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Putting Science into Standards

Driving Towards Decarbonisation of Transport: Safety, Performance, Second Life and Recycling of Automotive Batteries for e-Vehicles

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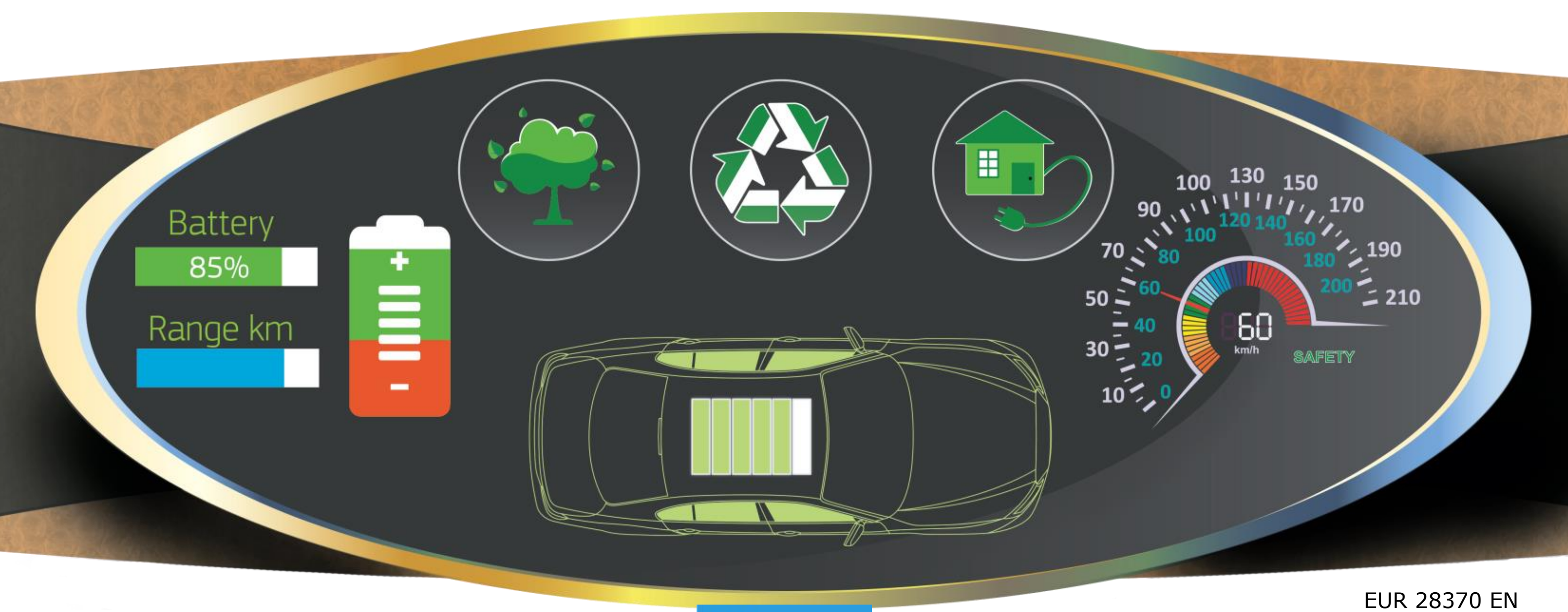

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Abstract
The Directorate-General Joint Research Centre (JRC) of the European Commission, together with the European Standardisation Organisations CEN and CENELEC, and the European Commission Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) have launched an initiative, within the context of the European Forum on Science and Industry, to bring the research, industry and standardisation communities closer together entitled "Putting Science into Standards" (PSIS). As part of this initiative, workshops are held to facilitate screening of emerging science and technology areas to identify those where concerted research and standardisation activities are required to enable innovation and promote industrial competitiveness. The fourth event of this series organised by the JRC, was held on the 22-23 September at the JRC's Petten (NL) site on the subject of " Driving Towards Decarbonisation of Transport: Safety, Performance, Second Life and Recycling of Automotive Batteries for e-Vehicles". This workshop aimed at establishing a consensus between research, industry, policy and standardisation communities on the relevant technical issues involved, on the scope and nature of standardisation measures needed and at identifying a common way forward, including identification of the regulatory needs. The workshop focused on identifying standardisation and pre-normative research activities for automotive batteries to guide further deployment of e-mobility.

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Introduction

The Directorate-General Joint Research Centre (DG JRC) of the European Commission, together with the European Standardisation Organisations CEN and CENELEC, and the European Commission Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) have launched an initiative, within the context of the European Forum on Science and Industry, to bring the research, industry and standardisation communities closer together entitled "*Putting Science into Standards*" (PSIS). As part of this initiative, workshops[*] are held to facilitate screening of emerging science and technology areas to identify those where concerted research and standardisation activities are required to enable innovation and promote EU industrial competitiveness.

The fourth event of this series organised by the JRC and CEN–CENELEC was held on 22-23 September 2016 at the JRC's Petten (NL) site on the subject "*Driving Towards Decarbonisation of Transport: Safety, Performance, Second Life and Recycling of Automotive*[†] *Batteries for e-Vehicles*".

The event is driven by Regulation (EU) No 1025/2012 [1] on European standardisation which states (article 9) that "*the Commission's research facilities shall provide European standardisation organisations with scientific input, in their areas of expertise, to ensure that European standards take into account economic competitiveness and societal needs such as environmental sustainability and safety and security concerns*". Moreover, the PSIS series of workshops satisfy Action 2 "*Linking research and innovation with standardisation*" of the European Joint Initiative on Standardisation (COM(2016)358) [2].

The topic of batteries for automotive applications is in line with Action 7 "*Become competitive in the global battery sector to drive e-mobility forward*" of the Integrated Strategic Energy Technology Plan (C(2015)6317) [3] that falls under the European Energy Union Package (COM(2015)80) [4].

Widespread deployment of electric vehicles (EVs) is a promising approach for decarbonisation of transport and curbing dependence on fossil fuels. Doing so facilitates achievement of European Union objectives which aim at reducing gas emissions in the transport sector by 60 % and at gradually phasing out conventionally-fuelled vehicles by 2050 [5]. Furthermore e-mobility brings opportunities in terms of economic growth, job creation, energy security, health and environmental protection [6-9]. Market analysis indicates that the sector is steadily moving towards increasing electrification with more than 75,000 pure electric, extended-range electric and plug-in hybrid electric vehicles registered in the EU in 2014 (constituting a 36.6 % rise compared to 2013) [10]. Globally, electric vehicle sales reached approximately 300,000 units in 2014 [11,12] and beyond 500,000 units in 2015 [13]. Initiatives to promote further market uptake of electric vehicles include government and regional incentives as well as investments in infrastructure [14].

Previous studies and investigations have identified a number of scientific-technical knowledge gaps (in addition to economic challenges) for vehicle traction batteries that

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[*] The three previous events can be found at:
https://ec.europa.eu/jrc/en/event/round-table-european-forum-science-and-industry-putting-science-standards-example-eco
https://ec.europa.eu/jrc/en/event/workshop/workshop-putting-science-standards-power-hydrogen-and-hcng
https://ec.europa.eu/jrc/en/event/conference/putting-science-standards-evidence-based-quality-assurance-example-breast-cancer

[†] In this report, the term "Automotive batteries" is used a synonym of "industrial batteries" as described in the Battery Directive 2006/66/EU [24]

need addressing to enable a fully-fledged deployment of e-mobility in the EU. This workshop aims at establishing consensus between the research, industry and standardisation communities on the scope and nature of the standardisation measures needed and at identifying a common way forward considering regulatory impacts. The workshop was attended by over 50 invited experts in the field.

Following three keynote presentations reflecting the views of EU policy, standardisation and industry, the workshop was structured in the following four technical sessions:

1. Safety evaluation in e-mobility: abuse scenarios, testing and mitigation
2. Performance assessment traction batteries for e-mobility
3. Second use applications
4. Recycling

In each session, invited speakers from research, industry and standardisation sectors presented the current state of the art and identified research and standardisation needs and priorities.

The presentations of the workshop can be downloaded from:

https://ec.europa.eu/jrc/en/event/workshop/putting-science-standards-driving-towards-decarbonization-transport

Presentations were followed by a moderated discussion between the experts participating in the workshop. Session rapporteurs presented a summary of each session.

This report presents a series of recommendations for policy makers and stakeholders on the topic of Automotive Batteries for e-Vehicles stemming from the exchanges between the participating experts at the workshop.

Safety evaluation in e-mobility: abuse scenarios, testing and mitigation

Battery safety constitutes one of the most relevant factors for consumer confidence in and widespread adoption of e-mobility in our society. Safety is and will remain a key aspect of e-mobility and two aspects go hand in hand in its assessment, namely the intrinsic characteristics of the battery and its foreseen application. Standards and regulations require testing in abusive conditions to evaluate the safety performance of batteries at different levels - from cell, module to pack level - and often set minimum requirements to ensure safe use of large size battery packs for EV application.

Abuse tests, classified in electrical, thermal and mechanical types, can lead to various potential hazards, such as chemical (e.g. electrolyte spillage, gas emissions), electrical (e.g. electrocution, arcing), thermal runaway propagation, fire or explosion or a combination thereof.

The various risks associated with a battery depend highly on its cell constituents. Tests to ascertain safety are needed, not only at cell level, but at different levels, including the complete system, with risks assessed (e.g. Failure Mode and Effect Analysis (FMEA)) at each level of integration: cell, module, system software (e.g. Battery Management System (BMS)), vehicle, etc.

The energy density of a specific battery is not an inherent hazard *per se*, but its thermal stability is. In this respect, some battery chemistries are inherently safer than others (e.g. $LiFePO_4$ cathode is more thermally stable than $LiCoO_2$ cathode or $Li_4Ti_5O_{12}$ anode is more stable than graphite anode). The development of thermally stable electrolytes (e.g. flame retardants, additives, solid-state), or safer separators, as well as the use of external protective devices (e.g. Positive Temperature Coefficients (PTCs), vents, fuses) result in improved battery safety. Additionally, exhaustive quality controls in production are paramount in this sense.

Overall, it was agreed by the experts that a sufficient level of safety can be reached if the battery is designed, controlled and used correctly. On the other hand, when enough energy is imposed to a system in an abuse test (e.g. external heat) any chemistry can be driven into thermal runaway. While thermal runaway and potential subsequent fire are associated with current Li-ion batteries used in automotive applications this may not necessarily be the case for future chemistries.

Finally, as part of battery safety management evaluation, aspects such as handling, shipping, storage and disposal of batteries as dangerous goods should not be overlooked.

Areas for future research

- Assessment of safety implications of new chemistries (e.g. Li-metal anode) and of new system designs / protection mechanisms.
- Further development of solid state batteries.
- Understanding of ageing path dependency and relationship between ageing status and battery safety at end-of-life (EOL) (e.g. relevant for second use applications).
- Study of failure mechanisms at different levels (cell, module, pack).
- Evaluation of Accelerated Rate Calorimeter (ARC) testing for inclusion in standards.
- Development of protocols for post-mortem analyses.

Areas for future standardisation

- Standards need to keep pace with technology developments to ensure that testing methodologies are suitable for novel battery systems (e.g. account for the formation of toxic gases (e.g. H_2S) upon thermal runaway in Li-S batteries, absence of flammable electrolytes in solid-state batteries).
- Standards need to address emerging applications (e.g. safety at EOL - second use applications).
- Fitness-for-purpose of safety test procedures. Safety-related test protocols in standards need to represent realistic abuse scenarios, from material level testing up to vehicle level testing. A classic example that raises concerns is the nail penetration test required in various standards, which tries to emulate, unsuccessfully, an internal short circuit.
- Repeatability and reproducibility of safety test results need to be ensured by the test procedure description. However, this is not the case in many situations (e.g. the nail penetration test is an example where the standards' description does not ensure repeatability).
- Differences in test conditions (e.g. resistance used in external short circuit test) and in pass/fail requirements (also known as hazard levels or test criteria) in current standards/regulations are an issue, making comparisons of test results difficult. For example, IEC standards define a minimum requirement for safety whereas UL standards are much more complex and comprehensive. Harmonisation between standards would be highly beneficial for the interested parties.
- Li-ion battery related standards for e-mobility need to be specifically developed to ensure appropriateness (e.g. IEC 62619-1 [15]) or at least be appropriately adapted from existing ones (e.g. IEC 62133-1 [16] and IEC 62133-2 [17] for Nickel and Lithium systems, respectively, adapted from IEC 62133 [18]).
- Need for a common terminology (e.g. 'safety', 'automotive').
- Harmonised classification of tests as reliability tests or as abuse tests.

Performance assessment of traction batteries for e-mobility

Battery performance (e.g. capacity, power output, efficiency) depends on both the battery chemistry and system design. Within the scope of standards and regulations battery performance is assessed through electrochemical cycling (e.g. galvanostatic charge/discharge, Hybrid Pulse Power Characterisation (HPPC) test profiles) which mimics the actual use of the battery in its application. Typical standards for characterising EV battery performance are ISO 12405-1 [19] and -2 [20] (high power and high energy applications, respectively).

An important factor to consider is that the correlation between stress factors used in laboratory tests and real-world performance is not straightforward.

Considerable efforts are underway not only to improve the performance of batteries (e.g. increase in capacity to address users' driving range anxiety), particularly in respect to their energy density, but also to further improve the efficiency of the electric powertrain relative to an internal combustion engine, which results in an increased vehicle efficiency and reduced fuel consumption.

The initial performance of a battery degrades over its lifetime, due to the effect of use (electrochemical ageing), of time (calendar ageing) and of mechanical stresses (mechanical ageing, e.g. vibrations, shocks). In the vast majority of cases these three types of ageing occur simultaneously, and it is extremely difficult to isolate the effect of one type of ageing from another. A challenging objective for battery manufacturers and OEMs is to maintain the initial, or close to initial, performance of the battery for as long as possible (e.g. in terms of capacity) without jeopardizing vehicle driving range or safety. The development of long-lasting systems (e.g. > 10 years of service) is urged by users but remains a challenge since battery degradation is influenced by multiple factors including temperature during operation and idling, load currents determined by the duty cycle, activity or inactivity, thermal management, cut-off voltage window, as well as type, frequency and rate of charging, etc. Overall, battery degradation (e.g. capacity fade, power fade, and efficiency reduction) is application specific and is extremely complicated to understand and characterise, mostly due to the simultaneous influence of different factors mentioned above. Therefore degradation testing procedures are inherently difficult to standardise. Furthermore battery performance and degradation tests are time consuming (e.g. several years required for extensive laboratory testing combined with field testing under actual application conditions), as well as costly.

Experts considered that the most relevant aspect in battery performance assessment relates to its degradation, and in fact durability (i.e. resistance to ageing) is almost always included in battery performance test procedures. In this context, modelling at cell, module, pack and system level has not only been identified as key to improve battery design (e.g. appropriate dimensioning of battery packs), operation (e.g. thermal management) and control (e.g. BMS, balancing algorithm), but also to provide accurate battery state estimation, in terms of open circuit voltage (OCV), state of charge (SOC), state of function (SOF) and state of health (SOH).

Areas for future research

- Significant improvement of battery performance beyond current capabilities is needed. New chemistries such as Li-Air or Li-S have the potential to achieve this goal.
- Improved understanding of ageing factors and their interactions. Work towards an improved accuracy for the assessment and monitoring of real-world battery ageing.

- Establishment of fit-for-purpose test methodologies (e.g. derived from empirical models) to address the degradation mechanisms relevant in a variety of cases (e.g. varying driving patterns, various climatic conditions). Simultaneous consideration of multiple ageing factors (e.g. temperature, driving profile) in test procedures.
- Advances in BMS embedded techniques (e.g. EIS) as on-board diagnostic tools (based on realistic driving protocols) for battery state determination e.g. status monitoring, remaining range, lifetime prediction and thermal state estimation (e.g. internal cell temperature / temperature distribution).
- Evaluation of the effect of mechanical ageing due to the presence of mechanical stresses, such as vibration and shock.
- Further development of models, algorithms and tools to assess performance from cell to module/pack/vehicle level.
- Investigate the need to develop specific tests for nano-based materials for battery electrodes, since current test procedures are designed for micro-scale materials.
- Establishment of a dedicated European database collecting the large amount of data generated in EU funded projects to analyse and learn from. "Big data" and "Meta-research" can be used for trend analysis and to draw conclusions with the help of experts. This considering that all the data is related to a certain chemistry and cell design. JRC was suggested as an enabler of this proposal. This suggestion can be a way to differentiate Europe from other big players such as US and China, who are well-ahead in terms of resources and capabilities.

Areas for future standardisation

- Specification of representative test conditions (e.g. ambient temperature, drive cycle, charging scenario, SOC window) to be included in the standards, also applicable to complex test objects and with simultaneous incorporation of multiple types of ageing.
- Development of suitable accelerated life testing protocols to shorten test times, activating the same ageing mechanisms as in non-accelerated testing while striking the right balance between sufficient specificity (e.g. chemistry, temperature range) and the need to maintain comparability.
- Standardisation of definitions, such as SOH. Currently SOH comparison between different systems, applications and manufacturers is not straightforward. There is a need for common terminology (e.g. durability).
- The effect of cell size should be taken into account in test protocols (e.g. the bigger the cells, the more gradients and inhomogeneities). Uneven current density distribution and temperature gradients lead to uneven ageing in different parts of the cell. In addition, a minimum number of viable test samples (e.g. >30 cells) needs to be defined in standards.

Second use applications

Battery second use involves transferring used batteries from an EV application (HEV, PHEV, BEV) into a second, less demanding one where energy and power density are less critical (e.g. stationary storage application for the electric grid to integrate renewable energy sources). Battery second use has the potential to enhance the sustainability of batteries by decreasing the net environmental impact and it can make financing of EVs more economically viable for OEMs and customers. However, this approach has risks in terms of profitability and liability. Hence, the business case for EV battery second use must be analysed from a market as well as a technical perspective. Currently car manufacturers are responsible for the vehicle battery pack, therefore they are the most critical players and have to find some value (e.g. reduction in the vehicle Total Cost of Ownership) for participating in a battery second use. Other stakeholders might be involved as well, such as electricity utility companies, recyclers and others such as SMEs.

For a profitable second use of EV batteries, additional costs (e.g. for testing or retrofitting) need to be minimised. Moreover, due to the fast developing nature of the market, near-future evolutions of battery systems/chemistries and price development might affect the business model.

Projections for electric vehicle sales (electric vehicles are expected to account for 35 % of all new vehicle sales in 2040 [21]) and for stationary electrical storage market (estimated globally by 2020 at US$ 400 Billion [22]) show a great potential for second use of EV batteries. Within the EU, the market for stationary applications is growing even faster than that for automotive applications. To ensure business viability of battery second use cost should be below 70$/kWh by 2022 [23]. However, other aspects need careful consideration as well:

- battery requirements, particularly in terms of energy and power density, are very different for first and second use such that characteristics of the repurposed pack may not be fully suitable for the second use application.
- the BMS, thermal management system and power electronics are tailor-made for each application and it is very unlikely that a BMS designed for EV application would be suitable for a second use application.
- remanufacturing, including disassembly and re-assembly of an EV battery pack, is a costly operation.
- the second use battery may have to compete with a future generation first use battery with possibly lower price, improved performance and better technology.
- the actual history of the battery during its first use is in most situations unknown and first use operating conditions may have an impact on the performance of the battery in second use. An optimal strategy to deal with some of those issues would require designing a battery to maximize its value over its entire extended life cycle (including first and second uses) and evaluating business opportunities already from the design phase. However this would imply some associated costs.

Multiple efforts in the development of Life cycle assessment (LCA) to assess EV battery environmental impact are being done by many parties. However unified guidelines or harmonized approaches for performing LCA do not exist and different analyses may yield conflicting results when second use applications are considered, due to variability in assumptions, scope of the application and scenarios (e.g. considerations for recycling, costs and energy involved in manufacturing).

In addition to those mentioned above, the topic of second use touches upon many other battery related aspects. These include: extension of producer liability, warranty, transportation, storage, manipulation, training of relevant personnel, safety and waste status / recycling (e.g. Directive 2006/66/EU [24]). To address these, a strong link between relevant actors and stakeholders along the battery value chain is necessary for establishing a viable solution for EV battery second use.

Areas for future research

- Evaluation of the type of tests necessary to assess battery reliability, safety and performance at end of its first use.
- Identifying and addressing technical and economic factors to be considered when modifying battery packs optimised for first EV use to enable their second use (e.g. higher voltage levels of grid-tied 800 V inverters and longer active operation times compared to lower nominal voltages, e.g. 400 V, and shorter active operation times in EVs).

Areas for future standardisation

- Clear definition of battery EOL to ensure a common understanding between all actors involved in first and second use applications with considerations for LCA methodologies and tools for its evaluation. Additionally, a clear definition of second use applications is also needed.
- Establish standards containing criteria and guidelines for evaluating battery status (e.g. SOH by EIS measurements, safety) and suitability for second use applications at EOL.
- Establish standards for the evaluation of. prior to the repurposing phase.
- Develop a system to ensure the traceability of a battery pack, capable of accessing its usage history (incl. information relevant for second use)
- Develop standards for the design for recycling, Circular Economy [25] implications, traceability and tracking.
- Guidance and standard practices on handling of batteries (e.g. for dismantling, storing) for relevant personnel.

Other areas for future consideration

- Collection of non-proprietary BMS record data from OEMs and battery manufacturers (which is not protected by confidentiality agreements) for the purpose of learning the battery history. The JRC may have a role in the data evaluation to provide unbiased, relevant information.
- Development of a standard interface (both hardware and software) to allow smooth integration of the battery pack from its first to its second application (e.g. standardised architecture suitable for both applications).

Recycling

The infrastructure for recycling of Li-ion automotive traction batteries is not yet well established compared to the recycling infrastructure for lead acid batteries. This is attributable to the fact that the numbers of Li-ion batteries at end-of-life needing recycling are still low. This is obviously expected to change in the coming years. However, actions need to be taken now to ensure that spent Li-ion batteries are recycled. Upscaling of recycling capacity to some several 100.000 t/year is crucial and deemed realistic. Recycling opens the potential to contribute to the supply security of critical raw materials. An extra implication is that EU battery recycling experience and technology will grow with increased recycling of automotive traction batteries.

Directive 2006/66/EC [24] sets requirements for battery collection rates with the objective of minimising the negative impact of waste batteries on the environment. In the Directive, EV traction batteries are classified as industrial batteries, which must be recycled at the end of their first or second use. Recently the Commission has started the Directive review procedure which is expected to be finalised at the end of 2017. One of the gaps identified in the Directive, which could be addressed in the review, is the lack of guidance for deciding whether a battery, unfit for continued use in its first application, qualifies for use in a second application, or whether it automatically becomes waste.

Currently traction batteries are collected and then discarded following one of two routes: i) through dealer channels (after sales) in case of for example recalls, malfunctioning or heavy accidents or ii) through authorised treatment facilities (ATFs) of deregistered vehicles at end-of-life (waste status of both the vehicle and the battery). This decision is taken by the OEMs or at battery collection points. To establish a legal framework, second use (and re-use) of batteries should be considered and defined in the Battery Directive.

Once the battery is classified as waste and goes into recycling, dismantling from the vehicle is a must. Within the European market, dismantling guidelines are freely available through the "International Dismantling Information System (IDIS) [26]", provided by OEMs and linked to end-of-life Vehicle (ELV) Directive 2000/53/EC [27]. After dismantling, the next step is the shipping by an ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road) compliant waste collector. Because there is only a limited number of recycling plants in Europe, the transport of batteries between MSs is currently common practice. The competent national authority has the responsibility to decide on means of transport, depending on the status of the battery pack (e.g. safe for transport, damaged/defective, showing risk of thermal runaway), with the dismantler/dealer deciding the form of packaging. Methods and guidelines for a safe and economical transport need improvement.

Following transport, the recycling of EV traction batteries entails additional actions such as disassembly (e.g. removal of BMS and thermal management system) and management of health and safety hazards due to for example high voltage which adds extra costs to the process compared to other types of batteries (e.g. portable batteries). These steps could be made easier when the need for disassembly is already considered in the battery pack design. To avoid extra safety concerns disassembly down to the cell components level (e.g. Cu foil, Al foil, separator) should not be required for recycling.

Up to now recycling of Li-ion traction batteries is not profitable, mainly because of transport costs and gate fees at waste processing facilities. Another aspect that needs to be considered is the required flexibility of the recycling process to deal with several chemistries, designs, input streams and applications. Li-ion batteries sourced from an EV need to be recycled together with those coming from portable, stationary or other applications. Flexibility in recycling technology is also needed to keep up with technology progress and to avoid limiting innovation. To enable their subsequent use, the quality of recycled products (e.g. alloys, slags for construction, Li when this becomes economically profitable) needs consideration as well.

Currently the guidelines for calculating the recycling efficiency (RE) set in Commission Regulation 493/2012 [28] are not fully clear, which leads to difficulties in the comparability of recycling efficiency data reported by different MSs. An issue identified by the experts is that the RE calculations do not account for incineration with energy recovery and for landfilling/elimination of final products. Both the Regulation [28] and the Directive [24] set requirements for reporting the RE. This reporting has to be done to the competent authority of the country where the recycling has taken place [28]. Experts claimed that different Member States (MSs) have varying interpretations of these requirements, therefore there is no uniform reporting across all MSs and some do not even publish or share these data, so registry at EU level is not fully accurate or complete. Moreover, Directive [24] does not cover the recycling of fuel cells and supercapacitors, which might require consideration in future revisions. Fairness, transparency and non-discrimination in terms of availability of comparable information from all recyclers must be pursued and encouraged.

Areas for future research

- Assessment of the contribution of battery recycling in overall battery cost.
- Strategies for recycling and recovery of critical raw materials, and evaluation of recycling efficiency for different battery chemistries.

Areas for future standardisation

- Harmonised calculation methods for Recycling Efficiency to avoid misinterpretation of data. This should include environmental aspects (e.g. waste streams, incineration with energy recovery, final landfilling/elimination) and inclusion in the Battery Directive 2006/66/EC [24] as requirement. EBRA guidance document [29] was suggested as potential starting point.
- Harmonised quantification of key indicators: CO_2 footprint, recycling percentage conforming to EC Regulations, toxicity (considerations for Li-ion ion batteries and supercapacitors would be needed), recycling cost.
- Standards providing guidance for handling of automotive traction batteries by personnel dealing with dismantling at the recycling plants. A first starting point for standardisation could be the "International Dismantling Information System (IDIS) [26]".
- Guidance on the classification of the status of a battery (e.g. damaged/defective, showing risk of thermal runaway), composition (e.g. presence of flammable electrolyte or not) and selection of correct transport containers and packaging methods to avoid safety risk. Currently a standard for labelling is under development (IEC 62902 [30]) but it does not offer a satisfactory solution to the matter according to the experts in the workshop.

Other areas for consideration

- Currently, fuel cells and supercapacitors are not included in the scope of the battery directive, with resulting concerns for the environment.

- Transfer of ownership needs to be considered in the Battery Directive 2006/66/EC [24], as wells as some guidance on how to define when a battery can follow the path of a second use or when it needs to follow the path of recycling. The potential involvement of JRC on this matter was suggested by industry.

Conclusions, outcomes and way forward

In addition to the areas for future research and standardisation previously identified, a number of priority topics of a common nature were also identified, and include the following:

- Standards for battery performance and safety assessment must:
  - mimic, in as far as possible, realistic service conditions and failure mechanisms (fit-for-purpose standards)
  - be sufficiently flexible to be able to cope with technology progress
  - consider metrology aspects to ensure reproducibility and comparability
- Harmonisation of definitions and of terminology is critically needed (e.g. for safety, durability, SOH, second use). For example, "battery" is defined differently in various standards and regulations (e.g. UN 38.3 [31], IEC 62133 [18], UL 2054 [32]).
- Standards on battery labelling need to adapt to the incorporation of new chemistries (e.g. Si anode).
- Uniform sizes, shapes, geometries of battery cells, packs, connectors, and arrangements of management devices will promote ease of handling in manufacturing and use and can also reduce costs. For example standardisation of modules both in terms of voltage (< 120 V DC for safe handling, repair, remanufacturing and dismantling/recycling) and size /weight (< 30 kg, for an easy compliance with transport regulations) was advised by the experts.
- Find ways to exploit results of past R&D projects, avoiding the confidentiality of research results. Establishment of dedicated databases for both performance and safety related matters (e.g. battery accident database/lessons learned).

Further recommendations include:

- Continue the exchange between research, industry and standardisation communities on technology, policy and standardisation issues for enhancing the role that batteries can play in contributing to overall EU integrated energy and climate policies (including long-term energy storage) and for enabling the elaboration of relevant business models.
- Liaise with already ongoing standardisation activities, duly considering global standardisation developments.
- Identify EU-specific standardisation requirements to meet industry needs.
- Gather all relevant actors and major stakeholders (Regulation EU 1025/2012 [33] on European standardisation) with the integration of national organisations in the process (e.g. German Association of the Automotive Industry, VDA).

Efforts for moving forward in the area of pre-normative research and EU standardisation can be framed within the following initiatives launched by the Commission:

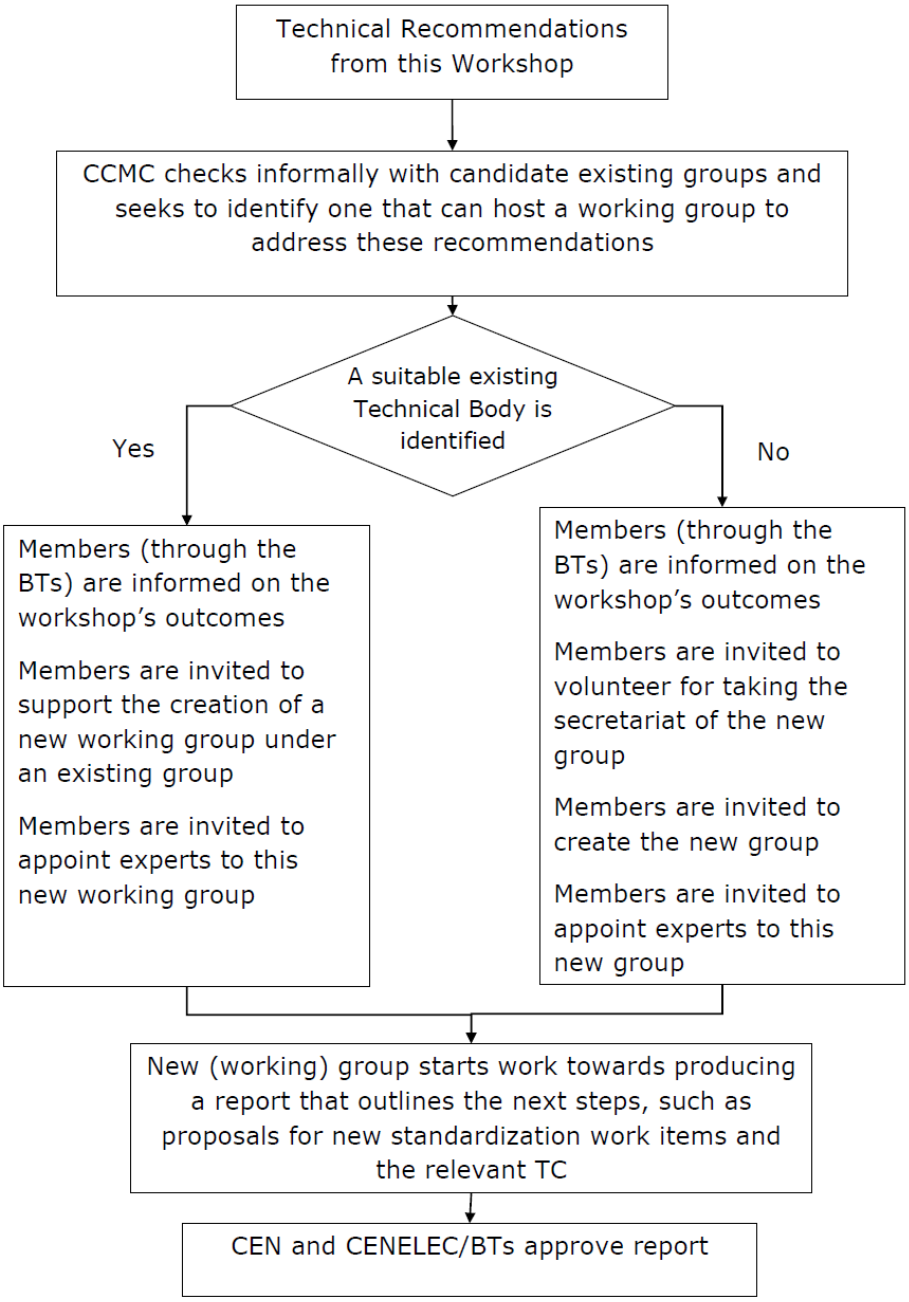
1. The Implementation Phase of Action 7 of the Integrated SET-Plan which is due to start in 2017 [3]. The Action 7 Declaration of Intent: "R&I related to Key Action 7 of the SET Plan will aim at developing and demonstrating technologies, manufacturing processes, science-based standards and regulations, to increase

performance and safety and reduce overall cost of battery systems used for storage purposes in the automotive and other sectors" and "In addition to the performance, cost and manufacturing targets, requirements include enhanced safety through risk mitigation as well as increased efficiency, reduction in the use of critical materials, reduced environmental impact and implementation of Eco-design (energy savings and solvent reduction) for advanced battery materials/components manufacturing processes. Furthermore, interoperability, system integration at pack level, standardization, regulations, workforce and education are important".

2 Action 2 of the Joint Initiative on Standardisation (JIS) [34]: Linking Research and Innovation with Standardisation, whose goal is "to establish a sustainable system that encourages the natural collaboration between researcher, innovators and standardizers and allows for the smooth uptake of research and innovation outputs into standardisation". This is achieved by identifying challenges to integrate research and standardisation (e.g. Putting Science into Standards workshops initiative, JRC Foresight studies, CEN–CENELEC 'Industry engagement' initiative), promoting the take up of standardisation in Horizon 2020 project calls and building strong networks of innovation actors and raise the awareness of how standardisation can support research activities.

In addition to the above, the conclusions/recommendations drawn above can be considered in the light of the Communication on Accelerating Clean Energy Innovation (COM(2016) 763), in particular to its priority on Energy Storage.

The schematic below identifies potential platforms and paths to enable further identification/evaluation/elaboration of the strategic topics and priorities identified in the workshop.



Flowchart 1. *Administrative recommendations on the way forward*
(CCMC: CEN-CENELEC Management Centre, BTs: Technical Boards, TC: Technical Committees)

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List of abbreviations

BEV	Battery Electric Vehicle
BMS	Battery Management System
EBRA	European Battery Recycling Association
EC	European Commission
EIS	Electrochemical Impedance Spectroscopy
EOL	End-of-life
HEV	Hybrid Electric Vehicle
LCA	Life Cycle Assessment
MSs	Member States
OEMs	original equipment manufacturers
OCV	Open Circuit Voltage
PHEV	Plug-in Hybrid Electric Vehicle
SMEs	Small and Medium-Sized Enterprises
SOC	State of Charge
SOH	State of Health

Annex 1: Programme

<u>22 September 2016: DAY 1</u>

(9:45-10:00) **Welcome and opening**

M. Steen (Head of Unit Energy Storage, JRC. C.1)

A. Ganesh (Director Innovation, CEN-CENELEC Management Centre)

(10:00-12:00) ***Keynote Presentations***

(each speaker 25 min with 5 min Q&A, with 30 min discussion at the end)

Moderator: **L. Brett (Project Leader BATTEST, JRC.C.1)**

Keynote 1, representing European Policy – **T. Constantinescu (Principal Adviser, DG ENER)**

Keynote 2, representing European Standards – **B. Thies (President, CENELEC)**

Keynote 3, representing European Industry – **J. Affenzeller (Secretary General, EGVIA)**

(12:00 -13:00) Lunch break

(13:00-14:45) **Session 1 *Safety evaluation in E-mobility: abuse scenarios, testing and mitigation***

(moderator 5 min outline and expectation; each speaker 15 min with 5 min Q&A; up to 40 min discussion at the end of the session)

Moderator:	**T. Constantinescu (Principal Adviser, DG ENER)**
Rapporteur:	**A. Kriston (Scientific Project Officer, JRC.C.1)**
Research needs**:**	**A. Würsig (Vice Head of the Department for Integrated Power Systems at the Fraunhofer Institute for Silicon Technology (ISIT))**
Industry:	**R. Benecke (Technical Lead Electromobility, Intertek)**
Standardisation:	**E. Durcik (Project Manager, R&D – Electrical Equipment Laboratory, EDF)**

(14:45-15:15) Coffee break

(15:15-17:00) **Session 2 *Performance assessment of automotive batteries***

(moderator 5 min outline and expectation; each speaker 15 min with 5 min Q&A; up to 40 min discussion at the end of the session)

Moderator:	**N. Omar (Head of the Battery Innovation Center Vrije Universiteit Brussel, VUB)**
Rapporteur:	**N. Lebedeva (Scientific Project Officer, JRC.C.1)**
Research needs**:**	**S. Wilkins (Senior Research Scientist Powertrains Department, TNO)**

Industry:	**A. Ahlberg Tidblad (Senior Engineer, Materials Technology Hybrid & Electronics, SCANIA CV AB)**
Standardisation:	**G. Mulder (Researcher, Energy Technology, VITO)**

19:30 Workshop dinner offered by CEN-CENELEC

23 September 2016: DAY 2

(9:00-10:45) **Session 3 *Second life applications***

(moderator 5 min outline and expectation; each speaker 15 min with 5 min Q&A; up to 40 min discussion at the end of the session)

Moderator:	**W. Tomboy (Director of the Industrial Battery Working Group, Recharge)**
Rapporteur:	**F. di Persio (Scientific Project Officer, JRC.C.1)**
Research needs**:**	**N. Omar (Head of the Battery Innovation Center Vrije Universiteit Brussel, VUB)**
Industry:	**B. in 't Groen (New Energy Technology, DNV GL)**
Standardisation:	**A. Chmura (EUROBAT)**

(10:45 -11:15) Coffee break

(11:15-13:00) **Session 4 *Recycling***

(moderator 5 min outline and expectation; each speaker 15 min with 5 min Q&A; up to 40 min discussion at the end of the session)

Moderator:	**A. Ganesh (Director Innovation, CEN-CENELEC Management Centre)**
Rapporteur:	**A. Pfrang (Scientific Project Officer, JRC.C.1)**
Research needs**:**	**H. Timmers (Manager Projects, ARN Advisory)**
Industry:	**F. Treffer (Head Business Line, Umicore)**
Standardisation	**A. Vassart (Secretary General, European Battery Recycling Association, EBRA)**

(13:00-14:00) Lunch break

(14:00-15:30) **Conclusions and open discussion for identifying next steps**

M. Steen (Head of Unit Energy Storage, JRC. C.1)
A. Ganesh (Director Innovation, CEN-CENELEC Management Centre)
F. Taucer (JRC.A.3)

- Rapporteurs' presentations
- Round table and open discussion
- Consensus on roadmap and agenda for action

(15:30-15:45) **Closure of meeting**

(16:00) Lab visit *(optional for interested participants)*

Annex 2: List of participants

Table 1. *List of participants*

Last Name	First Name	Affiliation
Adanouj	Ibtissam	European Commission, JRC.C.1
Affenzeller	Josef	EGVIA/AVL
Ahlberg Tidblad	Annika	SCANIA CV AB
Anderson	Louise	ENTSO-E
Bauer	Tom	G-SCOP lab, Université Grenoble-Alpes
Benecke	Ralf	Intertek
Binnemans	Peter	Eucobat aisbl
Bouessay	Isabelle	Group PSA
Brett	Lois	European Commission, JRC.C.1
Briere	Jean	FORSEE POWER
Chmura	Andrzej	EUROBAT
Constantinescu	Tudor	European Commission, DG ENER
Dautfest	Alexander	Fraunhofer
Débart	Aurélie	Renault SA
Destro	Matteo	Lithops
Di Persio	Franco	European Commission, JRC.C.1
Durcik	Elie	EDF
Figgemeier	Egbert	RWTH Aachen
Ganesh	Ashok	CEN-CENELEC
Gieb	Martin	European Commission, DG RTD
Girault	Jean-Luc	Bolloré/BlueSolutions
Gutiérrez	César	Fundación CIDETEC
Hoedemaekers	Erik	TNO
Hrastelj	Nineta	EuCheMS
In 't Groen	Bart	DNVGL
Koser	Uwe	Audi
Kosmidou	Theodora	European Commission, JRC.C.1
Kriston	Akos	European Commission, JRC.C.1
Lebedeva	Natalia	European Commission, JRC.C.1
Lejosne	Johann	CEA
Michallon	Philippe	CEA

Table 1. (*cont.*)

Last Name	First Name	Affiliation
Mulder	Grietus	Energy Technology at VITO
Novarese	Carlo	Lithops
Omar	Noshin	Vrije Universiteit Brussel, VUB
Pfrang	Andreas	European Commission, JRC.C.1
Podias	Andreas	European Commission, JRC.C.1
Popp	Hartmut	AIT Austrian Institute of Technology GmbH
Rahimzei	Ehsan	VDE e.V. Technik und Innovation
Ruiz	Vanesa	European Commission, JRC.C.1
Schmieder	Robert	VDE e.V. Technik und Innovation
Seitz	Steffen	PTB - Physikalisch-Technische Bundesanstalt
Steen	Marc	European Commission, JRC.C.1
Taucer	Fabio	European Commission, JRC.A.3
Thies	Bernhard	CENELEC
Timmers	Hector	ARN
Tomboy	Willy	Recharge
Treffer	Frank	Umicore
Van den Berghe	Luc	CEN-CENELEC
Van der Burgt	Jos	KEMA DNV GL
Van Deutekom	Huib	Bureau van Deutekom
Van lent	Johannes	Stibat
Vassart	Alain	EBRA
Westgeest	Alfons	EUROBAT
Wilkins	Steven	TNO
Williams	Anthony	Jaguar Land Rover
Würsig	Andreas	Fraunhofer Institut für Siliziumtechnologie ISiT
Ylkanen	Jyri	European Commission, DG ENER

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