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Battery requirements for future automotive applications

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Battery requirements for future automotive applications

EUCAR Overview

EUCAR is the European Council for Automotive R&D of the major European passenger car and commercial vehicle manufacturers. EUCAR facilitates and coordinates pre-competitive research and development projects, and its members participate in a wide range of collaborative European R&D programmes. The European automobile manufacturers are the largest private investors in R&D in Europe, investing more than €80 billion per year. EUCAR members are BMW Group, DAF Trucks, Ford of Europe, Honda R&D Europe, Hyundai Motor Europe, Iveco Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars and Volvo Group.

EUCAR Expert Group Battery Technologies

EUCAR is committed to supporting the targets of the European Green Deal. Its highest priority is to mitigate the impacts of climate change by reducing greenhouse gas emissions. To achieve these goals, EUCAR is committed to developing and providing sustainable powertrain technologies that enhance the quality of life for EU citizens.

Practical work on R&D issues is carried out by the EUCAR Expert Groups (EG), which comprise experts from the member companies. It is in the EGs where the research needs are identified and formulated. The Expert Group Battery Technologies (EG BT) focuses its work on improving the performance and efficiency of electric vehicles (EVs) while ensuring the industrial and economic feasibility.

Battery Requirements 2030-2035

The purpose of this document is to provide an automotive perspective on the requirement targets for the main traction battery in BEVs in 2030-2035. Based on today's understanding of the state of the art in battery technologies and their applications, and considering their projected development over the next decade, the expert group has set challenging targets for battery requirements. These targets are intended to serve as values that guide researchers, policymakers, and other interested parties in setting realistic goals that can be achieved within the specified timeframe. To track the fast-paced battery and EV development, the expert group recommends checking, expanding and updating this document version regularly. In this version, the targets are presented in a table for BEVs, with the focus on average mass market vehicles. Specific requirements of high-performance or speciality vehicles are not considered.

Automotive requirements widely differ due to a large variety of vehicle sizes and applications within the transportation sector. Vehicle segments, such as passenger cars, range from small two-seaters to large SUVs. Light commercial vehicles have different space and business needs, whereas medium- and heavy-duty trucks and buses serve different use cases. This version of the battery requirements will begin with overall driving range, power, and lifetime expectations from the industry and evolve into regularly updated versions in the following years to include other essential factors, such as performance, sustainability, recycling, and second-life applications. Battery technology is evolving at a rapid speed, with chemistries and cell designs optimised to improve certain key features. Comparison for automotive applications has therefore to be made on a system level rather than cell level, especially when improvements in only one area may need additional system components to ensure overall suitability. Therefore, the battery requirement targets presented in this document are not exclusive in nature but have to be considered in the context of specific transportation applications. The battery requirement targets are understood to provide a perspective for future research needs and invite researchers to go even beyond these targets and not as a limit.

Scope

The Battery Targets 2030-2035 proposes values for relevant characteristics of battery cells and battery packs. These values may vary depending on the application, vehicle segment, and driving range. This version will cover the BEV use cases:

- passenger cars with low range (~300 km),
- passenger cars with mid range (~300-600 km)
- passenger cars with high range (>600 km),
- commercial heavy-duty vehicles (CV HDV).

The Battery

A battery is an energy storage system used in automotive applications to supply power (watts) to electronic equipment. A battery system consists of a number of cells connected in series or parallel to provide the required power and energy for the targeted application. Each cell consists of two electrodes which can store the electric charge carriers. In charging mode, the charge carriers are brought to one electrode via an external charging source under the application of high voltage on the cell. When a charged cell is connected to an electrical device, electrons can flow through the external circuit to power the device, e.g., an electric machine. This process depletes the charge carrier from the anode, which can be observed by the drop-in voltage. The cell is fully discharged when its permissible lower voltage is reached; after that, it must be charged again before reuse. The operational voltage window of a cell is determined by the

materials used in the electrodes, allowing the cell to charge and discharge repeatedly within this voltage range.

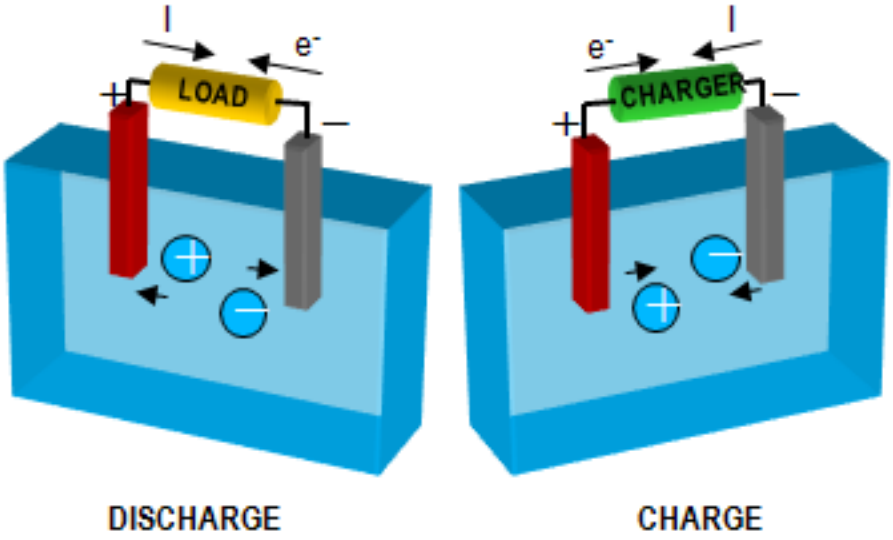

Fig. 1: Cell operations (Source: https://ti.arc.nasa.gov/tech/dash/groups/pcoe/battery-prognostics/battery-basics/)

Power capability of a cell is the ability of the cell to provide a high amount of current flow over a certain time duration, whereas the energy capability of the cell is the ability to provide the current flow over a longer duration until the cell is considered empty, which means that the lower discharge voltage is reached. The total number of charged carriers stored in a single cell and the potential difference between the anode and cathode determine the cell's energy content, whereas the speed at which the carriers can sustainably deliver charge to the electrodes determines the cell's power capability. Different cell chemistries are available and have their own advantages and disadvantages (see Figure 2).

Commonly known batteries used in automotive applications are lead-acid batteries. Individual cells with a nominal voltage of just over 2 volts are connected in series to form a 6-cell string, which reaches over 12 volts to supply power to the vehicle's board network. In an electrified car with a traction motor, higher power and energy are required beyond the capability of the lead-acid chemistry. Cells with lithium ion-based chemistries have proven to be most suitable for this application until now. They have a range of nominal voltage from 2 V to 3.75 V and have a much higher specific energy (Wh/kg) and energy density (Wh/l) compared to Lead-Acid cells.

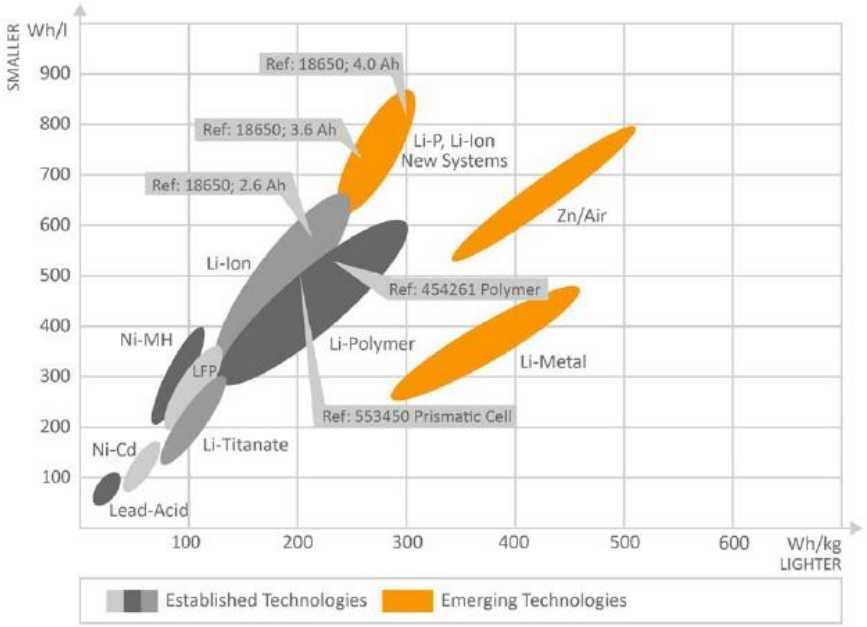

Fig. 2: Comparison of specific energy and energy density of established (grey) and emerging (orange) material systems in reference cells with various dimensions (18650 = cylindrical cell with 18mm diameter and 65mm height) DESCRIPTION (Source: E. Rahimzei, K. Sann, M. Vogel, Kompendium: Li-Ionen-Batterien im BMWi Förderprogramm IKT für Elektromobilität II: Smart Car – Smart Grid – Smart Traffic. Grundlagen, Bewertungskriterien, Gesetze und Normen. Juli 2015:

https://www.dke.de/resource/blob/933404/fa7a24099c84ef613d8e7afd2c860a39/kompendium-li-ionen-batterien-data.pdf)

Battery Chemistries

Currently commercialized LIB have a graphite-based anode in common. On the cathode side, LIBs consist of various types of materials, with each combination having distinct pros and cons in terms of costs, safety, performance, and other parameters. Currently, lithium cobalt oxide (LCO), known as a mature cathode chemistry, is the most predominant battery technology for consumer electronics. However, because of its structural instability in terms of overdelithiation, this chemistry is not suitable for EV applications [1].

For automotive application, two types of materials are dominating the market. Lithium manganese cobalt oxide (NMC) offers a high energy density and is produced in globally developed supply chains. However, it contains critical raw materials, has a high material cost and thermal properties challenging for system integration.

Thus, lithium iron phosphate (LFP) is currently increasing its market share due to low cost, use of more abundant materials and simplified system integration. On the downside, there is a significantly China-focused supply chain and a low energy density compared to NMC.

Most mobility applications in 2030-2035 will utilise Li-ion technologies (generations 3 and 4). Battery materials represent 50–70% of the cost, including the anode, cathode, electrolyte, and separator. These advanced chemistries are crucial for developing better-performing, safer, more cost-efficient, and more sustainable battery cells, thereby enabling the market uptake of battery technology. Most of the battery technologies beyond Li-ion chemistries are still in the prototype or research phase.

In the long term, solid-state batteries are a promising technology for use in high performance applications, such as sports and premium cars. Particularly, solid-state batteries with a Li-metal anode could lead to a significant increase of energy density, once the challenges of scale-up and system integration are solved. However, solid-state batteries are not expected to replace conventional LIB in the mass market in the foreseeable future due to higher expected cost.

In the meantime, developing LIB recycling is a crucial approach to easing the supply and demand matching problem at scale, which remains a key issue, as typically, industries remain too small today, and the processes they use remain too exotic. Moreover, power output remains a concern, and performance advantages require using the elusive metallic lithium anode.

One major aspect that should be considered is the range of mineral costs. If lithium, cobalt, and nickel costs suddenly increase, battery costs will be severely impacted. Thus, it is essential that suppliers collaborate closely with downstream customers and develop innovative processes to mitigate the effects of tight commodity supply [4].

An alternative path are sodium-ion batteries (SIB). With sodium being more abundant than lithium and hard carbon anodes instead of graphite, they could contribute to a diversification on the raw material side. However, the offered energy density is lower than for LFP. Whereas layered-oxide-based SIBs (NFM) could reach the lower end of LFP energy density in the future, the more cost-efficient olivine-based SIBs (NFPP) have a significantly lower energy density, making them applicable for stationary rather than for automotive application.

Besides the concerns for the material development for LIBs, the cell structure of battery cells, especially of prismatic cells, has a significant impact on EV performance. However, prismatic cells require high-end passive BTMSs (battery thermal management systems) because of their thermal instability. In the future, new cell structures that permit a cell to pack design (eliminating EV modules) could significantly reduce the complexities and material in battery pack designs [5].

Solid State Batteries

EV batteries on today's market are dominated by anodes of silicon, graphite, and their combinations with the conventional liquid electrolyte. There is a need for the lithium industry to build the capacity to address this need within the next 10 years before solid-state batteries reach commercialisation, as these batteries achieve higher capacities than incumbent Li-ion batteries only if they use metallic lithium anodes.

Most likely, the next generation of batteries will be solid-state batteries (SSBs) to challenge incumbent Li-ion technology, as the conventional LIB has reached a development bottleneck. Solid electrolytes are promising candidates for improving safety and enabling high energy density in Li-metal anode systems. Since 2013, patent publications for solid-state batteries have been steadily increasing. While the United States and Japan have long been leaders in driving innovation in this area, China has emerged as a significant player in recent years, accounting for more than 30% of patent filings in the space.

Based on numerous chemistry approaches, polymer electrolytes represent the most promising technology, while ceramic and composite electrolytes will require more time to develop. Early adoption of solid-state electrolytes is motivated by greater safety needs and potentially lower production costs. Early manufacturability will help determine which technology reaches the market first, but in the long run, a diversity of solid-state electrolyte materials is expected. On short term, semi-solid-state batteries are expected to enter the market and compete with conventional NMC-based LIBs in a comparable performance scale but potential benefits in system integration.

Assessing Technical Readiness of New Cell Chemistries

Technology Readiness Levels (TRLs) are a nine-point scale for describing the maturity of a technology, ranging from discovery (TRL 1) to proven operation in the intended environment (TRL 9). The European Commission adopted NASA's TRL model; Horizon guidance defines the levels as: TRL 1 basic principles observed; TRL 2 concept formulated; TRL 3 experimental proof of concept; TRL 4 validated in lab; TRL 5 validated in relevant environment; TRL 6 demonstrated in relevant environment; TRL 7 system prototype in operational environment; TRL 8 system complete and qualified; TRL 9 actual system proven in operational environment.

In **Horizon Europe**, TRLs are used in call texts to signal maturity expectations (e.g., many Innovation Actions expect end-of-project TRL 6–8; research actions target lower TRLs). National Contact Point guidance provides practical interpretation tools and stresses that TRL assessment is contextual and sector-specific.

How to read TRLs for components vs. systems:

- A **component** (e.g., a sensor, a cooling plate, a BMS controller, or a battery cell) can progress through TRLs by being validated and then demonstrated in **relevant/operationally representative** environments—sometimes within engineered testbeds or partial subsystems.
- A **system** (e.g., a complete battery pack integrated with BMS, thermal, structural and vehicle interfaces) only attains higher TRLs when the **integrated whole** is demonstrated/qualified in relevant or operational environments, not just because its parts are mature.

Practical implication for proposals: When a call text expects **TRL 7 at project end**, evaluators look for an **integrated system prototype** in an **operational environment** (industrial conditions and timing), not just mature components.

Why the system TRL is not the sum of component TRLs

It is a common misconception that if each component is "TRL 6 or 7," then the assembled system is automatically "TRL 6 or 7." In reality, **system-level TRL must be earned through integration and system-level demonstration**, and several factors make the step non-additive:

a) Integration creates new technical work

When components are combined, **new interfaces** (mechanical, electrical, thermal, software/data) appear that have never been exercised together. These interfaces can introduce instability, timing issues, EMI/EMC interactions, thermal bottlenecks, power integrity problems, and safety interlocks that were invisible in isolated tests. Authoritative guidance explicitly cautions that **having all components at TRL 6 does not automatically demonstrate a TRL 6 system**.

b) Emergent behavior and system hazards

Complex systems exhibit **emergent behavior** that is only visible under system-level stimulus and environment (e.g., fault cascades, timing races, coupled thermal-electrical dynamics). Technology Readiness Assessment (TRA) best-practice guides therefore require **system-level evidence**—not just component maturity—to substantiate a system TRL claim.

c) Environment fidelity matters

TRL definitions hinge on **environment**: lab (TRL 4), relevant (TRL 5–6), operational (TRL 7–9). A component might be tested in a wind-tunnel, thermal chamber, HIL bench, or pilot rig; the **system** must be shown in a **representative operational setting** with real interfaces, real duty cycles, and realistic operational constraints (time, throughput, regulation, safety). DOE and NASA materials emphasize scaling, fidelity, and commissioning steps that distinguish system TRLs from component TRLs.

d) Qualification, compliance, and lifetime

System TRLs require **qualification** (e.g., homologation, regulatory safety tests) and often **lifetime and reliability** evidence across design margins. These cannot be derived by summing component test reports; they require **system-level R&I campaigns** (e.g., thermal propagation tests at pack level, vehicle crash/safety validation).

e) Illustrative cross-industry examples

- **Aerospace optical instrument**: A new detector can reach TRL 6 as a component after environmental testing, but the **instrument** only reaches TRL 6 when the detector is **integrated**, optical/thermal interfaces are aligned, electronics/software are tuned, and the unit is demonstrated under **flight-like** conditions. NASA's system-level TRL examples highlight exactly this nuance.
- **Process/energy plant**: Pumps, analysers, and control skids may be individually TRL 7. A **plant** only reaches TRL 7–8 after integrated pilot/commissioning ("cold" with simulants, then "hot" with real feeds), verifying throughput, operability, and safety interlocks at scale.

Component vs. System TRL

- **Component TRL** indicates how mature a **part** is on its own or within a representative rig/subsystem. At higher levels (e.g., TRL 7), the component is **demonstrated in an operational environment**, which may be within a pilot line, vehicle mule, or field rig—but still focused on that component's intended function.
- **System TRL** indicates how mature the **integrated whole** is (architecture, interfaces, controls, safety). Achieving TRL 6–7 requires **system prototype demonstration** in a **relevant/operational** environment with realistic duty cycles and constraints; TRL 8–9 require **qualification and proven operation**.

Table 1: Comparative TRL table for component level and system level

TRL	Component	System
1–2	Scientific principle and concept for the part (materials, algorithms).	Concept for overall architecture and operating principles.
3	Experimental proof of concept of the part (bench/coin-cell/PCB proto).	Early system modeling; interface concepts; initial HIL/MIL.
4	Part validated in **lab** (alpha prototype meets key specs).	Subsystems planned; initial integration tests of a few elements.
5	Part validated in **relevant** environment (beta prototype with realistic interfaces).	Subsystem integration in relevant environment (e.g., mule rig).
6	Part **demonstrated** in relevant environment (engineering prototype).	**System prototype** demonstrated in relevant environment (high-fidelity rig/vehicle mule/plant section).
7	Part demonstrated in **operational** environment (on-line, in fleet/pilot).	**System prototype** in **operational** environment (industrial timing and constraints).
8	Part meets production/qualification requirements.	System complete and **qualified** (e.g., regulatory/homologation passed).
9	Part proven in commercial operation.	Actual system **proven** in operational environment.

TRL 1–9 system use-case examples

(*For each TRL, one **battery system** example. These are illustrative and mapped to the EC definitions.*) [1]

Note: "System" here means an integrated whole (not a single component).

TRL 1 — Basic principles observed

- **Battery system:** Literature research shows how constrained cell swelling affects pack-level safety; early theoretical framework for coupling mechanical preload with electro-thermal behavior. Examples include new materials and combinations for battery cell subcomponents (such as anode, cathode, separator, or electrolyte), with basic electrochemical principles observed, including novel material discoveries.

TRL 2 — Technology concept formulated

- **Battery system:** Concept for a pack architecture with distributed pressure sensing and adaptive thermal control; analytical models drafted. Detailed material compositions for battery cell subcomponents have been defined, with calculations and simulations verifying the theoretical concepts. A concept has been formulated for new battery chemistry or architecture.

TRL 3 — Experimental proof of concept

- **Battery system:** HIL/MIL setup shows feasibility of BMS logic for swelling-aware derating; simplified pack mock-up validates concept. Experiments have been conducted with small-scale cells (such as single- and multilayer cells), and performance indicators have been identified and validated through laboratory experiments and simulations.

TRL 4 — Technology validated in lab

- **Battery system:** Integrated sub-pack rig (cells + sensors + BMS + cooling emulator) meets core control and safety KPIs in the lab. Full prototype battery cells have been built and tested in laboratory and test-bench environments, with key characteristics such as charge and discharge performance, safety, and cycle life being validated.

TRL 5 — Technology validated in relevant environment

- **Battery system:** Pack subsystem validated in **relevant** environment (thermal/vibration duty cycles, automotive connectors, HVIL); interfaces to vehicle HIL exercised. Component testing and validation have been successfully completed, with a statistically significant number of battery

cells tested under real-world conditions. Cells in automotive formats (>10Ah) have been validated according to partial specifications for performance, safety, and cycle life.

TRL 6 — Technology demonstrated in relevant environment

- **Battery system:** Full pack prototype demonstrated in a **relevant** vehicle environment (mule car/dyno), showing thermal propagation robustness and functional safety responses. Battery cells with verified lifetime characteristics have been integrated into high-voltage battery storage and fitted with battery management systems, meeting all key requirements. Cells in automotive target formats have been validated for performance, safety, and service life, with initial demonstration of system integration into battery modules or packs, including BMS and thermal systems.

TRL 7 — System prototype in operational environment

- **Battery system:** Fleet of prototype vehicles operates in real duty cycles (public roads, fast-charge networks); field telemetry confirms KPIs; operational processes (diagnostics, service) exercised. Cell materials, formats, and characteristics for battery cells have been established, with production on pilot lines and successful validation in prototype vehicles. Cells in the target format and design are being validated according to full automotive requirements, with system prototypes tested in operational environments to confirm reliability and performance under real-world conditions.

TRL 8 — System complete and qualified

- **Battery system:** Final pack design passes **homologation/qualification** (e.g., thermal propagation, crash, EMC); SOP documentation frozen. Manufacturing and characteristics of battery cells are proven ready for series production, with cells in first series vehicles and the start of production ramp-up. Cells meet full automotive requirements, systems are qualified to automotive standards, and manufacturing processes are validated.

TRL 9 — Actual system proven in operational environment

- **Battery system:** Mass-produced vehicles in customer use demonstrate reliability, safety, and warranty metrics over the intended lifetime. Series production of battery cells is running smoothly, all ramp-up obstacles have been eliminated, and battery cells are verified and validated. The battery system is in mass production, deployed in vehicles, and has demonstrated proven performance and durability in customer use.

Table 2. Battery requirements for future Battery Electric Vehicle (BEV) applications serve as a set of targets to achieve and go beyond, taking into account the goal of an optimized cost-performance ratio for each vehicle segment.

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*		*LFP, LMFP, NMC, NCA, SSSB*		
Specific energy	Wh/kg	@1/3C charge and discharge at 25°C (charging with CC and CV step)	~180 to 260	250 to 450	250 to 450	250 to 450	450
Energy density	Wh/l	@1/3C charge and discharge at 25°C (charging with CC and CV step)	~300 to 600	400 to 900	400 to 900	650 to 900	600-750
Charging rate	C (1/h)	SOC 10%-80%, 25°C	3	3.5 to 6	3.5 to 6	3.5 to 6	2
Charging time	km/min	SOC 10%-80%, 25°C	~ 10	~ 20	~ 20	~ 20	
Self discharge	%	DOD 0%-90%, 25°C, 30 days	1	1	1	1	1
Cycle lifetime WLTP for cars Cycle lifetime for truck / bus	Energy flow (MWh)	25°C, DOD90%, SOH 100%-80%	~20	22 to 24	22 to 24	22 to 24	N/A
Hazard level	EUCAR safety levels		<= 4	<= 4	<= 4	<= 4	<= 4
Cost	€/kWh		130	50 to 70	50 to 70	50 to 70	50
BEV - Parameter at PACK level	**Unit**	**Condition**	**State of the art 2023 (approximated average values)**	**Target 2030-2035 Mass Market PC low range ~300km**	**Target 2030-2035 Mass Market PC mid range ~300-600km**	**Target 2030-2035 Mass Market PC high range >600km**	**Target 2030-2035 Mass Market CV HDV**
Cell volume per battery pack	%	Battery E/E excluded	40 to 90	40 to 90	40 to 90	40 to 90	
Cell weight per battery pack	%	Battery E/E excluded	60 to 80	60 to 85	60 to 85	60 to 85	
Lifetime expectation	km	DOD 90%	150,000	150,000	150,000	150,000	2,500,000

Parameters and Conditions

The list of parameters presented in the tables covers typical characteristics at the cell and pack levels that are considered in the automotive industry for evaluating technologies. Each parameter is accompanied by the condition under which the values should be achieved. It should be clear that all parameters need to be achieved at the same time. The targets are understood to provide a perspective for future research needs and invite researchers to go beyond this set of targets, and not to limit them.

These conditions are carried over from the existing battery datasheet created by cell manufacturers and commonly accepted by OEMs. Any deviation from standard conditions for future cell chemistries and technology can be accepted if the improvements are substantial and an automotive application is possible. However, the overall efficiency of the system should be considered while evaluating such technologies.

On a cell level basis, many material combinations appear promising when calculating and measuring first cell characteristics. Nevertheless, upon detailed consideration, many additional components are required to keep the system running that are not mentioned in detail, but are necessary.

For example, Solid State batteries that require additional system-level support components, such as heating or pressure pads, still need to be better on a system level than today's lithium-ion batteries. A comparison at the cell level alone is not sufficient to improve battery pack performance.

Also, for the so-called "lithium-air" batteries, it is often not mentioned that pure oxygen is required instead of a typical air mixture, and that, in some cases, a special oxygen tank must be carried to store oxygen in the system reversibly. These additional "features" reduce the potential of some technologies, but clearly need to be stated by the researchers if they are needed.

Similar deviation from targets and conditions can also be acceptable if overall improvement can be proven for specific applications. For example, certain cell technologies may not be suitable for passenger cars but can be shown to be beneficial when the total cost of ownership for commercial vehicles is considered. In such cases, certain parameters may not reach the challenging target, but improvements in other parameters provide a definite benefit for a specific application. In the case of the LTO cell chemistry, it has lower energy density compared to Li-ion NMC but offers very high cycle life and power capability. These characteristic makes it a viable candidate for certain commercial vehicle applications today.

EUCAR Research Recommendations

Advancing battery technologies and battery management systems for large-scale adoption of sustainable mobility solutions to enhance user experience and meet customer expectations. The aim is to improve the performance of battery-electric vehicles concerning range, durability, and affordability, while addressing sustainability through innovation in battery technologies and management systems for current and future cell chemistries.

Analysing of customer expectations and real-world user behaviour for battery development. Exploring different technologies (e.g. Li-Ion, L(M)FP, Na-Ion, solid-state), increasing overall performance of BEV while considering industrial feasibility (large-scale production). Assessing (integrate in battery development) the circular economy approach (design for sustainability), including recycling and second use. Improving battery safety and providing guidelines for first responders and management at the end-of-life: access, handling and transport of batteries. Innovating to replace hazardous materials and to substitute critical materials.

To address these challenges the EUCAR Battery Technology Experts present research priorities:

Advanced performance cell chemistries and materials

- Solid-state technologies with Li-metal anodes and/or anode-free chemistry
- Scale-up feasibility demonstration for all-solid-state chemistries
- Quasi-/semi-solid-state technologies as drop-in solutions in the existing process chain
- Prelithiation and Si-anodes as supplementation for higher performance in liquid-based chemistries
- Solid-state technologies with LFP/LMFP cathode with focus on lifetime and cost/performance ratio
- Advanced GEN3 cell chemistry with positive impact on application level or scaling.

Cost optimised cell chemistries and materials

- Sodium-ion batteries achieving performance parameters enabling to compete with state-of-the-art LFP, while maintaining a cost benefit
- LMR, LMNO, LMFP and further blends and chemistries - focus on extending lifetime (e.g. through high-voltage-stable electrolyte for LMR/LMNO) or improving charging rates, while maintaining a cost benefit compared to state-of-the-art LFP
- State-of-the-Art based chemistries (e.g. NMC) with improved performance or cost benefit to ensure best cost at application level.

Manufacturing processes and scale-up

- Integration of new cell chemistry in existing process technologies
- Drycoating, laser-drying, small dry-chambers and further process innovations to increase cost competitiveness and scaling
- Flexible production lines to produce more than one cell chemistry (and cell type)

System integration and vehicle application

- Impact of cell chemistries on system integration on battery pack or vehicle level to ensure maximum safeguarding of advantages cell properties to application level and enable best performing applications
    - Demonstration of benefits of advanced chemistries on system level, e.g. solid-state cells, blends, etc.

  - Demonstration of benefits of state-of-the-art and cost optimised chemistries e.g. improved thermal safety, or integration benefits
- New system integration concepts to enable best performance at application level

Resilience and supply chain security

- Innovations in Equipment Manufacturing for cell production and scaling
- Local European value chains for LFP and other cost performing chemistries
- Local European value chains for artificial graphite and/or is substitutes as anode material
- Local European CAM production

Charging infrastructure and the energy ecosystem integration

Charging solutions for a seamless and positive user experience: smooth and effortless user experience, regarding availability, affordability and convenience of charging; better integrate vehicles into the grid, enabling quick and smart bi-directional charging.

- Charging infrastructure for next-level quick charging (5-10 min from 10% to 80% SOC)
- Automation of charging process, automated parking, and system enabling for high-performance charging
- Innovations in comfort charging environment
- Optimization of battery lifetime in V2G application through operating strategy
- Innovations for customer acceptance to increase uptake of e-Mobility
- Merge of infrastructure and vehicles to benefit both, transition of energy and mobility
- AC-Bidirectional Charging
- Affordable DC-bidirectional charging equipment
- Evidence based contribution to regulatory consolidation

Recycling and circular economy

- Direct recycling for production scrap and close to production scrap
- Recycling technologies/strategies for LFP and other chemistries with a lower BOM value
- Energy- and cost-efficient recycling processes
- Recycling processes that ensure a high recycling efficiency while processing high troughput

Digitalisation and AI

- Accurate and efficient prediction of battery state through AI-supported modelling
- AI for in BMS, development acceleration, system development
- AI to improve quality in production
- AI to enable scaling in production processes

ANNEX 1 - Detailed Description of Parameters

Specific energy and energy density

Definition: The energy storage capacity of a cell or a complete battery pack system is characterised by the parameters specific energy (Wh/kg) and energy density (Wh/l), and is therefore[1] directly influencing the achievable driving range. The former is calculated by the product of specific charge density (Ah/kg) and cell voltage (V) and defines the stored energy content per mass of the cell. The energy density defines the stored energy content per volume of the cell and is calculated by the product of charge density (Ah/l) and cell voltage.

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*		*LFP, LMFP, NMC, NCA, SSSB*		
Specific energy	Wh/kg	@1/3C charge and discharge at 25°C (charging with CC and CV step)	~180 to 260	250 to 450	250 to 450	250 to 450	450
Energy density	Wh/l	@1/3C charge and discharge at 25°C (charging with CC and CV step)	~300 to 600	400 to 900	400 to 900	650 to 900	600-750

Unit: The unit of this parameter is Wh/kg and Wh/l, respectively.

Condition: To measure the capacity as representative as possible, but at a maintainable condition, a typical C-rate of 1/3C has been established. CCCV is the standard charging protocol for lithium-ion batteries[2]. This means that the cell is being charged with a constant current step with a corresponding C-rate of 1/3 until the upper charging voltage is reached, followed by a constant voltage phase at the upper charging voltage until the current drops below a certain threshold value. The cell is charged and discharged between the lower and upper cell voltages. Typical measurement temperature is room temperature, defined as 25°C.

Relevance: The higher the cell-specific energy, the lower the total weight of the complete battery pack, and thereby the lower the electric consumption upon driving. Installation volume in electric cars is typically much more limited, so more attention is spent on the energy density. As a rule of thumb, the higher the cell energy density, the more compact a battery pack can be designed. The total energy density at the pack level is dependent on many additional factors, such as thermal management and pressure units. An energy density benefit on the cell level can quickly be neutralised by special requirements on the system level that may take a lot of weight and space.

The defined target values are based on one of the most promising and potential cell technologies that may emerge in future lithium battery systems. This estimation comes from the all-solid-state technology where solid ion conductors replace the liquid electrolytes and opens potential to apply a metallic lithium anode with significantly increased energy compared to today's graphite-based anodes. New developments in different cell chemistries can offer improved performance and show potential even beyond solid-state cells. This would be considered in the subsequent version updates of this document as well as when such a situation arises.

[1] *Kompendium: Li-Ionen-Batterien im BMWi Förderprogramm IKT für Elektromobilität II: Smart Car – Smart Grid – Smart Traffic Grundlagen, Bewertungskriterien, Gesetze und Normen.*

[2] Moderne Akkumulatoren richtig einsetzen, A. Jossen or Lithium-Ion Batteries: State of the Art and Application Potential in Hybrid-, Plug-In Hybrid- and Electric Vehicles B. Ketterer, U. Karl, D. Möst, S. Ulrich.

Lithium-Ion batteries [3] can be divided into energy-optimised batteries with high capacities, lower power densities, and moderate discharge currents, and power-optimised batteries with lower energy densities, high power densities, and temporary very high discharge currents. Former are especially important for BEVs, because the driving range is dependent on the installed energy. In contrast, for PHEVs, the requirements for power density and, therefore, for high currents are much higher. This is especially valid during electric take-off and acceleration, where peak power is demanded from the electric drive train and vice versa during braking and recuperation of energy.

For further clarification, please see ANNEX 2 at the end of this document.

Specific power and power density

Definition: Two important parameters that cover most situations during e-driving have been established as continuous and peak power density. Continuous power density is a measure that should represent a continuous driving situation of an electric vehicle, whereas peak power density should be representative of acceleration or braking procedures. Both values are related to either weight or volume (like for the energy density). The main difference between continuous and peak power can be found in the duration of the power requirement and the required power output.

Unit: The unit of this parameter is W/kg and W/L, respectively.

Condition: As a representative value for continuous driving, the power capability for 180s at +25°C has been established. The value should be valid for SOC=100% to SOC=10% to ensure mobility over the entire state of charge range of a battery. For fast acceleration or recuperation, peak power values with shorter duration are more relevant. Typically, peak power is defined as 10s at an average SOC, e.g. SOC=50%. As for the energy density, continuous and peak power values are related to the cell's weight and volume, respectively. Therefore, the relevant unit for power values is W/kg or W/l.

Since electrified passenger cars have to operate as well at low temperatures, the value at -25°C is as interesting as for room temperature. Overall vehicle performance at the required operating temperature range and SOC range is specific to the application, and individual parameters are set accordingly by OEMs.

Heavy-duty vehicles (HDV) such as buses and trucks typically have lower acceleration and retardation rates compared to passenger cars. Hence, the condition for peak discharge power, corresponding to typical vehicle acceleration to normal traffic velocity (50-80 km/h), is 60s. However, the operating conditions with respect to ambient temperature and cold-start requirements are too diverse to form a strict condition for low-temperature performance.

Relevance: The values in the table for passenger cars are split in values for mid-range cars (~400km driving range) and high-range cars (~600km driving range). Assuming an electric consumption of 15kWh/100 km, the battery packs of mid-range cars will have ~60kWh, and for long-range cars ~100kWh. Corresponding to the installed energy, electric machines for these cars will deliver power between 125kW and 300kW. Therefore, the highest average C-rate of ~2,2 can be derived for continuous driving and thus the continuous power output of the cell should be around 1000 W/kg (450 * 2,2). For peak power requirements, which would represent a very fast acceleration or braking, a maximum C-rate of 4C is defined to cover most automotive use cases. As mentioned before, a BEV has to work at low temperatures,

[3] Kompendium: Li-Ionen-Batterien im BMWi Förderprogramm IKT für Elektromobilität II: Smart Car – Smart Grid – Smart Traffic Grundlagen, Bewertungskriterien, Gesetze und Normen (if source is necessary)

which means that a certain basic mobility needs to be ensured. This basic mobility would encompass the ability to start the car and drive at an average speed, provided the cell has been heated to more favourable working conditions. For these low temperature requirements, the value was set to 1/3 of the value at 25°C. It is assumed that the low temperature condition is only on an interim basis, since batteries heat up very quickly due to large inner resistances.

Similarly, a BEV HDV typically require peak discharge rates of 150-300kW depending on type and total weight. With battery sizes ranging from less than 100 kWh (opportunity charged) to more than 300 kWh (depot-charged), the peak discharge power may range from ca 1C-rate to 3C-rate.

Charging Rate

Definition: Charging rate is the continuous C-rate capability permissible in charging mode. Charging rate of a cell = Max. Charging continuous Current (A) / Nominal Cell Capacity (Ah)

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*		*LFP, LMFP, NMC, NCA, SSSB*		
Charging rate	C (1/h)	SOC 10%-80%, 25°C	3	3.5 to 6	3.5 to 6	3.5 to 6	2
Charging time	km/min	SOC 10%-80%, 25°C	~ 10	~ 20	~ 20	~ 20	

Unit: The unit of this parameter is (1/h)

Condition: Continuous charging rate can begin with an empty cell (0% SoC) and end when the upper cell voltage limit is reached (typically around 80% SoC at max continuous C-rate) at +25 °C

Relevance: The higher the charging rate, the higher the fast charging capability of the cell. This value is critical in reducing the charging time of BEVs and promoting long-distance drivability. For commercial HDVs, the required charge rate is directly related to the length of typical available charging opportunities such as lunch breaks, loading/unloading stops and working shift changes. It is clear that fast charging will affect the lifetime of a battery and needs to be considered when designing new cell technologies.

For example, if a 50 Ah cell can be continuously charged with a maximum current of 200 amperes, this cell has a charging rate of 200/50 = 4C

Clarification: The C-rate represents the rate at which level the battery is providing energy. It is a measure of the rate at which a battery is charged or discharged relative to its capacity. It is the charge or discharge current in Ampere divided by the cell capacity in Ampere-hours. The higher power with a higher discharge rate (C-rate). 1C means that the battery is fully charged and discharged within one hour, 2C is 30 minutes, and so on 10C=6mins, 100C=6 seconds. If we plot charge/discharge rates in Ampere versus battery capacity in Ampere-hours, we get straight lines for a given C-rate:

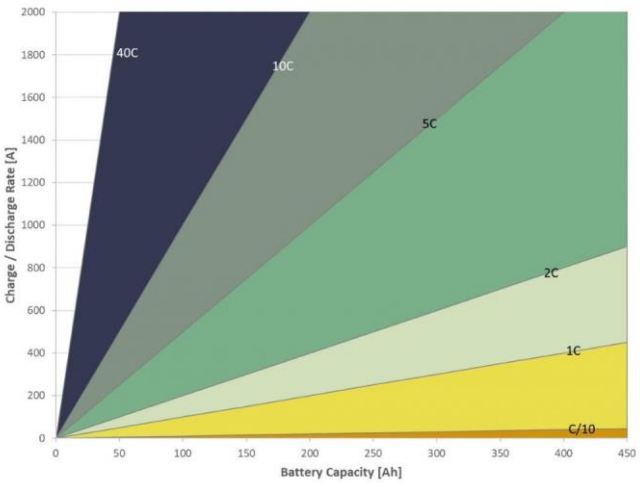

Fig. 3: Charge/discharge rates in Ampere versus battery capacity in Ampere-hours (Source https://www.batterydesign.net/electrical/c-rate/)

A battery electric vehicle would have a peak (10s) discharge rate up to around 5C, the charge rate would be around 2C (hence it would fast charge in 30 minutes). For comparison, a mobile phone, on the other hand, would have a discharge rate of around C/10, meaning it would last around 10 hours if it were being used.

Note: The reason why the battery charging time is expressed up to 80 % instead of 100 % is because the internal resistance of a battery rises as the state of charge increases. In other words, the more the battery is charged, the slower and less efficient it is to keep charging it. As a result, charging is quickest when the battery is empty. After an initial burst, the charger settles into a constant rate until the battery reaches about 80 per cent full. After that, the charging slows again – partly due to the decreased efficiency and to prevent the battery from being damaged by overheating or overcharging. The time it takes to charge between 80 and 100 per cent can vary based on a number of factors, such as battery heat. This is why it is possible to calculate how quickly the battery will reach 80 per cent, but not possible to provide a definitive time for a full charge.

Self-Discharge

Definition: Self-discharge is the reversible loss in capacity of a cell over time without any external electrical load.
Self-Discharge = Cell capacity loss over time (Ah) / Nominal capacity of the cell (Ah) *100

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*	*LFP, LMFP, NMC, NCA, SSSB*			
Self discharge	%	DOD 0%-90%, 25°C, 30 days	1	1	1	1	1

Unit: The unit of this parameter is (%)

Condition: Cell capacity loss measured after 30 days on a fully charged cell (SoC 100%) at +25 °C

Relevance: High self-discharge during vehicle parking, shipping or battery storage will reduce range and performance, and may, in severe cases, cause irreversible loss to cells. Cells and battery packs are typically shipped at partial SOC lower than 30% and may be stored for up to a year. Hence, the self-discharge must be low enough to avoid too low SOC (10%) and thus enable standard commissioning after storage.

Cycle Lifetime

Definition: Cycle lifetime is the amount of energy (Wh) throughput a cell can undergo through charging and discharging until its end of life (<= 80% SoH)
Cycle lifetime = Sum of energy over charge and discharge (Wh) until end of life of the cell.

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*		*LFP, LMFP, NMC, NCA, SSSB*		
Cycle lifetime WLTP for cars Cycle lifetime for truck / bus	Energy flow (MWh)	25°C, DOD90%, SOH 100%-80%	~20	22 to 24	22 to 24	22 to 24	N/A

Unit: The unit of this parameter is (Wh)
Condition: Cell is charged and discharged (typically between 5%SOC and 95%SOC, or as recommended by cell manufacturer) at +25 °C until 80% SOH (or as defined by each OEM)

Relevance: The higher the cycle lifetime, the higher the service life under operation. Long cycle life is directly proportional to the number of driven kilometres.

Whereas the average annual driving distance for passenger cars is 10 000 to 15 000 km, commercial HDVs are typically driven 50 000 to 150 000 km / year depending on type. Consequently, the cycle life requirement is typically five to ten times higher than for passenger cars.

Fast charging at high power has a detrimental effect on Li-ion battery cycle life as well as insufficient thermal management at extreme temperature operations.

Hazard Level

Definition: Hazard level of cells is the outcome of safety tests performed on the cells, and the outcome is classified under the commonly known EUCAR Hazard level table[4].

Hazard Level	Description	Classification Criteria & Effect
0	No effect	No effect. No loss of functionality.
1	Passive protection activated	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect/Damage	No leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell irreversibly damaged. Repair needed.
3	Leakage Δ mass < 50%	No venting, fire, or flame*; no rupture; no explosion. Weight loss <50% of electrolyte weight (electrolyte = solvent + salt).
4	Venting Δ mass ≥ 50%	No fire or flame*; no rupture; no explosion. Weight loss ≥50% of electrolyte weight (electrolyte = solvent + salt).
5	Fire or Flame	No rupture; no explosion (*i.e.*, no flying parts).
6	Rupture	No explosion, but flying parts of the active mass.
7	Explosion	Explosion (*i.e.*, disintegration of the cell).

Fig. 4: Various hazard levels defined by EUCAR members for the use of a cell level safety performance in EV

[4] https://www.rechargebatteries.org/wp-content/uploads/2013/07/Li-ion-safety-July-9-2013-Recharge-.pdf

BEV - Parameter at CELL level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell chemistry			*LFP, NMC, NCA*		*LFP, LMFP, NMC, NCA, SSSB*		
Hazard level	EUCAR safety levels		<= 4	<= 4	<= 4	<= 4	<= 4

Condition: Series of tests conducted according to regional standards such as SAE, GB/T, etc. Details of the testing conditions can be found in the appropriate documentation

Cost

According to the International Energy Agency[5], battery pack prices fell in all markets, but the extent of the drop varied significantly, with the fastest declines seen in China, where prices fell nearly 30% in 2024, compared to 10-15% in Europe and the United States. This widened the gap between battery prices in China and the rest of the world, increasing the competitive advantage of Chinese EV and battery producers. The faster pace of battery cost reduction and innovation in China has been enabled by fierce competition that has driven down profit margins for most producers (though not all), at the same time as driving up manufacturing efficiency and yields, as well as access to a large skilled workforce, and battery supply chain integration.

Battery chemistry also plays an important role, with lithium iron phosphate (LFP) batteries – the main battery chemistry used in China – being almost 30% cheaper per kilowatt-hour (kWh) than lithium nickel cobalt manganese oxide (NMC) batteries, which remain the most widely used batteries in the United States and Europe. NMC batteries still provide an energy density advantage, though the gap has narrowed in recent years. The energy density of LFP battery packs is about one-fifth lower by mass (Wh/kg) and about one-third lower by volume (Wh/L) than that of NMC packs. This is, however, partially offset by LFP's ability to reach 100% state of charge when required without significant degradation, whereas NMC batteries are typically limited to 80% to preserve long-term performance.

The higher energy density of NMC batteries remains an advantage for applications requiring longer ranges or operation in cold climates, where LFP technology is typically less effective. However, LFP batteries have now reached a performance level sufficient for most EV applications, making their lower cost a key advantage for automakers aiming to mass market

[5] IEA (2025), Global EV Outlook 2025, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2025, Licence: CC BY 4.0

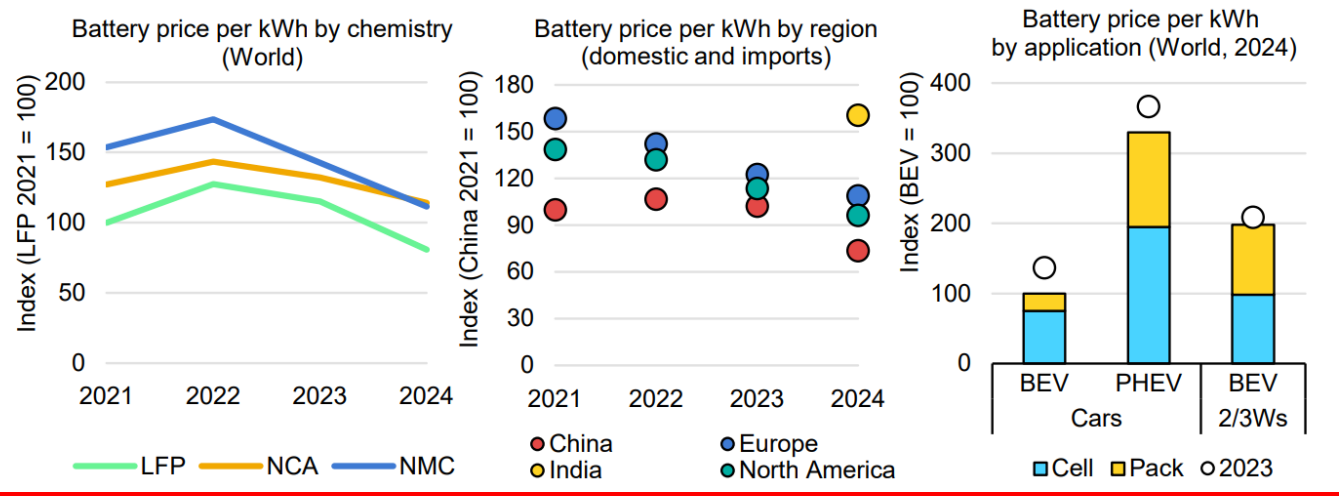

Fig. 5: Average battery pack price per watt-hour index by selected battery chemistry, region and mode, 2021-2024 (Source: IEA (2025), Global EV Outlook 2025, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2025, Licence: CC BY 4.0)

Definition: Cell costs are commonly described in $ or € per kWh (energy content) for BEV applications. The cell costs in $/kWh may be higher for cells used in high-power applications due to their lower energy content.

Cost per cell = Total cost per cell ($) / Cell energy content (kWh)

Unit: Cost is typically used as $/kWh (or €/kWh)
Condition: Cell energy content is estimated by considering the energy discharged from the cell at 100% SoC to 0% SoC at 25 °C at 1/3 C-rate

Relevance: The Cost of cells in a BEV is the most significant part of the overall vehicle costs. This indicator is important to understand the commercial viability of new cell technologies. However, in certain heavy-duty applications, the total cost of ownership may be more relevant than simply considering only the cell costs.

Cell Volume per battery pack volume

Definition: A battery pack is considered a closed hard case housing containing multiple cells connected in series and/or parallel, along with all the necessary connections and electronic components needed to manage the battery system. The packing ratio determines the total cell volume compared to the overall pack volume. Cell volume x number of cells / outer volume of battery pack x100

Unit: The unit of this parameter is (%)

BEV - Parameter at PACK level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell volume per battery pack	%	Battery E/E excluded	40 to 90	40 to 90	40 to 90	40 to 90	
Cell weight per battery pack	%	Battery E/E excluded	60 to 80	60 to 85	60 to 85	60 to 85	

BEV - Parameter at PACK level	Unit	Condition	State of the art 2023 (approximated average values)				
Cell volume per battery pack	%	Battery E/E excluded	40 to 90	40 to 90	40 to 90	40 to 90	

Condition: No specific conditions

Relevance: The higher the cell volume per battery pack volume, the higher the energy density of the battery system. Given the limited space in vehicles, this indicator is particularly relevant for increasing driving range. Innovations in battery construction and integration in vehicles can improve this value.

Cell Weight per battery pack weight

Definition: This weight ratio shows the proportion of the cell weight in comparison to the complete battery pack weight, including all the connections and the components, as well as the pack housing structure. Cell weight x number of cells / total weight of battery pack x100

Unit: The unit of this parameter is (%)

BEV - Parameter at PACK level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Cell volume per battery pack	%	Battery E/E excluded	40 to 90	40 to 90	40 to 90	40 to 90	
Cell weight per battery pack	%	Battery E/E excluded	60 to 80	60 to 85	60 to 85	60 to 85	

Condition: No specific conditions

Relevance: The higher the cell weight per battery pack weight, the higher the specific energy of the battery system. Additional weight decreases the efficiency of the vehicle and reduces payload. Innovations in lightweight and functional integration can, for example, improve this value.

Lifetime expectation

Definition: The Lifetime expectation of battery packs is the combined lifespan of the battery system in cycle life as well as calendar life.

Unit: The unit of this parameter is (total kilometres driven)

BEV - Parameter at PACK level	Unit	Condition	State of the art 2023 (approximated average values)	Target 2030-2035 Mass Market PC low range ~300km	Target 2030-2035 Mass Market PC mid range ~300-600km	Target 2030-2035 Mass Market PC high range >600km	Target 2030-2035 Mass Market CV HDV
Lifetime expectation	km	DOD 90%	150,000	150,000	150,000	150,000	2,500,000

Condition: Dependent on individual OEM

Relevance: Lifetime warranty conditions are defined to provide the expected lifetime of the battery system. This is typically aligned with the vehicle lifetime and can be up to two times higher for heavy-duty applications compared to passenger cars. Additionally, this condition is dependent on the application and environmental conditions.

Battery Pack Cost

Definition: Battery pack costs are commonly described in $ or € per kWh (energy content) for BEV applications. The pack costs in $/kWh may increase for high-power or PHEV applications due to their lower energy content.

Battery cost pack = Total cost of battery pack ($) / Battery pack energy content (kWh)

Unit: Cost is typically used as $/kWh (or €/kWh)

Condition: Total pack energy content is estimated by considering the energy discharged from the pack at 100% SoC to 0% SoC of the battery's operational SOC window (which is defined specifically by each OEM) at +25 °C at 1/3 C-rate

Relevance: This indicator is essential for understanding the reduction in the costs of battery system components. However, in certain heavy-duty applications, the total cost of ownership may be more relevant than simply considering only the battery pack costs.

General:

Moreover, thanks to its flexibility in terms of materials and design, Li-ion technology allows for the construction of batteries within a broad range of power to energy ratio (P/E) which enables their use in the entire range of electrified vehicles, from hybrid (HEV, P/E ~ 15), to plug-in hybrid (PHEV, P/E ~ 8), to fully electric (BEV, P/E ~ 3). 2–13 Fig. 1 shows the typical range of specific power and energy for the different types of electrified vehicles, as well as projected target ranges for the next generations of Li-batteries.

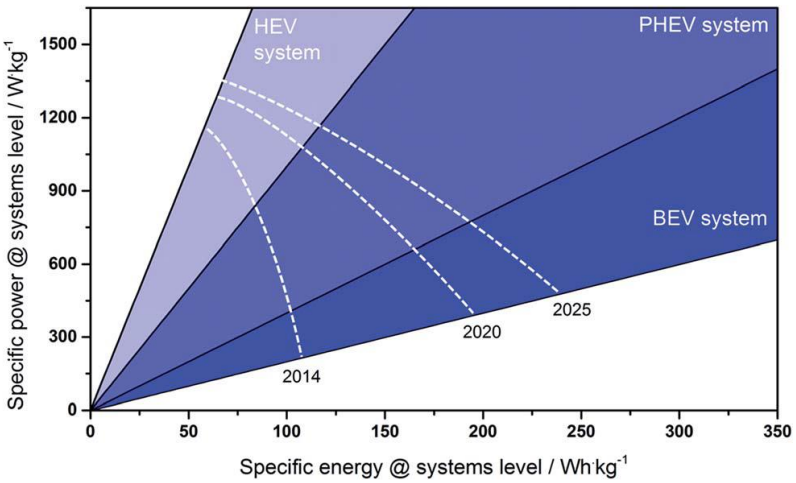

Fig. 5 Specific power and energy roadmap for battery pack for hybrid (HEV), plug-in hybrid (PHEV) and full electric (BEV) vehicles. Source: DOI: 10.1039/c5ta00361j

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[10] Kompendium: Li-Ionen-Batterien im BMWi Förderprogramm IKT für Elektromobilität II: Smart Car – Smart Grid – Smart Traffic Grundlagen, Bewertungskriterien, Gesetze und Normen (if source is necessary)
[11] EUCAR Hazard Levels from https://www.rechargebatteries.org/wp-content/uploads/2013/07/Li-ion-safety-July-9-2013-Recharge-.pdf
[12] IEA (2025), Global EV Outlook 2025, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2025, Licence: CC BY 4.0

ANNEX 2 – Acronyms and basic glossary

Acronym	Meaning
BEV	Battery Electric Vehicle
CCCV	Constant Current Constant Voltage
C-rate	Capacity rate
CV	Commercial Vehicles
DOD	Depth of Discharge
GB/T (standards)	Guobiao (Chinese National Standards)
HDV	Heavy-Duty Vehicle
LTO	Lithium Titanate Oxide
OEM	Original Equipment Manufacturer
PC	Passenger Car
PHEV	Plug-in Hybrid Electric Vehicle
SAE	Society of American Engineers
SI	International System of Units
SoC	State of Charge
SoH	State of Health
V	Voltage
WLTP	Worldwide harmonized Light vehicles Test Procedure

The following list of definitions has been created to explain this document; they indicate the meaning of those physical properties within the boundaries of the EUCAR “Battery requirements for future automotive applications” document.

Current

An electric current is a flow of electric charge. In battery cells this charge is often carried by ions in an electrolyte. The SI unit of electric current is the ampere (A), which is the flow of electric charge across a surface at the rate of one coulomb per second.

Voltage

Voltage is the difference in electric potential between two points. The SI unit of voltage is named volt (V),

Battery capacity

A battery's capacity is the amount of electric charge it can deliver at the rated voltage. The SI measures capacity in amp-hour (Ah).

C-rate

The C-rate is a measure of the rate at which a battery is being charged or discharged. It is defined as the current through the battery divided by the theoretical current draw under which the battery would deliver its nominal rated capacity in one hour. The SI unit for the C-rate is 1/h. C-rate is used as a rating on batteries to indicate the maximum current that a battery can safely deliver on a circuit.

Battery energy

The battery's energy is simply defined by the product of cell capacity in (Ah) * cell average voltage in (V) * the number of cells in a battery pack. The unit of battery energy is typically given in kilowatthours (kWh).

Power

Power is a general measure that is determined by the product of cells actual voltage (V) and the applied current (A). The unit is typically given in kilowatt (kW).

SOC

The state of charge (SOC) is an estimate of the device charge capability expressed as a percentage of the begin of life rated capacity and typically reached by obtaining specified voltages. If 50% of the cells charge carriers haven been discharged from cathode to anode its SOC is 50%.

SOH

SOH is an abbreviation for state of health. It is given in % and determines the battery's health condition which is referred to the actual capacity compared to the initial capacity. If a cell has a capacity of 50Ah after manufacturing and shows a remaining capacity of 40Ah after usage, SOH is calculated by 40Ah/ 50Ah *100 = 80%. 80% is a very important parameter in automotive applications since the end of life of a battery is determined when a cell has lost 20% of its initial capacity.

ANNEX 3 – Rationale for the different calculations in the document

On the energy density

To demonstrate that the given energy target values are plausible and can be realistically achieved, this document provides a basic calculation. Therefore, various assumptions for materials and electrode properties need to be fixed. The most important parameters in cell design are the electrode mixtures, the layer thicknesses corresponding to electrode loading and separator thickness, and the cell format.

For the cathode, a ratio of 80 vol-% of nickel-rich layered oxide, 15 vol-% of solid electrolyte and 5 vol-% of binder and carbon black has been assumed. A porosity of 3 vol-% has been introduced to consider the remaining porosity from the manufacturing process. The cathode loading was set to 5,8mAh/cm², resulting in a layer thickness <75µm when the aforementioned cathode mixture is applied, and thus in the same order of magnitude compared to today's lithium-ion batteries with liquid electrolyte.

The solid separator thickness was set to 15µm. In order to compensate for lithium-ion losses, the anode is over-dimensioned about 10% compared to the cathode and is made from 100 vol-% metallic lithium with 0 vol-% porosity.

The calculation has been done for prismatic cells in PHEV2 and BEV4 formats, and shows specific energies of 450 Wh/kg and 1000 Wh/l with a variation of ~ 5-10% depending on the chosen cell format.

An interesting fact for lithium-ion batteries is that Wh/kg and Wh/l most often show a relation factor of 2,2-2,5, which might be different for non-intercalation based technologies.