# The Dutch Battery Compass

## Battery cell orientational study, benchmarking and roadmap perspectives for the Netherlands

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## Executive summary

The Dutch Battery Compass is a national orientational study designed to position the Netherlands within the rapidly evolving global battery landscape. As the energy transition accelerates, batteries underpin electrification across transport, industry, and infrastructure. This study focuses on the cell level and maps technology and market trajectories between 2025 and 2035, benchmarking global developments against Dutch capabilities to guide policy, investment, and innovation strategy. It combines global benchmarking with a detailed analysis of Dutch industrial and R&D strengths across various industry sectors including passenger, heavy-duty and off-road industrial electric vehicles, 2-3 wheelers, aviation, drones, power tools, consumer electronics, maritime and stationary storage. Using both top-down (market) and bottom-up (technology) assessments, it evaluates key performance indicators such as cost, energy density, cycle life, charge and discharge rates, and power density to identify where Dutch technologies can lead and where action is needed.

The study shows that the competitiveness of several key Dutch industries will increasingly depend on cell-level innovation rather than solely on pack design. As system efficiency approaches its practical limits, future performance gains must come from advances at the cell level. This does not imply that pack engineering and specifications are unimportant, rather, it reflects that most current efforts focus on packs, while cell development remains underrepresented. To respond to this shift, coordinated and timely actions across industry, research, and policy will be required.

The first and most urgent action is to build or co-develop domestic capacity at the cell level. Establishing or partnering for battery cell production capability in high-dependency sectors such as heavy-duty, drones and aviation, where the further energy increase at some point could not be tackled solely by pack design optimization, is crucial for strategic industrial autonomy, resilience and national competitiveness. The continued reliance on non-European suppliers would expose Dutch industry to supply risks and missed value creation opportunities. To make cell production factory viable and ensure sufficient production capacity, collective demand should be established by clustering sectors with similar performance needs, for example off-road industrial and heavy-duty automotive vehicles, and stationary storage. This will create a critical mass of market pull and justify investments in production infrastructure and partnerships with European or international manufacturers. In addition, it would create a clear pathway for Dutch component manufacturers to integrate into large-scale battery production.

The second priority is to extend cycle life and production scale of next-generation components so that Dutch innovations can move beyond small niche markets. Current Dutch high-energy anode technologies already achieve excellent energy densities but lag in durability, limiting their applications to drones and consumer electronics.

Improving cycle life would unlock access first to other markets like 2-3 wheelers and power tools and then to major sectors such as electric vehicles, aviation, and heavy-duty transport. This can be achieved through collaborative innovation aiming for the cycle life increase, for instance, partnering with atomic layer deposition companies to develop advanced coatings or electrolyte producers to ensure better compatibility and stability, tailoring formation cycles to specific material properties, collaborating with battery management system developers and system integrators to optimize charging and discharging profiles to reach the best cycle life performance.

In addition to these key actions, several supporting steps are vital for building a resilient and future-proof ecosystem. Strengthening the manufacturing equipment base for next-generation components and cells in the Netherlands should be a priority to accelerate the transition of high-end technologies from lab to market. While large-scale domestic cell production may take time, Dutch companies can leverage their strengths in precision engineering, automation, and digital twinning to develop and supply critical manufacturing tools for the European battery industry. This effort is particularly important facing China's recent export restrictions on technologies related to advanced battery components, cells, and production equipment (Announcement No. 58 from 9 October 2025 of the Ministry of Commerce and the General Administration of Customs of China). Finally, establishing a system for continuous data and intelligence collection, consolidation and monitoring will be essential. Tracking global KPIs, technology roadmaps, and market shifts every two to three years will help ensure that Dutch strategies remain adaptive, anticipate supply chain risks, and stay aligned with European priorities.

Together, these actions will help the Netherlands evolve from a strong pack-engineering nation into a balanced value chain with minimized autonomy risks and more control points over global value chain. By aligning industrial policy, R&D investment, and cross-sector collaboration, the Dutch ecosystem can strengthen its competitiveness, autonomy, and contribution to Europe's sustainable battery value chain in the decade ahead.

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# Glossary

**ALD** – Atomic layer deposition

**BMS** – Battery management system

**CMP** – Cell–Module–Pack

**CTB** – Cell-to-Body

**CTP** – Cell-to-Pack

**EOL** – end of life

**EMS** – Energy management system

**EV** – Electric vehicle

**eVTOL** – Electric vertical take-off and landing

**GED** – Gravimetric energy density

**Gr** – Graphite

**Gr/SiO$_x$** – Graphite/silicon oxide composite

**HC** – Hard carbon anode (sodium-ion batteries)

**HD** – Heavy-Duty

**HE** – High-energy

**HP** – High-power

**LFMP** – Lithium iron manganese phosphate

**LFP** – Lithium iron phosphate

**LIB** – Conventional lithium-ion battery with liquid electrolyte

**LMO/LMNO** – Lithium manganese oxide / lithium manganese nickel oxide

**LMR** – Lithium manganese-rich material

**LM(N)O** – Lithium manganese (nickel) oxide

**LTO** – Lithium titanium oxide

**NMC(A)** – Lithium nickel manganese cobalt (aluminium) oxides

**N(T)O** – Niobium (titanium) oxide

**NVPF** – Sodium-vanadium fluorophosphates

**OEMs** – Original equipment manufacturers

**PBA** – Prussian blue analogues

**SEI** – Solid electrolyte interphase

**Si/C** – Silicon/carbon composite

**SSB** – (Semi) Solid-state battery with (semi) solid electrolyte

**VED** – Volumetric energy density

## Introduction and motivation

The global battery market is undergoing rapid transformation, driven by increasingly stringent requirements from system integrators and OEMs. Adoption of new technologies is no longer determined solely by technical performance and price but by their ability to meet evolving demands for autonomy, resilience, circularity, and competitiveness on a worldwide scale. These shifts create both opportunities and challenges for national industries.

For the Netherlands, positioning within this landscape requires more than following global trends; it demands a proactive orientation of industrial strengths, innovation capacity, and partnerships against the benchmarks that define competitiveness – a challenge made sharper by the fact that Dutch technologies are still establishing themselves within the global value chain. With batteries at the heart of the energy transition and electrification across transport, industry, and infrastructure, it is essential to understand where Dutch activities can lead, where they risk falling behind, and how to capture value in the global supply chain.

This study was motivated by the need to provide clarity: mapping the technological and market trajectories of battery applications, identifying blind spots, and aligning Dutch national ambitions with realistic pathways to competitiveness. Rather than prescribing milestones, it offers a structured synthesis of where technologies and markets are headed and how the Dutch ecosystem can position itself strategically.

## Scope

The study benchmarks application-specific **Gen 3-5 battery cells** [1] performance requirements against projected technology readiness between 2025 and 2035. Covering more than ten application domains including electric vehicles (EVs), trucks, buses, 2–3 wheelers, heavy-duty off-road vehicles, maritime, aviation, drones, consumer electronics, power tools, and stationary storage (<8 hours), the paper translates global trends into Dutch opportunities and risks.

The outcome of the study is not a prescriptive roadmap but a benchmarking-based orientation. By mapping today's and tomorrow's KPIs against industry needs, and aligning them with Dutch capabilities, the study highlights where interventions are required: from R&D and scale-up to international partnerships.

Its purpose is to inform policymakers, industry players, and research institutions with actionable insights that can guide collective efforts towards sustained competitiveness in the decade ahead.

## Methodology and approach

The study followed an iterative process structured around a V-shape **methodology**, combining alternating “helicopter” and “deep-dive” phases to ensure both breadth and depth of insight. In the “helicopter” phase, broad market studies were carried out to establish an overall view of the global battery landscape, capturing general market conditions, emerging trends, and technology trajectories across different application sectors and technologies. This high-level perspective provided the strategic context needed to frame the subsequent deep-dive work.

In the “deep-dive” phase, the focus shifted from global trends to the specific needs and realities of the Dutch battery cell ecosystem. A series of targeted interviews with Dutch companies, spanning pack builders, component suppliers, technology developers, and end users, as well as several revisions with the technology experts were conducted to validate and refine the findings from the “helicopter” phase. These interviews allowed the study to adapt global insights to national priorities, ensuring that the resulting orientational study was directly relevant to the Netherlands’ industrial capabilities, innovation strengths, and market opportunities. By repeating this cycle of “helicopter” and “deep-dive” phases, the research gradually converged on the Battery Compass, outlining gaps between global developments and the Netherlands’ specific role in the evolving battery value chain.

The study employed an **application-driven top-down and technology bottom-up approach** to ensure both technological feasibility and market relevance (**Figure 1**). The methodology unfolded in five key stages, each of which was covered through implementation of at least one iteration cycle described above:

1. **Evolution of industry needs from 2025 to 2035**

The study collected and benchmarked both current and future KPI targets for the battery pack for the period 2025–2035 across all mentioned application sectors. The key performance indicators included cost, gravimetric and volumetric energy density, charge speed, continuous and peak discharge rates, from which power densities could be derived, and cycle life. In addition to KPIs needs assessment, the ranking of KPIs importance was evaluated to identify the threshold for market entry of new technologies and critical requirements – pain points – for each industry to be addressed at the first place.

2. **From pack needs to cell targets**

Mass and volume utilization efficiency coefficients, along with the proportion of cell cost within the overall pack cost, were assessed to identify trends in pack design and to translate pack-level metrics into corresponding cell-level targets.

3. **Chemistry fit across applications**

The most common Li-ion batteries’ anode–cathode combinations, such as LTO, N(T)O, graphite and Si/C composites, pure Si and Li-metal anodes, and LFP, LFMP, LM(N)O, LMR, NMC(A) cathodes along with sodium-ion and lithium-sulfur batteries were matched to each application according to KPI requirements. These chemistries were selected because they represent either the current industrial standard or the most advanced candidates under active development in global roadmaps, ensuring both relevance and forward-looking perspective. For 2035 the study distinguished between chemistries "forecasted to be commercialized", which explicitly included in company roadmaps, and "technologically feasible", meaning they meet the anticipated performance parameters, but are not yet referenced in industry plans. Chemistries that failed to satisfy KPIs were classified as not applicable.

4. **Dutch capabilities & readiness**

The study evaluated current and forecasted Dutch technology maturity levels over a next decade, indicating both the most crucial KPIs and manufacturing readiness ranging from lab scale to full commercial deployment.

5. **Blind spots**

The study identified potential gaps and blind spots in the Dutch ecosystem and value chain, spanning technology, supply chain, market partnerships, and infrastructure. A gap analysis was carried out to prioritize interventions, including targeted R&D, the development of international partnerships, and initiatives aimed at cell performance enhancement, scaling production and capabilities.

This integrated approach ensured that the Battery Compass is both **technically robust** and **strategically actionable**, enabling policymakers, industry players, and research institutions to focus efforts where they can have the highest impact.

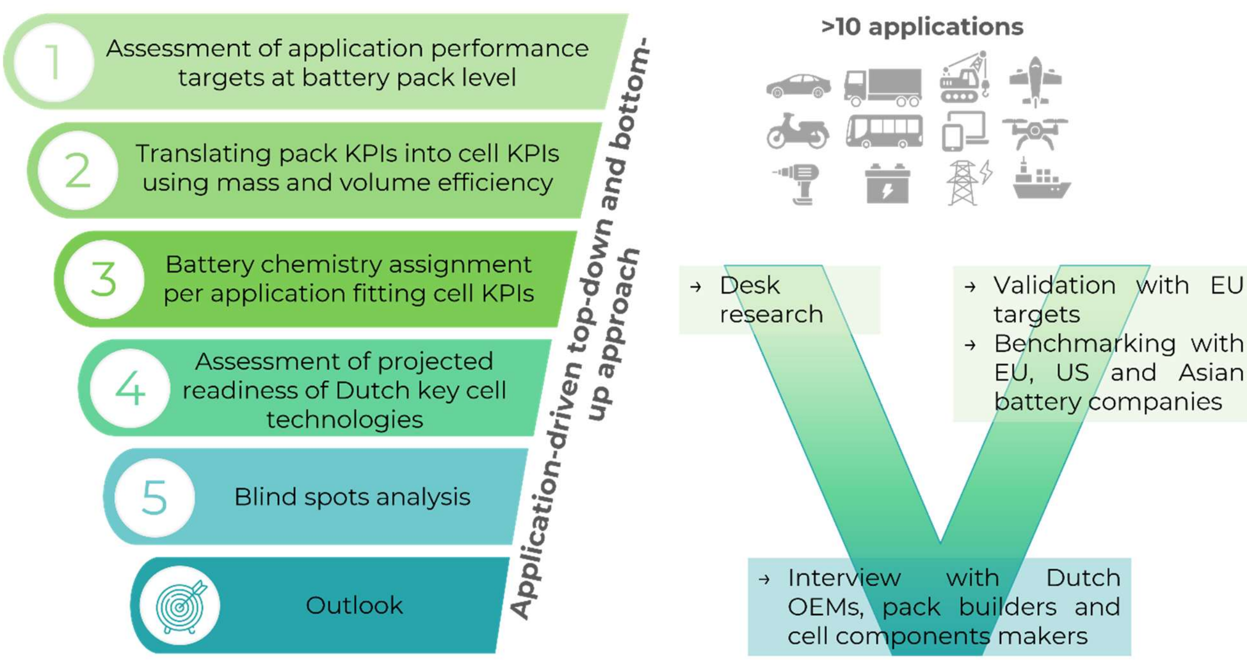



**Figure 1.** Methodology and approach of the Battery Compass

## Evolution of industry needs from 2025 to 2035

The study assessed a set of current (2025) and targeted (2035) key performance indicators across a wide range of applications, including average and premium electric vehicles, eTrucks and eBuses, off-road industrial vehicles (excavators, big forklifts, mobile cranes, diggers, bulldozers), aviation, drones, two–three wheelers, power tools (drills, saws, electric screwdrivers, lawnmowers, etc.), consumer electronics (earbuds, smartphones, smart watches, laptops), maritime high-energy (HE) (fishing vessel, inland container vessel, small tug, fast ferry, yacht, fast crew supplier, cruises, ships) and high-power (HP) (harbour tug, fishing aux, urban ferry, Ro-Ro ferry, waterbus, off-shore-, drilling-, fuel cell vessels) systems, and stationary high-energy (HE) and high-power (HP) storage.

The indicators evaluated included cost, gravimetric and volumetric energy density, charging speed, continuous and peak discharge rates (from which power densities can be derived), and cycle life. The choice of these KPIs was dictated by their direct link to the performance, competitiveness, and adoption of batteries across applications:

- **Cost** is the universal benchmark for market acceptance.
- **Gravimetric and volumetric energy density** capture the fundamental trade-offs between weight, space, and performance.
- **Charging speed** influences usability, convenience, and infrastructure requirements.
- **Continuous and peak discharge rates** reflect operational demands: continuous rates determine autonomous operation time, while peak rates define the ability to handle power-intensive events such as acceleration, lifting, or take-off.
- **Cycle life** governs total cost of ownership, reliability, and sustainability.

Together, these KPIs provide a balanced view that captures both technical feasibility and market relevance. Their selection ensures that the orientational study reflects the real thresholds that determine industrial competitiveness from 2025 to 2035.

Peak power density, an important parameter across many applications, is most often described in terms of C-rates. This convention reflects industry practice and provides a practical way to compare performance across different use cases. Duration of the peak power applied might also vary: the provided values correspond to <60 sec for heavy-duty and off-road industrial vehicles, aviation and drones <180 sec [2], maritime 60-180 sec [3], the rest are ≤ 10 sec [4].

Safety was not included as a KPI in this comparative analysis because Hazard Levels are largely consistent across applications, typically at or below level four, as is the operational temperature range [4]. Although cell-level safety tests are clearly defined, covering electrical, mechanical, thermal, environmental, abuse, and fire tests, safety at the cell level is in practice perceived as binary: passed or not passed the tests. For this reason, safety considerations should be more appropriately assessed at the module or pack level, where thermal management strategies and propagation behavior become decisive.

The KPIs ranges at the pack level for 2025 and 2035 are summarized in **Tables A1** and **A2** and were also plotted in radar charts, where for each axis the average values of the ranges were used (**Figure 2**). The radar charts for 2025 and 2035 show that performance needs for batteries vary widely across different use cases. The shapes of the radar plots differ strongly between applications. For instance, across the larger plot for eTruck & eBus, an increase in the operational requirements is expected from 2025 to 2035 in nearly all dimensions, especially in cost, energy density, and cycle life. The smaller plots reveal that each sector balances these factors differently, indicating that technology development will have to be tailored rather than universal. Each sector demands different specific trade-offs between energy density, cost, charging speed, cycle life, and power capability to meet its operational needs.

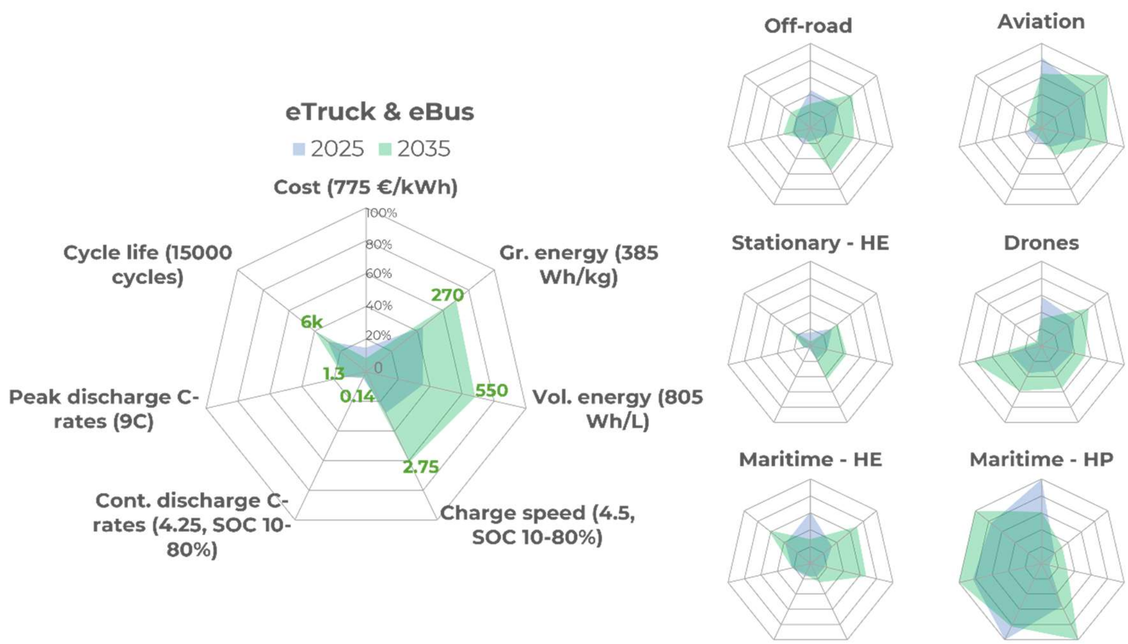



**Figure 2.** Normalized radar charts of the battery pack KPIs for different applications (the KPI were normalized to the maximum values, provided in brackets in the radar chart for eTruck& eBus, to make the comparative analysis of the industries' needs)

To complement KPI assessment, the importance of each metric, varying from the critical "5" to the low "1", was evaluated by measuring the sacrifice that can be made to set the battery packs KPIs threshold. **Figure 3** demonstrates the importance matrix of the assessed KPIs for average product categories and may vary depending on the niche, business model and each company's unique proposition.

| | Cost | Gr. Energy density | Vol. Energy density | Charge C-rate | Cont. discharge C-rate | Peak discharge C-rate | Cycle life |
|---|---|---|---|---|---|---|---|
| Aviation | 3 | 5 | 5 | 4 | 4 | 5 | 3 |
| Drones | 4 | 5 | 4 | 3 | 3 | 5 | 2 |
| Consumer el-s | 4 | 4 | 5 | 4 | 3 | 2 | 3 |
| Power tools | 5 | 4 | 4 | 3 | 3 | 5 | 4 |
| 2-3 wheelers | 5 | 4 | 4 | 3 | 4 | 3 | 4 |
| Average EV | 5 | 4 | 5 | 3 | 4 | 2 | 5 |
| Premium EV | 4 | 5 | 5 | 4 | 4 | 4 | 5 |
| eTruck & eBus | 5 | 4 | 4 | 3 | 3 | 2 | 5 |
| Off-road industrial | 5 | 3 | 4 | 4 | 4 | 4 | 5 |
| Maritime-HE | 4 | 2 | 4 | 2 | 2 | 2 | 5 |
| Maritime-HP | 3 | 2 | 2 | 4 | 3 | 4 | 5 |
| Stationary-HE | 5 | 2 | 3 | 2 | 3 | 1 | 4 |
| Stationary-HP | 3 | 1 | 1 | 3 | 2 | 5 | 5 |

**Acceptable sacrifice in KPIs that could be made:**

| | |
|---|---|
| 5 | <5% – **critical** importance |
| 4 | 5-10% – **high** importance |
| 3 | 10-20% – **medium** importance |
| 2 | 20-30% – **moderate** importance |
| 1 | 30-40% – **low** importance |

**Figure 3.** KPIs importance assessment

A column analysis of the matrix highlights several cross-cutting insights. Cost, gravimetric and volumetric energy density, and cycle life are the dominant drivers in most applications. Cost emerges as a universal constraint, although aviation, drones, consumers electronics, premium EV and high-power applications like maritime-HP, and stationary-HP demonstrate the highest flexibility to pay the highest premium. Gravimetric energy density is widely important, yet in some cases, such as off-road industrial vehicles, a heavier battery is actually beneficial as it contributes to vehicle stability. Maritime and stationary systems also can afford greater flexibility in battery placement, reducing the importance of gravimetric and volumetric performance. Volumetric energy density generally plays a stronger role, mainly due to integration requirements and space constraints within existing designs.

Interestingly, fast-charging capability was not rated as a priority for most applications. This may reflect the limited availability of fast-charging infrastructure, the prevalence of overnight charging practices, or the B2B business models of some interviewed partners – individually or in combination with other factors. Continuous discharge rates, which reflect autonomous operating time, are important but currently satisfactory across most applications. Peak discharge rates, closely tied to power density, remain essential only in applications, where short bursts of power are critical for propulsion, lifting, or take-off, like aviation, drones, power tools, premium EVs, off-road industrial vehicles, maritime and stationary high-power.

Cycle life is a decisive factor for nearly all applications, with the notable exceptions of aviation, drones, power tools, consumer electronics, and two–three wheelers, where replacement cycles are shorter and longer lifetimes less critical. An interesting pattern emerges when correlating cycle life requirements with warranty practices: in less demanding applications, battery warranties tend to be shorter, while in high-demand segments batteries often outperform warranty expectations, creating promising opportunities for second-life use.

The matrix can also be read from a technology-push perspective. In this view, the unique performance characteristics of emerging technologies can be matched to application “pain points” – KPIs with critical and high importance – allowing outlining of targeted market entry strategies. For instance, a technology offering high volumetric energy density and fast charging, but limited cycle life could initially be directed toward consumer electronics, off-road vehicles, or aviation – segments that value its strengths while tolerating its current limitations.

## From pack needs to cell targets

To translate performance targets from the module or pack level into cell-level metrics, it was first necessary to evaluate current and forecasted mass and volume utilization efficiency coefficients. Gravimetric energy density (GED) at the cell level was derived by dividing the corresponding pack value by the mass utilization efficiency coefficient, while volumetric energy density (VED) at the cell level was obtained by dividing the pack value by the volume utilization coefficient, as shown by formulas **(1)** and **(2)** below.

$GED_{cell} = \frac{GED_{pack}}{e_{mass}}$, where $e_{mass}$ – mass utilization efficiency coefficient **(1)**

$VED_{cell} = \frac{VED_{pack}}{e_{volume}}$, where $e_{volume}$ – volume utilization efficiency coefficient **(2)**

Most of the conducted interviews revealed that charge speed, continuous and peak discharge C-rates are often constrained by battery management systems (BMS) and thermal management systems capabilities rather than by cell chemistry, so in this study cell values were assumed to be equivalent to the ones of pack but, in reality, the majority of cell chemistries could be cycled faster. That finding underscores the importance of addressing (dis)charging rates for certain applications that prioritize them within a pack-level innovative solutions development. Cell price, unlike other KPIs, cannot be directly derived from pack-level. Instead, it was estimated separately, drawing on market forecasts and interviews with industry stakeholders. Price remains a highly volatile parameter, making reliable long-term predictions difficult. Nonetheless, the cell-to-pack price ratio offers a more stable and insightful metric, highlighting differences across applications and providing useful perspective on business and market trends. The resulting values at the cell level for 2025 and 2035 are summarized in **Tables A3** and **A4**, respectively.

Mass and volume utilization efficiency coefficients themselves provide important insights into the current state and direction of the battery market. Drones and consumer electronics, for example, exhibit the highest utilization coefficients and, therefore, are heavily dependent on cell-level innovation as improvements in chemistry or cell design translate almost directly into product performance gains and market competitiveness. Electric vehicles show a broader range of coefficients due to the gradual shift toward cell-to-pack (CTP) and cell-to-body (CTB) architectures, which aim to achieve efficiencies above 85% in mass and 70% in volume utilization. Other industries are also working toward higher efficiencies, but many remain tied to cell–module–pack (CMP) designs. For some, such as off-road industrial vehicles, these designs are essential given operational conditions. For heavy-duty automotive, the direction is not yet clear – whether the sector will follow the EV trend or continue with CMP solutions, especially given the parallel development of battery-swapping systems. In extremely high-safety applications such as aviation and maritime, improvements in mass and volume utilization remain modest. Here, strict safety requirements and complex thermal management systems dictate more conservative design choices.

## Innovation drivers: which sectors pull the cell frontier

Before assigning chemistries to specific applications and forecasting their future roles, it is important to identify which sectors are most interested in and, in some cases, dependent on advanced cell development and next-generation high-energy components. Reaching higher pack-level energy density targets can be achieved in two ways: by improving utilization efficiency or by enhancing cell-level performance. The history of LFP illustrates this point well: despite its moderate energy density, innovations in pack architecture, such as cell-to-pack (CTP) and cell-to-body (CTB) approaches, enabled the technology to deliver the required performance. In many applications, however, progress demands both pack- and cell-level innovation working in parallel.

To determine which applications are most influential in driving cell innovation, the analysis compared three dimensions: (1) technical requirements, focusing on energy density and cycle life as the most critical performance indicators, based on importance ranking (**Figure 3**); (2) dependency on cell innovation, captured by cell-to-pack volume and price ratios; and (3) willingness to pay for advanced solutions, which is inversely related to the importance of price at pack level.

Based on these parameters, summarized in **Table 1**, applications were grouped into four categories:

**Group 1**: Consumers electronics and drones

**Group 2**: Premium and average EVs, heavy-duty automotive (Trucks & Buses), off-road industrial vehicles, high-energy stationary storage (<8 hours), 2-3 wheelers, power tools.

**Group 3**: Aviation

**Group 4**: Maritime-high energy and high-power, high-power stationary.

**Table 1**. Application groups – performance, dependency on cell innovation, and willingness to pay

| Sectors | Energy density | Cycle life | C/P volume | C/P price | Willingness to pay | Innovation driver |
|---|---|---|---|---|---|---|
| **Group 1** | +++ | + | +++ | +++ | ++ | Cell |
| **Group 2** | ++ | ++ | ++<br>+++ (M) | ++<br>+++ (M) | + | Cell (M)<br>Pack |
| **Group 3** | +++ | ++ | + | + | +++ | Cell + pack |
| **Group 4** | + | +++ | + | + | +++ | Pack |

***Group 1:*** *Consumers electronics and drones*

***Group 2:*** *Premium and average EVs, heavy-duty automotive (Trucks & Buses), off-road industrial vehicles, high energy stationary storage, 2-3 wheelers, power tools.*

***Group 3:*** *Aviation*

***Group 4:*** *Maritime-high energy and high-power, high-power stationary.*

For **Group 1** (drones and consumer electronics), energy density remains the overriding priority up to 2035, while cycle life can be compromised. With high utilization efficiency and cell-to-pack price ratios, these markets are strongly governed by cell performance and cost. Their relatively high willingness to pay makes them attractive early adopters of advanced technologies, as they are prepared to support investment in scaling and cost reduction while leaving room for future improvements in lifetime.

The largest and most diverse **Group 2** demonstrates the lowest willingness to pay among all sectors, except for premium EVs. This, combined with moderate demands regarding the performance, means that they are less suited for early adoption of expensive innovations, favoring proven, robust, and cost-effective solutions. Nevertheless, projected utilization efficiency and cell-to-pack price ratios of mobility applications within this group, including EVs, buses, trucks, and 2–3 wheelers (marked as “M” in the **Table 1**), approach levels comparable to those of drones and consumer electronics by 2035. This indicates that mobility applications are transferring to the stronger dependence on the cell level performance and price within next 5-10 years, showing C/P volume utilization efficiency up to 85% and C/P price ratio from over 50% up to 90%. For EVs, this trend is already visible in the adoption of CTP and CTB architectures. For heavy-duty and light mobility applications, the challenge will intensify – once cell–module–pack (CMP) design reaches its maximum efficiency, further improvements in pack-level performance can only be achieved through advances in cell chemistry. Other applications in this segment, such as power tools or industrial off-road vehicles, and high-energy stationary storage still retain some room for optimization at the system level.

**Group 3**, represented by aviation, shows lower dependence on the cell-to-pack ratios but still faces extreme energy and moderate cycle life requirements. These cannot be met solely through pack design optimization, since gains are capped by strict safety standards and the additional volume of thermal management systems. Achieving performance targets in aviation therefore requires synchronized progress at both the cell and pack levels. Although high willingness to pay makes aviation a potential entry point for premium next-generation technologies, high safety standards and strict certification might be significantly limiting or impeding factors for new technologies adoption.

Finally, for **Group 4**, consisting of maritime and high-power stationary, where the energy density could be significantly sacrificed to reach the threshold with cycle life being decisive, the competitiveness comes from pack architecture, thermal management, certification, and operations & maintenance economics rather than from cell level innovations. Still, due to its flexibility on weight and volume and high willingness to pay, this sector provides increasingly open opportunities for alternatives to lithium-ion such as sodium-ion or redox-flow technologies.

## Chemistry fit across applications

Having identified KPIs at cell level and which sectors are most influential in pulling cell innovation forward, the next step is to examine how specific chemistries align with their technical and market requirements. Based on the translated KPIs at cell level, electrode chemistries were matched to the requirements of individual applications. The analysis considered both anode and cathode materials, distinguishing between conventional lithium-ion batteries (LIBs) with liquid electrolytes and solid-state batteries (SSBs) with (semi)solid electrolytes. In this study, no further separation between semi- and all-solid designs was made, as detailed cell formulations remain confidential within most manufacturers' portfolios. During this matching process it was established that not all KPIs were equally relevant for differentiating chemistries. Gravimetric and volumetric energy density, peak discharge rate (metric related to peak power density), and cycle life were selected as the decisive factors. Charge speed and continuous discharge rate were not differentiating criteria, as they could be sufficiently addressed across all chemistries. Cost, being highly volatile and market-dependent, was not used for selecting matching chemistries.

### Baseline 2025

For 2025, chemistries were first assigned purely on the basis of KPI values and then cross-validated against literature and the product portfolios of key market players. Applications were assigned to one of three categories:

- **Commercialized**: chemistries already deployed at industrial scale and available in the portfolios of global cell makers.
- **Technologically feasible**: chemistries that can meet the critical KPIs for certain applications from a technical standpoint but are not yet widely commercialized. These are typically at the pilot or early industrialization stage with several challenges still to overcome.
- **Not applicable**: chemistries failing to meet at least one differentiating KPI in any anode–cathode pairing.

These categories are shown in **Figures 4** and **5**, marked in green, light-grey, and dark-grey respectively.

In 2025, graphite and graphite/SiOx ($SiO_x$≤10 wt%) anodes paired with LFP or medium-nickel NMC cathodes (Ni≤0.8) clearly dominate across almost all applications. LTO anodes are also well established in the maritime sector, because of their exceptionally long lifetime, high power capability, and tolerance to lower temperatures.

Importantly, the industry focus has shifted in recent years. Cathode development, which once dominated, has reached a point of relative "saturation": LFP almost reached its maximal capacities and continues to decline in cost while NMCs with Ni content over 80% face safety limitations. As a result, innovation efforts increasingly concentrate on anodes, with particular attention to Si/C composites (typically ≤20 wt% silicon, often closer to 10 wt%). While highly promising, these composites are now concentrated in niche products rather than mainstream applications but are expected to gradually substitute graphite and graphite/SiOx.

High-Si content Si/C composites (Si≥80 wt%), pure silicon and Li-metal anodes, with limited cycle life and not yet large-scale production, can already meet the demands of consumer electronics, drones and some of eVTOL (aviation), power tools, 2-3 wheelers and have been already demonstrated in premium and average EVs trials both in LIB and SSB [5], [6], [7]. Beyond lithium-ion, sodium-ion batteries currently serve stationary storage needs, where lower gravimetric and volumetric energy densities are offset by sustainability advantages, and can potentially serve the maritime needs. While unsuitable as a standalone solution for EVs, sodium-ion is sometimes considered in hybrid configurations alongside lithium-ion [8].

**Forecast 2035**

Since the 2025 results aligned well with market reality, the same methodology was applied to forecast 2035. At this stage, only potential commercialization can be projected, based on two factors: (i) technological feasibility combined with global technology and manufacturing readiness and concrete announcements, and (ii) the assumption that cell-dependent industries will lead in adopting next-generation chemistries, while pack-focused sectors continue to rely on robust, mature solutions.

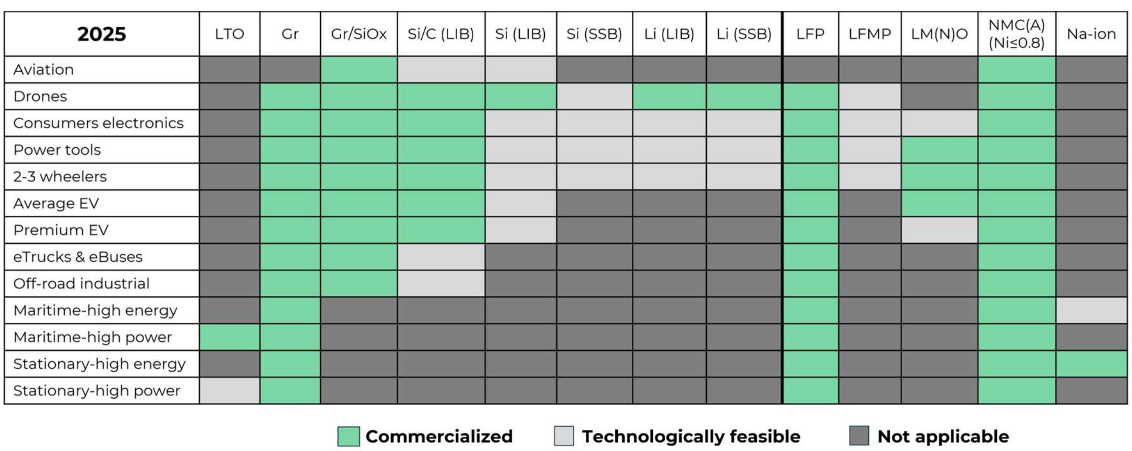
By 2035, Si/C composites are expected to dominate across many applications, with silicon content rising beyond 20 wt%. Graphite anodes will remain in use in certain segments such as stationary storage but is likely to be partially or fully replaced by more sustainable alternatives, including materials derived from bio-, polymer-, or oil-based waste streams. Next-generation anodes – high-silicon Si/C composites, pure silicon, and Li-metal – are projected to gain traction in broader markets such as 2–3 wheelers, light mobility, and EVs, supported by improved cycle life and the achievement of sufficient production volumes for niche applications. LTO, meanwhile, is expected to be gradually displaced by niobium or niobium–titanium oxides (NTO), which offer comparable robustness with greater energy potential.

Cathode diversity is also projected to expand by 2035. LFP is expected to be gradually replaced by LFMP, while high-voltage spinel LM(N)O may enter specific applications with high power demands driven, though unlikely to dominate as it was not present in the development roadmaps of the key manufacturing players. Lithium–manganese-rich (LMR) materials, previously explored for their high specific capacity and energy density but limited by issues such as voltage fade and instability at high states of charge, are now progressing toward commercialization, with large-scale production expected by 2028 [9]. Their strong energy performance positions them well for demanding applications such as drones, consumer electronics, EVs, heavy-duty automotive, and off-road industrial vehicles. To meet the broader demand for higher energy density, high-nickel NMC chemistries will take a leading role, with safety concerns addressed through electrode coatings, electrolyte innovations, or pack-level safeguards. It should be noted that the upcoming EU regulation on minimum recycled content effective from 2031 for industrial (>2 kWh) and EV batteries, requiring 16% cobalt, 6% lithium, and 6% nickel, may influence the cost and availability of cathode materials, potentially leading to slight deviations from the forecasted trends.

Sodium-ion is expected to solidify its role in stationary storage, where energy density is not the limiting factor, and to extend into maritime applications either independently or as hybrid systems with lithium-ion. Potential penetration of hybrid systems of Li-ion and Na-ion batteries into light mobility, EVs, and heavy-duty applications is also foreseen [8].

### Overall outlook

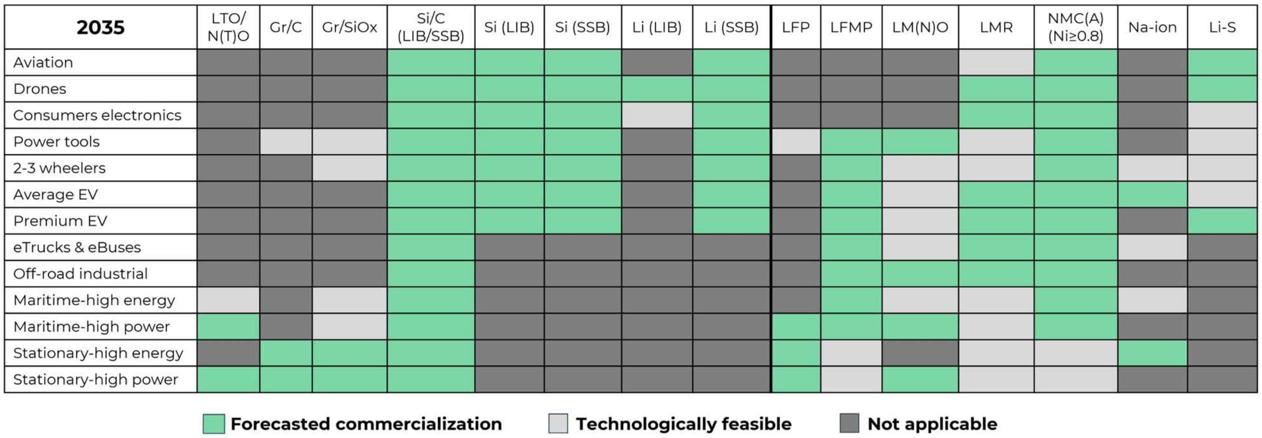
The decade ahead points to a shift from cathode-led to anode-led innovation, with Si/C composites emerging as the new workhorse material. High-Si Si/C composites, pure-Si and Li-metal anodes are expected to broaden the application range potentially up to premium and average EVs and eAviation, and foothold on the consumer electronics and drones' markets. The coming decade will likely see incremental advances across multiple chemistries for metal-ion batteries, each tailored to the balance of energy density, cycle life, safety, and sustainability required by different applications. Still, any disruptive breakthrough in the Li-S and Li-$O_2$ technologies, which can deliver much higher energy density and already can deliver comparable to pure-Si and Li-metal anodes cycle life [10], [11], might significantly disturb the metal-ion batteries market.




**Anodes**
LTO – $Li_4Ti_5O_{12}$
Gr – graphite
Gr/$SiO_x$ – graphite/silicon oxide composite ($SiO_x$ ≤10 wt%)
Si/C – silicon/carbon composite (Si≤20 wt%)
Si – high Si (Si/C, Si≥80 wt%) and pure silicon anode
Li – metallic Li anode

**Cathodes**
LFP – $LiFePO_4$ (polyanionic)
LFMP – $LiFe_xMn_{1-x}PO_4$ (polyanionic)
LMO/LMNO – $LiMn_2O_4$ / $LiMn_{2-x}Ni_xO_4$ (spinel)
NMC(A) – $LiNi_xMn_yCo_zAl_aO_2$, x+y+z+a=1 (layered)
Na-ion – PBA ($Na_xM[Fe(CN)_6]$) or NVPF ($Na_3V_2(PO_4)_2F_3$) | Hard-carbon

**Figure 4.** Application x Chemistry matrix 2025




**Anodes**

LTO – $Li_4Ti_5O_{12}$
N(T)O – $Nb_2O_5$ ($TiNb_xO_{2+2.5x}$)
Gr/C – graphite, carbon
Gr/$SiO_x$ – graphite/silicon oxide composite ($SiO_x$ ≤10 wt%)
Si/C – silicon/carbon composite (Si<80 wt%)
Si – high Si (Si≥80 wt%) and pure silicon anode
Li – metallic Li anode

**Cathodes**

LFP – $LiFePO_4$ (polyanionic)
LFMP – $LiFe_xMn_{1-x}PO_4$ (polyanionic)
LMO/LMNO – $LiMn_2O_4$ / $LiMn_{2-x}Ni_xO_4$ (spinel)
LMR – $Li_{1+x}Ni_{1-x-y-z}Mn_yCo_zO_2$ (layered)
NMC(A) – $LiNi_xMn_yCo_zAl_aO_2$, x+y+z+a=1 (layered)
Na-ion – PBA ($Na_xM[Fe(CN)_6]$) or NVPF ($Na_3V_2(PO_4)_2F_3$) | Hard-carbon

**Figure 5.** Application x Chemistry matrix 2035

## Dutch capabilities & readiness

To evaluate the readiness of Dutch next-generation anode technologies, the development pathways of high-silicon, pure silicon, and Li-metal anodes were plotted against graphite and Si/C composites (Si <80 wt%) as reference points. Two dimensions were considered: gravimetric energy density (**Figure 6a**) and cycle life over time (**Figure 6b**). The graphs also include the KPI ranges of the four previously defined application groups, shown as colored windows for comparison.

The first graph shows that Dutch high-energy anode technologies already meet, and in many cases exceed, the energy density requirements of most applications. By contrast, Si/C composites with lower silicon content (Si <80 wt%) cannot reach the same energy levels as high-silicon, pure silicon, or Li-metal anodes. Nevertheless, because they are expected to mature earlier and be less costly, Si/C composites will likely remain in use for drones, consumer electronics, and aviation to some extent.

The second graph suggests that over the next decade Dutch companies will be well positioned to strengthen their role in Group 1 markets, particularly consumer electronics and drones, while also meeting the needs of power tools and 2–3 wheelers within Group 2. However, the largest markets in Group 2 – EVs, heavy-duty and off-road industrial vehicles, and high-energy stationary storage – place greater emphasis on long lifetime and cost efficiency rather than extreme energy density. These priorities are less addressed within the current Dutch battery ecosystem. For instance, Si/C composite anode technologies with Si content below 80 wt.%, which better match the major players' needs, is underrepresented in the current innovation focus.

At the high end, aviation remains only partially addressed: despite promising targets for energy density, limited progress on cycle life will restrict the ability to fully meet requirements in the next ten years. Group 4 applications, which demand exceptionally long cycle life, are also unlikely to be covered by Dutch metal-ion technology developments. These markets are driven more by pack engineering than cell innovation and therefore open opportunities for less-energy-density solutions, like sodium-ion batteries, redox-flow technologies, and also stronger partnerships with leading EU players active in these segments.

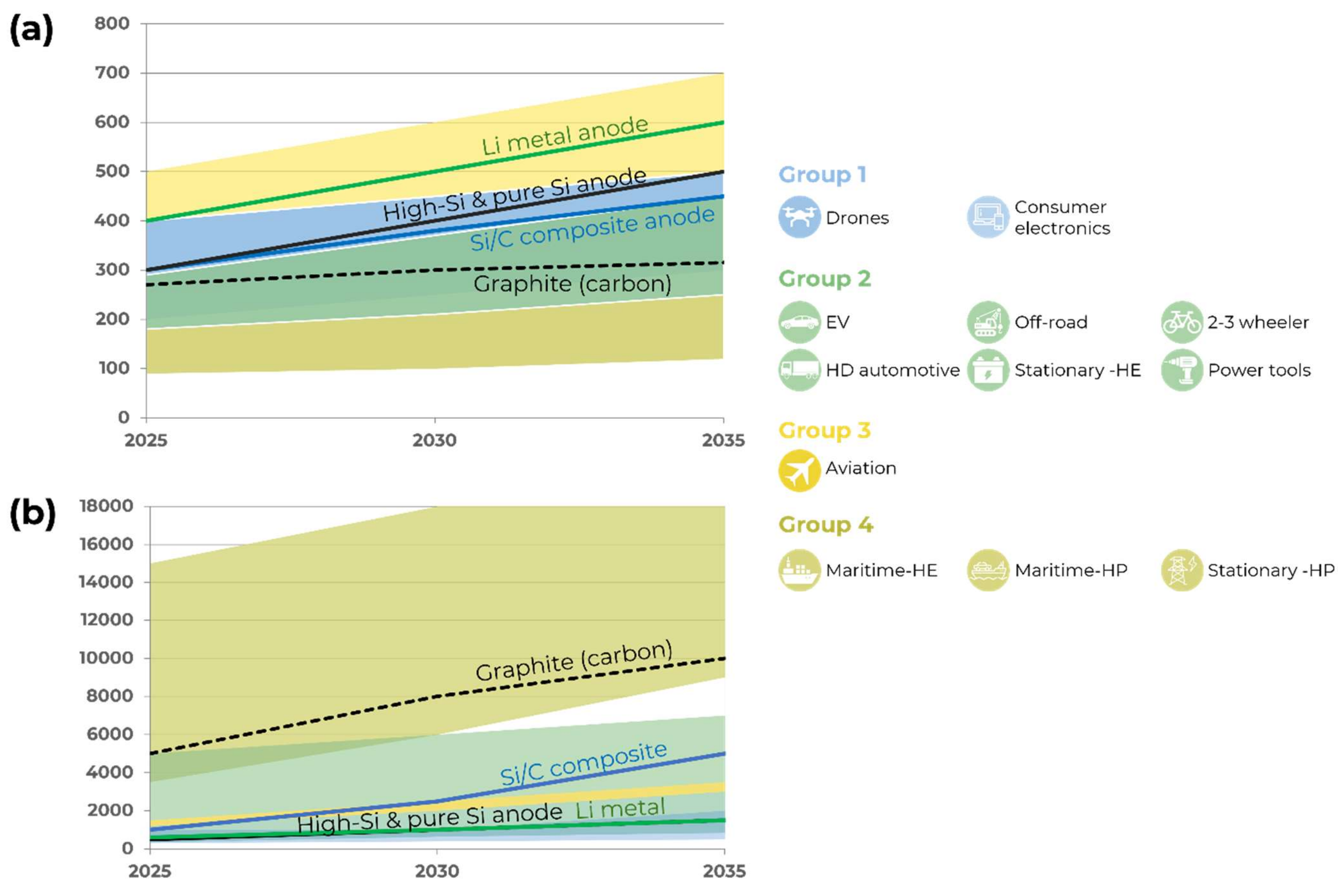



**Figure 6.** Evolving application demands vs. Trajectory of Dutch new battery anode technologies (a) gravimetric energy density and (b) cycle life over time

Based on the chemistry match to the applications and also global roadmaps of the EU, US, Chinese and Korean cell makers, the current battery cell chemistry roadmap by application and cell KPI targets 2025–2035 was summarized in **Figure 7**. The roadmap combines projected requirements for gravimetric and volumetric energy density and cycle life across different applications (shown in red) with the corresponding battery chemistries. These chemistries are represented as combinations of cathodes, anodes, and cell types – either conventional lithium-ion (LIB) or solid-state batteries (SSB) – with symbols placed near the relevant target values. In addition, the roadmap includes the timelines publicly announced by leading manufacturers in Europe, the United States, and Asia for the release of specific cell technologies (shown in purple). Blue part reflects the targets of the Dutch anode companies in different technologies as well as their planned production volumes.

Overall, Dutch developments are aligned with global trends. However, while international players plan to commercialize cells with high-Si, pure Si, and Li-metal anodes as early as 2027–2030, reaching at least the minimum entry thresholds for EVs, Dutch roadmaps do not yet foresee meeting these requirements within the same timeframe. To remain competitive in the largest market segments, the Dutch ecosystem will need to accelerate cycle life improvements and push 2030 and 2035 targets by roughly 50%.

In terms of production volumes, Dutch companies already achieve output levels sufficient for cell validation at pilot scale, including customer validation runs requiring batches of more than one tonne of active material annually. By 2030–2035, volumes are unlikely to meet mainstream market demand but will be sufficient to enter niche, energy-density-driven applications across multiple sectors.

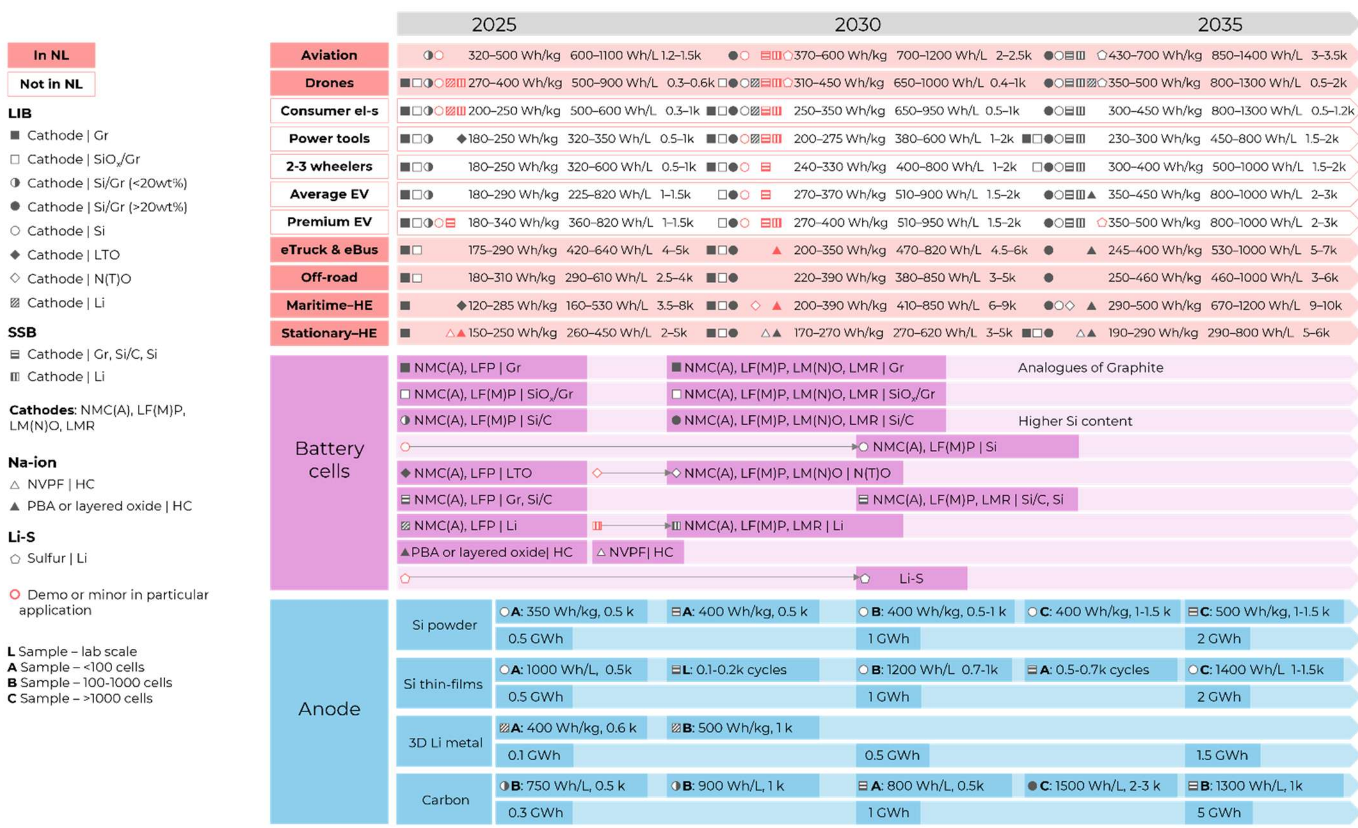



**Figure 7.** Battery cell chemistry roadmap by application and cell KPI targets & Dutch anode industry capabilities 2025–2035

## Summary and blind spots

Based on the conducted market research, several gaps and blind spots were identified in the Dutch battery value chain. These span industries and market focus, technology outlook, and value chain structure, and they highlight where targeted action is needed to align national efforts with global developments.

1. **Industries and Market Focus**

   Dutch OEMs are currently stronger in pack design, particularly for heavy-duty, off-road industrial vehicles, maritime, drones, and aviation. Each of these sectors, however, has different features and shows specific challenges:

- **The drone industry is an early adopter of new technology and strongly dependent on cell performance.**
  Drones already operate with high mass and volume utilization, leaving little room for further efficiency gains at pack level. Because gravimetric and volumetric energy density are critical, the sector must rely on next-generation chemistries and is willing to pay a premium for them. Peak power density is another decisive factor, as it underpins take-off, maneuvering, and landing. Currently, this performance is often limited by battery management systems (BMS) and thermal management than by cell chemistry.
- **Heavy-duty vehicles will increasingly depend on cell innovation once cell–module–pack (CMP) design reaches its limits.**
  By 2035, heavy-duty vehicles are expected to become increasingly dependent on cell innovation once cell–module–pack (CMP) design reaches its maximum efficiency, and further improvements in chemistry and cell design will be translated directly into performance gains and competitiveness.
- **Aviation faces extreme energy density requirements that can only be achieved through a combination of improved pack efficiency and advanced cell performance.**
  While pack builders and system integrators are pushing for higher utilization, their ability to deliver major improvements is limited by stringent safety standards and the need for more sophisticated thermal management systems. As a result, the role of the cell becomes decisive: without cell-level breakthroughs, aviation cannot meet its performance targets. This makes the aviation sector a powerful driver of next-generation technologies, as pack-level optimization alone cannot close the gap.
- **Maritime and stationary sectors are system-centric but still need targeted cell improvements.**
  These applications benefit most from system and pack engineering, yet they cannot entirely avoid cell-level innovation as demand for energy density grows. In

the Dutch context, cell components solutions for these markets are missing[1], so stronger connections to foreign players are needed.

2. **Technology Outlook**

   LIB remains dominant across most applications to 2035, with gradual integration of SSB for higher performance niches and Na-ion for cost , circularity and autonomy sensitive or safety-prioritized sectors.

- **Si/C composites with lower silicon content (Si <80 wt%) are forecast to replace graphite and dominate across many applications.**
  These materials offer a practical balance between higher energy density and manufacturability, making them suitable for both price-driven and performance-driven markets. However, in the Dutch context, Si/C with Si content below 80 wt.% remains underrepresented in current roadmaps, leaving a gap in addressing the technologies that will likely define mainstream applications by 2035.
- **Pure silicon and Li-metal anodes already deliver energy densities that match the needs of most applications, but their cycle life targets must be at least 50% higher to ensure competitiveness and real earning potential.**
  At present, lifetime performance is not sufficient for EV market, eAviation and even less so for heavy-duty vehicles, where durability is decisive. Meanwhile, global players plan to introduce cells with these anodes into EVs as early as 2027–2030. To stay aligned with this trajectory, Dutch efforts must accelerate cycle life improvements – raising current targets by at least 1.5 times – while maintaining today's strong pace of production scaling.
- **High-nickel NMC and LFMP chemistries are expected to dominate, supported by incremental improvements in energy density.**
  These cathodes align well with global market trajectories, but Dutch efforts currently remain centered mainly on mid-NMC. This focus leaves a gap in testing and validating compatibility with other advanced cathodes, potentially limiting the ability to integrate into future supply chains that demand a wider chemistry portfolio.
- **Charging speed is of secondary importance for most applications but remains a differentiator in premium EVs and consumer electronics.**
  Across mainstream markets, charging performance is more often constrained by pack architecture and infrastructure than by cell chemistry. Yet in premium EVs, where rapid charging is a decisive selling point, it continues to be critical. Here, advancing cycle life becomes even more urgent, since fast charging without sufficient durability risks undermining reliability and market confidence.

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[1] *This conclusion does not apply to long-duration stationary storage (>8 hours), where the Netherlands already hosts several strong and active players contributing to technology development and deployment.*

3. **Value chain:**

The broader ecosystem also shows structural blindspots:

- **Dutch OEMs are currently less dependent on cell performance, as rising energy density demands can still be met through more efficient pack engineering, but this balance might shift over the coming decade.**
  As forecasted packing efficiency approaches its limits by 2035, further energy density improvements will have to come from cell-level innovation. This will require a clearer balance of investment between pack design and next-generation cell development. Without such shift of focus towards cell-level improvements, Dutch players risk losing their competitive edge, as international players are already more deeply engaged in co-developing next-generation cells with cell-manufacturers.
- **The absence of domestic cell production is a critical gap that threatens economic security and competitiveness.**
  Key sectors such as aviation, heavy-duty and off-road industrial vehicles, stationary storage and drones require specialized cells, yet the Netherlands currently lacks local capacity in cathodes, electrolytes, large-scale cell manufacturing, and equipment supply. Without intervention, reliance on external production chains will persist, exposing the ecosystem to risks of dependency and missed opportunities for value creation.
- **Markets such as e-bikes and power tools align well with Dutch competencies and are increasingly cell-dependent, but opportunities are not yet utilized.**
  These sectors are increasingly cell-dependent and align well with Dutch competencies, yet they remain dominated by foreign OEMs. Stronger connections and closer engagement with international manufacturers are needed to convert technical capabilities into real market presence. Without this step, the Netherlands risks missing accessible entry points into global battery value chains.

## Action driven recommendations

### Industry ambitions and tailored goals

The next decade will be decisive for how Dutch industry positions itself within the global battery value chain. Each application sector, heavy-duty and off-road industrial vehicles, maritime, aviation, drones, and stationary storage, has distinct priorities in terms of autonomy, resilience, circularity, and competitiveness. It is therefore essential to define clear ambitions for each sector. These ambitions should guide adjustments in national activities, investment priorities by making clear where to invest and where not, and shape policy incentives, ensuring that every sector pursues a trajectory aligned with its unique requirements.

Because there is no universal solution in battery cell technology, goals must be tailored by industry group. Once these individual goals are set, shared needs should be identified across sectors. This opens the possibility of creating a collective demand signal, strong enough to influence technological development and investment decisions. For example, off-road industrial vehicles, heavy-duty transport, and stationary storage mainstreams share required technological characteristics to some extent. By pulling demand, these sectors could accelerate technological responses from both cell and component makers while strengthening national autonomy and earning potential.

### The urgency of Dutch/European cell supply

At present, the Netherlands and much of the EU remain dependent on Asian cell supply, although several European cell manufacturers are already operational. The Netherlands hosts a few promising next-generation cell developers, yet their production capacity remains small, reaching only tens of MWh annually. This output is sufficient to serve early adopters but far from meeting the volumes required for large-scale demand. While pack efficiency has traditionally been a Dutch strength, reliance on imported cells carries growing risks. In fact, as pack designs become more efficient, dependence on cell performance increases. For drones, heavy-duty and aviation applications in particular, cell-level innovation will be unavoidable within the next decade. This makes limited domestic and EU-scale production a strategic bottleneck. To address this, investment strategies must consider both international partnerships and the potential establishment of domestic cell production facilities.

### Sector-specific pathways

<u>Heavy-duty automotive, off-road industrial vehicles and drones:</u> These sectors will increasingly rely on advanced cells as pack-level optimization reaches its limits. Without targeted investments in either international supply chains or domestic cell production, competitiveness risks being eroded.

Aviation: Similar to heavy-duty and off-road vehicles in some of the characteristics, aviation, however, demands extreme energy density on top of cycle life improvements. Here, entering the eVTOL market first may offer a steppingstone: certification requirements are less stringent, and collaboration with system integrators and pack builders can accelerate validation.

Maritime and stationary: The sector's cycle life needs suggest that strategic partnerships with Dutch and European suppliers of niobium or niobium–titanium oxides (NTO) and Na-ion technologies are the most efficient way forward, rather than attempting to build local capacity from scratch. For long-duration stationary storage systems (over eight hours), complementary technologies such as redox-flow, salt-flow, iron–air, and formic acid batteries, which are out of the scope of this study, should also be taken into consideration as part of the broader strategic outlook.

**Opportunities for components and collaboration**

For Dutch component makers, domestic markets are limited – there is little presence of consumer electronics, power tools, 2–3 wheelers, or EV OEMs. Growth therefore depends on international collaborations, particularly with EU, US, and Asian players. At the same time, Dutch expertise can help push cycle life improvements not only through intrinsic material innovation but also through cooperative approaches like partnering with atomic layer deposition (ALD) companies to develop coatings and artificial SEI layers, collaborating with battery management systems (BMS) and system integrators to optimize charging/discharging profiles, develop more efficient thermal management systems and tailor formation cycles to specific component characteristics. Such cross-industry initiatives can extend cycle life, validate components for targeted applications, and strengthen Dutch visibility in international supply chains.

**Equipment and cell manufacturing**

To expand into broader markets, production capacity must scale in line with market demand while maintaining exceptional quality and speed. Enhancing the throughput, precision, and reliability of next-generation components' manufacturing tools, such as thin-film deposition, powder and spatial or atomic layer deposition machines, is essential. These technologies enable the development of advanced cell concepts and will determine the pace at which Dutch innovations move from laboratory prototypes to industrial-scale production.

In light of China's recent export control limitations (Announcement No. 58 from 9 October 2025 of the Ministry of Commerce and the General Administration of Customs of China) on items related to lithium batteries including cell production equipment, strengthening the European and Dutch cell-manufacturing equipment base has become even more critical. The Netherlands can capitalize on its established expertise in semiconductor, solar, and advanced manufacturing to develop and supply essential tools for electrode fabrication, coating, winding, staking and formation processes. By applying automation, digital simulation, and process-control know-how, Dutch companies can play a key role in bridging the Lab-to-Fab transition, accelerating the industrialization of next-generation battery technologies while reducing Europe's strategic dependencies.

**Further steps for intelligence and mapping**

This orientation study represents only part of the value chain. Future work should extend to pack-level orientation, addressing safety as complex multiparameter KPI, thermal management, and battery management system (BMS) and energy management system (EMS) integration in greater detail. In addition, modeling potential second-life applications – based on collected energy density values, cycle life expectations, and end-of-life criteria (e.g., 80% residual energy, or 90% in aviation) – could support circularity strategies and propose second use chain. Linking chemistry forecasts with market volumes would also help predict critical materials waste streams and recycling needs. The outlined path of adoption of conventional battery cells with new components and solid-state batteries highlights potential focus electrodes and niches for Dutch companies specializing in coatings, surface engineering, and advanced interfaces. Anticipating which chemistry and cell designs will dominate is equally valuable for equipment makers, guiding their investment in tools tailored to future production. Here, additional detail on cell geometries and capacity will be required to refine strategic planning.

**Continuous monitoring**

Finally, to remain competitive, KPIs and technology trends should be monitored continuously. A structured evaluation every two to three years will ensure that national targets remain aligned with global developments, that disruptions are detected early, and that Dutch industry maintains a forward-looking position in the global battery landscape.

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[RM] Roadmaps of the key cell makers (Samsung SDI, LG Energy Solutions, SK On, Sunwoda, BYD, CATL, ATL)

## Appendix

**Table A1.** Battery pack KPIs 2025

| Application | Cost, €/kWh | GED, Wh/kg | VED, Wh/L | Charge C-rate (SOC 10-80 %), 1/h | Continuous discharge C-rate, 1/h | Peak discharge C-rate, 1/h | Cycle life (80% EOL), cycles | Cell/Pack mass efficiency, % | Cell/Pack volume efficiency, % | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Aviation | 500 – 800 | 210 – 300 | 360 – 500 | 1 – 1.2 | 0.3 – 1.2 | 1.5 – 2 | 1200 – 1500 | 60 – 65 | 45 – 60 | [12], [13], [14], [15] |
| Drones | 250 – 300 | 230– 360 | 425 – 810 | 1 – 2 | 1 – 3 | 5 – 10 | 300 – 600 | 85 – 90 | 85 – 90 | [15], [16], CIBF |
| Consumers electronics | 300 – 800 | 160 – 225 | 400 – 540 | 1 – 2 | 0.5 – 1 | 1 – 2 | 300 – 1000 | 80 – 90 | 80 – 90 | [17], IB, CIBF |
| Power tools | 150 – 300 | 72 – 125 | 128 – 175 | 0.5 – 2 | 0.3 – 1 | 2 – 5 | 500 – 1500 | 40 – 50 | 40 – 50 | [16], IB, CIBF |
| 2–3 wheelers | 150 – 300 | 140 – 200 | 130 – 250 | 0.3 – 0.6 | 0.15 – 0.3 | 2 – 3 | 500 – 1500 | 70 – 75 | 35 – 40 | [16], [17], [18], [19], IB, CIBF |
| Average EV | 80 – 120 | 120 – 190 | 180 – 450 | 1.5 – 2 | 0.1 – 0.3 | 3 – 6 | 1000 – 1500 | 65 – 90 | 55 – 80 | [4], [12], [17], [20], [21], [22], [23], [24], IB, CIBF |
| Premium EV | 100 – 140 | 150 – 220 | 200 – 600 | 2 – 3 | 0.08 – 0.25 | 3 – 8 | 1000 – 1500 | 65 – 85 | 55 – 75 | [22], [23], [25], IB, CIBF |
| eTruck & eBus | 80 – 150 | 140 – 200 | 250 – 320 | 0.5 – 2 | 0.12 – 0.18 | 1 – 1.5 | 4000 – 5000 | 70 – 80 | 50 – 65 | [4], [12], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], IB |
| Off – road industrial | 200 – 350 | 130 – 200 | 175 – 275 | 0.3 – 1 | 0.2 – 1.5 | 1 – 3 | 2500 – 4000 | 65 – 70 | 45 – 60 | [12], [16], [36], [37], [38], [39], [40], [41], IB |
| Maritime–HE | 400 – 550 | 80 – 170 | 70 – 210 | 0.5 – 1 | 0.4 – 1 | 1 – 3 | 3500 – 8000 | 60 – 65 | 40 – 45 | [12], [42], [43], [3], [44] |
| Maritime–HP | 750 – 800 | 60 – 90 | 60 – 90 | 1 – 4 | 3.5 – 5 | 7 – 8 | 8000 – 15000 | 60 – 65 | 40 – 45 | [12], [42], [45], [46], [47] |
| Stationary–HE | 100 – 150 | 100 – 150 | 130 – 200 | 0.5 – 1 | 0.15 – 0.2 | 0.5 – 1 | 2000 – 5000 | 60 – 65 | 45 – 50 | [12], [17], [48], IB, CIBF |
| Stationary–HP | 150 – 200 | 60 – 100 | 80 – 90 | 1 – 2 | 1 – 2 | 1 – 2 | 8000 – 10000 | 60 – 65 | 40 – 50 | [12], [1] |

**Table A2.** Battery pack KPIs 2035

| Application | Cost, €/kWh | GED, Wh/kg | VED, Wh/L | Charge C-rate (SOC 10-80 %), 1/h | Continuous discharge C-rate, 1/h | Peak disc harge C-rate, 1/h | Cycle life (80% EOL), cycles | Cell/Pack mass efficiency, % | Cell/Pack volume efficiency, % | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Aviation | 400 – 600 | 320 – 450 | 550 – 720 | 1.5 – 1.7 | 0.25 – 0.6 | 1 – 1.5 | 3000 – 3500 | 65 – 75 | 55 – 65 | [12], [13], [15], interviews |
| Drones | 80 – 200 | 315 – 475 | 720 – 1235 | 1 – 3 | 2 – 5 | 5 – 20 | 500 – 2000 | 90 – 95 | 90 – 95 | [15], interviews |
| Consumers electronics | 200 – 500 | 285 – 380 | 760 – 1105 | 2 – 3 | 0.2 – 0.5 | 1 – 2 | 500 – 1200 | 85 – 95 | 85 – 95 | Interviews, RM |
| Power tools | 100 – 200 | 140 – 210 | 250 – 520 | 2 – 3 | 0.2 – 0.3 | 5 – 10 | 1500 – 2000 | 60 – 70 | 55 – 65 | RM |
| 2–3 wheelers | 100 – 200 | 255 – 280 | 425 – 700 | 1 – 2 | 0.12 – 0.15 | 1 – 3 | 1500 – 2000 | 70 – 85 | 70 – 85 | RM |
| Average EV | 50 – 80 | 298 – 405 | 560 – 850 | 2 – 2.5 | 0.08 – 0.2 | 3 – 6 | 2000 – 3000 | 85 – 90 | 70 – 85 | [4], [12], RM |
| Premium EV | 70 – 100 | 300 – 450 | 560 – 850 | 3.5 – 4 | 0.08 – 0.15 | 5 – 10 | 2000 – 3000 | 85 – 90 | 70 – 85 | RM |
| eTruck & eBus | 50 – 80 | 220 – 320 | 450 – 650 | 1.5 – 4 | 0.12 – 0.15 | 1 – 1.5 | 5000 – 7000 | 80 – 90 | 65 – 85 | [4], [12], interviews, RM |
| Off – road industrial | 120 – 200 | 190 – 300 | 300 – 550 | 2 – 3 | 0.15 – 1 | 2 – 4 | 3000 – 6000 | 65 – 75 | 50 – 65 | [12], interviews, RM |
| Maritime–HE | 150 – 300 | 220 – 320 | 440 – 650 | 0.7 – 1.5 | 0.2 – 1 | 1 – 3 | 9000 – 10000 | 65 – 75 | 55 – 65 | [12], interviews, RM |
| Maritime–HP | 450 – 500 | 90 – 150 | 200 – 300 | 4 – 5 | 3 – 4 | 8 – 10 | 10000 – 20000 | 65 – 75 | 50 – 60 | Interviews, RM |
| Stationary–HE | 30 – 50 | 130 – 190 | 190 – 520 | 1 – 3 | 0.08 – 0.1 | 0.5 – 1 | 5000 – 6000 | 65 – 70 | 55 – 65 | [12], interviews, RM |
| Stationary–HP | 70 – 100 | 130 – 150 | 200 – 275 | 2 – 5 | 2 – 5 | 2 – 5 | 10000 – 20000 | 65 – 70 | 50 – 60 | Interviews, RM |

Battery Competence Cluster - NL

**Table A3.** Translated battery cell KPIs 2025

| Application | Cost, €/kWh | GED, Wh/kg | VED, Wh/L | Charge C-rate (SOC 10-80 %),1/h | Continuous discharge C-rate, 1/h | Peak disc harge C-rate, 1/h | Cycle life (80 % EOL), cycles | C/P price, % | Validation source |
|---|---|---|---|---|---|---|---|---|---|
| Aviation | 300 – 400 | 320 – 500 | 600 – 1110 | 1 – 1.2 | 0.3 – 1.2 | 1.5 – 2 | 1200 – 1500 | 35 – 50 | [13], [49] |
| Drones | 150 – 200 | 270 – 400 | 500 – 900 | 1 – 2 | 1 – 3 | 5 – 10 | 300 – 600 | 50 – 70 | [49], CIBF |
| Consumers electronics | 300 – 700 | 200 – 250 | 500 – 600 | 1 – 2 | 0.5 – 1 | 1 – 2 | 300 – 1000 | 40 – 90 | IB, CIBF |
| Power tools | 100 – 200 | 180 – 250 | 320 – 350 | 0.5 – 2 | 0.3 – 1 | 2 – 5 | 500 – 1500 | 35 – 65 | IB, CIBF |
| 2–3 wheelers | 80 – 120 | 180 – 250 | 320 – 600 | 0.3 – 0.6 | 0.15 – 0.3 | 2 – 3 | 500 – 1500 | 30 – 40 | [50], IB, CIBF |
| Average EV | 60 – 90 | 180 – 290 | 225 – 820 | 1.5 – 2 | 0.1 – 0.3 | 3 – 6 | 1000 – 1500 | 50 – 75 | [12], [20], [24], [50], [51], [52], [53], [54], IB, CIBF |
| Premium EV | 90 – 110 | 180 – 340 | 360 – 820 | 2 – 3 | 0.08 – 0.25 | 3 – 8 | 1000 – 1500 | 65 – 80 | [55], IB, CIBF |
| eTruck & eBus | 60 – 110 | 175 – 290 | 380 – 640 | 0.5 – 2 | 0.12 – 0.18 | 1 – 1.5 | 4000 – 5000 | 40 – 75 | [12], [53], IB, CIBF |
| Off – road industrial | 150 – 160 | 180 – 310 | 290 – 610 | 0.3 – 1 | 0.2 – 1.5 | 1 – 3 | 2500 – 4000 | 40 – 50 | [53], IB, CIBF |
| Maritime–HE | 150 – 200 | 120 – 285 | 160 – 530 | 0.5 – 1 | 0.4 – 1 | 1 – 3 | 3500 – 8000 | 30 – 40 | [42], [53], CIBF |
| Maritime–HP | 300 – 350 | 90 – 150 | 130 – 225 | 1 – 4 | 3.5 – 5 | 7 – 8 | 8000 – 15000 | 35 – 45 | [42], [56], [57] |
| Stationary–HE | 60 – 90 | 150 – 250 | 260 – 450 | 0.5 – 1 | 0.15 – 0.2 | 0.5 – 1 | 2000 – 5000 | 40 – 60 | [52], IB, CIBF |
| Stationary–HP | 100 – 150 | 90 – 170 | 160 – 225 | 1 – 2 | 1 – 2 | 1 – 2 | 8000 – 10000 | 50 – 75 | IB, CIBF |

**Table A4.** Translated battery cell KPIs 2035

| Application | Cost, €/kWh | GED, Wh/kg | VED, Wh/L | Charge C-rate (SOC 10 -80 %), 1/h | Continuous discharge C-rate, 1/h | Peak disc harge C-rate, 1/h | Cycle life (80% EOL), cycles | C/P price, % | Validation source |
|---|---|---|---|---|---|---|---|---|---|
| Aviation | 200 – 300 | 430 – 700 | 850 – 1400 | 1.5 – 1.7 | 0.25 – 0.6 | 1 – 1.5 | 3000 – 3500 | 30 – 50 | Interviews, RM |
| Drones | 50 – 200 | 350 – 500 | 800 – 1300 | 1 – 3 | 2 – 5 | 5 – 20 | 500 – 2000 | 50 – 90 | Interviews, RM |
| Consumers electronics | 200 – 400 | 300 – 450 | 800 – 1300 | 2 – 3 | 0.2 – 0.5 | 1 – 2 | 500 – 1200 | 40 – 90 | Interviews, RM |
| Power tools | 60 – 90 | 230 – 300 | 450 – 800 | 2 – 3 | 0.2 – 0.3 | 5 – 10 | 1500 – 2000 | 30 – 45 | Interviews, RM |
| 2–3 wheelers | 50 – 100 | 300 – 400 | 500 – 1000 | 1 – 2 | 0.12 – 0.15 | 1 – 3 | 1500 – 2000 | 35 – 50 | Interviews, RM |
| Average EV | 45 – 70 | 350 – 450 | 800 – 1000 | 2 – 2.5 | 0.08 – 0.2 | 3 – 6 | 2000 – 3000 | 55 – 90 | [12], interviews, RM |
| Premium EV | 60 – 90 | 350 – 500 | 800 – 1000 | 3.5 – 4 | 0.08 – 0.15 | 5 – 10 | 2000 – 3000 | 60 – 90 | Interviews, RM |
| eTruck & eBus | 45 – 70 | 245 – 400 | 530 – 1000 | 1.5 – 4 | 0.12 – 0.15 | 1 – 1.5 | 5000 – 7000 | 55 – 90 | [12], interviews, RM |
| Off – road industrial | 60 – 90 | 250 – 460 | 460 – 1000 | 2 – 3 | 0.15 – 1 | 2 – 4 | 3000 – 6000 | 30 – 45 | Interviews, RM |
| Maritime–HE | 70 – 100 | 290 – 490 | 680 – 1200 | 0.7 – 1.5 | 0.2 – 1 | 1 – 3 | 9000 – 10000 | 20 – 30 | Interviews, RM |
| Maritime–HP | 150 – 200 | 120 – 230 | 330 – 600 | 4 – 5 | 3 – 4 | 8 – 10 | 10000 – 20000 | 30 – 40 | Interviews, RM |
| Stationary–HE | 20 – 40 | 190 – 290 | 290 – 800 | 1 – 3 | 0.08 – 0.1 | 0.5 – 1 | 5000 – 6000 | 40 – 80 | Interviews, RM |
| Stationary–HP | 30 – 50 | 185 – 230 | 330 – 550 | 2 – 5 | 2 – 5 | 2 – 5 | 10000 – 20000 | 30 – 50 | Interviews, RM |