CCQM Task Group on Metrology for Li-ion Batteries

Final Report

1. Introduction

Lithium-ion batteries have become a fundamental technology across modern society. Their use ranges from consumer electronics to electric vehicles and large-scale stationary energy storage. This rapid expansion has created several challenges that are not always easy to address. Research institutions, manufacturers, testing laboratories, and service stations need to evaluate various battery parameters such as the state of health, the internal resistance, hazardous temperatures, material compositions, including those of recycled materials, and others. However, the respective measurement procedures are often proprietary, and measurement traceability and comparability across institutions and countries are most often not verified. Even though several metrological research projects have addressed this issue in the past for various measurement quantities, no metrological services have been established at national metrology institutes (NMI) up to now that support the equivalence of measurements on the basis of the CIPM-MRA.

The Consultative Committee for Amount of Substance (CCQM) launched the Task Group on Metrology for Li-ion Batteries with the aim to clarify whether the global metrology system needs to support specific measurement services related to Li-ion batteries and, if so, how this should best be achieved. The Task Group brought together metrological expertise from various Working Groups of various Consultative Committees, such as from electrochemistry (EAWG), inorganic analysis (IAWG) and electrical metrology (CCEM). Its mandate includes the identification of key measurands, the assessment of their relevance to international comparability, and the exploration of potential long-term structures under the CIPM-MRA.

The central element of the Task Group's work has been a dedicated stakeholder workshop held jointly with the VAMAS project TWA 0, Project T5 "Key Metrological Parameters for Lithium-ion Cell Standardization," which perfectly complemented the aim of the Task Group. The VAMAS project included an international round-robin comparison on a defined set of battery cell parameters, aiming to obtain experience in the conduction and evaluation of such a new type of comparison measurement and to quantify measurement uncertainty and interlaboratory reproducibility. The workshop was held across two days, on 23 and 24 September 2025, and gathered contributions from NMIs, research organizations, regulatory and standardization bodies, and industry. An online survey was conducted in parallel to enable stakeholders to provide further input. The present document presents the main findings from the workshop and the survey.

2. Task Group Framework and Timeline

The CCQM Task Group on Metrology for Li-ion Batteries was established in May 2023. Its initial mandate covered a two-year period, but CCQM approved an extension until April 2026. The Task Group has been coordinated by Steffen Seitz (PTB), with support from Andy Wain (NPL) as deputy chair. The group reports to CCQM but collaborates with other working groups and Consultative Committees (such as the CCEM) when necessary. This reflects the fact that Li-ion battery measurements span multiple domains, including electrical quantities, chemical composition, thermal properties, and material characterization. The Task Group had four primary objectives:

- to compile an overview of potential metrological services relevant to Li-ion batteries across NMIs,
- to assess which measurands may require international comparability under the CIPM MRA,
- to engage with industrial, regulatory, and scientific stakeholders through a workshop, and
- to formulate recommendations for the future development of metrology and standardization in this field.

The presentations and discussions of the workshop and the survey form the basis for the recommendations presented in this report.

3. Summary of Workshop Results

The workshop attracted around 50 participants on each of both days, coming from academia, metrology, industry, and standardization organizations (see figure 1). They are active in material development, characterization, and testing, battery manufacturing, recycling, automotive, tools, and other areas, and were equally interested in all levels of assembly of Li-ion batteries, i.e., materials, cells, modules, and packs. The first day of the workshop was dedicated to measurements at the system level (cells, modules, packs), while the second day was dedicated to measurements at the material level.

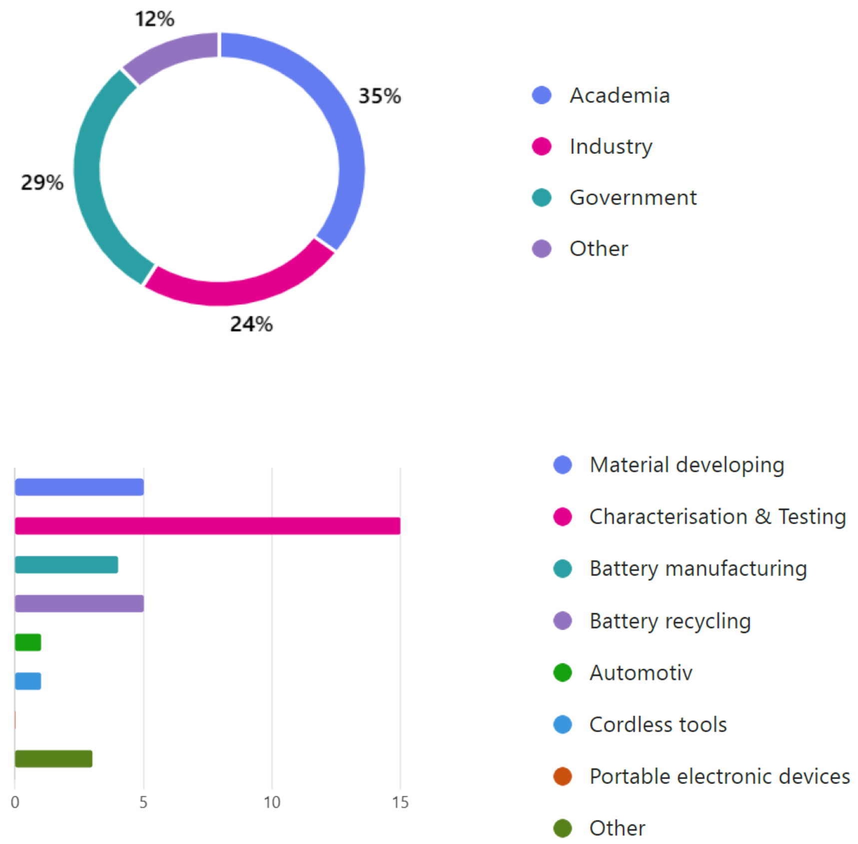

Figure 1. Types of organization and application focus areas of workshop participants

3.1 Measurement challenges and the need for comparability

Across all stakeholder groups there was broad agreement that measurement comparability for Li-ion cells is currently limited. Laboratories employ a wide variety of testing protocols and operational definitions. Identical cell types often show significant measurement scatter when tested in different laboratories. Contributors emphasized that this scatter complicates research, slows down standardization efforts, and can affect industrial decision making. A majority mentioned that calibration and measurement uncertainty are two of the main challenges.

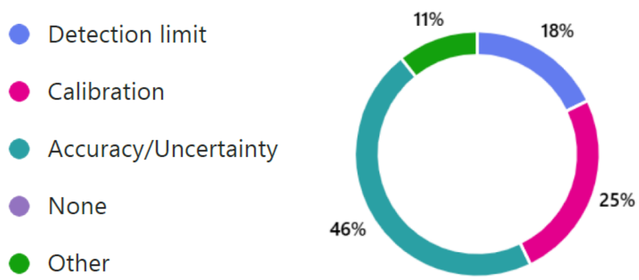

Figure 2. Identified challenges limiting measurement comparability

The survey results show that accuracy and uncertainty were rated as the most important challenges. Stakeholders noted uncertainty contributions from temperature control, cycling procedures, fitting routines for impedance data, sample preparation in materials analysis, and shipment-induced variations in cell condition.

Preliminary results of the VAMAS round robin study were also presented. They demonstrated the need for detailed measurement protocols and well-defined measurement quantities. Under such conditions, electrical parameters can be measured with good interlaboratory reproducibility. This has been exemplarily demonstated for the coulomb efficiency of commercial 1.3 Ah lithium cobalt oxide pouch cells. The solid lines in Figure 3 indicate measurements at the coordinating laboratory, while the dashed lines indicate the measurements of partcipants, the results of which were evaluated by the time the workshops was held.

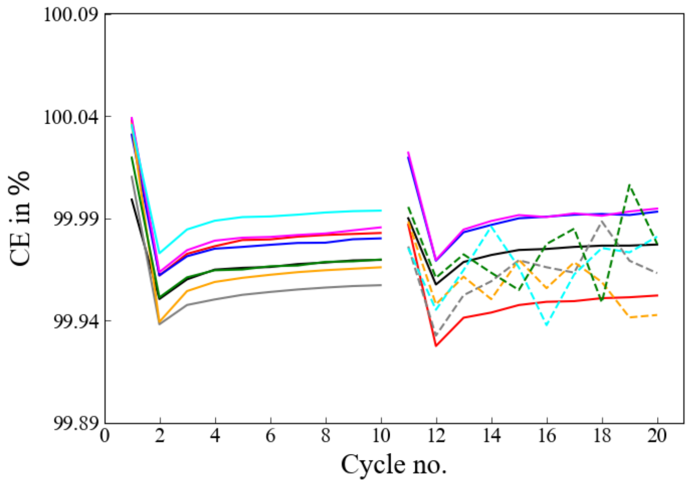

Figure 3. Preliminary VAMAS round robin results showing reproducibility of coulombic efficiency (CE)

3.2 Importance of electrochemical impedance spectroscopy and state of health measurements

Parameters derived from electrical measurements, such as the internal resistance, state of health, or state of charge, have been mentioned in the survey as most relevant for the participants, together with measurements of material composition, i.e., with respect to recycling. Electrochemical impedance spectroscopy (EIS) was identified as the diagnostic method that would be appreciated for determining such parameters, especially the state of health, in a fast and non-destructive manner that should ideally be implemented in a battery management system. However, the discussions at the workshop also showed that EIS-based measurands are currently not defined in a sufficiently precise or operational way. Operators and available battery measurement equipment extract different parameters from impedance measurements, use different measurement procedures and models, or interpret features of impedance spectra differently. It has been stressed that the electrical measurements themselves do not suffer from inappropriate traceability or low measurement uncertainty, since voltages, currents, and resistances can be measured with sufficient accuracy traceable to the SI, even though the calibration of impedance meters at the small impedance ranges

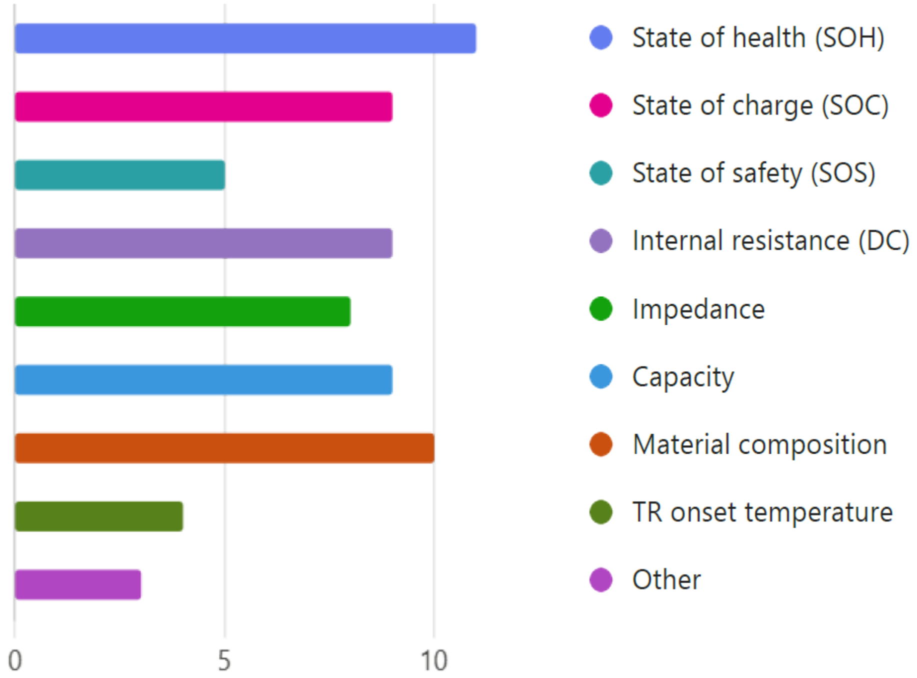

Figure 4. Relative importance of derived properties

required for high-energy cells, modules, and packs (mΩ and µΩ range) remains a challenge. Adequate specification of derived measurands, of corresponding measurement procedures and models, and the quantification of their measurement reproducibility and uncertainty are lacking. As long as these deficiencies have not been addressed, metrological services such as reference procedures, benchmark data sets, or interlaboratory comparison schemes cannot be meaningfully developed. A key task for the battery community is therefore to define which impedance-derived quantities are to be measured in a reproducible way, under which conditions they are valid, and how they relate to battery properties. Hence, at present, metrology should rather help to quantify these conditions on solid metrological grounds. Only once this foundation is established can the comparability and traceability of impedance-based measurement quantities be systematically addressed.

3.3 Materials and component measurements

A similar situation exists in the field of material composition analysis, particularly impurities or traces of substances in the context of battery recycling. Stakeholders emphasized that the chemical quantities of interest are not yet formally defined for the highly heterogeneous matrices found in recycled materials, such as black mass. It remains unclear which analytes must be quantified, in which chemical forms, and at what accuracy and uncertainty levels they are relevant for assessing material quality or regulatory compliance. Without this clarity, the development of appropriate reference materials, standardized sample preparation protocols, and traceable analytical methods remains difficult. Defining the relevant measurands is therefore a prerequisite for any subsequent metrological support, including interlaboratory studies, uncertainty evaluation, and the establishment of reliable calibration and quality control frameworks.

3.4 Interactions with standardization bodies

Contributions from IEC experts highlighted ongoing standardization work. It was noted that standardization efforts often rely on performance principles rather than prescribing specific material properties. Stakeholders agreed that metrology can support such standards by ensuring that underlying measurements are comparable and by providing guidance on uncertainty evaluation. Presenters also emphasized that the battery landscape evolves rapidly and that standardization committees increasingly require input from metrology to ensure robustness. This is particularly true for electrochemical measurements, where differences in equipment and procedures can lead to divergent results.

3.5 Overall conclusions from stakeholders

Despite the diversity of contributions, some clear conclusions could be drawn:

- There is strong demand for improved international comparability in electrochemical and electrical battery parameters, including derived parameters such as state of health and state of charge.
- EIS has high potential to become a standardized diagnostic tool but requires the development of a metrological sound foundation.
- Identification and clear specification of reference procedures, evaluation models, and quantification of respective measurement uncertainty would be valuable.
- Round robin studies are essential to identify sources of variability.
- There is interest in long-term collaboration between NMIs and standardization bodies, but coordinating such activities may be somewhat challenging.
- There is no need to establish traceability structures within the context of the CIPM-MRA for the discussed battery parameters, before the above-mentioned issues have been resolved.

4. Conclusions and Recommendations

The workshop and survey demonstrated broad interest in improved comparability of Li-ion battery measurements. The evidence suggests that the global metrology community can play a significant role in supporting emerging standards and enhancing industrial reliability.

The actual measurement signals (voltages, currents, time, frequencies, temperatures) are well embedded in the CIPM-MRA and do not require further implementation, except for low impedance standards. However, derived parameters, such as the state of health, often lack standardized definitions, measurement procedures and models, and a sound metrological evaluation.

A central outcome is the identification of impedance measurements and EIS as methods to determine the state of battery cells, modules, and packs, and that they should be implemented in battery management systems where possible. However, their implementation in routine battery testing requires further standardization on solid metrological grounds, including overcoming proprietary approaches used by companies. Further research is needed to understand the effects of equipment, measurement conditions, battery history, fitting models, and interpretation methods on the derived parameters and their measurement uncertainty. Metrological work in these areas would support the development of reference procedures and data sets that could become part of international standards.

The workshop has shown that, for material composition analysis, particularly in battery recycling, the relevant chemical measurands and their required accuracy are not yet clearly defined for the usually heterogeneous matrices. It is recommended that metrology support investigations and research into how these measurands can be reasonably defined. The quantification of the associated measurement requirements is a prerequisite for developing reference materials, standardized procedures, and traceable analytical methods.

The discussions have also highlighted the usefulness of coordinated interlaboratory comparisons provided the measurands and measurement procedures are adequately specified. Preliminary results from the VAMAS round robin study confirmed the importance of harmonized protocols. Future studies should target impedance measurements directly and must include a wider range of ageing conditions, although this may require additional resources from NMIs.

The implementation of measurements and CMCs intended to characterize the state of Li-ion batteries, or more generally alkali-metal batteries, within CC working groups in the context of the CIPM-MRA appears premature at present. Accordingly, no cross-CC activities are currently required to coordinate the measurements and CMCs distributed across different CCs. However, it is recommended to monitor the rapidly evolving market and the harmonization efforts associated with it, as the need to develop appropriate traceability structures may arise unexpectedly quickly.

Annex

A - TG participants

Name of contact	**Institution / country**
Steffen Seitz	PTB / Germany
Andy Wain	NPL / United Kingdom
Matthias Bruchhausen	JRC / European Commission
Andreas Pfrang	JRC / European Commission
Gert Rietveld	VSL / Netherlands
Stanislav Maslan	CMI / Czechia
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Zoltan Mester	NRC / Canada
Haifeng Wang	NIM / China
Kazumi Inagaki	AIST / Japan
Johannes Hoffmann	METAS Switzerland
Johanna Noireaux	LNE / France
Kyungmin Jo	KRISS / Korea
Serap GENÇTÜRK TOSUN	TUBITAK / Turkey
Susmit Kumar	Justervesenet / Norway

B – Meetings (online)

Date	**Main content**
03.07.2023	Core group meeting, outline of the objectives, brainstorming on the tasks, administrative actions
06.10.2023	Exchanging ideas whom to invite to become TG member, review of existing metrology project
04.03.2024	First meeting of larger group, outlining the TG and its objectives, getting known, discussion of format of the workshop
04.06.2024	Discussion on potential measurement quantities relevant for the workshop
10.09.2024	Discussion on measurement quantities, their categorization and prioritization, and on stakeholder contacting
13.11.2024	Updating the measurands file, introduction of VAMAS study and decision for a combined TG/VAMAS workshop, discussion on the framework of the workshop and an approximate date
30.04.2025 27.05.2025 29.08.2025 09.09.2025	Preparation of the workshop: flyer, invitation, registration, stakeholder engagement, setting-up the conference room, identification and invitation of potential presenters, devising survey questions, discussion of workshop flow
23&24 Sept 2025	Workshop
02.10.2025	Debriefing and conclusions