

Batteries + Europe

BATTERIES EUROPE SECRETARIAT

D3.7 - KPIs Benchmarking & Target KPIs II

Work Package 3 – R&I for European Industrial Competitiveness

T3.4 – Benchmarking on KPI assessment to measure the impact of R&D activities in batteries.

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1 INTRODUCTION

The experts from the six working groups of the collaborative effort between Batteries Europe and BEPA (Batteries European Partnership Association) have undertaken a comprehensive review of the Key Performance Indicators (KPI) values. This review aims to incorporate the latest advances in research, industrial developments, and battery-related regulations. Furthermore, this endeavour has provided the opportunity also to assess and, if necessary, correct the values and the definitions included in the glossary. Ultimately this version introduces the integration of a more application-oriented approach in transport and stationary energy storage related activities and separates advanced materials at material and cell level.

The KPI values provide critical insights to different actors and for different uses:

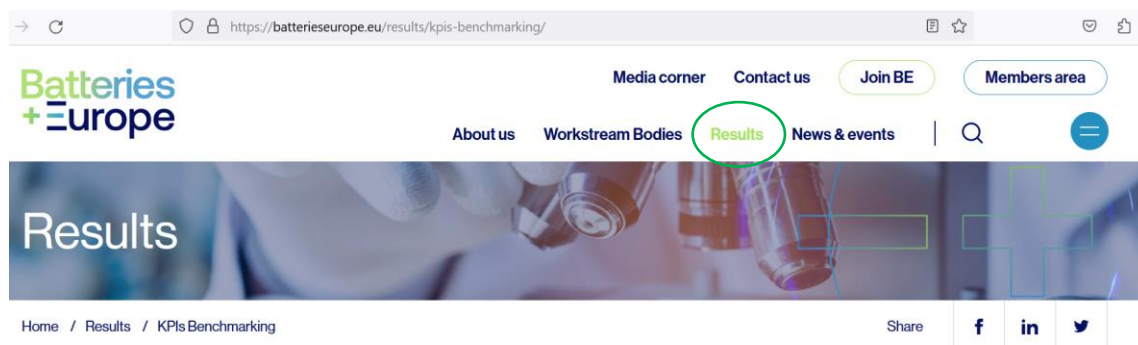
- To researchers to benchmark the progress of their R&I projects.
- To industry stakeholders to understand long-term objectives and challenges.
- To policy makers to integrate them into upcoming regulations and policy statements.
- To funding agencies to have a reference for supporting research towards the achievement of a sustainable European battery value chain.

This report consolidates the main proposals and conclusions made by experts in each thematic working group and facilitates the understanding of the KPI tables themselves.

1.1 Where to download the KPI Value tables

KPI tables are available to download and use in Batteries Europe website (direct link [here](#)), following these two screenshots:

- 1) Access Batteries Europe website, click on Results section on the toolbar and go to KPIs Benchmarking section.



Strategic Research & Innovation Agenda
 Technology Roadmap
 Position Papers on Cross-cutting topics
 Reporting methodologies
 Publications from the European Commission
 Publications from Scientific Journals
 KPIs Benchmarking

KPIs Benchmarking

- 2) In the “KPIs Benchmarking” section scroll down and double click to download the Excel file “Batteries Europe_KPI_REVISION_WG1-WG6” and the report “KPIs Benchmarking II”.

Strategic Research & Innovation Agenda
 Technology Roadmap
 Position Papers on Cross-cutting topics
 Reporting methodologies
 Publications from the European Commission
 Publications from Scientific Journals
 KPIs Benchmarking
KPIs Benchmarking January and October 2023
 International Observation

KPIs Benchmarking January and October 2023

This section provides a set of battery-related KPIs that have been defined jointly by BE and BEPA members. The document is structured by domain, according to the six WGs, to improve the readability and to reflect the working process, even there are some KPIs that are relevant for several domains. The excel gathers the KPI values per working group, indicating a disclaimer to facilitate its understanding by pointing the approach and the boundaries of the work done. These include referenced baseline values from 2023 (carefully evaluated according to reliably published data) and future expected values, framed in 2027, 2030, 2035 or 2050, depending on the type of KPI.

Strategic Research & Innovation Agenda
 Technology Roadmap
 Position Papers on Cross-cutting topics
 Reporting methodologies
 Publications from the European Commission
 Publications from Scientific Journals
 KPIs Benchmarking
KPIs Benchmarking January and October 2023
 – KPIs Benchmarking I, January 2023
 – KPIs Benchmarking II, October 2023
 International Observation

KPIs Benchmarking II, October 2023

KPIs Benchmarking II, October 2023 [Download](#)

The Excel file ‘Batteries Europe KPI revision’ is organized by Working Groups, with each Working Group gathering the most relevant KPIs as identified by experts with their corresponding values, explanations and sources. These KPIs include referenced baseline values from 2023 (which have been carefully assessed based on reliable published data) and future expected values, framed for the years 2027, 2030, 2035 or 2050, depending on the type of KPI.

These are the Working Groups, with their corresponding number of sheets in the Excel file:

- WG1 New and emerging technologies (1 tab)
- WG2 Raw materials and recycling (1 tab)
- WG3 Advanced materials (21 tabs)
 - Material level (9 tabs)
 - Cell level (12 tabs)
- WG4 Cell design and manufacturing (1 tab)
- WG5 Application and integration: Mobile (4 tabs)
 - All transport modes (1 tab)
 - Road and Off-Road (1 tab)
 - Waterborne (1 tab)
 - Airborne (1 tab)

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- WG6 Application and integration: Stationary (2 tabs)
 - Fundamental KPIs (1 tab)
 - Secondary KPIs (1 tab)

To identify the new contributions, modifications and proposals compared to the first edition (January 2023), the modified KPIs are written in **red** and the new KPIs added to previous version are written in **green**. See below the screenshot of WG4 as an example.

Disclaimer:

- KPIs focus only on the cell manufacturing process, starting with the slurry mixing, active material preparation is not included unless explicitly stated in the description
 - all KPIs are for TRL 9, as the objective is commercial cell production
 - target values may differ depending on cell type, target application and design considerations (design to life, design for power density etc.); generally the KPI refer to commercially relevant energy-rich Li-ion cells for automotive or energy storage applications
 - the columns "comments" and "source" provide further information to understand the approach behind each KPI
 - For all KPIs, target values for 2030 are defined. Depending on the availability of literature sources and expert information within the Working Group, additional target values are defined for 2023, 2027 and 2035. Values for 2050 are planned to be added in future iterations

WG4 CELL DESIGN & MANUFACTURING									
KPI	Description	TRL Level or higher	Unit	2023	2027	2030	2034	Comments	Source
Li battery cell production	Automotive and other markets (Li-ion and next generation post-lithium) battery cell production in Europe	9	GWh/year	75	379 GWh by 2025	886	>1 TWh	High level KPI for international benchmarking, for Li, started from 2015 value: 0.20 GWh/year based on public announcements >1,500 GWh by 2030 for 2020: assume that entire fleet is electrified in future other cell chemistries could be considered in further lines (e.g. Sodium-ion) Target for 2030 in line with ECA Special Report 15/2023 (713 - 1197 GWh)	Batteries for energy storage in the EU - Status Report on technology development, trends, val chains and markets, JRC, 2022 ECA Special Report: The EU's industrial policy on batteries - New strategic impetus needed (2023)
Energy consumption	Refers to all the energy consumed to manufacture an energy storage system (cell), in kWh, per kWh of energy system's nominal energy. Includes process steps from slurry mixing to cell finishing, in Europe. Overall values, including waste.	9	kWh/kWh	50		25	10	Targets have been amended according to latest research. Value for 2023 has been lowered, ambitious target for 2035 has been added. Target for 2030 is also in line with Frey, Noerlvolt, etc. announcement	Merve Erakca et al., 2021 Schutte, Degen, 2022 Drachenfels et al., 2023 UKBIC Report, 2020 Degen et al. 2023 (https://www.nature.com/articles/s41560-023-05-z1)

Navigation tabs: WG3_Gen4 Na-ion Stationary | WG3_Van. Redox Flow | WG3_Adv. Mat. to reduce weight | WG3_Adv. Mat. ultra-fast char. | **WG4_Cell design&manufacturing** | WG5_Transport | +

2 EXECUTIVE SUMMARY

The new KPI value tables align with the requirements of the New Battery Regulations, covering aspects such as recycling content, energy consumption and CO₂ footprint. They also incorporate the latest research outcomes for certain chemistries, advancements in materials and technologies, and the experienced gained from battery mass manufacturing in Europe. These three drivers, along with the information and demands received from industry and sector-oriented applications, have guided the revision process to update the initial edition of the KPIs Benchmarking & Target KPIs, which was first released in January 2023.

The next edition is expected in October 2024. In the coming year, the aim is to involve testing bodies in the reflection, particularly those relevant to cell design and manufacturing related activities.

Working Group 1 - New and Emerging Technologies:

After careful consideration, WG1 has determined that no changes to the KPIs or glossary were necessary at this time. However, the importance of staying up to date with emerging technologies and industry developments was recognized. As a result, it is planned to add new chemistries to the KPIs in the next revision, ensuring that we continue to reflect the latest advancements accurately. Additionally, the glossary underwent a review, incorporating the new changes necessitated by the evolving landscape, and no further modifications were proposed.

Working Group 2 - Raw Materials and Recycling:

The integration of the New Battery Regulation¹ (adopted in July 2023) requirements into the KPIs provides a broader overview of the challenges ahead on recycled content targets and recycled content targets for manufacturing scrap. In addition, the importance of cost metrics for recycling processes has been reflected on the KPI value tables, whose prioritization has not been changed.

The Glossary embeds new concepts coming from the mentioned New Battery Regulation and is complemented with the materials classification and the sections on second life and circular economy model.

Working Group 3 - Advanced Materials:

A completely new Material level KPI has been created to complement the existing Cell-level KPI reviewed to integrate the latest research and industrial developments. Notably, cost-to-performance chemistries like LFP/LMFP, with the CTP design, closed the gap with specific NMC chemistries. Meanwhile, sodium-ion technologies entered mainstream production and competed with the established LFP market.

Experts reviewed the glossary term "Gravimetric energy density" specifically at the cell level, denoted as Wh kg⁻¹, and found that it should be more appropriately referred to as "Specific Energy" since the

¹ [Regulation \(EU\) 2023/1542 of the European Parliament and of the Council of 12 July 2023](#) concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC.

term "density" implies volume, which is not relevant in this context. It's important to note that the unit, Wh kg⁻¹, remains unchanged.

The process done highlighted the importance of involving standard testing bodies in KPI revision and proposals.

Working Group 4 - Cell Design and Manufacturing:

The challenge Europe is facing to deploy the battery mass production manufacturing capabilities has been the driver for the revision process, giving new approaches to innovate in battery technologies design and manufacturing, with a strong emphasis on manufacturing processes for battery cells, modules and packs. The energy consumption and the CO₂ footprint in manufacturing are the two main new KPIs. These will require future revisions to reflect the progress in the industry as battery cell manufacturing sites are scaled up across Europe.

Working Group 5 - Application and integration: Mobile:

The new KPI values table has been enriched with the incorporation of application oriented KPI values to reflect the road, airborne, off-road and waterborne transport modes, identifying values at pack/system level for the given sectors.

Working Group 6 - Application and integration: Stationary:

The KPI values have been classified into two groups: fundamental KPIs, which are of high relevance for both the industry and research community, and secondary KPIs, that are relevant for stationary energy storage but refer to specific use cases. This categorization allows to differentiate KPIs that are transversal to different use cases and the rest.

3 KEY PERFORMANCE INDICATORS

The Working Groups have done the revision of the former KPIs to update -when necessary- the values and the glossary, identify new ones, and prioritize them. The debate and brainstorming have had different outcomes depending on the WG's scope, that is summarized below.

3.1 WG1 New and emerging technologies

After careful consideration, the experts of WG1 have determined that no changes to the KPIs or glossary were necessary at this time. However, the experts will continue doing its revision focusing on the long term to integrate KPI linked to new chemistries in the next revision, ensuring that we continue to reflect the latest advancements accurately.

3.2 WG2 Raw materials and recycling

The main objective of the KPI revision process in WG2 was to align dates, values and definitions to the new Batteries Regulation, adopted in July 2023.

The KPI framework, divided into 3 tasks on recycling, raw materials (sourcing, tracking processes) and sustainability was maintained as was the prioritization of the defined indicators. Some revision was made in the Recycling task, where the baseline indicators were removed, and the recycled content targets were updated to be fully aligned with the new Batteries Regulation. A KPI “*Cost metrics*” defining the cost of the recycling process (now and future) was provided as a recommendation. In this specific case, a defined value was not given since the recycling cost strongly depends on many parameters, such as the type of feed (black mass, battery, scrap manufacturing), different products at the output of the recycling plant (materials technical grade and battery grade, cathode chemistries, purified solution, etc.) and several business models (including buy and sell, toll milling).

The glossary of some KPIs was updated considering new definitions included in the Battery Regulations, specifically *Collection Rate* and *Recycling Efficiency*. The definition of “*Primary Raw Material*” was also provided in the glossary to complement the classification of the WG2 General terms.

The Glossary section of “*Second life of batteries and circular economy model*” was simplified since some previous definitions were overlapping at some extent. Two terms are now listed, namely “*Share of repurposed batteries*” and “*Share of batteries sent at EoL*”.

Additional KPIs, including those related to the second life batteries, circular economy model and the Carbon footprint of recycling technologies will be reported in forthcoming versions, because of collaboration activities with WG5/WG6 and WG4, respectively.

Summary of the terms improved on the glossary to integrate latest research outputs:

General terms

Term	Definition
Primary raw materials	Primary raw materials are virgin materials, natural inorganic, or organic substances, such as metallic ores, industrial minerals, construction materials or energy fuels, used for the first time. ²

Total recycling battery materials

Term	Definition
Recycling efficiency (%)	The ratio, expressed as a percentage, obtained by dividing the mass of output fractions accounting for recycling by the mass of waste batteries' input fraction, in relation to a recycling process. ⁴
Collection rate (%)	Based on Annex XI of Batteries Regulation ⁴ , Producers of the relevant category of batteries or, where appointed in accordance with Article 57(1), producer responsibility organizations, and Member States shall calculate the collection rate as the percentage obtained by dividing the weight of waste batteries, collected in accordance with Articles 59, 60 and 69, respectively, in a given calendar year in a Member State by the average weight of such batteries that producers either make available on the market directly to end-users or deliver to third parties in order to make them available on the market to end-users in that Member State during the three preceding calendar years. The collection rate shall be calculated for portable batteries in accordance with Article 59, and for LMT batteries in accordance with Article 60 respectively.

Second life of batteries, circular economy model

Term	Definition
Share of repurposed batteries	Capacity (Ah) of batteries (EV-IB) placed on the market for the first time after repurposing (second life). "Preparation for Repurposing: any operation, by which a <u>waste battery</u> , or parts thereof, is prepared so that it can be used for a different purpose or application than that for which it was originally designed. Repurposing: any operation that results in a battery, that <u>is not a waste battery</u> , or parts thereof being used for a purpose or application other than that for which the battery was originally designed.
Share of batteries sent at EoL	Capacity (Tonnes CRM) of batteries (EV-IB) taken back (collected) and received at EoL facilities directly towards recycling. Preparation for Recycling: treatment of waste batteries prior to any recycling process, including, inter alia, the storage, handling and dismantling of battery packs or the separation of fractions that are not part of the battery itself.

3.3 WG3 Advanced materials

At the pinnacle of WG3's efforts, new Material-level Key Performance Indicator (KPI) tables were established, and concurrently, the existing Cell-level KPIs underwent updates. Notably, significant advancements in cost-to-performance chemistries, exemplified by LFP/LMFP in the CTP design, bridged the divide with certain NMC chemistries. Simultaneously, Na-ion technologies made their foray into mainstream production, actively challenging the established LFP market. Our work also underscored the imperative need for the inclusion of standard testing bodies in our endeavours.

The rapid progress in materials development and cell technology prompted updates to Cell-level KPIs and the introduction of new Material-level KPIs. The WG Expert meetings were convened to complete this work and refresh the Cell-level KPI tables. During these meetings, members reviewed and discussed their contributions to the KPI tables, highlighting the need for number revisions and providing the underlying justifications. For instance, hazard levels required adjustments due to definitions of cell testing conditions and the multiple criteria needed to meet each hazard level class. Additionally, there was extensive debate, particularly regarding power metrics, which emphasized the necessity of involving testing bodies in the working groups. The process of arriving at these figures involved a thorough review of cell specifications, material specifications from manufacturers and resellers, as well as scientific publications and reports.

The completely new Material level KPI tables, were created to complement the existing Cell-level KPI tables, which were also. The new Material level KPI tables are listed here below. The table below provides an overview of the new identified Material level KPIs and their corresponding published Cell Level KPIs.

Table 0. Overview of the new *Material level KPI tables* and their corresponding *Cell level KPI tables*.

Table Number	Cell Level KPI tables (name prefixed with CL)	Material level KPI tables provided. (Given the same name, separate file)
1	CL - WG3_Non-SSB - Mobility – Cost	1
2 a, 2b	CL - WG3_Gen 3 LiB-Mobility - Performance	1. Where cell Voltage < 4.5V 1. Where cell Voltage > 4.5V
3	CL - WG3_Gen 4a LiB – Mobility	1
4	CL - WG3_Gen 4b LiB – Mobility	1
5	CL - WG3_Gen 4c LiB – Mobility	1
6	CL - WG3_LiB Stationary- Comm HP	1
7	CL - WG3_LiB Stationary – Utility	1
8	CL - WG3_Gen3 Na-ion Stationary	1
9	CL - WG3_Gen4 Na-ion Stationary	1

The listed materials KPI tables, prefixed with ML, provide individual cathode, anode and electrolyte KPIs for each class of materials that goes into a cell which then depending on the cell format and assembly process generates the published and reviewed Cell Level KPI tables which have the same name as the material-specific tables, but with the prefix changed to CL.

A class on materials for cathodes for example would be layered type or olivine type while for anodes it would be graphite or composite (e.g. Si-Gr). The equivalent for electrolytes would be liquid, polymer, composite, or inorganic.

Each Material Level KPI table should be read in hand with the corresponding Cell Level KPI table. For example:

ML - WG3 Non-SSB - Mobility – Cost read with ***CL - WG3 Non-SSB - Mobility – Cost***

In 2024, WG3 anticipates significant updates to Na-ion KPIs at both cell and material levels, and also particularly within the LFP and its derivatives. This is driven by emerging cell concepts and the growing maturity of LMFP technology. The experts project a decrease in cell costs, alongside improvements in Wh.kg⁻¹, Wh.L⁻¹ and charging rates. To align with EU Critical Raw Materials regulations², the experts predict a rise in the adoption of cobalt-free alternatives. Additionally, the aim is to involve standard testing bodies in future WG revisions.

3.4 WG4 Cell Design and Manufacturing

The KPI developed by the WG4 experts aim to support the research on upscaling of innovative and sustainable battery manufacturing capabilities (mass production) in Europe. To this end, they provide a guiding reference for innovation in the design and manufacturing of battery technologies on a commercially relevant scale (TRL 9), with a strong emphasis on manufacturing processes for battery cells, modules, and systems. Compared to the previous iteration, the KPI list reflects progress and a higher level of ambition regarding energy consumption and in particular the CO₂ footprint.

To ensure the KPI's are applicable for stakeholders from industry, research, and public authorities it is vital to be clear on their scope and definition. This aspect of the WG4 KPI list has been critically reviewed and improved during the review period. The emphasis on TRL 9 has been affirmed. The KPI focus on the manufacturing process steps are kept agnostic regarding active material selection. For KPI that depend on active material selection and design considerations (e.g. design for power vs. design for energy vs. design for cycle life), a high-TRL energy rich Li-ion cell for automotive and energy storage applications shall be considered as a reference cell. For the avoidance of doubt, if metrics on material level (such as emissions or costs) factor into the target values for a specific KPI, it is explicitly stated in the description.

For several KPI, the previously proposed target values could be confirmed by the experts, partially backed up by updated literature sources. Improvements could be noted regarding CO₂ emissions and energy consumption of the production processes. The target values have been updated accordingly. The CO₂ footprint is now indicated as a manufacturing footprint (excluding upstream emissions from material production) as well as on cell level (cradle-to-gate footprint including upstream emissions), to reflect the core focus of the Working Group, and additionally the impact cell design and manufacturing have on the material CO₂ footprint per cell, e.g. by decreasing scrap rates, reducing material losses and using alternative materials.

² [Critical Raw Materials regulations](#)

To keep the KPI list comprehensible, no cell type-specific or material-specific KPI were added for the moment, as those would have been highly dependent on the target application. If specific module/pack designs and cell types (other than energy-rich automotive Li-Ion cells) should emerge as a relevant industry reference in the future, the addition of such KPI can be re-evaluated in future revisions. In any case, future revisions of the Cell Design and Manufacturing KPI list are necessary to reflect the progress in the industry as battery cell manufacturing sites are scaled up across Europe.

3.5 WG5 Application and integration: Mobile

The definitions of KPIs for applications in general is not a straightforward task, mainly because performances are tailored by the different cases and integration. WG5 experts decided to tackle this issue with an iterative-step process: each step is checked back before phasing the new one, to consider new discoveries during time.

- There was a mandatory first step (done in the first release of the KPI document and tables) to minimize the KPI list, to have a common ground for all transport modes and a general view.

In this second revision of the document and KPIs tables, the main challenges for WG5 have been:

- A throughout and critical look at the general KPIs, to update values if needed, to endorse with new literature references and to add or delete KPI entries.
- A second phase that countered in defining values for the main transport modes. For this reason, the original list has been extended by including the KPIs listed in the glossary, implying the transition from KPIs at cell level to KPI at pack/system one. It allowed the KPIs to be specific for determined applications.

So, in addition to All Transport Mode, specific KPIs and values has been introduced in the table for Airborne, Waterborne, Road and Off Road. Most of these new values have been deduced by the experts' knowledge, gathering feedback from external stakeholders, comparison with other WGs or literature-based, while All Transport Mode one was not substantially changed. The direction of the work has been to extend the KPI table looking at the specificity of the transport mode and at the view of the battery into an integrated system.

Next step will be a critical look at the tables, also reviewing together with other partnerships dedicated to a specific transport mode or group of relevant stakeholders. Rail transport-specific table will also be added.

3.6 WG6 Application and integration: Stationary

The main issue in the definition of the stationary storage KPIs, is that stationary applications are a wide range of cases with quite different requirements each. The WG6 experts have defined macro-areas of

applications for the Batteries Europe Roadmap³ and are going to apply that rationale also for the KPIs. This main goal is not straightforward and needs to be approached by steps.

- First the values were checked if still acceptable. Then the KPIs were prioritized as either the most important or the most transversal as possible: those, indeed, that could be a quality criterion for most stationary applications. A deep work of consolidation of the data has been done both by internal discussion and by literature data.

In the current document and table, the experts decided to maintain the transversal approach, with values acceptable for all the technologies on the market because the identification of a series of case studies with a specific KPI lists and value is still ongoing.

- The initial number of KPIs was reduced to 12 and labelled as “most important” and a list of “secondary KPIs” has been maintained, although some of them could be important depending on the application.

All KPIs are provided at system level from a battery system perspective and by the view of the integration into the energy system: KPIs are considered not only related to the performance of the isolated battery system, but also related to the critical issues deriving from the integration of the stationary storage system within a wider operating system.

Following key challenges will be addressed in the next review, such as the inclusion of KPIs related to cost competitiveness and sustainability (Cost and Environmental Impact), whose definition and value determination are quite complex and require interaction with the others WG and Task Forces.

³ [Batteries Europe Roadmap](#).

4 CONCLUSION

A comprehensive review and update has been conducted across all Working Groups during the KPI revision process, each focusing on specific aspects of the Batteries Europe initiative. These efforts aimed to align the KPIs and glossary with the evolving landscape of battery technologies and regulations.

One of the key outcomes of this revision was the harmonization of the glossary with new definitions introduced in the Battery Regulations. Specific concepts, such as "Collection Rate" and "Recycling Efficiency," were integrated into the glossary. Furthermore, to ensure clarity and consistency, a definition for "Primary Raw Material" was added, complementing the overall classification of terms.

While some Working Groups saw no changes in their KPIs during this revision, future updates are planned to incorporate new KPIs, particularly those related to emerging battery technologies and sustainability initiatives. Collaboration with other Working Groups and Task Forces will be crucial in this regard.

The KPI revision process highlighted the importance of standard testing bodies in ensuring the accuracy and relevance of the metrics. The discussions and adjustments were informed by data consolidation, literature references, and industry advancements.

Looking forward, the Batteries Europe initiative anticipates significant updates in KPIs, particularly for areas like Na-ion technologies and energy density. The focus remains on aligning with EU regulations, reducing environmental impact, and ensuring clarity for stakeholders in the industry, research, and public authorities. Continuous engagement with testing bodies and industry stakeholders will be a vital component of future revisions.