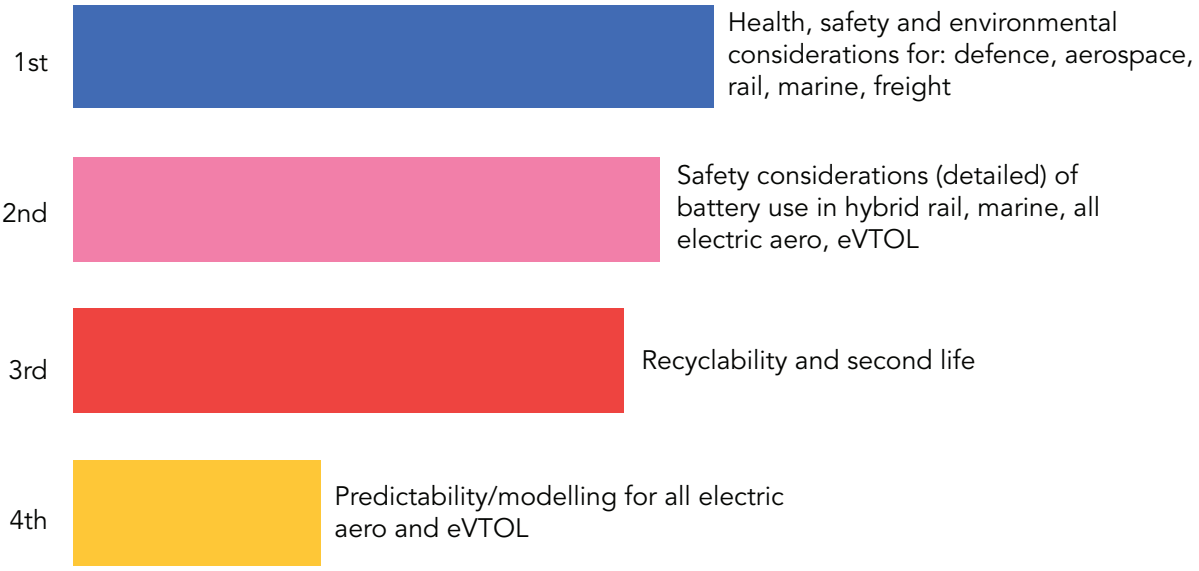
It is critical any standards activities align with international efforts to prevent burden on industry. Make use of the existing BSI committees in this area where possible and support them in influencing for the benefit of UK industry

I think there may be an area missing around Design for Emergency services safety, how do they know what they are facing and how best to deal with it. This isnt Just Fire as it Includes gasses and electrical safety.

Activity to link other groups working across supply chain for vehicle electrification & cross sector awareness

Applications in other sectors such as defence and aerospace, which have strong regulatory environments/standards and specific requirements and where compatibility with international standards is important

Please rank the roadmap recommendations in priority order. Rank 1 being top priority

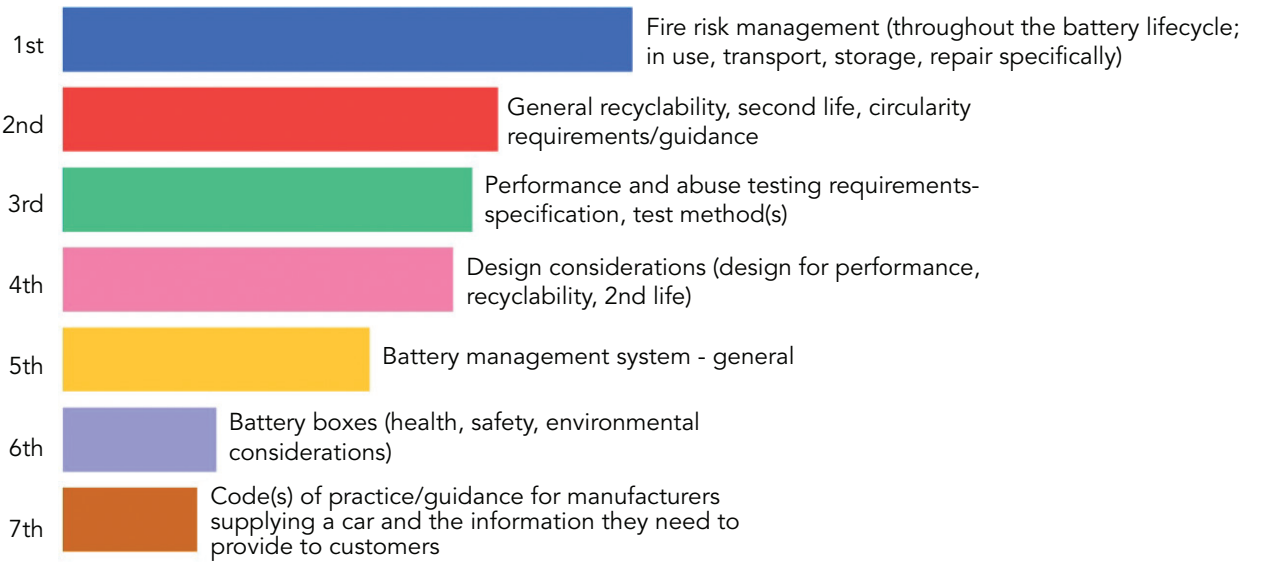


Is there anything missing from this list of solutions/measures? Please add as free text

- Mining (underground) and Construction (Idling)
- (Fast) Charging infrastructure
- Modular design of Power systems for BEVs is impacting the Charging Technology and subsequent standardisation - would be good to compare cross sector
- (Fast) Charging infrastructure
- Off-highway and agricultural vehicles/machines (e.g. JCB and Caterpillar style machinery). Unique use cases in often challenging environments.
- In defence, aerospace and other sectors which are highly regulated, assessment of whether new standards are needed / how to complement existing standards

Workshop 2 – Polling results

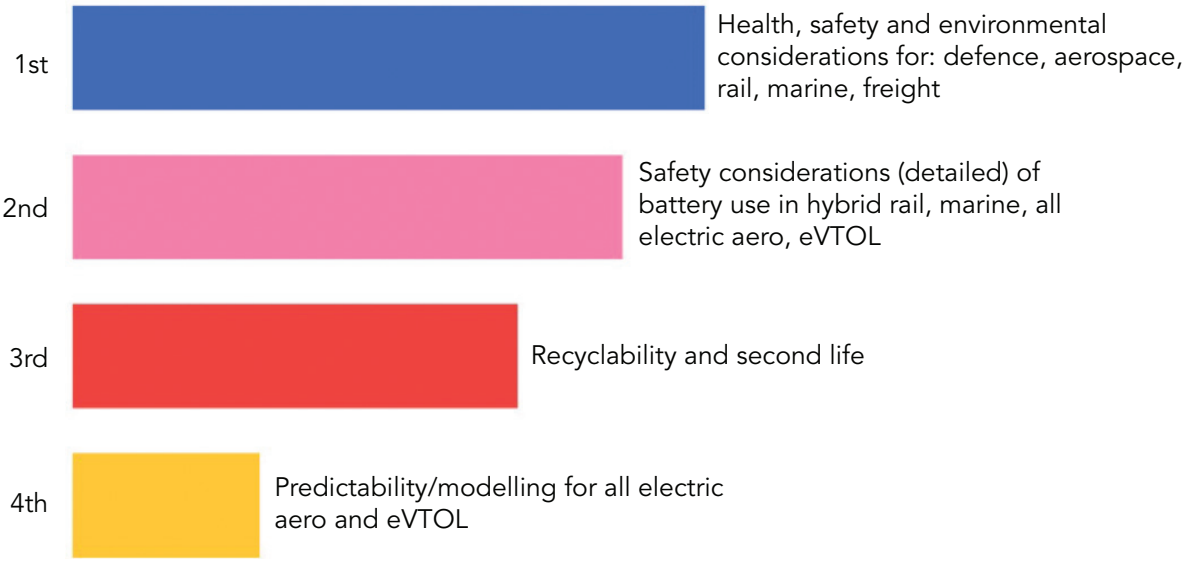
Please rank the roadmap recommendations in priority order? Rank 1 – 7 (1 being top priority)



Is there anything missing from this list of solutions/measures? Please add as free text

- Not from my perspective
- There needs to be an expectation of some agility with standards for batteries because it is a rapidly changing technology and different lithium Ion chemistries can behave significantly differently. eg. different combustion products, vapours etc
- Training of personnel In various support sectors, such as mechanics, apprentices
- Not perhaps a high priority but commonality of modules. Interfaces etc would be useful for a number of markets
- BMS solutions can have significant impact on fire safety prevention and second life cell reusability. Standards should focus on improving these aspects as port of battery system design
- Standard test methods for materials, components and cells (mainly for use in RV)) are missing, particularly for emerging L-ion chemistries and other types of battery
- Safety systems in general. notjust fire mitigation - this is a rapidly developing area, with learning from production programmes and Faraday Challenge reseorch projects which need developing into next iteration good practice
- I actually placed codes and standards a lot higher on my list. I believe customers should be made aware of the evolving issues related to EV's and for Instance over charging etc
- I think it gives good coverage There is a lot of overlap between the points which may make separating out Individual standards difficult. Batteries in fuel cell systems may pose unique challenges. A watching brief on unique new chemistry challenge
- Unless it already exists, advice to medical services of the noxious gases that escape from U-ion battery explosions. Thought on defining the new terms that are part of this vocabulary to improve clarity and understanding. Register of events
- Several of the materials in batteries are carcinogenic, the control of these during manufacutring requires consideration (and I think is in the most part) but also during a fire or recycling process - how are these controlled

Please rank the roadmap recommendations in priority order. Rank 1 being top priority



Is there anything missing from this list of solutions/measures? Please add as free text

- The list seems to be complete.
- stationary storage (eg grid , microgrid & home)
- Stationary storage - residential
- Stationary storage - safety for use of batteries.
- Consumer batteries e.g drones, hoverboards, etc mostly on safety again
- Medical devices and wearables
- Off highway could have unique challenges. Some of these vehicles may be hybrid with other technologies which could affect standards. Standardised infrastructure interaction.
- Grid balancing may have been mentioned but I don't recall seeing it
- Charging standardisation

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