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Benchmarking International Battery Policies

A cross analysis of international public battery strategies focusing on Germany, EU, USA, South Korea, Japan and China

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Contents

Contents

1. Executive Summary

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Europe is poised to take a decisive step in the transition toward decarbonized sectors such as energy and transport through the promotion of electric mobility and stationary storage solutions. In this context, a European battery ecosystem with scaled production and circular supply chains will be established over the next few years. Such transitions, however, are now being driven by international crises, the war in Ukraine and other geopolitical developments. Here, the concept of technology sovereignty adds an important dimension and comes at a time when traditional alliances have become more fragile and the role of geopolitical access or access to critical technologies including battery materials and cells, which are required for the above-mentioned energy transition has returned to center stage.

As a result, countries worldwide are renewing or adapting their political strategies for battery technologies, which include funding strategies as well as agendas. This is why our report is analyzing the different battery policies and targets with focus on three categories of different battery technologies (conventional lithium-ion batteries, solid-state batteries, and alternative batteries), also comparing other conditions, such as the amount of public funding and publications and patent numbers. We focus here on the political goals and strategies of Japan, South Korea, China, the U.S., Europe and within it Germany.

Our findings show that:

- All countries have goals directly related to the development of a complete value chain for batteries to become less dependent on international supply chains.
- All countries have set goals regarding the electrification of mobility, most often using the share of sales of electric vehicles (EVs) as a metric. Advanced battery technology and upscaling of production capacities play a role in achieving higher market penetration of EVs.
- All countries are focused on the EV-market, some have also included other application fields (stationary storage, air-transport/drones, military use).
- All countries want to be climate neutral by 2050 or before (Germany by 2045), except China (by 2060).
- The specific objectives regarding sustainability and circularity (recycling of batteries) vary greatly between the different regions of the world: In the EU, Japan and Germany, there are specific KPIs for recycling technology, but the U.S. and South Korea also have dedicated policies. China is now also focusing more on improving the circularity of batteries.

Political objectives and strategies by country or region

Japan (as an early technology leader) has traditionally strongly focused on the supply side and strategically planned the R&D strategies with roadmaps and milestones (such as the roadmaps of the national research and development agency or organization - NEDO). The development of solid-state batteries and specific types of alternative batteries in particular was supported while setting key performance parameters (KPIs) as targets. However, as Japan recognized that it was steadily losing ground in market competition and that the era of conventional lithium-ion batteries will continue for the time being, the priority has recently been given to increasing production capacity and ensuring the domestic and global market in lithium-ion batteries, for example within a Battery Industry Strategy formulated in 2022.

South Korea aims for international leadership regarding its battery industry. The comprehensive Korean-battery strategy from 2021 shows a clear R&D focus on commercializing three types of advanced batteries (lithium-sulfur, lithium-metal and solid-state batteries). South Korea has supported not only the promotion of its EV-industry, but also provided direct support for its battery manufacturers (for example by giving large tax credits). As a unique feature of the national strategy, three large private companies are going to invest a large amount (about 30 billion euros) together with the government. The newly elected government of 2022 announced strategies to strengthen the battery industry, including countermeasures to the U.S.'s Inflation Reduction Act.

While China for a long time has massively relied on demand-side policies and has treated battery technology as an element of its New Energy Vehicle strategy for the huge domestic market, it is now shifting more and more toward a targeted battery strategy with increasing supply-side measures.
As of 2022, China has the largest market share in the battery industry and is continuously trying to strengthen its global market position. Whereas for a long time, China had focused on performance parameters such as energy density, it is now increasingly including qualitative parameters such as safety. The government has very specific goals about sustainability, for example with regard to positioning in the EU market. A lot of key performance parameters are set not only by ministries (such as in the Industrial Development Plan for Electric Vehicles 2021-2035) but also by industry associations.

Germany has historically pursued an open technology strategy for battery technology with many different measures, but did not publish a specific strategy on performance parameters until recently. Under the comprehensive strategy "Battery Research Roof Concept" (German: Dachkonzept Batterieforschung) updated in January 2023, several supply-side measures were introduced, the development of production processes at larger scales particularly were prioritized to address the lack of production capacity. Also, project activities and funding under the framework of the IPCEIs (Important Projects of Common European Interest) together with the European industry are aiming at aligning with the EU policy on cross-cutting issues such as sustainability, recycling and digitalization of batteries.

In this context and time frame the updated roof concept takes into account the overarching goal of building a technologically competitive and sustainable battery value chain for Germany and Europe. The current roof concept also includes several milestones and performance parameters to be achieved within the coming years.

Across Europe – the EU is pushing forward the development of a competitive and sustainable battery value chain using several activities and initiatives, such as public-private partnerships and the aforementioned instrument of IPCEIs. The overall battery policy can be described as supply side, but includes some demand-side elements regarding the end of the value chain (with respect to Electric Vehicle purchasing). Under initiatives like Batteries Europe and the Batteries Europe Partnership Association (BEPA) Strategic Research and Innovation Agendas (SRIAs) have been published, which describe a clear technological roadmap and specific performance parameters for the battery cell chemistries. An update is currently under preparation. Since the EU's main priority is tackling environmental problems, the EU sets ambitious and concrete goals for the sustainability and recycling of batteries. The new Batteries Regulation to introduce circular economy principles and mandatory sustainability requirements has also been adopted.

Under the Biden Administration, the United States is aiming at establishing a sustainable and competitive battery value chain for a variety of reasons: to fight against climate change, create new employment, support technology sovereignty and for national defense. Therefore, the U.S. has invested in both supply- and demand-side policies in a well-balanced way. As for innovation policies, the U.S. has taken rather a technology-open strategy in their R&D funding programs, but the newly published national blueprint sets performance parameters, not only for single technical parameters but for other important aspects, such as the cost and sustainability of batteries as well. With the Inflation Reduction Act 2022, the U.S. wants to stimulate its economy and to increase its resilience. This program intends to provide a strong response to China's economic and technological leadership or dominance and provides enormous incentives and, in some cases, imposes obligations to relocate production to the U.S.

The fear of deindustrialization is present in Europe as well and a European answer to the industrial and geo-political shifts is also urgently needed, especially since a European battery value chain or even broader ecosystem will be established in the next few years - whether by European or non-European actors. Therefore, research agendas, close to market funding and government support measures, as well as political framework conditions and regulation must go hand in hand even more strongly in the coming next years.

Technical objectives and milestones of the countries or region

Although the various world regions put different emphasis on some of the emerging battery technologies, it can be seen that all international strategies refer to lithium-ion batteries as the benchmark, solid-state batteries are currently regarded as the technology of the future and alternative battery technologies such as sodium-ion batteries possess the potential to increase technology sovereignty and improve sustainability. All the strategic goals are focused on the years 2025 to 2030 and beyond.

The focus for the target technologies and cell chemistries of each country or region is on the following points:

- China is focusing on LIBs, SSBs, metal-sulfur, and especially Li-sulfur batteries.
- South Korea is focusing on LIBs, SSBs, and next-generation batteries (not specified), but mentions Li-sulfur and Li-metal batteries as alternative battery types.
- Japan is focusing on LIBs, SSBs and alternative battery types (fluoride shuttle and zinc-anode batteries).
- The U.S. follows a technology-open approach, but a lot of research is being done on SSBs and alternative battery types.
- The EU has sets its focus on lithium-ion (Gen.3a +Gen.3b), solid-state and alternative battery types such as redox-flow, metal-air and sodium-ion batteries.
- Germany is focusing on LIBs, SSBs, sodium-ion and other alternative batteries.

Interestingly, all of the public strategies focus on more than just one specific technology type. They are aiming to diversify and all of them include SSBs and alternative types other than the more conventional lithium-ion batteries. Whereas some countries are already very specific regarding the type of technology (e.g. JP, CN), others chose a more technology open approach (U.S., EU).

Table 1: Overview of public battery strategy of the main international players.

Country	Official strategies	Main objectives	Main KPIs
EU	EU action plan on batteries (2018); Batteries Europe: SRA (2020); BEPA/Batt4EU: SRIA (2021); Green Deal Industrial Plan (2023); EU Batteries Regulation (2023); Update of the SRIA (2024)	Becoming a leading supplier of sustainable battery technologies; establishment of competitive and sustainable value chain in EU	Large number of KPIs for gen 3, gen 4 and gen 5 batteries in SRIA, e.g. specific energy, energy density, charging rate, cycle life, cost.
US	National Blueprint for Lithium Batteries 2021-2030; DOE's Actions to Bolster Domestic Supply Chain of Advanced Batteries (2021); Better energy storage act (2021); Inflation Reduction Act (2022)	Competitive US value chain; International leadership in R&D Independence from competitors, especially China; supply of domestic market	KPIs for lithium ion batteries by 2026 (Battery 500); KPIs for battery technologies incl. solid-state and Li-metal, that achieve a production cost <60 $/kWh, 500 Wh/kg, and cobalt- and nickel-free by 2030 (Blueprint)
CN	Made in China 2025; Industrial Development Plan for EV 2021-2035; National Key R&D Program	Development and production of batteries and EVs in China (autonomy); Further expand capacities along the value chain	large number of KPIs for liquid electrolyte-based lithium-ion/ solid-state/alternative batteries, set not only by ministries, but also by the associations (e.g. CATARC and NMSAC)
JP	Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (revised in 2021); Battery Industry Strategy (2022, METI)	To strengthen industrial competitiveness in battery field; Increasing focus on securing production capacity	KPIs for the cost of LIB pack <10,000 yen/kWh by 2030 (Green Growth Strategy); KPIs for zinc anode/fluoride batteries and next-generation batteries (NEDO); KPIs for recycling technology (NEDO)
KR	K-Battery Development Strategy (2021); Innovation Strategy on Secondary Battery Industry (2022, MOTIE); post-IRA public-private joint strategy for batteries (2023, MOTIE)	To become world's No.1 battery powerhouse by 2030	KPIs mainly for solid-state, lithium-sulfur and lithium-metal batteries (K-Battery strategy)

Key performance indicators (KPIs) set across the countries

The comparison of the KPIs for the gravimetric energy density shows that overall the countries seem to have different areas of focus. Whilst the U.S. has its goals high with regard to Li-ion and Li-metal batteries with liquid electrolyte, China is most ambitious in terms of the target for solid-state battery cells. The target of alternative batteries are more diversely defined, depending on the cell chemistry. In general, there are higher targets for mobility applications and lower targets mainly for stationary applications.

For lithium-ion batteries, China has a more ambitious target than the EU in the short-term (until 2025).
The U.S. is very ambitious with a mid-term target of achieving 500 Wh/kg gravimetric energy density at the cell level already by 2030 followed by China. It is worth noting that the ambitious target set by the U.S. is not well specified in the National Blueprint (to be achieved by "revolutionary battery technologies") and the document also mentions solid-state and Li-metal as examples. Therefore, we have categorized the Blueprint KPI both as lithium-ion batteries and solid-state batteries in the following graphs. In addition, currently, the Battery500 consortium in the U.S., whose second project phase runs until 2026, pursues a concept using a conventional layered oxide cathode, a lithium metal anode and a liquid electrolyte, to achieve 500 Wh/kg.

In terms of solid-state batteries, only China has defined a target for 2025. Regarding the targets until or beyond 2030, China again is the most ambitious, with the EU (Gen 4b and 4c) and the U.S., followed by the EU (Gen 4a) and South Korea.

Japan is the only country with KPIs for alternative battery types by 2025, but these are for prototype projects. Only South Korea set KPI targets for lithium-metal batteries before 2030 (2025-2028), reflecting its focus on early commercialization of the technology. China's KPIs are not so well specified the type of battery to be pursued, but seem very ambitious compared to the other countries. The EU has a very ambitious target for post-lithium batteries by 2030, which is as high as for China. The other KPIs for alternative battery types by 2030 or beyond (sodium, redox-flow and metal-air) are all for stationary storage applications and are below the targets of Japan and China. Germany's KPI for sodium-ion batteries is very similar to the EU's.

Figure 1: Roadmaps for the gravimetric energy density of LIBs compared with KPIs of established battery cells (source: own representation based on official documents and market reports).

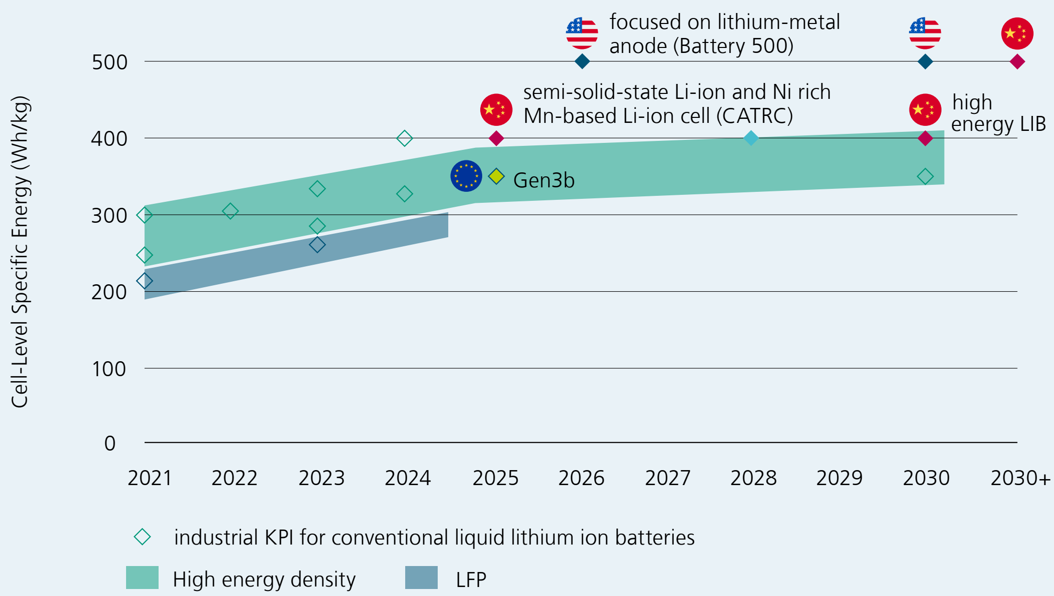


Figure 2: Roadmaps for the cell-level specific energy of SSBs compared with KPIs of established battery cells (source: own representation based on official documents and market reports).

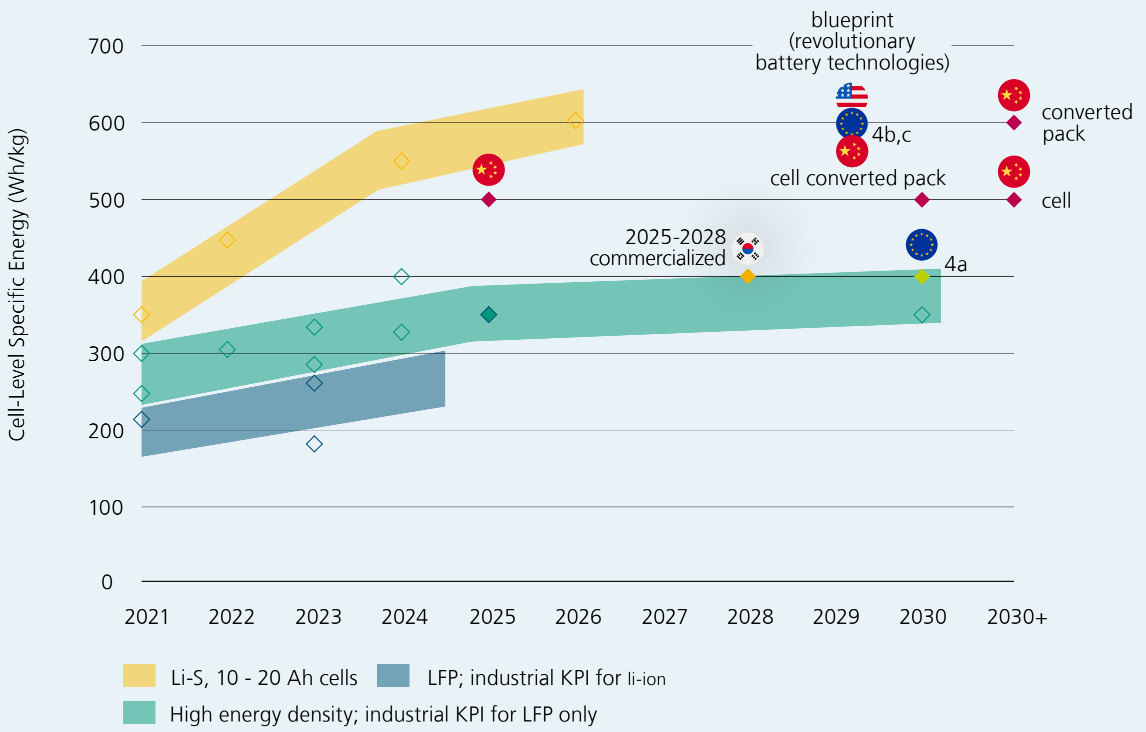
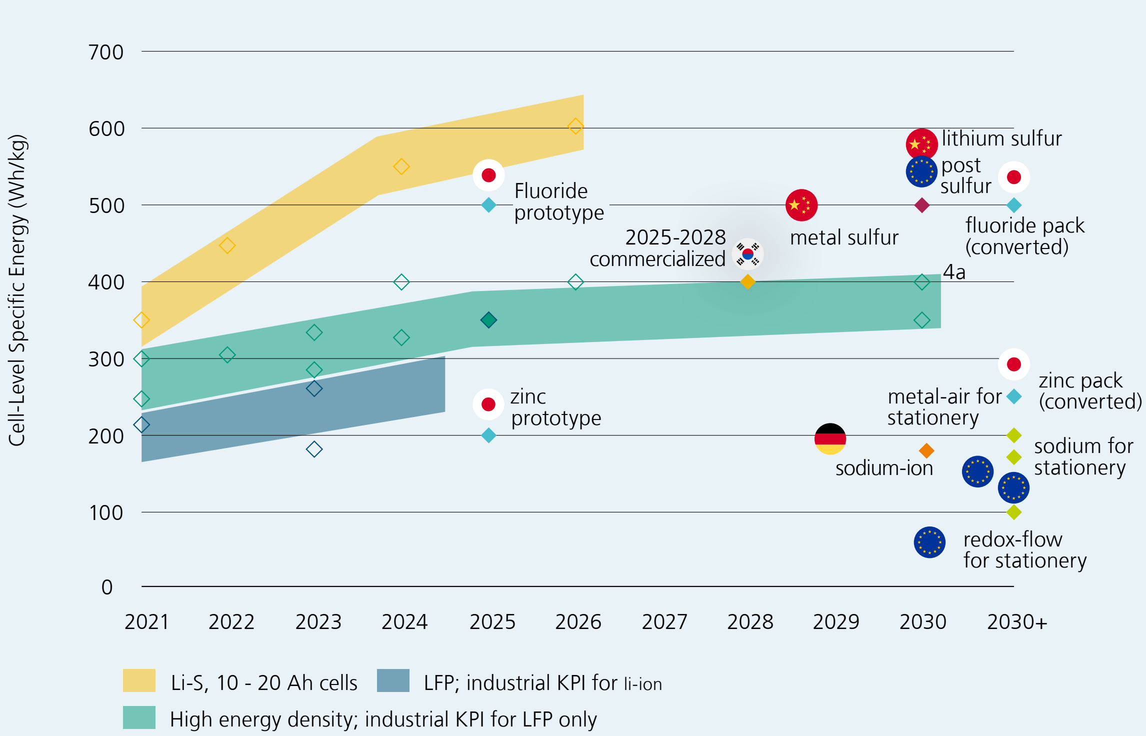


Figure 3: Roadmaps for the cell-level specific energy of alternative batteries compared with KPIs of established battery cells (source: own representation based on official documents and market reports).



Besides the gravimetric energy density countries have also set targets for further KPIs such as volumetric energy densities, cycle life etc. as well as cost targets. The cost targets, for example, are similar in all countries and technologies with values of 50-60 €/kWh, for the years 2030 to 2035, possibly because alternative battery technologies also need to be able to compete with LIBs as the benchmark.

Although setting a number of KPIs can be helpful to align R&D efforts, establishing a lot of KPIs in different areas (e.g., gravimetric/volumetric energy density, cycle life, calendar life) and achieving them simultaneously can also be viewed as too challenging because some KPIs have a trade-off relationship (e.g., energy density vs. cycle life or cell safety). Also, they strongly depend on the individual application and use case being addressed.

Overall, China, the EU, and Japan tend to define many KPIs to promote R&D activities.

China's KPIs appear in various documents. Among them, the most important are the two technology roadmaps announced by CATARC and China SAE, respectively. These two organizations are known as key intermediaries in battery policy formulation, coordinating the policy discussion among different stakeholders and experts. Furthermore, the funding guidelines of national key R&D programs also contain specific KPIs to be achieved.

In the EU, KPIs are mostly articulated in the Strategic Research and Innovation Agendas (SRIA) from BEPA and Batteries Europe. As the SRIAs are discussed in a public-private partnership with many technical experts and are used as input to specify the objectives of Horizon Europe calls, the EU KPIs tend to be realistic. In addition, the EU Battery Regulation has recently introduced recycling targets.

In Japan, most KPIs are included in NEDO's basic plan for its projects and/or funding guidelines. Interestingly, the country has a higher number of "ambiguous" KPIs, meaning that they are difficult to assess due to the increased uncertainty of alternative battery technologies. NEDO has two types of KPIs for alternative batteries: one is to be achieved within a project period (test cell), and another shows a future vision when the technology is commercialized. Conversely, as in the U.S., the newly launched Green Innovation Fund provides a limited number of KPIs with a technology-open approach (the KPIs are expected to be achieved by "advanced batteries", including SSBs).

In contrast to these three countries or regions, the U.S. focuses on a smaller number of core KPIs. For example, the Battery Blueprint's medium-term goal is to showcase battery technologies that achieve a production cost of less than $ 60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free. Under a technology-open approach, the KPIs are to be achieved by "revolutionary battery technologies", including solid-state and Li-metal batteries.

South Korea's KPIs are mostly derived from the K-Battery Development Strategy. The main KPIs reflect the strategic goal of the strategy, "commercializing SSB, lithium-sulfur, and lithium-metal batteries by 2027, 2025, and 2028, respectively". As the country focuses on the early commercialization of these new technologies by industrial actors, the K-Battery Strategy includes qualitative targets (e.g. application) and numerical indicators for SSBs and alternative batteries are limited to energy density.

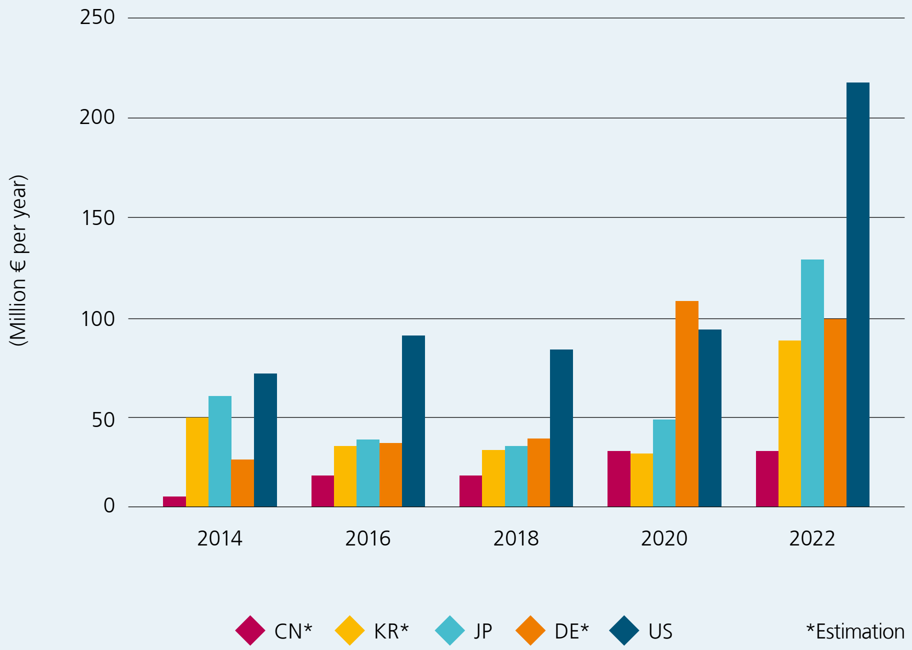
Germany did not have any KPI targets until the roof concept was recently updated in January 2023. While the previous roof concept emphasized the transfer of technology from research to industry and the strengthening of production technology, the updated version also highlights an aspect of technological sovereignty as well as a stronger focus on scalability. As such, one of the five areas of action in the new strategy is the development of promising future technology variants, with specific targets for the development of SSBs, sodium-ion batteries and other alternative batteries.

We found that each country sets and uses its technical KPIs differently. In the three countries with a higher number of KPIs, in particular, the funding guidelines specified program support for the technical KPIs.

Funding strategies in the individual countries

All the countries considered have strengthened public R&D funding since 2014. Many of the countries have experienced a rapid expansion, especially since around 2020, due to new strategies (U.S.: Bipartisan Infrastructure Act, JP: Green Growth Strategy, KR: Secondary Battery Innovation Strategy) and strategic programs (DE: Roof Concept of Battery Research in 2023, formerly Roof Concept of Research Factory in 2019). The funding has doubled and in part tripled for all countries compared to the level of funding before 2020.

Figure 4: Trend of the public R&D funding from leading ministries/agencies in the major countries.



Conclusions and outlook

Strategies are constantly being developed
All countries have relatively up-to-date strategies – and additional updates are being carried out all the time, certainly due to the "critical phase" of market ramp-up and diffusion between 2020 and 2030, the establishment of battery ecosystems globally and the current geo-political situations and the corresponding attempts to maintain or achieve technology sovereignty. Given the rapidly changing global policy climate, governments need to be more responsive to the external environment. For example, the enactment of the Inflation Reduction Act by the United States had a large impact on other countries and the EU and South Korea announced their new strategies as a countermeasure.

Strategies are becoming more market and industry oriented as battery and EV markets develops
All countries and states have specific strategies for the development of battery technology and in the last years there seems to have been a shift toward higher technology readiness levels (TRLs), industrial policies and value chain support as well as demand-side policies for EV-uptake.

Strategies are breathing the spirit of technology sovereignty amid geopolitical tensions
The external factors (pandemic, climate crisis, wars) and the unstable political environment reinforce the momentum of competition between the largest international battery players and their quest for more autonomous battery production. The transition toward electric mobility and renewable energies has been accelerated by the climate crisis and the Russian attack on Ukraine. The aspiration for more technology sovereignty was being expressed in all of the strategies well before 2022, and the pandemic with the resulting disruptions in global value chains seems to have played a big role here. The economic tensions between China and the U.S. are also evident in their strategies and funding budgets for battery technology.

Strategies increasingly combine supply and demand side measures for the development of circular ecosystems
There doesn't seem to be one right way to support battery technology development: while some are focusing more on research and supply side measures, others use a lot of demand-side-measures. In the case of China, this broad strategy with special emphasis on demand side measures for EVs has been successful in building a robust, internationally competitive battery value chain in the country. Other countries now seem to be following this lead. The stricter regulation and focus on sustainability and circularity of batteries in the EU (and to some extent the U.S.) also seem to have an effect on the other countries. Here the principle of following the "higher standard" can be observed for countries which are aiming to penetrate foreign markets.

Strategies are relying more on key performance indicators (KPIs) and include also alternative technologies

Where industrial competitiveness is concerned, R&D capacity and the achievement of KPIs are only some of the relevant factors, alongside production, other economic factors and, for example, a skilled workforce. All the major countries have strengthened public R&D funding in the last few years. Each country has defined a different numbers of KPIs with varying degrees of feasibility. Different countries are placing varying emphasis on some of the emerging battery technologies. However, it can be seen that basically all international strategies refer to lithium-ion batteries as a benchmark, solid-state batteries as a future technology currently under consideration, and alternative battery technologies to potentially increase technology sovereignty and achieve better sustainability.

Recommendations

The renewal or updating of strategies, market and industry orientation, and attempts to develop sustainable battery ecosystems are regarded as positive directions and provide orientation. The context and aim of the strategies can vary of course (e.g. depending on the country´s political positioning, funding strategies, R&D strategies, industry policy, sustainability goals etc.), but strategies should be renewed in a specific and defined timeframe (not too often) and with a mandate from the organization (the body publishing the strategy must demonstrate a clear understanding of the role and liability of the strategic goals).

Therefore, it would also be beneficial to clarify or understand what the core KPIs are for each individual country, taking into account trade-off features between different KPIs, and how the KPIs should be interpreted in the actual R&D activities (i.e., a strict mandate to achieve or just a future vision).

In all countries and regions, there is evidence that more effort is being devoted not only to formulating strategic goals, but also on monitoring the status quo and the development of the global situation so that the governments, as well as other key stakeholders, can reflect on their own policies and strategies (or even align international strategies) well in advance. Monitoring can help assess different technological, economic, and sustainable pathways, including the progress of alternative technologies. Policies and strategies can thus be underpinned by a more substantiated and reliable (data)base. However, neutrality should be ensured, and a holistic assessment framework should ideally provide more transparency and be coordinated with the key stakeholders and interest groups.

2. Introduction

2.1. Intention and context of the international benchmark

Europe is facing a crucial step in the transition to decarbonized sectors such as energy and transport sectors through electric mobility and stationary storage solutions. In this context, a European battery ecosystem with scaled production and circular supply chains shall be established in the coming years. Such ecosystems are also being built in other regions of the world, raising the question of technological competitiveness and industrial leadership.

In addition to intensifying international technology competition, a competition between political and value systems has recently emerged. Meanwhile, the transition to renewable energy and green mobility is being driven by international crises, the war in Ukraine and other geopolitical developments. The concept of technology sovereignty adds an important dimension to the established arguments for a policy oriented towards economic competitiveness and transformation and comes at a time when traditional alliances have become more fragile and the role of geopolitical access or access to critical technologies has returned to center stage.

In this context, countries around the world are renewing or adapting their policy strategies including funding strategies and agendas.

In this report, we will focus on the key international players in terms of technological and market leadership: Japan, China, South Korea, the U.S. and the EU (and therein Germany). In this dynamic international context, the policy benchmarking aims to provide an overview of the repositioning, strategies and the battery related policies and objectives of these countries and world regions in order to enable a cross-country analysis. The graph below illustrates the timeline for the publication of the key national strategy documents for the development of battery technology in these six countries or regions.

The objective of this report is to provide an overview of the strategic programs and activities for battery development by the governments of the most relevant international battery regions. A detailed analysis of the public battery policies, the framework conditions, funding programs and strategic technological objectives (KPIs) of six countries will provide the basis for a cross-analysis between the states that can support strategic orientation.

Figure 5: Overview of the publication timeline for main strategic battery documents in the past five years.

2.2. Methodology and content overview

Before compiling the relevant information and analyzing the key strategic documents for each country or world region (CN, JP, KR, U.S., EU, DE), a framework for analysis of the public battery strategies was developed with the following categories:

Political objectives and strategies

- Main actors and initiatives
- General policy objectives with respect to battery development

Funding strategies for batteries

- Past and current funding strategies
- Funding priorities and instruments
- Funding budgets

Strategic technical objectives with regard to battery development

- Specific technological focus of funding programs and strategies
  - objectives for lithium-ion batteries
  - objectives for solid-state batteries
  - objectives for alternative battery technologies
- Technical objectives and milestones (KPIs)

The relevant information is presented in a descriptive form for each country, before comparing them with each other. After the initial analysis of the cases, some additional subcategories were derived from the materials for the cross-analysis of the country strategies (see chapter 10).

Table 2: Categorization of battery technologies (taken from the SRIA of Batteries Europe, p.21).

Battery generaion	Electrodes active materials	Cell Chemistry/Type	Forecast market deployment
Gen 1	■ Cathode: LFP, NCA ■ Anode: 100 % carbon	Li-ion Cell	current
Gen 2a	■ Cathode: NMC111 ■ Anode: 100 % carbon	Li-ion Cell	current
Gen 2b	■ Cathode: NMC523 to NMC 622 ■ Anode: 100 % carbon	Li-ion Cell	current
Gen 3a	■ Cathode: NMC622 to NMC 811 ■ Anode: carbon (graphite) + silicon content (5-10 %)	Optimised Li-ion	2020
Gen 3b	■ Cathode: HE-NMC, HVS (high-voltage spinel) ■ Anode: silicon/carbon	Optimised Li-ion	2025
Gen 4a	■ Cathode: NMC ■ Anode: Si/C ■ Solid electrolyte ■ Solid state Li-ion	Solid state Li-ion	2025
Gen 4b	■ Cathode: NMC ■ Anode: lithium metal ■ Solid electrolyte	Solid state Li metal	>2025
Gen 4c	■ Cathode: HE-NMC, HVS (high-voltage spinel) ■ Anode: lithium metal ■ Solid electrolyte	Advanced solid state	2030
Gen 5	■ Solid electrolyte Li|O_2 - lithium air/metal air ■ Conversion materials (primarily LiS) ■ New ion-based systems (Na, Mg or Al)	New cell gen: metal-air/ conversion chemistries/ new ion-based insertion chemistries	>2030

For the categorization of the technological objectives, three aggregated categories for the battery chemistry types were considered:

1) Gen. 1-3 (lithium-ion batteries with liquid electrolyte),
2) Gen. 4 (solid-state-batteries) and
3) Gen. 5 alternative battery types (e.g., metal-ion, metal-air, metal-sulfur batteries).

The EU definition for different "groups" of battery technologies was under discussion in the German debate already since the beginning of battery funding before 2010, and in particular the generation labeling assumes an evolutionary development in steps from one battery generation to the next.

The KPIs were then categorized into these three technology groups and ordered according to their timeline (until 2025, until 2030 and beyond 2030). The next step was to **assess the technological feasibility based on technical expertise and relevant scientific sources.** The following categories were introduced as categories for this technical assessment:

- Realistic
- Ambitious
- Ambiguous (Questionable)
- Underambitious

In the following chapters, a detailed analysis of these categories and the respective policy targets for the above-mentioned battery types will be presented for each country or world region.

3. Public battery strategy of Germany

3.1. Political objectives and strategies

3.1.1. Main Actors and Initiatives

The German Federal Ministry of Education and Research **(BMBF)** is one of the most relevant political actor in the field of battery research, with funding ranging from basic to application-oriented along the battery value chain from materials to battery systems (also including transfer and upscaling). It has published the strategic program as a roof concept (released at the end of 2018 and renewed in 2023). This strategy combines various funding measures and programs under one roof („Dach") to support the development of a battery cell production in Germany [4].

The German Federal Ministry for Economic Affairs and Energy (BMWi), now the German Federal Ministry for Economic Affairs and Climate Action (BMWK), is another important political actor, especially with regard to the upscaling of battery production, and is involved in the activities around the European Battery Alliance and the funding of the IPCEIs.

In addition to BMBF and BMWK, there are other ministries in Germany with important contributions to battery funding (e.g. BMVI, UBA, etc.), regional funding agencies (e.g. emobilBW), etc. that actively support the research and innovation along the battery value chain.

Furthermore, there are several initiatives to be mentioned such as:

- Batterieforum Deutschland, funded by the BMBF and coordinated by the Competence Network Li-ion-batteries (Kompetenznetzwerk Lithium-Ionen-Batterien e.V.; KLiB), which organizes an annual conference in Berlin[1], and the Beirat Batterieforschung Detuschland as an advisory panel for the BMBF and its strategic research planning.
- National Platform Future of Mobility (NPM) was founded in 2018 by the Federal Minister of Transport on the basis of the coalition agreement of the 19th legislative period. The aim of this platform is to discuss strategic decisions for future mobility with relevant stakeholders.

  In addition to the initiatives above, Germany has a rich landscape of R&D actors, consisting of universities,

Figure 6: Policy timeline and strategic objectives of Germany.

2018: High-Tech Strategy 2025: Overarching science and innovation policy, one of the 12 missions is "Building up battery cell production in Germany. Dachkonzept (roof concept) for Batteries "Battery research in Germany- materials, processes, cell production", which aligned its battery funding by combining the past and ongoing activities

2019: First IPCEI on Batteries was approved (EU)

2021: Second IPCEI on Batteries (EuBatIn) was approved (EU)

2023: Update of Dachkonzept for Battery Research "Sovereignty for sustainable value creation of tomorrow"

Objectives described in Dachkonzept 2.0 (excerpted)

2026:

- At least 1/15 publication share and at least 15 % patent share
- The production of competitive battery cells based on secondary materials is possible

2030:

- At least one modern battery cell production facility on a gigafactory scale with European machinery and equipment – mainly from Germany
- Recycling of at least 90 wt.-% of the end-of-life battery materials produced at cell level into battery cell production is possible
- The scalable production of SSBs and Na-based batteries demonstrated in at least one production line

[1] Batterieforum Deutschland: https://www.batterieforum-deutschland.de/

research and technology organizations and public-private partnerships.

Important strategic documents in the context of battery development are (selection)

- High-Tech Strategy 2025 (Battery Cell Production in Germany) [5].
- Roof Concept Strategy for Batteries "Battery Research in Germany - materials, processes, cell production [4], which was updated in January 2023 as "Roof Concept Battery Research – sovereignty for sustainable value creation of tomorrow" [1]
- Important Projects of Common European Interest (IPCEIs) with German contribution [6].

3.1.2. General Policy Objectives with respect to battery development

An overarching political strategy for Germany with relevance to batteries is the High-Tech Strategy 2025, which aims to bring the country to the forefront of technological developments in order to secure jobs and prosperity. Mobility is one of the societal challenges for which battery technologies are seen as a key element. The development of battery cell production capacities in Germany is one of the corresponding missions in the High-Tech Strategy [5].

Table 3: Overview of public battery strategigies and key characteristics Germany with focus on main actors.

Aspects	Description
Overall strategic goals	The comprehensive strategy "Dachkonzept (roof concept)" published in 2018 and updated in 2023 describes the strategic objectives of battery research in Germany. To establish a technologically sovereign, competitive and sustainable battery chain for Germany and Europe [1]
Current R&D performance (publications and patents) [2]	6.6 % global share of patents (2016-2020) (accounting for approx. 44% of the patents from EU28) 5.9 % global share of publications (2017-2021) (accounting for about 35% of EU28 publications)
Current market status (raw materials, components, cells)	Components: 4% global share of cathode production (2023) Cell production: 0.88GWh (0.2% share) of EV battery cell sales in 2022 xEV sales market: 0.75 million vehicles in 2021
Technological focus/targets	The new roof concept includes more specific objectives than the previous strategy, such as: ■ Increase the share to at least approx. 6.7% for publications and 15% for patent applications by 2026. ■ Demonstrate the scalable production of a rechargeable SSB and sodium-based battery cell on at least one research production line by 2030. In addition, KPIs are newly set for SSBs, sodium batteries and other alternative batteries (Zn, Al, Fe, Ca and Mg based systems are mentioned).
Production focus/target	30 % of global battery demand from German and European production [3] At least one modern battery cell production facility on a gigafactory scale with European machinery and equipment - mainly from Germany - by 2030 [1]
Recycling focus/targets	The new roof concept has set several objectives for battery recycling and circular economy, e.g. the returning of at least 90 wt.% of the end-of-life battery materials produced at cell level can be returned to battery cell production by 2030 [1]
Response to IRA	Not explicitly mentioned in the roof concept
Major instruments	■ The 7th Framework Program for Energy Research (BMWK and BMBF) supports battery development as a topic. ■ The BMWK contributes to the coordination of two IPCEIs on batteries, investing in areas with higher TRL ■ Funding instruments under the roof concept with more than 800 million euros over a decade, including – The "Excellent Battery" program with 40 million euros – Various Competence Clusters with about 74 million euros – Development of a research factory for battery cell production (FFB) with 500 million euros ■ ClustersGoIndustry with three modules: cluster module, transfer module and accompanying module.

The funding and support measures initiated in the last decade have built out a German research community and industrial network. In terms of research activities, the share of publications on batteries in Germany has developed from less than 5 to well over 5 percent [7]. The share of patent applications has remained stable at over 10 percent, although this highly competitive field is expanding dynamically with established and new players on the market [7].

Battery production is one of the missing links in the value chain and an identified gap in Germany and Europe. Until 2020, Germany has still not have a significant share of battery cell production capacity compared to global installations, which were on the level of more than 400 GWh. For the next decade (i.e. until 2030+), annual battery cell production capacities of 400-500 GWh in Germany and 1,900-2,100 GWh in Europe have been announced. Compared to the global announcements of 4 to almost 8 TWh (even up to 14 TWh beyond 2030), this would mean a potential share of 10 percent of the global battery cell production capacities in Germany and 20 percent or more in Europe [8]. On the other hand, it is pointed out that although Germany and Europe are expected to increase their cell production capacity in the next decade, there are still gaps in the upstream – the estimated share of battery raw materials and active materials for the EU and Norway in 2030 is much lower than the estimated demand [9].

Germany's Climate Action Law from 2016 originally included a goal to make the country completely climate neutral by 2050[2]. In May 2021, the Climate Action Law was updated with a new goal of achieving the same by 2045. In addition, the goal of reducing emissions by 55% from 1990 levels by 2030 is to be changed to 65% [10]. The national climate law adopted in 2019 sets annual reduction targets for the sectors until 2030, which are in line with the European greenhouse gas emission reduction plans. For the transport sector, the reduction target is 42.1 %, while the "cut status" from 2019 compared to 1990 is only 0.6 %, which means that special efforts are to be made in this sector [10]. In order to support the climate targets, incentives for e-mobility have been introduced: since 2016, there is a purchase premium for the purchase of an EV of up to 6,000 euros per car (financed by the government and the OEMs). Other measures include tax credits for the purchase of EVs from 2020, as well as subsidies for the improvement of the charging infrastructure and public procurement of EVs. Starting in 2022, EV drivers will also be able to sell their emission reductions (THG quotas) to oil companies. Since the summer of 2021, the BMVI has been providing 500 million euros in funding for public EV charging infrastructure. Since 2018, there has been a funding program for the public procurement of electric buses with around 630 million euros [11].

The German climate targets and policies for electric mobility are embedded in the framework of EU legislation, the activities of the BATT4EU partnership, funding programs such as the IPCEIs, but also in EU regulations such as a new battery regulation.

All the German funding measures for battery development aim to be aligned with European measures (such as the European Green Deal, the IPCEIs and the Strategic Research Agenda (SRIA)).

The overall German goals for battery development can be summarized as follows:

- Domestic battery cell production of smart and sustainable batteries
- 30 % of global battery demand from German and European production [3]
- Leadership in R&D
- The central goal of the German "Roof concept batteries" is to establish a technologically sovereign, competitive and sustainable battery value chain in Germany and to achieve a more efficient transfer of research results into applications.

[2] which means to achieve „net greenhouse gas neutrality"

3.2. Funding strategy for batteries

3.2.1. Past and current funding strategies

The development of specific funding strategies for battery development began in Germany with the establishment of the Integrated Energy and Climate Program in 2007 and the National Electromobility Development Plan by 2008 [12].

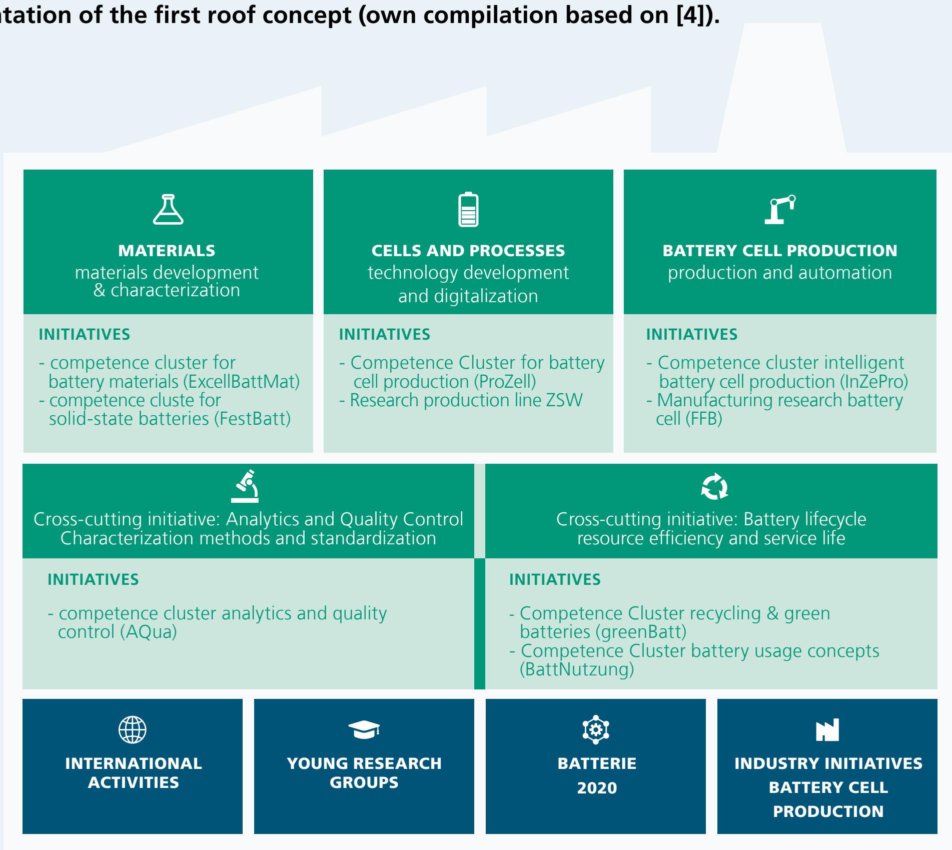
The "Government Program on Electromobility" was published in 2011 and summarizes the current status of German efforts in the field of electromobility [13]. Overall, the German government has already established a large number of political funding measures for the development and implementation of electromobility in Germany in the last years [14]. In addition to basic research by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) in the field of batteries, the BMBF's funding measures within the "LIB 2015" innovation alliance and the STROM key technologies for electromobility projects were among the most important R&D funding measures for third-generation lithium-ion batteries and post-LIB for electromobility [14]. The "Lithium-ion batteries (LIB 2015)" funding program was initiated in 2009 with the aim of developing one of the most important key technologies for the widespread use of technologies with low or zero CO_2 emissions [4].

Two other notable battery projects were SafeBatt and Alpha-Laion (focusing on battery safety and the development of traction batteries for EVs, respectively), which were lighthouse projects of the National Platform for Electromobility [12].

In order to transfer excellent research to the industrial scale, the BMBF decided in 2018 to realign its battery funding by combining the past and ongoing funding activities and programs under the umbrella of the so-called "Dachkonzept" (roof concept). The goals of the roof concept are to support the battery research, to establish battery cell production in Germany, and to achieve a more efficient transfer of research results into applications [4]. One part of the roof concept is the establishment of the "Research Factory for Cell Production (Forschungsfertigung Batteriezelle, FFB)", which is built in Münster and funded with 500 million euros [15].

The roof concept combines measures with both mission-oriented and thematically open aspects, and all parts are intended to work together to bring research results to the next level along the value chain [4]. Synergies with the European Green Deal and the IPCEI projects on batteries, which are co-funded by the BMWK, are to be created.

Figure 7: Presentation of the first roof concept (own compilation based on [4]).



A more general energy research program is the 7th Energy Research Program, in which battery development figures are listed as one of the topics [16]. In the framework of this program, the BMWK has published a call for projects [17] on battery cell production.

Since 2019, the BMWK has been contributed to the coordination of two IPCEIs on batteries [18], for which it has published a call for projects. Under the European instrument of IPCEIs, it is possible to invest in areas of higher TRL without breaching the internal market regulations on state aid.

The BMWi's call for "Research in the Focus Area Battery Cell Production" [17] is closely related to the IPCEI program and funds industrial consortia projects in the areas of

- Sustainability of batteries and recycling
- Digitalization of the battery production and the life cycle
- Innovations in testing and certification procedures
- Applications of next generation battery technologies

Thematically open measures are the open calls in various funding initiatives of the BMBF and BMWi (e.g. Battery 2020, 7th Energy Research Program).

Battery 2020 is a BMBF funding measure for the research on materials and processes for secondary batteries, which was first launched in 2014. It also includes joint projects for various applications. Among others, Battery 2020 is supposed to enable a variety of applications with different battery technologies in different phases of innovation. These activities seek to create a bottom-up pool of ideas and innovation by involving industrial stakeholders. In addition, there are thematically open funding initiatives under the roof concept, such as international activities, junior research groups and industrial partnerships for battery cell production. These are bottom-up-approaches in which ideas and innovations from industry are to be included [4].

The mission-oriented measures under the roof concept include the subtopics of research on materials development and characterization, process development and digitalization, production and automation, as well as on circularity/recycling and sustainability of batteries. All these measures are accompanied by activities to improve the efficiency and longevity of batteries and to protect resources [4].

The priorities of the updated roof concept, published in 2023 and subtitled "Sovereignty for a sustainable value creation of tomorrow", are not only to build up production capacities, but also to reduce dependence on the countries outside Europe. The new strategy also identifies the research on new types of batteries (solid-state batteries, sodium-ion batteries and other alternative batteries without lithium) as one of the five main pillars of the strategy, in the context of securing technological sovereignty in the future. In contrast to the previous strategy, the new strategy includes specific battery performance targets for each cell chemistry [1].

3.2.2. Funding priorities and instruments

The funding priorities of the IPCEI program are on sustainability and recycling, digitalization of the battery production, testing and certification, and application of new battery technologies of the next generation [18]. The BMWK strategy for batteries focuses on enabling a diverse ecosystem along the entire battery value chain, sustainability along the entire battery life cycle, and digitalization [18].

The funding priorities of the BMBF roof concept are first and foremost on lithium-ion battery research and the development

Table 4: Initiatives under the roof concept [4].

Nr.	Modules & Initiatives	Key Topics
1	Fab-Modul Materials	■ Initiative Competence Cluster for Battery Materials (liquid electrolytes) ■ Initiative Competence Cluster for Solid-State Batters (solid electrolytes)
2	Fab-Modul Cell and Processes]	■ Initiative Competence Cluster Battery Cell Production ■ Initiative Research Production Line
3	Fab-Modul battery cell production	■ Initiative Competence Cluster for Intelligent Battery Cell Production – Initiative Research Fab Battery Cell (different cell formats)
4	Cross-Cutting initiatives	■ Cross-cutting initiative analytics and quality control – Competence Cluster for Analytics and Quality Control ■ Cross-cutting initiative battery life cycle – Competence Cluster for Recycling and Green Batteries – Competence Cluster for Battery Usage Concepts

of upscaling and production processes, although research on other technologies such as solid-state batteries is also funded. The aim is to establish battery cell production capacities in Germany, primarily for automotive application in EVs. Almost all parts of the value chain are addressed, including the end of the value chain with measures and funding for recycling [4].

The roof concept program integrates different activities and instruments - from research fabs and facilities, competence clusters to cross-cutting initiatives, networks and open calls. Different key topics are implemented through three fab modules and (cross-cutting) initiatives.

In contrast, the new roof concept defines the following five fields of action:

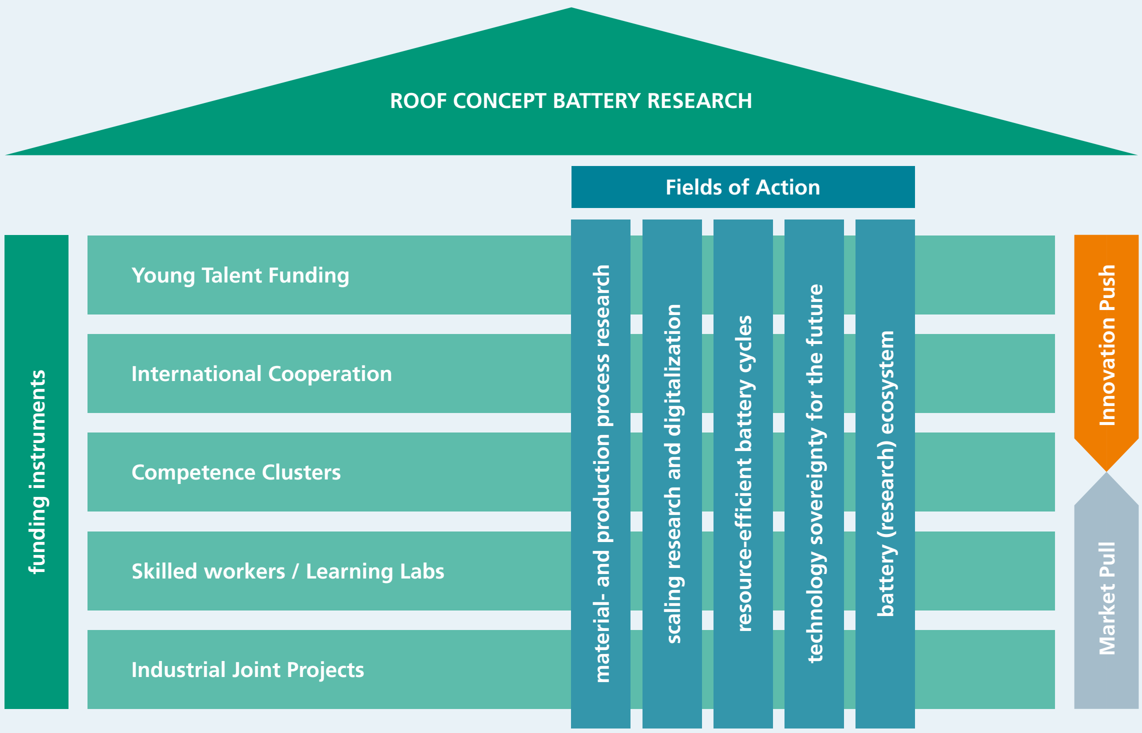
1. materials and production process research
2. scaling research and digitalization for the production
3. resource-efficient battery cycles
4. securing technology sovereignty for next generation batteries
5. building a battery ecosystem

and attempts to align various funding instruments, with both innovation-push and market-pull approaches to promote these fields of action [1].

3.2.3. Funding budgets

- Within the 7th Framework Program for Energy Research
  - From 2012 to 2020, approx. 136 million euros have been allocated for batteries for mobility and approx. 56 million euros for energy storage research for electrochemical storage [19].
  - In order to accompany and support the development of the battery value chain in the context of the IPCEIs, BMWi launched "Research in the Focus Area Battery Cell Production" in 2021 with a budget of 180 million euros [17]
- Approximately 13 billion euros (total German public + private investment in the two IPCEIs) [6], including 1.5 billion euros from BMWi [20].
- The BMBF has been supporting battery research for a decade with more than 800 million euros [1].

Figure 8: Overview of the updated roof concept (own compilation based on (BMBF 2023)).



3.3. Strategic technical objectives with respect to battery development

3.3.1. Specific technological focus of funding programs and strategies

The general funding focus of the roof concept was on battery cells and processes [4], which was articulated in the names of the competence cluster programs.

In the ***ProZell*** competence cluster, the focus is on the optimization of various production steps of the battery cell and the assessment of costs and environmental impacts. In addition, a digital twin of the battery cell production is being developed. Furthermore, there is the research production line in Ulm and the Fab module "Research Fab Battery Cell ***(Forschungsfabrik Batteriezelle)***", which is a partnership with Fraunhofer, MEET (University of Münster) and PEM (RWTH Aachen), in which the large scale production of different battery technologies and cell formats is to be researched. The aim of the ***InZePro*** competence cluster is to develop intelligent battery cell production with reducing production costs and improving product quality.

Other cross-cutting initiatives under the roof concept are the greenBatt competence cluster and the ***AQua*** competence cluster. ***GreenBatt*** explores the conditions for energy- and material-efficient battery development with life cycle engineering and the reduction of the material cycles through recycling, while ***AQua*** focuses on analytics and quality control [4].

In the competence cluster for battery materials ***ExcelBattMat***, for example, research on conventional lithium-ion batteries (LIBs) based on liquid electrolytes is funded. The focus is on the development of materials for advanced LIBs, their scalability and processability, and the analysis of their properties. For the analysis, new methods and approaches for digitalization are being developed, and for the scalability there is a strong exchange with the cell process technology ***(ProZell).***

Research on solid-state batteries (SSBs) is part of the roof concept strategy within the strategic module "Materials" in the competence cluster ***FestBatt.*** The focus is on solid-state electrolytes covering all major material classes of sulfide-based, oxide-based and polymeric solid electrolytes. The scalability of SSB production will be investigated in the "innovation laboratories" of the Fraunhofer FFB starting in 2024. Furthermore, the optimization of synthesis routes with regard to upscaling is aimed at, in order to enable the provision of low-cost and high-quality electrolytes for solid-state batteries [4].

After the update of the roof concept, a new call for proposals, **"*Clusters Go Industry*"** was published. The new funding guideline aims at the consolidation and continuation of successful research activities in order to use the know-how gained from the previous activities of the competence clusters in a profitable and purposeful way in the long term and to achieve the goal of the roof concept. The guideline consists of three modules: a cluster module to initiate a new cluster or to continue/expand an existing cluster, a transfer module to promote industrial transfer and scaling-up, and an accompanying module to strengthen the science-technology dialog between industry and science [21].

3.3.2. Technical objectives and milestones (KPIs)

KPIs for solid-state batteries

Under the new roof concept, the target for solid-state batteries by 2026 is to develop a rechargeable, multi-layer cell with solid-electrolytes with more than 200 cycles and an energy density of >800 Wh/l. The strategy also sets qualitative objectives for this type of battery, such as the establishment of research production facilities for various solid-state battery cells by 2026 (e.g. innovation labs at Fraunhofer FFB or Fraunhofer ZESS in Braunschweig) and the successful demonstration of scalable production of a solid-state battery cell on at least one research production line by 2030 [1].

KPIs for alternative batteries

In the category of alternative batteries, further Me-Ion (e.g., Na-Ion, Mg-Ion), Me-S and Me-Air are being funded [1].

In the roof concept document, the target for alternative batteries, especially those for sodium-ion batteries, is to achieve more than 190 Wh/kg as standard for large-format sodium-ion batteries, and to achieve a cycle life of at least 3,500 cycles.

In addition, the strategy aims to upscale at least one cobalt- and nickel-free cathode material and one sustainable and low-cost anode material for sodium-ion batteries, to be demonstrated on an industrial scale, and to determine the degree of drop-in capability of sodium-ion battery technology by 2026. By 2030, the production of sodium-ion batteries should be successfully demonstrated on at least one research production line.

The key objective for other types of alternative batteries (Zn, Al, Fe, Ca and Mg based systems are mentioned) is to achieve at least 1,000 cycles in cycle life for another alternative battery technology. In addition, the alternative battery technology should lead to the achievement of TRL 6-7 and to the establishment of at least one start-up company by 2026, and to the successful demonstration of the production of at least one alternative technology on at least one research production line, by 2030.

KPIs for batteries in general

The new roof concept also sets a recycling target: at least 90 wt. % of the materials produced at cell level at the end of battery life should be recycled into battery cell production.

Table 5: German KPIs for solid-state batteries until 2026 [1].

KPIs until 2026 (solid-state)	KPI (DE)	Technological feasibility assessment
Specific energy (multilayer cell)	800 Wh/l	**Ambitious** – Zero excess or so-called "anode-free" cell concept will allow high volumetric energy content at this level. Thin passive components (especially the solid electrolyte separator) are key to maximizing energy per volume. However, the realization of a multilayer cell for >200 charge/discharge cycles will remain a challenge until 2026.
Cycle life (multilayer cell)	200 cycles	**Ambitious** – While some single-layer SSBs at lab-scale have already demonstrated several hundred of full equivalent cycles, achieving a multilayer SSB with high energy density of 800 Wh/l and high cycle count by 2026 is challenging.

Table 6: German KPIs for sodium-ion batteries until 2030 [1].

KPIs until 2030 (sodium-ion)	KPI (DE)	Technological feasibility assessment
Specific energy	>190 Wh/kg	**Realistic** – current high-energy Na-Ion Batteries with layered oxide cathodes achieve up to 160 Wh/kg at the cell level. Chinese cell manufacturer CATL's corporate roadmap has announced >200 Wh/kg at the cell level for its next-generation Na-Ion battery [22].
Cycle Life	3,500 cycles	**Realistic** – for certain cell chemistries and specific cycling conditions. The Chinese cell manufacturer HiNa has demonstrated ~4000 cycles for a high-power Na-ion cell with 145 Wh/kg [23].

Table 7: German KPIs for alternative batteries until 2026 [1].

KPIs until 2026 (other batteries)	KPI (DE)	Technological feasibility assessment
Cycle Life	1,000 cycles	**Ambiguous (Questionable)** – Defining only a cycle life target for an alternative battery technology without specifying further technical or economic targets (energy/power density or costs) is very vague. Typically, battery technologies must meet a set of performance criteria (e.g. low-cost, high-power and high cycle life) to be commercially successful.

Table 8: German KPIs for batteries in general (recycling) until 2030 [1].

KPIs until 2030	KPI (DE)	Technological feasibility assessment
Recycling (cell level)	90 wt % of used battery materials	**Ambitious** – Recycling is urgently needed to close the material loop of spent batteries. The recycling targets st are challenging not only technically but also in terms of economic feasibility especially given the growth of battery technologies with lower metal value (LFP, Mn-rich or Na-ion batteries) compared to conventional Li, Ni, Co based high-energy batteries (NMC).

4. Public battery strategy of the EU

4.1. Political objectives and strategies

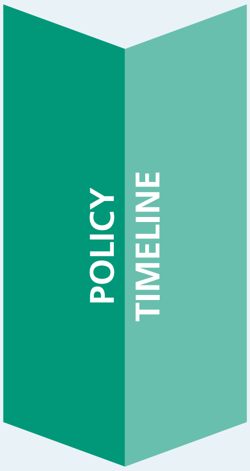
4.1.1. Main Actors and initiatives

The European Commission (EC), as a supranational institution, assumes the role of the EU executive and proposes directives and regulations as well as funding measures to the European Parliament, the European Council and the Member States, which coordinate and fund the Important Projects of Common European Interest (IPCEIs). The first IPCEI on batteries was notified in 2019 by the Member States Belgium, Finland, France, Germany, Italy, Poland and Sweden to support research and innovation in the common European priority area of batteries. The second IPCEI, called "European Battery Innovation", starting in 2021, was jointly prepared and notified by twelve Member States (Austria, Belgium, Croatia, Finland, France, Germany, Greece, Italy, Poland, Slovakia, Spain and Sweden). [29]

In 2019, the European Technology and Innovation Platform (ETIP) Batteries Europe was launched to identify gaps and needs with stakeholders from the European battery community and to explore roadmaps together with other associations [25]. Batteries Europe has been set up as an initiative and technology platform and is managed by InnoEnergy as the EC tenderer. For the European Commission, Batteries Europe has the role of coordinating research and innovation activities and bringing together the key stakeholders from the public and private sectors. It has developed a Strategic Research Agenda (SRA) in 2020, involving approx. 500 experts.

The Batteries European Partnership Association (BEPA) was launched in 2020 as a private membership association, regrouping all relevant battery stakeholders. BEPA provides input to help identify R&D priorities and call topics for the Horizon Europe Work Programs[3]. The Batteries European Partnership (Batt4EU) is a public-private partnership between the European Commission and the European battery community (represented by BEPA), including industry stakeholders, research organizations and other associations [25]. It is the largest European partnership for batteries and it has developed a Strategic Research and Innovation Agenda (SRIA) with technical KPIs in June 2021. The role of BATT4EU is to coordinate the R&I activities along the industrial value chain over different Technology Readiness Levels (TRLs). It recommends calls for the Horizon Europe Pillar 2 Work Program and creates networks between

Figure 9: Policy timeline and strategic goals of the EU.



2018: EU Strategic Action plan on Batteries as part of the Europe on the Move
2019: European Green Deal / The EC approved the first IPCEI on batteries
2020: Battery2030+ Roadmap and Strategic Research Agenda (Batteries Europe)/ Circular Economy Action Plan, in which "batteries and vehicles" is one of the seven key product value chains
2021: Strategic Research and Innovation Agenda (Batt4EU) for the Horizon Europe calls / The EC approved the second IPCEI on batteries
2023:

- Green Deal Industrial Plan as a response to the Inflation Reduction Act
  - Net-Zero Industry Act:
    Relaxing state aid rules and the Sovereignty Fund are under discussion
    Loosening state aid rules and the Sovereignty Fund are under discussion
- The new EU Batteries Regulation was adopted, which sets the recycling targets
- Update of the Strategic Research and Innovation Agenda (planned) for the next Horizon Europe calls

Goals by 2030

- Establish the world's best innovation ecosystem in Europe (Batt4EU)
- Commercialize next-generation battery technologies in order to enable zero-emission mobility and renewable energy storage (Batt4EU)
- Almost 90 % of the Union's battery annual demand being met by the Union's battery manufacturers, translating into a Union manufacturing capacity of at least 550 GWh in 2030 (Net-Zero Industry Act)

Goals by 2035

- All new cars and vans registered in Europe will be zero-emission (Fit for 55)

[3] https://bepassociation.eu/about/bepa/

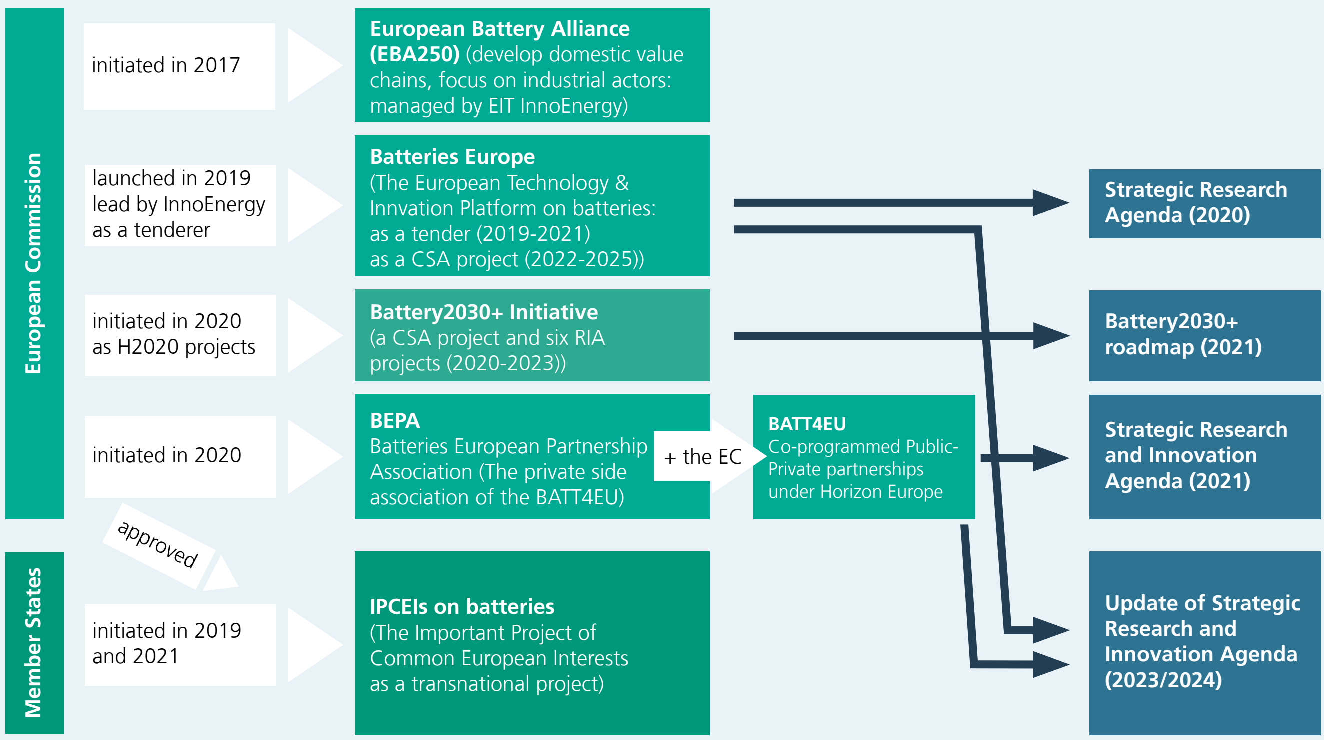
industry, Research and Technology Organizations (RTOs), universities and other battery stakeholders [25]. Together with the Sustainable Batteries Regulation, BATT4EU seeks to ensure that batteries in the EU meet safety and sustainability standards. The vision is to create the world's best innovation ecosystem by 2030 with a competitive, sustainable, and circular European battery value chain [25]. BEPA is updating the SRIA in close cooperation with ETIP Batteries Europe and plans to publish a new document by 2024.

The European Battery Alliance (EBA250) was also launched by the European Commission in 2017 to facilitate collaboration and enable the development of a domestic battery value chain. The EBA brings together more than 400 industry and innovation stakeholders from science and politics. [30].

The Horizon program funded the Coordination and Support Action (CSA) Battery2030+, which brings together all relevant actors in battery R&D to support the objectives of the Green Deal, the UN Sustainable Development Goals as well as the European Action Plan on Batteries and the SET-Plan. Battery2030+ has published a long-term technology roadmap [31].

An overview of the key actors involved in the official EU battery strategy can be summarized in the figure below.

Figure 10: Overview of key actors and strategies for the EU.



Key strategies and documents are:

- Battery Directive [32] and the new EU Battery Regulation [27]
- EU Strategic Action Plan on Batteries (2018) [33]
- Strategic Energy Technology (SET) Plan [34]
- European Green Deal in 2019 [35]
- Battery 2030+ Roadmap as a long-term technological roadmap [31]
- Circular Economy Action Plan for cleaner and more competitive Europe. Part on batteries. [36]
- Strategic Research Agenda (SRA) for Batteries in 2020 [24]
- The Strategic Research and Innovation Agenda (SRIA) of the BATT4EU Partnership in 2021 [25]
- Update of the Strategic Research and Innovation Agenda to be published by the end of 2023

Table 9: Overview of public battery strategies and main characteristics the EU with focus on main actors.

Aspects	Description
Overall strategic goals	Leading supplier of sustainable battery technologies; establishment of a competitive and sustainable value chain in the EU
Current performance (publications, patents, batteries/EVs production capacity) [2]	15.0 % global share of patents (2016-2020) – Strength in Redox-Flow (25 %, the second highest share) 16.7 % global share of publications (2017-2021), similar level of the publication shares as in the U.S. (16.2 %) 15.0 % global share of patents (2016-2020) Strength in Redox-Flow (25 %, second highest share) and Al-Ion batteries (20 %, second highest share)
Technological focus/targets	Batteries Europe SRA (2020) and Batt4EU SRIA (2021) set many KPIs for Gen.3 (liquid electrolyte based lithium-ion), Gen.4 (solid-state) and Gen.5 (alternative) batteries [24, 25]
Production focus/targets	Close to 90 % of the Union's annual demand for batteries to be met by the Union's battery manufacturers, translating into a Union manufacturing capacity of at least 550 GWh in 2030 (Proposal of Net-Zero Industry Act) [26]
Recycling focus/targets	EU Batteries Regulation (2023) with mandatory recycling targets (collection of waste, minimum percentage share of materials recovered from waste, recycling efficiency, recovery of materials) and carbon footprint declaration requirements for specific types of batteries [27]. Critical Raw Materials Act (CRM): The Regulation sets clear benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030.
Response to the IRA	Green Deal Industrial Plan (2023) to create a supportive environment for the expansion of the EU manufacturing capacity for net-zero technologies. For example, relaxation of state aid rules and a new European Sovereignty Fund are under discussion [28].
Major instruments	■ Two IPCEIs (6.1 billion euros in total, paid by the Member States) to support battery production ■ Horizon 2020/Europe calls, in cooperation with the BATT4EU partnerships (293 million euros EU contribution in 2021/2022 work program) for R&D activities ■ European Investment bank support (more than 1 billion euros of financing in 2020, leveraging 4.7 billion euros in total) ■ Individual EU countries are using the Recovery Fund to invest in the battery sector and gigafactories.

4.1.2. General Policy Objectives with respect to battery development

The EU, through its different organs and related initiatives, has formulated a number of different policies and strategies that are relevant to the development of battery technologies in the areas of decarbonization, energy, raw materials, circular economy and innovation. The following are the main objectives that set the direction for the public policy on batteries.

With the European Green Deal and the commitment to the Paris Agreement, the EU wants to achieve a rapid transition from fossil fuels to renewable energy sources and the electrification of industrial sectors such as transport and energy, for which batteries are the key enabling technology. The EU aims to make Europe climate neutral by 2050 and to decouple economic growth from resource use [35]. Sustainable batteries play a strategic role in this context, enabling climate-friendly mobility and decoupling energy production from energy consumption. As the transformation of the transport sector in EU countries gains momentum, the demand for batteries in Europe is continuously increasing and is expected to continue growing tremendously in the coming years [25]. In order to meet the growing demand for battery cells, a significant increase and expansion of production capacity is required. In addition, the current high dependence on non-European battery cell suppliers is seen as a significant risk factor for security of supply. The EU is therefore striving to establish European battery cell production to cover as much of the battery value chain as possible within the EU. The central arguments for this are the achievement of climate targets, securing the competitiveness of the European industry and establishing a battery value chain with a minimal environmental footprint.

The goals of the EU Green Deal will be implemented for battery technology with the Strategic Action Plan for Batteries [33]. This represents a holistic support concept for the development of a closely networked and competitive battery value chain. Specifically, the Action Plan provides for:

1) Securing access to raw materials outside the EU, development of raw material sources within the EU and access to secondary raw materials through battery recycling;
2) Strengthening of technological capacities through research and innovation;
3) Support of highly scaled and competitive battery cell production;
4) Education of human capital in all parts of the value chain;
5) Promotion the sustainability of batteries.

Regulations related to batteries or their applications

EU legislation, such as the Batteries Directive from 2006, applies to all types of batteries, regardless of cell chemistry, size or design. The aim is to avoid batteries containing hazardous substances, to achieve high recycling rates and set provisions on labelling for the removability of batteries. It has a major impact on all stages of the value chain and in particular on distributors, end-users and operators [37].

New conditions and developments have led to the need to update the Battery Directive [38]. Among these developments is the increasing (exponential growth) demand for batteries, leading to an increase in demand for raw materials (in particular cobalt, lithium, nickel and manganese) with a significant environmental impact. In addition, the waste of spent batteries is increasing and the number of lithium batteries ready for recycling is expected to increase 700-fold between 2020 and 2040. The aim of the updated Directive, which is part of several initiatives accompanying the European Green Deal, is to achieve circularity in the sector. The proposal for the new regulation was published by the EC in December 2020 [39] and finally adopted in July 2023 as the new EU Batteries Regulation [27].

The aim is to put in place minimum sustainability standards and extended producer responsibility for batteries placed on the EU single market. The new regulation would introduce circular economy principles (e.g. closing material loops, minimum recycled content) and mandatory sustainability requirements (carbon footprint rules, labeling, performance, safety and durability criteria and creation of a battery passport) [40]. For example, the regulation sets mandatory targets for recycling (waste collection, minimum percentage of materials recovered from waste, recycling efficiency, material recovery) and will also require the carbon footprint declaration for EV batteries, industrial rechargeable batteries with a capacity greater than 2 kWh and LMT batteries [27].

Another relevant policy is the new Circular Economy Action Plan (March 2020), which sets the objectives to improve the collection and recycling rates of all batteries. The Plan addresses seven key product value chains with priority, batteries and vehicles being one of them. The following changes are highlighted [36]:

- Rules on recycled content and measures to improve collection and recycling rates of all batteries, ensure recovery of valuable materials and provide guidance to consumers
- Addressing non-rechargeable batteries with a view to progressively phasing out their use where alternatives exist
- Sustainability and transparency requirements for batteries taking into account, for instance, the carbon footprint of battery production, ethical sourcing of raw materials and security of supply, and facilitating reuse, repurposing, and recycling
- Rules on mandatory recycled content for certain materials in components for end-of-life vehicles are to be revised. This may also have an impact on the recycled content of valuable battery materials.

In more recent strategic documents, such as the SRIA, the EU sets the objective to be the leading supplier of sustainable battery technologies (lifecycle sustainability is key for the European Green Deal goals) and to achieve the establishment of a competitive and sustainable value chain in the EU and increase domestic production capacity [25].

After the Russian attack on Ukraine, the European Commission announced the REPowerEU Plan in May 2022 as a way to rapidly reduce dependence on fossil fuels. Among other things, the plan aims to support an accelerated deployment of renewable energy. However, energy storage and batteries are barely mentioned in this new policy [41].

Public policy as incentives for e-mobility and battery development

The EU wants to encourage the purchase and use of zero- and low-emission vehicles (ZLEV) with a super credits systems that will apply to passenger cars with emissions of less than 50 g CO_2/km (NEDC) in the years 2020 to 2022 [42].

The European Green Deal sets a target of 13 million zero-emission passenger vehicles stock by 2025, with a voluntary target of a 15 % share of EVs in total vehicle sales by 2025 and 35 % by 2030 [43]. Some European governments and cities have announced their intension to ban the sale of internal combustion engine (ICE) vehicles [44]. For example, many cities, including Copenhagen, Milan and Paris have signed the Fossil-Fuel-Free Street Declaration which bans ICE vehicles from 2030. France and Italy have already committed to 100 % zero-emission vehicle sales by 2040. These developments demonstrate the need for alternative transportation and energy systems supported by high-performance and sustainable battery technologies.

EU's response to the U.S. Inflation Reduction Act (IRA)

Following the announcement of the Inflation Reduction Act (IRA) in the U.S., the EC has already expressed its concerns regarding the protectionism enshrined in the IRA [45]. As a countermeasure, the EU released its Green Deal Industrial Plan in February 2023 to create a supportive environment for the expansion of EU manufacturing capacity for net-zero technologies. Under the plan, the amendment of the Temporary Crisis and Transition Framework is discussed, to support investment in the EU by relaxing state aid rules [28]. The EC also proposed the Net-Zero Industry Act as part of the Green Deal Industrial Plan to simplify the regulatory framework and improve the investment environment for net-zero technologies. For the battery industry, this strategy would aim for almost 90 % of the EU's annual battery demand to be met by its manufactures, which would mean an EU manufacturing capacity of at least 550 GWh in 2030 [26].

In addition, the EC will facilitate the use of existing EU funds to finance cleantech innovation, manufacturing and deployment, such as REPowerEU, InvestEU and the Innovation Fund. In the medium term, a new European Sovereignty Fund is under discussion to maintain a European edge in critical and emerging technologies relevant to the green and digital transitions [28].

The EC is also negotiating a Critical Raw Materials agreement so that the U.S. government will treat the EU as an FTA-like partner for the purposes of the IRA.

4.2. Funding strategy for batteries

4.2.1. Past and current funding strategies

In the past there have been several funding programs related to batteries.

Between 2007 and 2016, 135 battery-related projects were supported by the EU R&I Framework Programs receiving 375 million euros in funding 180 million in private co-funding [34]. From 2014 to 2020, the central funding program for research and innovation in the EU was Horizon 2020, which has allocated 1.34 billion euros to projects for energy storage until 2020 [25].

In 2017, the EC launched the European Battery Alliance (EBA) to support the scale-up of battery manufacturing capacity in the EU, building a collaborative platform with key industry stakeholders, interested Member States and the European Investment Bank. In 2018, a dedicated strategic action plan on batteries was adopted as part of the "Europe on the Move" mobility program.

In 2019, the European Technology and Innovation Platform (ETIP) "Batteries Europe" was launched by the European Commission to develop a global strategic R&I agenda for batteries.

Through the Horizon program, the Coordination and Support Action "Battery 2030+" was established, which later published the Battery 2030+ roadmap. A total of 42 million euros from the H2020 program were allocated to calls in line with this roadmap [25]. This long-term technology roadmap focuses on different topics in a chemistry-neutral approach, such as the integration of smart functionalities with sensing and self-healing, but also other cross-cutting areas such as manufacturability and recyclability. In terms of cell chemistry, the following categorization is made:

- Generation 3: advanced lithium-ion batteries
- Generation 4: solid-state batteries with lithium-metal anode
- Generation 5: lithium-air batteries, lithium-sulfur batteries

The roadmap also mentions future battery chemistries and post-lithium battery chemistries (Na-ion, multivalent metal-ion, metal-air, redox flow, etc.). Narrative short- medium- and long-term goals are given for these topics.

There are calls for projects within the main EU funding program: Horizon Europe Work Program 2021-22. Under the call "Cross-sectoral solutions for the climate transition" there is the program "A competitive and sustainable European battery value chain" with a budget of 293 million euros [46].

To build critical mass for battery value creation in the EU, two battery IPCEIs have been approved by the Commission in 2019 and 2020, involving 60 companies from 12 member states. The companies will receive a total of 6.1 billion euros in public funding, which is expected to leverage many times more private investment in cell production capacity expansion, recycling and materials development and reprocessing [25]. The first IPCEI with 3.2 billion euros, approved in 2019, was notified jointly by Belgium, Finland, France, Germany, Italy, Poland and Sweden, with the commitment of 28 leading companies such as BASF, Solvay, Endurance, Umicore or BMW for innovative projects. At the beginning of 2021, a second IPCEI with a budget of 2.9 billion euros was approved and notified by twelve Member States (Austria, Belgium, Croatia, Finland, France, Germany, Greece, Italy, Poland, Slovakia, Spain and Sweden) and with the commitment of 66 companies such as Varta, Northvolt, Tesla or Keliber.

In February 2021, the European Parliament approved the largest stimulus package to date - the 672.5 billion euro Recovery Fund. The funds (312.5 billion euros in grants and 360 billion euros in loans) will be used to finance economic recovery and strategically important projects to achieve climate and sustainability goals and digital transformation [47]. Individual EU countries are using these funds to invest in the battery sector and gigafactories [48]. There are currently 22 gigafactories planned in the EU to manufacture battery cells [49].

4.2.2. Funding priorities and instruments

Under Horizon 2020, 114 million euros were available for R&D on next-generation batteries, while a total of 500 million euros were requested by applicants. For the specific area of solid-state batteries, 25 million euros were foreseen, while 101.9 million euros were requested through project proposals.

Several industrial and public initiatives are underway to build significant production capacity for lithium-ion batteries in general. The research and innovation alliances at EU (Batteries Europe) and national level (e.g. Batterie2020 in Germany) also support research on solid-state batteries as an emerging technology.

The European Commission has declared battery research and innovation a European priority area and has approved two IPCEIs on batteries. The first was notified jointly by Belgium, Finland, France, Germany, Italy, Poland and Sweden. These Member States will provide up to 3.2 billion euros over the coming years, and are expected to leverage an additional billion euros in private investment [50]. In the framework of this IPCEI, consortia of companies have been formed with the aim of building battery manufacturing capacity. The focus is on lithium-ion batteries with both liquid and solid electrolytes (the first consortia for the battery IPCEI include Opel, SAFT, BMW, VARTA and BASF [50]).

In early 2021, the European Commission approved the second major European project for battery cell production called "European Battery Innovation - EuBatIn", which is coordinated by Germany [51]. The second battery IPCEI coordinated by Germany and includes France, Belgium, Austria, Italy, Poland, Sweden, Finland, Slovakia, Croatia and Greece.

The public-private partnership BATT4EU has developed the Strategic Research and Innovation Agenda (SRIA), which defines key R&D topics. For its implementation, 925 million euros will be allocated within the partnership between 2021 and 2030. BATT4EU coordinates the execution of the R&D, the implementation of its results and advises the Commission on priority technology areas and activities to be included in EU funding programs. In the framework of the Green New Deal and through a participatory process with a wide range of stakeholders, the BATT4EU initiative developed the SRIA with six key R&I areas to improve the competitiveness and sustainability of the European battery sector:

- Area 1 Raw materials and recycling:
  sourcing in Europe, recovering valuable metals and materials from end-of-life electronics.

- Area 2 Advanced materials and manufacturing:
  focusing R&D activities on advanced materials (cathode, anode, separator, electrolyte materials), developing European battery cell mass production capability.

- Area 3 Battery end-uses and operations:
  battery systems for transport and mobile applications, investments in cost-effective energy storage to improve grid flexibility and stability.

- Area 4 Safety:
  investments in battery safety (intrinsic safety of electrochemical components) to enable trust and adoption of e-mobility.

- Area 5 Sustainability:
  economic, social and environmental sustainability as a key differentiator for EU battery technology, holistic perspective integrating environmental and social life cycle assessments and multi-criteria decision analysis.

- Area 6 Coordination:
  comprehensive and coordinated research and technology roadmaps for short- and long-term, strategic coordination and alignment across the value chain to achieve sustainability and economic impact objectives.

The SRIA details technical and specific objectives and provides milestones and timeframes for activities and expected outcomes.

4.2.3. Funding budgets

- Two IPCEIs: in total 6.1 billion euros paid by the Member States, which is expected to leverage an additional 14 billion euros in private investment [52].

- 1.34 billion euros in Horizon 2020 (2014-2020) to projects for energy storage on the grid, low-carbon mobility and more, including battery energy storage [25].
  - Approximately 293 million euros for battery related projects in the Horizon Europe Work Program 2021/2022 [46].
- The EC envisages to dedicate up to 925 million euros to action within the scope of the BATT4EU between 2021 and 2030 for the implementation of the SRIA [25] under the Horizon program.
- Battery-related projects are also supported by the European Investment Bank, with more than 1 billion euros of financing in 2020, leveraging a total of 4.7 billion euros [53].

4.3. Strategic technical objectives with respect to battery development

4.3.1. Specific technological focus of funding programs and strategies

The SRA provides (among others) battery KPIs for specific cell chemistries, namely lithium-ion batteries (Gen. 3, for mobility and stationary application) and solid-state batteries (Gen. 4). For alternative batteries (Gen. 5), only the target TRLs for each battery chemistry are mentioned. The document also presents a detailed and comprehensive set of KPIs for each application area (e.g. light-duty BEV, medium- and heavy-duty BEV, light-duty PHEV, etc.) but notes that the KPIs are based on a subjective recommendation by some of the key stakeholders and will be open to further consultation [24].

In the SRIA, the goal is to move from the technology focus of commercial lithium-ion batteries to advanced lithium-ion batteries (Gen. 3), to solid-state batteries (Gen. 4), and then from 2035 to post Li-ion batteries (Gen. 5) [25]. Since the SRIA used the SRA as an input, the two documents show very similar KPIs for Gen. 3 and Gen. 4 technology, as examined in the next section.

The objectives of the SRIA are more focused on outcomes and less on specific technologies, even though KPIs are defined for the different generations of battery technologies are. For example, there are also many strategic objectives related to the development of the value chain, i.e. for raw materials, processing or end-of-life management and recycling.

The operational objectives of the SRIA [25] are:

- 60 % increase in battery energy density (compared to 2019 baseline)
- 30 % increase in battery power density and charging rate (compared to 2019 baseline).
- Double cycle lifetime (compared to 2019 baseline).
- 60 % of cost reduction (compared to 2019 baseline).
- Ensure battery safety in the different target application sectors - Develop and adopt safety assessment methodologies (target EUCAR safety level 4 for automotive, level 2 for aviation and waterborne).
- Implement worldwide best available technologies (BATs) in manufacturing and recycling operations.
- enhance the sustainability of the main supply chains of battery's raw materials and achieve the lowest possible carbon footprint of the supply chain from raw materials extraction through battery manufacturing, use and recycling (recycling efficiency in % and CO_2 footprint of batteries over their full life cycle)

The Battery2030+ roadmap is rather mission-oriented as the Green Deal aiming for sustainable and high-performance batteries at the same time to reach the the European Green Deal goals and advocating a chemistry-neutral approach [31]. However, Battery2030+ highlights the need for research on post-lithium battery chemistries (sodium-ion, multivalent metal-ion, metal-air, redox flow, etc.) and unknown future battery technologies.

Lithium-ion batteries:
The main R&D focus for Li-Ion battery technologies according to the SRIA is to improve energy density, but also to improve application relevant KPIs [25].

The SRIA states that research should focus on high capacity/high voltage stable active cathode materials. These should be combined with high-capacity anodes and new liquid electrolytes and separators with reduced thickness and cost. Another goal would be NMP-free processing.

Solid-state batteries:
In the SRIA, solid-state batteries - including organic, inorganic and hybrid materials - are referred to as Gen. 4 batteries. There are the different generations of Gen. 4 batteries: 4a) NMC cathode + Si/C composites + solid electrolyte, 4b) NMC cathode + Li metal + solid electrolyte and 4c) high-voltage cathode + Li metal + solid electrolyte [25].

Alternative battery technologies:
In the SRIA, post-Li-ion or alternative battery technologies are referred to as Gen. 5 batteries. Examples of post Li-ion Gen. 5 technologies are Li-Air, Li-sulfur, Na-ion, multivalent metal-ion, other metal-air or redox-flow batteries. As stated in the SRIA, these alternative battery technologies will become more relevant after 2030. However, these battery technologies are prominent in the SRIA. For beyond-Li batteries, the focus is on mobility applications, but also on stationary storage applications.

4.3.2. Technical objectives and milestones (KPIs)

Mid-term objectives and technical milestones (until 2030)

The overarching vision of the BATT4EU partnership is to have the best innovation ecosystem in the world for a competitive, sustainable and circular European battery value chain. Europe should be ready to commercialize next-generation battery technologies by 2030 to enable zero-emission mobility and renewable energy storage [25]. Other strategic objectives to be reached by 2030 are the decarbonization of battery raw material processing and the sustainable production of raw materials for new battery technologies.

The strategic actions of the area "processing of primary and secondary battery-grade materials" of the SRIA until 2028 are:

- Development and evaluation of tracing and labelling technologies through the whole life cycle (CSA)
- Estimating the resource/resource basis in the EU and the requirements for raw materials sourced outside of EU
- Recovery of metals and chemicals from new sources such as industrial or urban wastes
- Development of new graphite-based feedstock in synthetic graphite production

Long-term objectives and technical milestones for the EU (beyond 2030)

In terms of long-term objectives beyond 2030, the Batt4EU partnership has only defined KPIs for alternative (Gen.5) battery technologies.

For Gen.5 batteries for mobility application, BATT4EU wants to develop different materials systems and technologies, such as metal-air, metal-sulfur and new ion-based systems, with a time to market of 2030 (+) [25].

KPIs for lithium-ion batteries (by 2025/by 2030)

In addition to the objective of sustainable processing, refining and recycling of raw materials and battery grade graphite, the following short-term strategic objectives by 2025 have been identified in the SRIA [25] specifically for LIB (Table 10).

While these are more general KPIs relevant to LIBs, these KPIs are mentioned in the SRIA for Gen. 3b (commercial Li-ion to advanced Li-ion), in line with the Batteries Europe SRA[4] (Table 11).

In the Horizon Europe Work Program 2021/2022 there are several calls for battery projects with specific KPIs, including one on "Advanced high-performance Generation 3b (high capacity / high voltage) Li-ion batteries supporting electro mobility and other applications" [46]. The call defines the KPIs by 2025 and beyond in line with the SRIA.

Table 10: EU's KPIs on Gen.3 batteries until 2025.

KPIs until 2025 (gen. 3)	KPI (EU)	Technological feasibility assessment
Weight reduction cell/pack battery packaging	70 %	**Realistic** – The reduction of the cell/pack packaging mass fraction may be achieved by increasing cell format (e.g. 18650 -> 21700 -> 46xx format) or by novel pack concepts (e.g. cell-to-pack or cell-to-chassis technology).
EV driving range	>20 %	**Realistic** – This may be achieved through multiple strategies: a) use of lightweight materials (also beyond the battery pack), b) use of increasingly energy-dense batteries. c) optimization of other vehicle properties (tires, aerodynamics).
Charging time Power capability	<10 min >350 kW	**Ambitious** – Ambitious for high-energy LIBs, especially for full charge (from 0-100 % SoC); regular fast charging may negatively affect battery health. Progress may be made through optimized electrode design (low-tortuosity), as recently announced in CATL's fast-charging Shenxing LFP-battery (fast charging to 80 % SoC within 10 minutes) [54].

Table 11: EU's KPIs on Gen.3b batteries until 2025.

KPIs until 2025 (Gen. 3b)	KPI (EU)	Technological feasibility assessment
Specific energy (cell level)	350-400 Wh/kg 750-1000 Wh/l	**Ambitious** – Advanced high-energy Gen.3b lithium-ion batteries (e.g. high-silicon anode vs. high-capacity lithium/manganese-rich cathode) may reach specific energies of up to 400 Wh/kg on cell level. However, this value is likely to mark the physicochemical limit of insertion-based cell chemistries, not relying on a lithium metal anode. To achieve higher energy contents, batteries based on lithium-metal anodes (or anode-free cell concepts) are needed. The volumetric energy of large-format cylindrical LIB cells with 46xx-format and high-energy active materials (without silicon) reaches up to 710 Wh/l. Companies such as the U.S. startup Amprius have announced ultra-high energy density LIB cells with silicon nanowire-based anodes and liquid electrolyte with 1300 Wh/l. The cyclic lifetime is likely to be lower than that of a conventional LIB in such an energy-density optimized cell.
Power density (cell level)	700 W/kg and 1500+ W/l	**Realistic** – Discharge currents up to 2C are feasible with high-energy cells.
Operating Voltage	>4.7 V	**Ambiguous** – Only very few cathode active materials with relatively low technological maturity, e.g. $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO) or $LiCoPO_4$ allow such high cell voltages for LIBs. The high operating voltage alsois beyond the electrochemical stability window of state-of-the-art liquid electrolytes. Anode material chemistry also impacts the resulting operating voltage. High-capacity Si/C anodes composite typically result in a lower cell voltage (-300 mV) compared to graphite-based LIBs.
Cycle life	>3,000 (high-capacity applications) >2,000 (high-voltage applications)	**Realistic** – High-energy LIBs (without Si-based anode) should reach 3000+ deep cycles. High-voltage cells require a stable electrolyte formulation for these high cycle numbers. However, high cycle numbers are challenging to reach with Si-based anode materials (Gen. 3b), which are known to immobilize lithium each cycle and thus lead to rapid capacity decay. Cycle life beyond 1000 cycles has recently been reported by a U.S. startup company.
Cost (pack level)	<100 €/kWh	**Realistic** –However, rising raw material costs due to rapidly increasing demand and supply chain issues might jeopardize this cost target, as materials contribute significantly to battery costs. The battery market is currently diversified in terms of cell chemistry, e.g. low-cost LIBs based on LFP cathode and premium LIBs based on NMC cathode.

These KPIs for lithium-ion batteries are listed in the SRA under "Research & innovation on Li-ion batteries for stationary storage applications" [24]. The targets in the SRIA under "outcome until 2030" are basically the same as the KPIs in the SRA, with the addition of the pack-level cost target.

In the Strategic Action 4 of the SRIA, Li-ion (Gen. 3) batteries for stationary storage for commercial high-power applications have the following KPIs [25] (Table 12). For cost per cycle, the KPI is <0,05 €/kWh/cycle for utility-scale applications, but this KPIs is difficult to assess.

[4] In the SRA, the time to market is defined as "2025(+)" (Batteries Europe 2020).

Table 12: EU's KPIs for Gen.3 batteries for stationary storage until 2030.

KPIs until 2030 (Gen. 3 for stationary storage)	KPI (EU)	Technological feasibility assessment
Energy density (cell level)	>500 Wh/l	**Realistic** – feasible with LIB technology.
Cycle life	>6,000 cycles	**Realistic** – e.g. for LFP/C-based LIBs.
Rate capability	5-6C (for backup charging stations)	**Realistic** – feasible with a high-power LIB.
Cost (pack level) (only in the SRIA)	75 €/kWh	**Realistic** – considering a Ni/Co-free cathode chemistry.

Table 13: EU's KPIs for Gen.3 batteries for utility-scale appliations until 2030.

KPIs until 2030 (for utility-scale applications)	KPI (EU)	Technological feasibility assessment
Energy density (cell level)	>500 Wh/l	**Realistic** – feasible with LIB technology.
Cycle life	Lifetime of 10,000+ cycles	**Realistic** – e.g., for LFP/C-based LIBs.

KPIs for solid-state batteries (until 2030)

The SRA and the SRIA states that developments should range from the use of conventional materials (Gen4a) to the use of Li-metal based anodes (Gen4b) with or without high voltage cathode materials (SRA [24], SRIA [25], P.53); (Table 14).

KPIs for alternative battery technologies (beyond 2030)

The general KPIs for alternative battery technologies (Gen 5, mobility application) for the timeline beyond 2030 are the fo llowing (Table15).

Other KPIs for Gen. 5 batteries in stationary storage applications are summarized in Table 16. Under the Gen. 5 category, there are also specific KPIs for redox-flow batteries in the SRIA (Table 17).

Furthermore, there are given specific KPIs for metal-air batteries (Table18). For this type of batteries from Gen.5, again th e KPI for cost per cycle is given : <0.5 €/kWh/cycle.

Table 14: EU's KPIs for solid-state batteries until 2030.

KPIs until 2030 (Gen.4)	KPI (EU)	Technological feasibility assessment
Specific energy (cell level; for Gen 4a)	>400 Wh/kg >800 Wh/l	**Ambitious** – These energy contents are very challenging to achieve with conventional (i.e., non-lithium metal) insertion/intercalation materials (Gen4a) in conjunction with any solid electrolyte.
Energy density (cell level; for Gen 4b and 4c)	>500 Wh/kg >1000 Wh/l	**Realistic** – These targets appear realistic when using a lithium-metal anode or anode-free cell concept, especially with respect to volumetric energy.
Charging rate	ability to operate at a charging rate of 3-5C	**Realistic** – Dendrite formation during charging at high rates will be the prime challenge for fast charging.
Cycle life	cycle life up to 3,000	**Ambitious** – Highly efficient plating and stripping of lithium metal is critical to achieve these high cycle numbers. However, Automotive applications typically do not require a cycle life beyond 1000 deep cycles (in most cases 500 deep cycles is sufficient).
Battery cost	Cost at pack level how to below 75 €/kWh	**Ambitious** – The amount of lithium required and the necessity for energy-intensive processing of both lithium metal and solid electrolytes that require dry atmospheres are cost-intensive and thus might jeopardize the target.

Table 15: EU's KPIs for Gen.5 batteries beyond 2030.

KPIs beyond 2030 (Gen. 5)	KPI (EU)	Technological feasibility assessment
Specific energy and energy density	>500 Wh/kg and >1,000 Wh/l	**Ambitious** – These energy density targets are likely to require a lithium-metal anode (Li/S or Li/O_2). >500 Wh/kg are realistic for Li/S batteries, while >1000 Wh/l could be achieved with Li/O_2 batteries.
Cost (pack level)	<75 €/kWh	**Realistic** – especially for sodium-ion batteries (SIBs)

Table 16: EU's KPIs for Gen.5 batteries for stationary storage beyond 2030.

KPIs beyond 2030 (Gen. 5 stationary storage)	KPI (EU)	Technological feasibility assessment
Specific energy and energy density (cell level)	180 Wh/kg and 500 Wh/l	**Realistic** – Currently, 160 Wh/kg can already be achieved commercially and the development target lies at 200 Wh/kg.
Cycle life	>6,000 cycles	**Realistic**

Table 17: EU's KPIs for Gen.5 batteries (redox-flow batteries) beyond 2030.

KPIs beyond 2030 (Gen. 5 redox-flow)	KPI (EU)	Technological feasibility assessment
Specific energy (cell level)	100 Wh/kg	**Realistic** – The advantage of RFBs is that the storage tanks containing the catholyte/anolyte can be scaled at will.
Energy density	>50 Wh/l	**Realistic** (on fluid level)
Cycle life	>15,000 cycles	**Ambitious** – Current vanadium-based redox flow batteries achieve 2,000 cycles.

Table 18: EU's KPIs for Gen.5 batteries (metal-air batteries) beyond 2030.

KPIs beyond 2030 (Gen. 5 metal-air)	KPI (EU)	Technological feasibility assessment
Specific energy (cell level)	>200 Wh/kg	**Underambitious** – The high specific energy of both the lithium-metal anode and the air/oxygen anode should allow for much higher specific capacities [55].
Energy density	800 Wh/l	**Realistic**
Cycle life	2,000-5,000 cycles	**Ambitious** – Cycle life is the major challenge for metal-air technologies, which currently barely exceed 50 cycles.

Table 19: EU's KPIs for batteries in general (recovery of materials) .

KPIs (all recycling)	KPI (EU)	Technological feasibility assessment
Recovery of materials **(by 2027)**	90 % for Co, 90% for Cu, 50 % for Li and 90% for Ni (90% for Pb)	**Realistic**
Recovery of materials **(by 2031)**	95 % for Co, 95 % for Cu, 80 % for Li and 95% for Ni (95 % for Pb)	**Ambitious** – Dedicated hydrometallurgical routes will be likely required to meet these targets. High lithium yields are particularly difficult to achieve [57].

KPIs for battery recycling

The new Batteries Regulation sets the following recycling efficiency target for lithium-based batteries by 2025 [27] (Table 19). In addition, the new Batteries Regulation sets a ta rget for recovery of materials in all recycling [27] (Table 20).

Table 20: EU's KPIs on lithium-based batteries (recycling efficiency).

KPIs (Lithium-based)	KPI (EU)	Technological feasibility assessment
Recycling efficiency **(by 2025)**	65 % by average weight of batteries	**Ambitious** – Industrial recycling routes (hydro- and pyrometallurgy) for LIBs are currently being developed. Design for recycling at cell and pack level will be critical to achieve high recycling efficiency. Current developments to improve the user experience, such as deeper integration of battery cells into the application (mobile phones, but also cell-to-chassis in EVs), potentially lower recycling efficiency and thus circularity. Efficient collection schemes (e.g. spoke/hub system for pre-treatment/metallurgy) for spent end-of-life batteries will also be crucial for high recycling efficiency. In addition, a complex material stream with diverse cell chemistries may require labelling (Battery Passport), pre-sorting or adaptive recycling processes. The economic feasibility of alternative battery chemistries with low metal value (e.g. LFP-LIBs or Na-ion batteries) is currently not given.
Recycling efficiency **(by 2030)**	70 % by average weight of batteries	**Ambitious** – Industrial recycling routes (hydro- and pyrometallurgy) for LIBs are currently being developed. Design for recycling at cell and pack level will be critical to achieve high recycling efficiency. Current developments to improve the user experience, such as deeper integration of battery cells into the application (mobile phones, but also cell-to-chassis in EVs), potentially lower recycling efficiency and thus circularity. Efficient collection schemes (e.g. spoke/hub system for pre-treatment/metallurgy) for spent end-of-life batteries will also be crucial for high recycling efficiency. Achieving high absolute percentage points of efficiency, particularly for non-transition metal elements, becomes increasingly difficult and costly, the higher the target is [56]. In addition, a complex material stream with diverse cell chemistries may require labelling (Battery Passport), pre-sorting or adaptive recycling processes. The economic feasibility of alternative battery chemistries with low metal value (e.g. LFP-LIBs or Na-ion Batteries) is currently not given.

5. Public battery strategy of the U.S.

5.1. Political objectives and strategies

5.1.1. Main Actors and initiatives

In the U.S., battery policy is shaped by the following public actors:

- U.S. Department of Energy (DOE)[5]: DOE establishes policies and incentives for batteries developed for electric vehicles and stationary energy storage. It funds battery development through grants, tax credits, and research funding.
  It also operates a system of national laboratories and technical facilities for research and development. [61]
  - Office of Energy Efficiency and Renewable Energy (EERE): With the programmatic priority of Decarbonizing transportation across all modes: air, sea, rail, and road, EERE leads U.S. researchers and other partners in making transportation cleaner and more efficient through solutions that put electric-drive vehicles on the road and replace oil with clean domestic fuels. EERE manages a portfolio of electric vehicles, engine efficiency, and clean domestic fuels to unlock cost-effective opportunities to reduce oil dependence, prevent pollution, and create jobs designing and manufacturing better cars, trucks, and petroleum alternatives. [62]
  - Vehicle Technologies Office (VTO): Within DOE, the Vehicle Technologies Office (VTO), under the Office of Energy Efficiency and Renewable Energy (EERE), is the division focused on research, development, and deployment of efficient and sustainable transportation technologies, including advanced battery technology. With respect to batteries, VTO focuses on reducing the cost, volume, and weight of batteries, while improving the performance and durability of vehicle batteries [63, 64].
  - Advanced Research Projects Agency-Energy (ARPA-E): Under the DOE, ARPA-E advances high-potential, high-impact energy technologies in an early-stage and supports projects based on thematic-open calls or a program for specific topics (including those related to batteries). [65]
  - Office of Basic Energy Sciences (BES): BES programs target basic scientific research that would become the foundation for new energy technologies, such as better batteries, to advance DOE's missions. [66]
  - Loan Programs Office (LPO): LPO provides debt financing for the commercial deployment of large-scale energy projects, including 17.7 billion dollars in direct loan authority to support U.S. manufacturing of fuel-efficient, advanced technology vehicles and qualifying components [67]. LPO provides more than 40 billion dollars in debt financing to support the deployment of large-scale energy infrastructure projects in the United States.
- Energy Information Administration (EIA): collects, analyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment. [68]
- U.S. Department of Defense (DoD)

Relevant public-private actors:

- Federal Consortium on Advanced Batteries (FCAB): is led by DOE. Its member organizations are various federal agencies across the government to ensure a coordinated approach to the domestic supply of lithium batteries [59].

- Joint Center for Energy Storage Research (JCESR): brings together national laboratories, universities, and industry stakeholders to collaborate on next-generation battery technology, supported by DOE [69].

- National Laboratories: works on 13 projects through a Battery Manufacturing Lab Call with nearly 15 million dollars in total funding over three years to establish public-private partnerships that address engineering challenges for advanced battery materials and devices, with a focus on de-risking, scaling, and accelerating the adoption of new technologies [70].

- ReCell Center: DOE's first advanced battery recycling research and development center. A national collaboration of industry, academia, and national laboratories working together to advance recycling technologies throughout the battery life cycle for current and future battery chemistries [71, 72].

- Battery500 Consortium: A collaboration led by Pacific Northwest National Laboratory (PNNL) between national labs and university to research more reliable, higher performing vehicle batteries. The VTO launched an innovation center for the consortium in 2016. The "500" refers to the KPI target of 500 Wh/kg specific energy at the cell level [73].

- LiBridge: Public-private partnership to develop the lithium-based battery value chain in the U.S., including initiatives such as NAATBatt International, New York Battery and Energy Storage Technology Consortium (NY-BEST), and New Energy Nexus, representing more than 600 industry stakeholders [74]. In 2022, strategy forums on the realization of the Blueprint Goals are planned by LiBridge.

[5] Organization chart of DOE: https://www.energy.gov/organization-chart

Key strategic documents:

- Energy Storage Grand Challenge Roadmap, [58]
- National Blueprint for Lithium Batteries, [59]
- "Long Duration Storage Shot", (U.S. DOE, EERE, 2021)
- Build Back Better Act (BBBA) (U.S. Government, 2021) was rejected, and the Inflation Reduction Act was finally signed into law in August 2022 as an amendment
- Infrastructure Investment and Jobs Act (also known as the Bipartisan Infrastructure Deal), (U.S. Government, 2021)
- DOE's Actions to Bolster Domestic Supply Chain of Advanced Batteries [75]

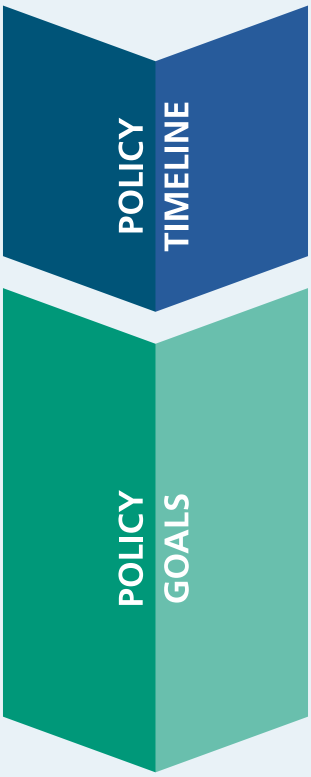
5.1.2. General Policy Objectives with respect to battery development

With the start of the Biden administration, the U.S. has put the fight against climate change at the top of its agenda. The administration aims to make the U.S. climate neutral by 2050 [76]. Biden's Clean Energy Investment Plan calls for a historically high public investment of 2 billion dollars in clean technologies to spur economic development and create jobs and a sustainable industrial base in the U.S.. Of this amount, 174 billion dollars is earmarked for jumpstarting the domestic electric vehicle market, building the battery value chain, and deploying charging infrastructure and electrifying public transportation. The U.S. government's goals for ZEVs are to have 3.3 million dollars ZEVs in LDV stock in eight U.S. states combined by 2025, to have 30 % ZEV sales for all new medium- and heavy-duty commercial vehicles by 2030, and 100 % by 2050 in 15 regions/states [43].

The U.S. also aims to become a global leader in climate-friendly technologies such as batteries [77]. To this end, the government has adopted a series of incentives in to improve U.S. competitiveness in the battery sector. In December 2020, the DOE unveiled a comprehensive energy storage technology strategy that outlines a program to advance battery technology. The central goal is to build a value chain capable of meeting all U.S. market demand for energy storage capacity by 2030 [58]. In particular, dependence on China is to be significantly reduced in this strategically important area in the future [78].

The National Blueprint for Lithium Batteries, released in June 2021, is a 10-year plan to build a sustainable and competitive battery value chain in the U.S. [59]. It includes the following goals: 1) secure access to critical raw materials by building a diversified supply (mining domestically and partnering with external suppliers) and promoting domestic recycling and substitution of critical materials through innovation; 2) expand battery materials processing and production capacity to meet domestic demand; 3) strengthen U.S. battery manufacturing, including electrode, cell, and battery system manufacturing; 4) create a recycling ecosystem and circular economy; and 5) strengthen U.S. leadership in battery technology through

Figure 11: Policy timeline and strategic objectives of the U.S.



2020: Energy Storage Grand Challenge Roadmap (DOE)

2021:

- Actions to Bolster Domestic Supply Chain of Advanced Batteries (DOE)
- National Blueprint for Lithium Batteries (FCAB)
- Infrastructure Investment and Jobs Act was passed

2022: Inflation Reduction Act was passed

Mid- and Long-term objectives described in the Blueprint (excerpted)

2025:

- Develop improved processes for existing materials to decrease cost and improve performance that enables a $ 60/kWh cell cost

2030:

- Eliminate cobalt and nickel in lithium-ion batteries
- Reduce the cost of EV pack manufacturing by 50 %
- Integrate recycled materials as a key component of a circular battery economy
- Create incentives for achieving 90 % recycling of consumer electronics, EV, and grid-storage batteries
- Accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including solid-state and Li-metal, that achieve a production cost of less than $ 60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free

intensive R&D and skills support. The National Blueprint advances the goals of international leadership in R&D and independence from competitors, particularly China, and sufficient supply of batteries for the domestic market [59].

The goal of creating a sustainable and competitive battery value chain is motivated not only by economic reasons, but also by national defense considerations, as the Department of Defense (DoD) "*requires reliable, secure, and advanced energy storage technologies to support critical missions carried out by joint forces, contingency bases, and at military installations*" ([59] , p.14).

The Biden administration wants to include stationary storage in the Federal Battery Storage Procurement Tax Credit. It also wants to strengthen the U.S. recycling, domestic battery materials, cell and pack production, and invest in the next generation of batteries for EVs. In summary, the central goal of the U.S. government is to build a value chain that is capable of meeting its own demand for energy storage capacity by 2030 and to expand a domestic manufacturing supply chain for advanced battery materials and technologies [75].

Table 21: Overview of public battery strategies and main characterisitics the U.S. with focus on main actors.

Aspects	Description
Overall strategic goals	**To build a value chain capable of meeting its own demand** for energy storage capacities by 2030 [58] By 2030, the U.S. and its partners will **establish a secure battery materials and technology supply chain** that supports long-term U.S. economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements [59].
Current R&D performance (publications and patents) [2]	8.5 % global share of patents (2016-2020), second strongest performance – Highest share in Li-air (29 %), Na-sulfur (27 %) and Li-sulfur (26 %) batteries 16.2 % global share of publication (2017-2021) – Publications share similar to the EU (16.7 %) – Strength in SSB (22 %), Na-sulfur (21 %), Redox-Flow (23 %) batteries, etc.
Current market status (raw materials, components, cells)	Component production: 2 % global share of electrolyte and 2 % of separator (2023) Cell production: 9.3 GWh (2.1 % share) of EV battery cell sales in 2022 xEV sales market: 1.49 million vehicles in 2021
Technology focus/targets	By 2030, accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including SSBs and Li-metal, that achieve a production cost of less than $60/kWh, a specific energy of 500 Wh/kg, and are Co- and Ni-free [59].
Economic/production focus/ targets	To have 3.3 million dollars ZEVs in LDV stock in eight U.S. states combined by 2025, to have 30 % ZEV sales for all new medium- and heavy-duty commercial vehicles by 2030 and 100 % by 2050 in 15 regions/states [43]
Recycling focus/targets	By 2030, create incentives for achieving 90% recycling of consumer electronics, EV, and grid-storage batteries [59].
Response to the IRA	–
Major instruments	**Consists of both demand-side and supply-side measures:** ■ Inflation Reduction Act: Tax credit for EVs (maximum 7,500 dollars per vehicle) and for domestically manufactured battery components, cells and modules. ■ Bipartisan Infrastructure Law: DOE projects for domestic advanced battery manufacturing and recycling with 2.91 billion dollars [60], investments in EV charging infrastructure, etc. ■ Advanced Technology Vehicles Manufacturing Loan Program through the DOE Loan Programs Office has 17.7 billon dollars, which will be expanded by an additional 3 billion under the IRA. ■ Public-private partnerships: Battery 500 with 50 million dollars in Phase 1 (2016-2021) / 75 million dollars in Phase 2 (2021-2026) and Li-Bridge. ■ Innovation policies: DOE VTO battery R&D funding (approx. 110 million dollars per year), ARPA-E programs, DOE Battery Recycling Prize, etc.

5.2. Funding strategy for batteries

5.2.1. Past and current funding strategies

In the past, there have been various efforts to increase the development of batteries for electric vehicles, through demand-side instruments and tax or credit incentives to stimulate demand. For example, during the Obama administration, a 7,500 dollars tax credit for the purchase of plug-in vehicles was provided in 2005 [69]. There was also the Energy Policy Act of 1992 and its update in 2005, which began to introduce renewable energy and the development of energy storage research on batteries.

In terms of R&D support, the DOE has been increasing funding for battery research for a decade. The annual amount of public funding from the DOE was around 60 million euros in 2011 and has been steadily increasing, reaching around 90 million euros in 2017 [7].

Currently, the funding strategy for batteries in the U.S., consists of both demand-side (demand-pull, e.g. incentives, tax credits, loans or public procurement) and supply-side (supply-push, e.g. R&D funding projects, infrastructure funding) instruments. Recently, the U.S. government has a adopted a series of investments and incentives for better energy storage batteries and the development of a domestic supply chain [79]. Interestingly, the programs prioritize U.S. companies that use North American intellectual property and do not use materials from a "foreign entity of concern" [79].

5.2.2. Funding priorities and instruments

The "DOEs Actions to bolster domestic supply chain of advanced batteries" not only published the National Blueprint strategy, but also announced several policies:

- DOE invests 200 million dollars to support battery technology research, development, and demonstration through federally funded grants, cooperative agreements, and research and development (R&D) contracts. In this context, a regulation tries to ensure that all innovations developed through public projects are substantially manufactured in the U.S. [75].

- A loan program will assist manufacturers of advanced technology vehicle battery cells and packs to re-equip, expand, or establish such manufacturing facilities in the U.S. In addition, the government will promote public procurement and evaluate the opportunity to deploy battery storage at federal sites and issue a call for projects for federal sites.

- In addition, the DOE has launched the Energy Earthshots Initiative with the Long Duration Storage Shot, which sets a target of reducing the cost of grid-scale energy storage by 90 % within the decade (approximately by 2030) for systems that deliver 10+ hours of duration.

On the demand-side, the U.S. has a number of laws and incentives to increase demand for electric vehicles, many of them at the state level [69].

- The Inflation Reduction Act introduces an investment tax credit, including 7,500 dollars for electric vehicles, for standalone energy storage, such as batteries or other storage devices. [80]. According to the proposal of the guidance, the requirements for the tax credit will be as follows [81]:
  - To be eligible for the credit, electric vehicles are required to undergo final assembly in North America
  - To qualify for the 3,750 dollars tax credit, a certain threshold of critical minerals in the EV battery must be extracted or processed in the U.S., in the countries with which the U.S. has a free trade agreement,or recycled in North America. The threshold percentage increases each year from 40 % in 2023 to 80 % in 2027.
  - For the remaining 3,750 dollars, the percentage of the value of the battery's components that were manufactured or assembled in North America exceeds certain thresholds. The threshold percentage increases each year from 50 % in 2023 to 100 % in 2029.

- Certain vehicles will not qualify for the credit if the vehicle contains critical minerals or battery components from a foreign entity of concern (for vehicles placed in service after December 31, 2024 and 2023, respectively).

- Procurement of EVs and Li-ion batteries by the U.S. Army: plans to electrify part of its vehicle fleet [82]. Another demand driver is large-scale grid storage in the power sector [83]. Additional tax credits, infrastructure spending and loan guarantees are planned to expand installed storage capacity.

In terms of supply-side instruments, the government is providing incentives and public funding to battery manufacturers, as well as funding battery R&D for new technologies. The U.S. government is also providing more incentives and public funding for manufacturers, as well as for the sourcing of raw materials.

- Under the Infrastructure Investment and Jobs Act (Bipartisan Infrastructure Deal), the DOE will fund projects for domestic advanced battery manufacturing and recycling with 2.91 billion dollars [60]. Specifically, it will fund battery

material refining, production plants, battery cell and pack manufacturing facilities, and recycling facilities – with the aim to create clean energy jobs.
  - A number of investments in EV infrastructure and demonstration projects to boost EV adoption: 7.5 billion dollars to build a national network of 500,000 EV chargers, 5 billion dollars to replace school buses with zero-emission vehicles, 250 million dollars for electric ferry pilot programs, 36 billion dollars for new vehicle electrification initiatives [69].

Due to limited domestic mining capacity, a low-cost, stable, and responsibly sourced supply of critical minerals has been prioritized [84]. With respect to critical resources, the recent Infrastructure Investment and Jobs Act includes 320 million dollars for an Earth Mapping Resources Initiative to map critical minerals and 140 million dollars for a Rare Earth Elements Demonstration Facility to improve U.S. capacity to extract rare earth elements.

There are also measures to directly support manufacturing actors in the U.S. battery supply chain:

- Public financing support includes tax credits [85], grant programs [86], use of public financing institutions such as the Export-Import Bank [87], loan guarantees, and subsidized direct loans [67].

- The Inflation Reduction Act also has a section titled "Advanced Manufacturing Production Credit", which includes tax credits for domestically manufactured battery components, cells and modules.

- Another source of public funding for battery manufacturing is the DOE's Loan Program Office (LPO), and its Advanced Technology Vehicles Manufacturing Loan Program (ATVM) currently has 17.7 billion dollars in loan authority, which will be increased by another 3 billion dollars under the IRA. In addition, the Energy Act of 2020 added energy storage technologies to the list of eligible industries.

Regarding public-private partnerships, there are several government-supported initiatives, including Battery500 and Li-Bridge.

- In October 2021, DOE announced Li-Bridge, a new public-private partnership to bridge the gap in developing a robust and secure domestic lithium battery supply chain. The initiative will bring together key stakeholders and organize national forums to discuss opportunities and challenges across the supply chain of batteries. Argonne National Laboratory is leading the coordination of this partnership as the facilitator between private industry and the FCAB, which also released the National Blueprint Strategy [74].

- Battery500 Consortium and Advanced Battery Materials Research Program: Phase 1 (2016-2021) of the consortium, with 50 million dollars, focused on liquid and solid-state electrolytes, diagnostics, modelling, metallic lithium, sulfur- and air-based cathodes and electrolytes, and sodium-ion batteries. In Phase 2 (2021-2026), the VTO provides 75 million dollars in funding for projects that seek to achieve the specific energy target of 500 Wh/kg at the cell level [88].

Innovation policies also play an outsized role in U.S. battery strategy. According to the VTO's 2020 Batteries Annual Progress Report, DOE VTO battery R&D funding in FY 2020 was approximately 110 million dollars. Its R&D focus has been on the development of high-energy batteries for EVs as well as very high-power devices for hybrid vehicles [89]. Recently, VTO is expanding its R&D efforts to eliminate cobalt and nickel in Li-ion battery cathodes. In addition to its grant programs, DOE supports the Critical Materials Institute, one of its Energy Innovation Hubs, which focuses exclusively on eliminating the need for materials affected by supply disruptions.

The ARPA-E program provides funding for high-potential, high-impact energy technologies that are too early for private sector investment. For example, the ongoing ARPA-E's RANGE program launched in 2013 with 36 million dollars for 22 projects, and the IONICS program started in 2016 with 37 million dollars for 16 innovative new projects [65]. Innovative technologies and processes to secure critical minerals or build a manufacturing base are emphasized. The efforts to find substitutes, eliminate the need for materials affected by supply disruptions, and expand recycling as a means of reducing import dependence, are significantly boosted [90].

The DOE EERE has launched a "Battery Recycling Price" competition in 2019 to stimulate innovation in this direction with 5.5 million dollars. The 3-phase prize competition aims to develop and demonstrate processes that, when scaled up, have the potential to capture 90% of all spent lithium-ion batteries (LIBs) for eventual recycling of critical materials (particularly cobalt and lithium) and reintroduction into the supply chain. Currently, 7 winner teams selected from Phase II are competing in the final pilot validation phase [91, 92].

Other countries' Reaction to the Inflation Reduction Act

After the enactment of the Inflation Reduction Act in the U.S., several countries announced the following countermeasure policies.

It appears that the governments of South Korea and Japan are trying to encourage their domestic companies to invest in North America, so that they would be benefited from the IRA. This may be because the objective of these countries' battery policies is not only to secure domestic production capacity, but also to achieve a certain global share (KR is targeting 40 % and JP 20 % of a global share by 2030). Since the enactment of the IRA, several Korean and Japanese automotive and battery companies have announced new investments in production facilities in North America.

In contrast, the EU wants to strengthen production capacity within the EU region. They are trying to find a way to strike a balance between establishing their sovereignty and falling into protectionism.

For China no official information and reaction was found how to countermeasure to the IRA. However, the existence of the "foreign entity of concern" clause certainly creates uncertainty for Chinese companies and has effects when it comes to building battery factories in the US. With it´s global positioning along the battery value chain and geograficально across the globe (with stronger focus on Asia and Europe), China however does not seem to fear a relevant impact on it´s battery industry – at least in the short to mid term.

Table 22: Overview of the reaction of major countries to the U.S. IRA.

Country	Reactions
EU	Green Deal Industrial Plan (2023) to create a supportive environment for scaling up EU manufacturing capacity for net-zero technologies. For example, relaxation of state aid rules and a new European Sovereignty Fund are under discussion.
South Korea	Post-IRA Public-Private Joint Strategy for Battery Industry Development (2023), including support for battery companies' and material suppliers' investments in facilities within North America (7 trillion won), LFP projects to help companies enter overseas markets, changes to tax credit rates, R&D for next-generation battery, etc.
Japan	The Japan-U.S. Critical Minerals Agreement (CMA) (2023) was signed between the U.S. and Japanese governments, expecting to be recognized as a country that has a free trade agreement with the U.S., one of the requirements for obtaining tax break through the IRA.
China	No official reaction was found.

5.2.3. Funding budgets

The sum of the current public funding in the different measures and programs related to battery development and EV uptake are approximately 175.4 billion euros:

- 5 billion euros for DOE's loan program for battery venture capital+ 2.6 billion euros on mining and recovery of resources for batteries [75]
- 156 billion euros to jumpstart the domestic electric vehicle market, build the battery value chain, and deploy charging infrastructure and electrify public transportation [76]
- ARPA-E Range research program with 32 million euros, ARPA IONIC-research program with 33 million euros [69]
- 187 million euros for Electric Vehicles Battery Research [61]
- DOE invests 179 million euros to support battery technology research, development, and demonstration through federally funded grants, cooperative agreements, and research and development (R&D) contracts [75]
- 4.9 million euros for a Battery Recycling Prize [92]
- 291 million euros for an Earth Mapping Resources Initiative to map critical minerals, 127 million euros for a Rare Earth Elements Demonstration Facility [69].

5.3. Strategic technical objectives with respect to battery development

5.3.1. Specific technological focus of funding programs and strategies

In the new version of the National Blueprint for Batteries Strategies, there are many different objectives, ordered by short and long term (by 2025 and 2030) – but they are categorized by parts of the value chain and often of a qualitative nature, with very few measurable KPIs. We can see that the U.S. government is rather pointing to production costs as KPIs (almost no specific KPIs on energy densities and technologies), and also towards incentives through public procurement and demand-side instruments [59].

The U.S. programs and strategies focus more on functional parameters and targets (e.g., cost, specific energy) than on a specific cell chemistry, and could therefore be considered more technology-open. However, as the comprehensive strategy is called "National blueprint for lithium-ion batteries", there is a focus on first generation or advanced lithium-ion batteries [59]. On the other hand, more and more focus is expected on other types of batteries based on the DOE FY2022 Congressional Budget Request, where the explanation for the budget increase for the battery and electrification section included enhanced R&D focused on lithium-metal, solid-state, and next-generation battery technologies [93].

ARPA-E's ongoing RANGE Program focuses on aqueous batteries (including alternative batteries such as zinc-air battery), non-aqueous batteries, solid-state batteries and multifunctional batteries. The ARPA-IONICS program focuses on high-performance separators and electrodes based on solid ion conductors for LIB and fuel cell applications [69].

As competition in R&D and supply chain security in the battery field has intensified between different countries, the key performance objectives in the strategic documents have changed rapidly.

According to the 2020 Annual Progress Report, the DOE VTO has established the overarching goal of developing an electric vehicle that can provide the full driving performance, convenience, and price of an internal combustion engine vehicle [89]. In addition, FY2021 Congressional Budget Justification describes the targets as follows; "*… identify new battery chemistry and cell technologies with the potential to reduce the cost of electric vehicle battery packs by more than half, to less than $ 100/kWh (ultimate goal is $ 60/kWh battery cell cost), increase range to 300 miles, and decrease charge time to 15 minutes or less by 2028.*" [93]. However, DOE FY2022 Congressional Budget Request included the new objectives to be achieved by projects which are aligned to the Blueprint-Strategy as follows [93];

- reducing electric vehicle (EV) battery cell cost by 50 % to $ 60/kWh by 2030 to achieve EV cost parity with internal combustion engine vehicles
- eliminating dependence on critical materials such as cobalt, nickel, and graphite, reducing battery supply chain vulnerabilities by 2030
- establishing a lithium battery recycling ecosystem to recover 90 % of spent lithium batteries and re-introducing 90 % of key materials into the battery supply chain by 2030

This shift in focus may reflect increasing global competition on battery costs and supply chain security, as well as a new focus on sustainability and circular production.

The DOE-funded Battery500 Consortium aims to achieve the KPI of 500 Wh/kg and 1,000 charge/discharge cycles for advanced Li batteries (i.e. Li metal anode || NMC cathode with liquid electrolyte). It has received 75 million dollars from the VTO for Consortium Phase 2, which will run from 2022-2026 [94]. The goal is to develop next-generation batteries that outperform current lithium-ion batteries in terms of specific energy.

According to the Progress Reports on Advanced Battery Materials Research (BMR) Program & Battery500 Consortium (2021 Q4) [88], Battery500 Consortium seeks to develop a commercially viable lithium (metal) battery technology with a cell-level specific energy of 500 Wh/kg before 2026 (end of phase 2) through innovative electrode and cell designs that enable the extraction of the maximum capacity from advanced electrode materials. In addition to achieving high specific energy, the project aims to achieve 1,000 cycles for the technology developed.

5.3.2. Technical objectives and milestones (KPIs)

Short-term objectives and technical milestones (by 2025)

The Blueprint Strategy lists near-term objectives (by 2025) with a more general function with regard to the battery value chain [59]:

- Establish reliable sources and supplies of raw materials

- Increase safe and sustainable U.S. production capacity of critical battery minerals
- Support the establishment of resilient domestic supply chain
- Create incentives for the growth of domestic battery materials processing, support the development of materials processing innovations to produce low/no cobalt active materials and enable scale up
- Develop improved processes for existing materials to reduce cost and improve performance that enables a $ 60/kWh cell cost
- Development of novel cell designs that reduce processing time, enable faster cell assembly, and decrease formation costs
- Dedicate resources for scale-up and commercialization of novel technologies and manufacturing techniques
- Develop form-fit-function battery standards for defense, EV, and grid applications
- Develop a federal policy framework for supporting U.S. companies in manufacturing of electrodes, cells, and packs domestically and that encourage demand growth for lithium-ion batteries
- Foster the design of battery packs for ease of second use and recycling
- Establish successful methods for collecting, sorting, transporting, and processing recycled lithium-ion battery materials, with a focus on reducing costs
- Increase recovery rates of key materials such as cobalt, lithium, nickel, and graphite, develop processing technologies to reintroduce these materials into the supply chain
- Develop methodologies for proper sorting, testing, and balancing for second use applications, establish federal recycling policies to promote collection, reuse, and recycling of lithium-ion batteries
- Develop partnerships for technology transfer and standardization of pre-application testing protocols to ensure battery technology invented in the U.S. stays in the U.S.
- government-wide standardization of lithium-based battery technologies and configurations, enhancing the ability of niche government markets such as defense to rapidly transition lithium-based battery technology to their programs and benefit from a robust, equitable, sustainable domestic supply chain
- develop a plan for enhancement of IP protection strategies, research security, domestic manufacturing export-control policies, and for engagement of international allies
- identify workforce needs in the industry and support educational programming

Mid-term objectives and technical milestones (until 2030)

A general mid-term goal of the Energy Storage Grand Challenge Roadmap is to reduce the cost of long duration storage by 90 % [58].

The National Blueprint Strategy mentions some general mid-term goals (by 2030) [59]:

- Development of cobalt- and nickel-free cathode materials and electrode compositions that improve important metrics such as energy density, electrochemical stability, safety and cost and outperform their current commercial, imported counterparts. Also, recycled materials should be integrated as a key component of circular battery economy.
- Being able to meet critical defense battery demand with multiple-source domestic suppliers
- Reduce the cost of EV pack manufacturing by 50 % through development and validation of next-generation pack materials, component, and design innovations, and advanced manufacturing and assembly techniques
- Create incentives for achieving 90 % recycling of consumer electronics, EV, and grid-storage batteries
- Develop federal policy requiring the use of recycled materials in cell manufacturing materials streams
- Accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including solid-state and Li-metal, that achieve a production cost of less than $ 60/kWh, a specific energy of 500 Wh/kg (Battery 500 sets this target for 2026, the National Blueprint under mid-term for 2030), and are cobalt- and nickel-free.

Long-term objectives and technical milestones (beyond 2030)

A general long-term KPI in the National Blueprint is to increase the public procurement measures and to achieve 100 % of clean energy supply in all administration infrastructure by 2035 [59].

KPIs for lithium-ion batteries (until 2025/until 2030)

In the National Blueprint strategy, one objective is to develop improved processes for existing materials to reduce cost and improve performance to enable cell cost levels of $ 60/kWh [59].

The goal of the Battery500 Consortium is to develop commercially viable lithium battery technologies with cell-level specific energy of 500 Wh/kg over 1,000 cycles [95].

The VTO Batteries R&D Program structure includes the Battery Materials Research (BMR) Program for advanced battery materials, the Applied Battery Research (ABR) Program for high-energy and high-power cells, and the Developer Program for the full system development & testing [96]. The ABR Program's the cell level targets are 350 Wh/kg, 750 Wh/l, reaching 1000 cycles and more than 10 years of calendar life. At the system level, the goal is to reach $ 100/kWh EV pack cost, a fast charge (80 % SOC in 15 minutes).

However, for all these KPIs, there is no precise timeline given. For the Battery500 Consortium KPIs, the second project phase will last until 2026, so we refer to these KPIs in this section:

Table 23: The U.S.'s KPIs for LIBs until 2025 (2026).

KPIs until 2025 (2026) for LIBs	KPI (U.S.)	Technological feasibility assessment
Specific energy (cell level)	500 Wh/kg (Battery 500)	**Ambitious** – This specific energy density target requires a lithium-metal anode as well as a high active-to-inactive material ratio (i.e. thin separators and current collectors, thick electrodes with low electrolyte excess). Liquid electrolytes typically have a lower density, which gives them an advantage over solid electrolytes when it comes to the resulting specific energy (given the same volume). The Chinese Academy of Sciences has recently published a report on a 700 Wh/kg prototype battery using a Li-rich cathode [97].
Cycle life	1,000 cycles (Battery 500)	**Ambitious** – he biggest challenge (besides safety) in the Battery500 endeavor is to achieve large cycle numbers beyond 1000 cycles, as the high reactivity of lithium metal with the electrolyte is known to reduce the active amount of cyclable lithium with each cycle, thus reducing capacity and cycle life. However, it should be noted that many high-energy applications (including EVs) may not require four digit cycle numbers.
Cost	≤$60/kWh cell cost [59]	**Realistic** – While this cost target is unlikely to be reached with disruptive high-energy technologies, such as those being pursued by the Battery500 consortium (i.e. lithium-metal anode), this cost target may be reached with entry-level LIBs (graphite || LFP cell chemistry) or alternative low-cost cell chemistries such as sodium-ion batteries (SIBs).

Table 24: The U.S.'s KPIs for LIBs until 2030.

KPIs until 2030 (for LIB)	KPI (U.S.)	Technological feasibility assessment
Energy density (cell level)	500 Wh/kg [59]	**Ambitious** – See comment for the same KPI by 2025 from the Battery500 Consortium.
Battery cost	U.S. $ 80/kWh manufactured cost for EV battery packs with 300 miles range [58]	**Realistic** – 300 miles (˜480 km) driving range will require a battery pack energy content of ˜60 kWh. The cost target of U.S.$ 80/kWh at the pack level is ambitious for NMC-based cell chemistries, but may be achieved with LFP-based LIBs.

Table 25: The U.S.'s KPIs for solid-state batteries until 2030.

KPIs until 2030 (for SSB)	KPI (U.S.)	Technological feasibility assessment
Energy density (cell level)	500 Wh/kg [59]	**Ambitious** – While 500 Wh/kg is technically feasible for a Li-metal based SSB, most development targets of SSB startup companies for the late 2020s are below 500 Wh/kg. Meanwhile, CATL has announced a non-specified condensed battery with up to 500 Wh/kg, which might be SSB-based.
Cost (cell level)	≤60 $/kWh [59]	**Ambitious** – The material and processing costs for SSBs are still unclear, but are estimated to be high due to the air and moisture sensitivity of the materials. For lithium, a supply gap has been predicted for the late 2020s, which would impact both anode and solid electrolyte costs.

KPIs for solid-state batteries (until 2030)

Here, the mid-term goal of the National Blueprint is to accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including

solid-state and Li-metal, that achieve a production cost of less than $ 60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free.

6. Public battery strategy of Japan

6.1. Political objectives and strategies

6.1.1. Main Actors and initiatives

The Japanese Ministry of Economy, Trade and Industry (METI) is the most important ministry for R&D in the energy sector, including battery technology. METI also plays a central role in formulating both energy and industrial strategies in Japan. For example, the Green Growth Strategy through Achieving Carbon Neutrality in 2050 was developed under the leadership of METI.

In addition, in November 2021, METI established a new public-private council (Storage Battery Industry Strategic Council) to discuss the changing environment of the battery industry and an industrial strategy to strengthen the competitiveness of batteries in terms of securing resources, strengthening the supply chain, human resources, expanding the demand, recycling and reuse, and international cooperation. The Council is composed of experts from battery manufacturers, material manufactures, other relevant private/academic stakeholders and government officials. Based on the results of the discussion, METI released a Battery Industry Strategy in August 2022 [98].

The New Energy and Industrial Technology Development Organization (NEDO) is a national research and development agency that creates innovation by promoting technology development through its programs. Under the jurisdiction of METI, NEDO has been organizing national funding projects and programs in battery fields for long years. NEDO has also developed and updated a technological roadmap for batteries to efficiently promote the development of battery technologies that meet future demand through the cooperation among industry, academia, and government, in order to maintain and improve the international competitiveness of Japanese industries [102]. However, the updating of the NEDO roadmap has stopped after the 2013 version, although NEDO originally planned to revise its battery roadmap from 2019 to 2020, according to the tender information.

The Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and two funding agencies under the MEXT (Japan Society for the Promotion of Science (JSPS) and Japan Science and Technology Agency (JST)) also support battery research and relevant research fields, but focus more on basic research and networking activities between academic and industrial actors.

The Battery Association of Japan (BAJ) is the industry association that conducts research and studies on batteries/battery appliances and promotes measures related to environmental protection, recycling, standardization, quality control and product safety. The Battery Association for Supply Chain (BASC) is another association newly established in April 2021 to promote the international competitiveness of the battery supply chain. About 100 relevant enterprises are members of this association. In the process of formulating a new strategy in Storage Battery Industry Strategic Council, METI invited these associations to the council meeting to obtain policy recommendations.

LIBTEC is the Collaborative Innovation Partnership established in 2010 under the initiative of METI to develop evaluation techniques needed to shorten development time. Its members are 35 companies (as of September 2021), including manufacturers of automobiles and motorcycles, batteries, and materials. LIBTEC provides evaluation of battery materials developed by its members and has also taken a leading role in NEDO's solid-state battery development projects.

Key strategic documents

- The Green Growth Strategy through Achieving Carbon Neutrality in 2050 [99], issued in December 2020 and updated in June 2021.
- The Battery Industry Strategy, formulated based on the discussion at the Storage Battery Industry Strategic Council [98].
- The Basic Plan for the GX was approved by the Cabinet in 2023 [103].
- The technical objectives of NEDO projects are often described in the basic plan of each project and/or in funding guidelines.

6.1.2. General Policy Objectives with respect to battery development

In response to the Paris Agreement, Japan initially set the goal of reducing GHG emission to achieve a mid-term target of a 26 % reduction in GHG emissions by 2030 compared to 2013 levels, and an 80 % reduction by 2050, in its' Plan for Global Warming Countermeasures [104].

However, in October 2020, newly appointed Prime Minister Yoshihide Suga declared a more ambitious goal of achieving a carbon-neutral, decarbonized society by 2050. In addition, at the Leaders' Summit on Climate in 2021, Suga stated that Japan aims to reduce its GHG emissions by 46 % in fiscal year 2030 from fiscal year 2013 levels, and will continue to make strenuous efforts to achieve the lofty goal of cutting emissions by 50 %. To reflect this policy shift, the revision of Japan's long-term strategy under the Paris Agreement and the National Determined Contribution was approved by the Cabinet Office in October 2021 and submitted to the UNFCCC [105].

Against this background, METI formulated the Green Growth Strategy through Achieving Carbon Neutrality in 2050 in December 2020 in collaboration with related ministries and agencies. This strategy is an industrial policy to lead the challenging goal of achieving carbon neutrality by 2050, a vision presented by the Suga administration, and aims for a positive cycle of economic growth and environmental protection. To encourage companies to take on ambitious challenges, a special fund of 2 trillion yen (approx. 12.7 billion euros) per 10 years was established in NEDO (Green Innovation Fund).

The Green Growth Strategy was further specified and updated in June 2021. In this updated version, the government placed more emphasis on increasing battery production capacity, securing raw materials, and recycling and reusing technology. With regard to battery technology, the government aimed to

- Increase domestic production capacity for automotive storage batteries to 100 GWh as early as possible by 2030.
- Achieve a price of 10,000 yen (approx. 64 euros)/kWh or less for an in-vehicle battery pack , which will bring the economic efficiency of electric vehicles and gasoline vehicles to parity, a system price of 70,000 yen (approx. 446 euros)/kWh or less (including installation costs) for household storage batteries with solar panels, and a system price of 60,000 yen (approx. 382 euros)/kWh (including installation costs) for storage batteries installed in factories and other business and industrial sectors, as early as possible until 2030.
- Achieve a cumulative deployment of approximately 24 GWh by 2030 for household and commercial/industrial storage batteries combined.
- Commercialization of all-solid state lithium-ion batteries from 2030 onwards.
- Commercialization of more innovative batteries (such as fluoride batteries, zinc batteries, and polyvalent ion batteries) around 2035.

And to achieve these targets, the government will focus future efforts on:

1) Lowering battery prices through the economics of scale,
2) Securing mineral resources,
3) Research and development/technology demonstration,
4) Promoting reuse and recycling,
5) Developing rules and standardizations [99].

Under the strategy, the Japanese government will also promote the electrification of the mobility sector and strive to make the country a leader in this field. It is stated that the government will take comprehensive measures to make electrified vehicles (EV, FCV, PHEV, and HV) account for 100 % of new passenger vehicles sold each year by 2035. As for commercial vehicles, for light-duty vehicles of 8 tons or less, the government aims to make 20-30 % of new vehicle sales electrified vehicles by 2030, and 100 % of new vehicle sales electrified vehicles and vehicles capable of using decarbonized fuels such as synthetic fuels combined by 2040. For heavy commercial vehicles over 8 tons, the government aims to introduce 5,000 units of electrified vehicles in advance in the 2020s [99].

The "Green Growth Strategy through Achieving Carbon Neutrality in 2050" outlines the examples of plans for specific regulatory reform and standardization in the automobile and battery sectors;

- Leveraging of technology-neutral fuel economy regulations.
- By FY 2021, the institutional framework for making CO_2 emissions visible throughout the lifecycle of storage batteries, ensuring ethical procurement of materials, and promoting reuse and recycling, etc., will be considered. Also, the implementation methods for making CO_2 emissions visible, etc., will be put into practice as soon as possible.

Another type of incentive-based instrument is included in the Act on Strengthening Industrial Competitiveness. It provides a tax credit of up to 10 % or a special depreciation of 50 % for the introduction of production facilities for products with significant decarbonization effects (including lithium-ion batteries) and equipment that both decarbonizes production processes and increases added value, from August 2021 [99].

In terms of battery-specific policies, Japan had heavily focused on solid-state batteries, especially through R&D funding by NEDO. However, in the public-private council held in March 2022, METI expressed its view that the government should now invest more to strengthen the production base of liquid electrolyte-based LIBs in Japan. Based on the discussion at this council, METI finalized a new "Battery Industry Strategy" in August 2022, which set three additional targets [98]:

- 1st target: Establish a domestic production base of 150 GWh per year of LIBs and materials no later than 2030, taking into account production not only for domestic automotive use but also for export and stationary use.
- 2nd target: Ensure 600 GWh production capacity (to secure 20% market share even if the global market expands to 3000 GWh in 2030) in the global market in 2030 by all Japanese companies.

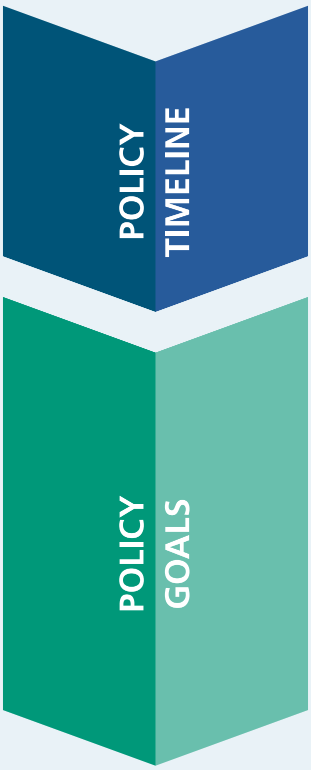
- 3rd target: Full-scale commercialization of all solid-state batteries around 2030 and securing the technology leadership position even after 2030.

Recently, the Cabinet approved the Basic Plan for GX (Green Transformation). Against the backdrop of climate change and Russia's invasion of Ukraine, the government will introduce new instruments to achieve decarbonization, stable energy supply and economic growth at the same time.

Response to the U.S.'s Inflation Reduction Act

In March 2023, the Japan-U.S. Critical Minerals Agreement (CMA) was signed between the governments of the U.S. and Japan. The agreement establishes several new commitments and areas for joint cooperation regarding EV battery critical minerals supply chains, including those related to the non-imposition of export duties on critical minerals and engagement, information sharing, and enforcement actions related to labor rights in the extraction and processing of critical minerals [106]. With this agreement, the government of Japan expects to be similarly recognized as a country with a free trade agreement with the U.S., one of the requirements for obtaining tax break through the Inflation Reduction Act.

Figure 12: Policy timeline and strategic objectives of Japan.



2020: Green Growth Strategy through Achieving Carbon Neutrality in 2050
2021: Update of the Green Growth Strategy, the launch of the Green Innovation Fund in NEDO
2022: Battery Industry Strategy (METI)
2023:
- The Basic Plan for the GX (Cabinet) with the intention to implement public-private investment in battery production and R&D
- Japan-U.S. Critical Minerals Agreement (CMA

Goals by 2030
- An automotive liquid LiB pack price of 10,000 yen/kWh, full-scale commercialization of all solid-state batteries around 2030 (Green Growth Strategy)
- 150 GWh of a domestic production base per year of liquid LiBs and materials, 600 GWh production capacity in the global market (Battery Industry Strategy)
- To establish domestic battery recycling system (Battery Industry Strategy)

Goals by 2033
- To begin the sales of EVs and PHEVs equipped with innovative batteries (e.g., zinc-anode, fluoride batteries) in Japan (NEDO RISING-3)

Goals by 2035
- To make EV, FCV, PHEV, and HV account for 100 % of new passenger vehicles sold each year (Green Growth Strategy)

Table 26: Overview of public battery strategies and main characteristics in Japan[6] with focus on main actors.

Aspects	Description
Overall strategic goals	To strengthen industrial competitiveness in the field of batteries, shifting priorities to securing production capacity (in both domestic and global markets) of LIBs, while still pursuing commercialization of SSBs around 2030 [98].
Current R&D performance (publication and patent) [2]	37.1 % global share of patents (2016-2020), the strongest performance among the 6 major countries/region . – Strength in Li-ion (42%) and Al-ion (42%) batteries 4.5 % global share of publications (2017-2021), the weakest performance among the 6 major countries/region.
Current market status (raw materials, components, cells)	Component production: 12 % global share of anode, 8 % of cathode, 12 % of electrolyte and 22 % of separator (2023) Cell production: 40.5 GWh (9.3 % share) of EV battery cell sales in 2022 xEV sales market: 0.90 million vehicles in 2021
Technological focus/targets	To commercialize SSBs around 2030 [99]. To begin domestic sales of EVs/PHEVs with advanced batteries (zinc-anode/fluoride batteries) from 2033. NEDO also has KPIs for these batteries [100].
Production focus/targets	Domestic production base of 150 GWh per year of LIBs and materials and 600 GWh production capacity in the global market (20 percent share) by 2030 [98]. To make electrified vehicles (EV, FCV, PHEV, and HV) account for 100 % of new passenger vehicles sold annually by 2035 [99].
Recycling focus/targets	To develop technology that can look forward to the recovery of at least 70 % lithium, 95 % nickel and 95 % cobalt [101]. To establish domestic recycling system by 2030 [98].
Reaction to the IRA	Japan-U.S. Critical Minerals Agreement (CMA) (2023) was signed, expecting to be similarly recognized as a country that has a free trade agreement with the U.S., one of the requirements for obtaining tax break through the IRA.
Major instruments	■ NEDO R&D projects (approx. 5-6 billion yen per year) for the development of material evaluation technology for SSBs and the development of alternative batteries. ■ NEDO Green Innovation Fund (120.5 billion yen for a decade) for advanced batteries, materials and recycling technology. ■ METI's support for battery production, introduction of clean vehicles and stationary batteries (total 166 billion yen in FY 2021-2022), and securing raw materials through JOGMEC, etc. ■ A new Transition Bond is planned under the Basic Plan for GX, which envisages public-private investment of 7 trillion yen.

[6] In this section, we used the exchange rate 1EUR=157 yen, referring to the ECB rate on 30/06/2023

6.2. Funding strategy for batteries

6.2.1. Past and current funding strategies

In Japan, NEDO has played an important role in R&D funding for battery research.

For example, NEDO has a long history of supporting the development of material evaluation techniques for lithium-based batteries. Development of Material Evaluation Technique for Next Generation Batteries (FY2010-2014) was initiated with the establishment of the Consortium for Lithium-ion Battery Technology and Evaluation Center (LIBTEC) to develop the technology for evaluating various new battery materials [107]. Subsequently, Development of Material Evaluation Techniques for Advanced and Innovative Batteries (FY2013-2017) was launched with the aim of establishing a material evaluation technology that will serve as a common benchmark for the battery industry, promoting the rapid proposal of new materials by domestic material manufacturers, and improving the development efficiency of domestic battery manufacturers [108].

NEDO has also long supported R&D projects for alternative battery technology. The Research and Development Initiative for Scientific Innovation of New Generation Batteries (RISING) (FY2009-2015) was the project aimed at establishing the basic technology to improve the performance of existing batteries and to realize innovative batteries by elucidating a basic reaction mechanism in a battery [109]. Then in FY2016, NEDO launched the successor project called Research and Development Initiative for Scientific Innovation of New Generation Batteries 2 (RISING2) (FY2016-2020), which aimed to develop the four different types of alternative batteries: fluoride shuttle battery, zinc-air battery, conversion-type battery, and sulfide battery [110].

Following the completion of the Development of Material Evaluation Techniques for Advanced and Innovative Batteries (FY2013-2017), the Development of Material Evaluation Techniques for Advanced and Innovative Batteries (Phase 2) (SOLiD-EV) (FY2018-2022) was initiated to continue the development of evaluation technology for solid-state batteries. As for alternative battery technologies, the Development of Innovative Batteries for Electric Vehicles (RISING3) project (FY2021-2025) was launched after RISING-2, narrowing the target to the development of fluoride battery and zinc-anode battery.

In addition to these projects, the Green Growth Strategy through Achieving Carbon Neutrality in 2050 allocated 2 trillion yen (approx. 12.7 billion euros) per 10 years as a Green Innovation Fund in NEDO for 14 priority areas.

As part of the "Mobility and Battery" area, a call for proposals for "The Development of Next-Generation Batteries/Motors" projects was opened in November 2021, and 14 projects were selected in April 2022. NEDO also provides funding for the projects through the other EV-related calls for "Development of In-Vehicle Computing and Simulation Technology for Energy Saving in Electric Vehicles" and "Smart Mobility Society Construction" projects under the Green Innovation Fund [111].

As of 2021, there was no national R&D funding program that focused solely on liquid electrolyte-based lithium ion batteries. In the Basic Plan of SOLiD-EV released in 2018, NEDO supported the view that the development of a liquid electrolyte-based lithium ion battery is already a technology field in which individual companies would focus on R&D to customize their products based on their business strategies [112]. However, the updated version of the Green Growth Strategy through Achieving Carbon Neutrality in 2050 states that it is important to conduct R&D on materials for all-solid-state batteries "with an awareness of improving performance and productivity that could contribute to lowering the price of liquid electrolyte-based lithium ion batteries, taking into account the similarities in materials between them" [99]. Reflecting this notion, the Green Innovation Funding does not specify the types of batteries to be funded (but refers to the solid-state battery technology as an example) [101]. In fact, there is a project to develop high-capacity and high-power lithium-ion batteries under the program [113].

For a long time, the government has intensively invested in the development of solid-state batteries and next-generation technology through NEDO's projects. However, recently, METI has been trying to change its strategy so that Japanese companies will not completely exit the market before solid-state batteries are commercialized. To this end, new subsidy programs have already been launched to expand production and demand (see 6.1.4).

According to the Battery Industry Strategy, METI will prepare seven pillars of countermeasures by aligning existing instruments to achieve the targets of the strategy [98];

1. Policy package for further expansion of domestic base to achieve production targets
2. Strategic formation of global alliances and global standards
3. Securing upstream resources
4. Development of next-generation technologies
5. Expansion of a domestic market
6. Strengthening human resource development
7. Improving the domestic business environment

In addition, in February 2023, the Cabinet approved the Basic Plan for the GX: Green Transformation Policy, which describes the policy instruments to achieve 150 trillion yen of public-private investment for Japan's green transformation.

The strategy indicates that the government intends to implement 7 trillion yen (approx. 44.6 billion euros) of public-private investment in battery production and R&D over the next 10 years [103].

Table 27: List of NEDO battery-related projects from FY2009 (Source: Own compilation based on the website of NEDO (https://www.nedo.go.jp/).

Period (FY)	Projects	Priority	Budget
2021-2030	Green Innovation Fund / Development of Next Generation Batteries and Motors	High-performance batteries, battery materials, recycling technology	12.05 billion yen per year on average for battery technology
2021-2025	Development of Innovative Batteries for Electric Vehicles (RISING-3)	Next-generation batteries for EV/PHEV use	2.375 billion yen in FY 2021 Approx. 11-12 billion yen for five years
2018-2022	Development of Material Evaluation Techniques for Advanced and Innovative Batteries (Phase 2)	Material evaluation techniques for all-solid-state batteries	2.15 billion yen in FY 2021 Approx. 10 billion yen for five years
2016-2020	Research and Development Initiative for Scientific Innovation of New Generation Batteries 2 (RISING-2)	Next-generation batteries for EV/PHEV use	3.4 billion yen in FY 2020
2013-2017	Development of Material Evaluation Techniques for Advanced and Innovative Batteries	Material evaluation techniques for advanced/all-solid-state lithium-ion batteries	0.37 billion yen in FY 2017
2012-2016	Development of Advanced Technology for the Application and Commercialization of Lithium-Ion Batteries	Lithium-ion batteries for EV/PHEV use	1.45 billion yen in FY 2016
2011-2015	Development of Technology for Large-Scale Battery System with Safety and Low-Cost	Energy storage device and system for stationary use	0.90 billion yen in FY 2015
2010-2014	Development of Material Evaluation Techniques for Next-Generation Batteries	Material Evaluation techniques for batteries	0.23 billion yen per year on average
2009-2015	Research and Development Initiative for Scientific Innovation of New Generation Batteries (RISING)	Improving existing batteries and realizing innovative batteries for EV use	3.1 billion yen in FY2015

6.2.2. Funding priorities and instruments

National R&D projects in NEDO

In general, NEDO's funding is offered as R&D project budget for contract research or subsidy to universities, research institutions, and private companies, etc.

The SOLiD-EV project is led by the Consortium for Lithium-ion Battery Technology and Evaluation Center (LIBTEC). In addition to LIBTEC, 10 universities, 4 national research institutions, and one general incorporated foundation are participating in the project. The funding priorities of SOLiD-EV are mainly on the common fundamental technology with a focus on the material evaluation technology for all-solid-state batteries which serves as a common industrial benchmark [112].

The representative institution of RISING-3 is Kyoto University, and other 14 universities, 8 private companies, 1 national research institution, 1 inter-university research institute corporation, and one general incorporated foundation are collaboratively involved in the project. The funding priorities of RISING-3 are the research and development of alternative batteries, especially fluoride battery and zinc-anode battery with the aim of their early commercialization [100].

The Green Innovation Fund mainly targets at the private sector and encourages the participation of SMEs and venture companies, although universities, research institutions, and collaborative innovation partnerships are allowed to join a project as a member of the project consortium in some cases. The newly launched the Development of Next-Generation Batteries/ Motors program under the Green Innovation Fund focuses on high-performance batteries, materials and production technologies for high-performance batteries, reduction of the amount of critical raw materials needed, and reduction of GHG emission during the production process, as well as recycling technology. Projects with TRL 4 to 7 (based on the IEA definition) are to be funded [101].

Other instruments

To increase domestic battery production capacity, METI launched a new funding program with 100 billion yen from the FY2021 supplementary budget. This fund can support part of the costs needed to largely introduce the production/recycling technology of advanced batteries and their materials [114].

In addition, the government has recently expanded demand-side policies. In 2021, METI launched the Promoting the Introduction of Clean Energy Vehicles and Infrastructure subsidies to encourage the purchase of EVs, PHEVs, and FCVs and the development of charging and hydrogen refueling infrastructure. 37.5 billion yen from the FY2021 supplementary budget and 15.5 billion yen from the FY2022 budget were allocated for this new subsidy [114]. In addition, 13 billion yen (in FY 2021) was allocated as a subsidy to accelerate the introduction of stationary batteries to increase the proportion of renewable energy [114].

With regard to securing raw materials, METI is considering increasing the risk money supply for resource exploitation through the Japan Oil, Gas and Metals National Corporation (JOGMEC), an independent administrative agency in charge of ensuring a stable supply of natural resources in Japan [98].

6.2.3. Funding budgets

As R&D project funding by NEDO:

- Approximately 10 billion yen (approx. 64 million euros) and 11-12 billion yen (ca. 707-692 million euros) are planned for the five-year SOLiD-EV (solid-state batteries) and RISING-3 (alternative batteries), respectively.
- From the Green Innovation Fund, up to 120.5 billion yen (approx. 768 million euros) will be invested in battery-related technology over 10 years under the Development of Next-Generation Batteries/Motors program [101].

An estimated total of all battery funding by NEDO between 2009 and 2022 is approximately 92 billion yen = 586 million euros[7].

In addition to NEDO funding, METI has launched the programs to expand lithium-ion battery production and the market from FY 2021-2022 [114]:

- 100 billion yen (approx. 0.64 billion euros) to support large-scale introduction of production and recycling technology.
- 53 billion yen (approx. 0.34 billion euros) subsidies to promote the introduction of clean energy vehicles and infrastructure.
- 13 billion yen (approx. 83 million euros) for subsidies to accelerate the introduction of stationary batteries.

[7] When only approximate budgets for the whole project period are available, the budget for FY 2021 is regarded as the average per year. When only the budget for a particular year is available, the budget for the whole project period is calculated by multiplying the period by the particular year budget.

6.3. Strategic technical objectives with respect to battery development

6.3.1. Specific technological focus of funding programs and strategies

Solid-state batteries:
The SOLiD-EV project addresses the development of common fundamental technology for first-generation all solid-state batteries with sulfide-based electrolytes and for next-generation all solid-state batteries with oxide- or highly ion-conductive sulfide-based electrolytes, as well as numerical analysis and evaluation methods for international standardization. In addition to technology development, the project also includes social system design research based on policy, market, and technology analysis. In terms of an application area, the result of this project is expected to be used in EVs/PHEVs.

Alternative battery technologies:
The RISING-3 project focuses on the development of fluoride batteries and zinc-anode batteries for EV/PHEV use, both of which are expected to have high energy density, improved safety in terms of ignition risk, and reduced raw material supply risk.

RISING-3 consists of the following five work packages:

1. Development of high-performance and low-cost electrode active materials and electrolyte
2. Development of composite electrode structure
3. Cell design, prototyping and performance evaluation
4. Development of simulation technology
5. Evaluation to ensure that the cells developed during the project can meet the performance targets for practical use and life cycle assessment for a cell and a battery pack

NEDO set performance targets for a 2Ah class cell of a fluoride battery and a 5Ah class cell of a zinc-anode battery, to be achieved at the end of the project (NEDO, 2021).

6.3.2. Technical objectives and milestones (KPIs)

KPIs for LIBs (until 2030)

According to the Green Growth Strategy, the Japanese government aims to achieve, a price of 10,000 yen (ca. 64 euros) /kWh or less for an automotive liquid electrolyte-based lithium-ion battery pack, as early as possible until 2030 [99].

KPIs for solid-state batteries (until 2025/until 2030)

In the basic plan of SOLiD-EV, NEDO described an example of target specifications for the commercialization of battery packs using first-generation solid-state batteries (SSBs) with sulfide-based solid electrolytes, which will prevail around 2025[8] and a battery pack using solid-state LIBs with highly ion-conductive sulfide- or oxide-based electrolytes which will prevail around 2030[9] [112]. However, NEDO mentioned that target specification of a battery pack would be considered during the process to crystalize the project and would be set to clearly differentiate the battery from a conventional liquid electrolyte-based LIB. Therefore, their example of target specifications is excluded from the assessment and comparison (Chapter 10) because it is unclear whether the project is actually committed to achieving these KPIs.

Table 28: Japanese KPIs for LIBs until 2030.

KPIs until 2030 (for LIBs)	KPI (JP)	Technological feasibility assessment
Battery cost	<10,000 yen (ca. 64 €)/kWh	**Realistic** – The price targets are in line with most roadmaps in other regions of the world, although it is difficult to foresee. While battery cell costs have fallen by 90 % over the past decade due to economies of scale (gigafactories), they are rapidly on the rise (since late 2021) due to raw material shortages and supply chain issues. Batteries with lower content of critical raw materials (e.g. sodium ion or possibly Zn-metal based batteries) may become more important in the mid-term.

KPIs in the Green Innovation Fund (technology-open, including SSBs) (until 2030)

Under the Green Innovation Fund (FY2021-2030), NEDO aims to establish the underpinning technology and production technology necessary to achieve the full-commercialization of storage batteries by 2030 with the following performance [101]:

1) A volumetric energy density of 700-800Wh/l or more for a battery pack (high-capacity system).

2) A power density of 2,000-2,500 W/kg or more and a volumetric energy density of 200-300 Wh/l or more for a battery pack (high-density system).

Other indicators need to be properly defined by applicants. In particular, the cost target must be set to gain market competitiveness, taking into account the fact that the Japanese government aims to achieve a price of 10,000 yen (approx. 64 euros) /kWh or less for automotive battery pack based on liquid electrolyte-based lithium-ion batteries, as early as possible until 2030.

With respect to recycling technology, NEDO solicited proposals for the technology that can look forward to the recovery of at least 70 % lithium, 95 % nickel and 95 % cobalt of a quality that can be reused as battery material at a cost equal to the market price (compound/metal alone).

Notably, the funding program guideline does not specify the types of batteries to be used to meet these targets (but do mention to solid-state batteries as an example).

The following KPIs (Table 29) set for the Green Innovation Fund appear to be technology-open:

Table 29: Japanese KPIs for next generation batteries (including SSBs) until 2030.

KPIs by 2030 (for next-gen LIBs)	KPI (JP)	Technological feasibility assessment
High energy battery: Energy density (pack level)	≥700-800 Wh/l	**Ambitious** – However, this target could be achievable by using an 'anode-free' or Lithium-metal anode based all solid-state batteries with thin separator.
High-power battery: Energy density (pack level) Specific power	200-300 Wh/l 2,000-2,500 W/kg	**Realistic** – HEV applications, however, require specific power only up to 1500 W/kg.
Recycling rate on metal basis	≥70 % of Lithium ≥95 % of Nickel ≥95 % of Cobalt	**Ambitious** – Ambitious targets, especially for Li, but these targets are in line with European recovery targets. [24]

[8] NEDO described an example of target specifications for commercialization of battery packs using 1st generation solid-state batteries (SSBs) with sulfide-based solid electrolytes, as below:

Energy density: 600 Wh/l, 300 Wh/kg for a battery pack; Power density: 2000 W/kg for a battery pack; Capacity for a battery pack: 40 kWh for EV use, 20 kWh for PHEV use; Charging time for a battery pack: 6 hours (normal) / 20 minutes (rapid) for EV use, 3 hours (normal) / 10 minutes (rapid) for PHEV use; Cycle lifetime: 1500 cycle for a battery pack; Calendar lifetime: 10 years for a battery pack; Battery cost: 15,000 yen/kWh; Vehicle environmental temperature: -30～60℃; Battery safety: possible to ensure safety of the same level with gasoline car; Electrical cruising range: 400km for EV use, 200km for PHEV use; Weight and volume of a battery pack: 133 kg, 67 L for EV use, 67 kg, 33 L for PHEV use.

[9] NEDO described an example of target specifications for commercialization of a battery pack using solid-state LIBs with highly ion-conductive sulfide- or oxide-based electrolyte as below:

Energy density: 800 Wh/l, 400 Wh/kg for a battery pack; Power density: 2500 W/kg for a battery pack; Capacity for a battery pack: 40 kWh for EV use, 20 kWh for PHEV use; Charging time: 6 hours (normal) / 20minutes (rapid) for EV use, 3 hours (normal) / 10 minutes (rapid) for PHEV use; Cycle lifetime: 2000 cycle; Calendar lifetime: 15 years; Battery cost: 10000 yen (ca. 63.7 euro) /kWh; Vehicle environmental temperature: -30～60℃; Battery safety: possible to ensure safety of the same level with gasoline car; Electrical cruising range: 480km for EV use, 240km for PHEV use; Weight and volume of a battery pack: 100kg, 50 L for EV use, 50 kg, 25L for PHEV use.

KPIs for alternative battery technologies (until 2025/beyond 2030)

According to the basic plan of RISING3, NEDO set a milestone for the development of prototype cells of fluoride ion shuttle battery (FiB) and zinc-anode battery as follows [100]. For the fluoride ion shuttle battery, NEDO aims to develop a 2 Ah level prototype cell that demonstrates the KPIs (Table 30).

The working principle of the fluoride ion shuttle battery relies on the use of a metal anode Ma (where M_a = Ag, Cu, Co, Sb, Bi, Ni, Pb, Fe or Ce) combined with a metal fluoride cathode M_aF_x (where M_b = Ca, Ba, Mg, La and x = 2,3), separated by a solid ion conductor or ionic liquid. The advantage of this innovative battery concept lies in the variety of applicable combinations of positive and negative active materials, which are not dependent on the availability of elements such as lithium. [116]

In contrast to a lithium-ion battery, the active materials do not react with the host ion (Li+ or F-) based on an intercalation mechanism, but rather on a conversion-type mechanism, which involves a complete rearrangement of the crystal structure upon fluoride uptake and release. While the theoretical and initial practical capacities are high, conversion-type materials often show rapid capacity fading upon cycling as well as low energy efficiency due to high polarization. Thus, most reports in literature show less than 50 charge/discharge cycles. It should also be noted that the electrochemically inactive solid electrolyte is currently much thicker than the active electrodes of cathode and anode, which negatively impact the resulting energy content. However, improvements in this respect should be possible. It is also worth mentioning that the ionic conductivity of the applied solid electrolytes such as LaF_3 is temperature-dependent, and the maximum capacity of the active material can only be achieved at elevated temperatures (˜150°C).

Achieving practical energy densities above 1000 Wh/l in a 2 Ah prototype for potential automotive applications (which would require even larger cells) will be very challenging, although there are reports of laboratory thin-film cells that claim to have achieved these targets already. [115]

For a rechargeable battery utilizing a zinc-metal-based anode (e.g. a rechargeable zinc battery with cathodes based on air, MnO_2 or carbon materials), NEDO aims to develop a 5 Ah-level prototype cell that demonstrates ≥200 Wh/kg and 500 Wh/l at the cell level. For these KPIs, however, it is difficult to find publicly available data and references on the specific technological approach behind these targets, since this project is in an early stage of development.

Rechargeable batteries using a zinc-metal anode promise cost benefits since zinc is much more abundant than lithium and is mined on a large scale (>11 million tons per year). Zinc is furthermore also compatible with aqueous electrolytes, which are inexpensive and nonflammable. Rechargeable zinc-anode batteries are likely to have a lower environmental impact compared to lithium-ion batteries. In the primary battery sector, non-rechargeable alkaline batteries based on a zinc anode, MnO_2 cathode and an aqueous alkaline electrolyte are ubiquitous as low-cost power sources (e.g. AA and AAA cells). However, these alkaline batteries have limited rechargeability. Despite the tendency for Zn dendrite formation during charging, the technology is claimed to be intrinsically safe. Regarding energy content, the theoretical values of Zn-air batteries amount to 1,218 Wh/kg and 6,136 Wh/l, while the corresponding Li-air batteries promise 5,928 Wh/kg and 7,989 Wh/l. The difference in nominal cell voltage (1.66 V for Zn-air vs. 2.96 V for Li-air) is a major differentiator [117].

Considering the current research status of Zn-air batteries, which have been the research focus of the RISING2 project from FY2016-2020 [110], the development targets of the RISING3 project [116], in which the focus has been widened towards other Zn anode cell chemistries, are mostly realistic, while scaling up to a 5 Ah format prototype is likely to be the major challenge.

According to the latest basic plan of RISING3, the outcome target of this project is to begin the sales of EVs and PHEVs equipped with innovative batteries in Japan in 2033 and to increase domestic sales to 1 million units per year by 2037. In addition, from 2038 onwards, while continuing to sell around one million units per year domestically, the exports of the vehicles equipped with the advanced batteries will begin, with the goal of increasing overseas production to four million units per year by 2047. NEDO has set the following performance goals for commercialization [100]. In terms of battery safety, the goal for the fluoride battery is to achieve no ignition or smoking in the event of an anomaly such as internal short circuit or overcharge. For calendar life, the target is to achieve over 15 years.

NEDO also provides pack-level KPIs for zinc-anode batteries beyond 2030, where the cathode material or electrolyte chemistry is not specified, which would directly affect the attainable energy content through its capacity or voltage stability. Pack-level energy targets of ≥200 Wh/kg and energy density of 400 Wh/l are defined. Other related targets are very similar to those for fluoride batteries. The major challenge will be to scale the technology to the pack level and to achieve long cycle and calendar life cycle and calendar life.

Table 30: Japanese KPIs for fluoride batteries (prototype) until 2025.

KPIs until 2025 (for fluoride ion shuttle battery)	KPI (JP)	Technological feasibility assessment
Specific energy (cell level)	≥500 Wh/kg	**Ambitious** – While the specific capacity of individual components, such as the Cu/CuF_2 cathode (>600 mAh/g(Cu) at 80°C) [115], exceeds the performance of most Li ion electrodes, it will be challenging to transfer these values to larger cells for extended cycling.
Energy density (cell level)	1,000 Wh/l	**Ambitious** – In most literature reports the electrochemically inactive metal fluoride-based solid electrolyte is significantly thicker than the active electrodes, which negatively impacts volumetric energy density. The solid electrolyte layer would need to become significantly thinner to achieve the targeted energy density. Likewise, the positive and negative electrode films of the cathode and anode need to become significantly thicker to achieve high energy contents. [115]
Charging rate	≥1C	**Ambitious** – Most reports use rates of <1C. Finding a suitable room temperature fluoride ion conductor constitutes a major challenge. Most cycling literature occurs at temperature of 80 °C and above, which is not practical for most EV/PHEV application, this technology is targeted for.
Cycle life	≥90 % SoH after 100 cycles (10 % degradation 100 cycles)	**Ambitious** – Most FiB cycling data in the literature show <50 cycles

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Table 31: Japanese KPIs for zinc-anode batteries (prototype) until 2025.

KPIs until 2025 (for rechargeable Zn-anode battery)	KPI (JP)	Technological feasibility assessment
Specific energy (cell level)	≥200 Wh/kg	**Ambiguous (Questionable)** – Resulting energy content will depend on applied cathode and electrolyte chemistry. To achieve high energy content, high degree of zinc utilization and minimization of passive components is necessary.
Energy density (cell level)	≥500 Wh/l	**Ambiguous (Questionable)** – Resulting energy content will depend on applied cathode and electrolyte chemistry. To achieve high energy content, high degree of zinc utilization and minimization of passive components is necessary.
Charging rate	≥3C	**Ambitious** – Most reports apply rates of <2C.
Cycle life	≥90 % SoH after 100 cycles (10 % degradation 100 cycles)	**Realistic** – Depending on electrode thickness, depth of discharge and applied rate, up to 1,000 cycles have been reported in the literature [117].

Table 32: Japanese KPIs for fluoride batteries beyond 2030.

KPIs beyond 2030 (for fluoride ion shuttle battery)	KPI (JP)	Technological feasibility assessment
Specific energy (pack level)	≥400 Wh/kg	**Ambitious** – see comment for 2025.
Energy density (pack level)	900 Wh/l	**Ambitious** – see comment for 2025.
Rapid charging time	<20 mins	**Ambitious** – Most reports apply rates of <1C
Calendar lifetime	≥15 years	No assessment possible due to low technological maturity.
Battery cost	≤10,000 yen (ca. € 64)/kWh	No assessment possible due to low technological maturity.
Cycle life	≥2,000 cycles	**Ambitious** – Most literature reports on fluoride ion shuttle batteries show cycling data in literature show fewer than 50 cycles before reaching their end-of-life criterion.

Table 33: Japanese KPIs for zinc-anode batteries beyond 2030.

KPIs beyond 2030 (for zinc-anode battery)	KPI (JP)	Technological feasibility assessment
Specific energy (pack level)	≥200 Wh/kg	**Ambiguous (Questionable)** – Resulting energy content will depend on cathode and electrolyte chemistry applied. To achieve high energy content, high degree of zinc utilization and minimization of passive components is necessary.
Energy density (pack level)	≥400 Wh/l	**Ambiguous (Questionable)** – Resulting energy content will depend on cathode and electrolyte chemistry applied. To achieve high energy content, high degree of zinc utilization and minimization of passive components is necessary.
Rapid charging time	<20 mins	**Ambitious** – Fast charging (high current density) might promote undesirable zinc dendrite formation, which may pose a safety risk..
Battery cost	≤10,000 yen (ca. € 64)/kWh	**Realistic** – Assuming use of low cost materials such as zinc anode and MnO_2 cathode and an aqueous alkaline electrolyte..
Calendar lifetime	≥15 years	**Ambitious** – Good sealing and dry and cool operation are required. Primary alkaline batteries have a calendar life of up to 10 years.
Cycle life	≥2,000 cycles	**Ambitious** – Dendrite-free zinc deposition is required.

7. Public battery strategy of South Korea

7.1. Political objectives and strategies

7.1.1. Main Actors

In South Korea, policies or programs are generally determined by the central government, with a strong industry involvement in the decision-making process. The President of Korea is also the highest authority on the research matters, supported by advisors based in the President's Office [14].

Key governmental bodies to shape battery policy in the Republic of Korea are:

- Ministry of Trade, Industry, and Economy (MOTIE, renamed from Ministry of Knowledge Economy/MKE in 2013) plays an important role in energy policy and R&D. Under MOTIE, Korea Energy Technology Evaluation and Planning (KETEP) and Korea Evaluation Institute of Industrial Technology (KEIT) work as organizations to plan and evaluate energy R&D programs for MOTIE.
- Ministry of Science and ICT (MSIT) is responsible for policy-making and promotion of science and technology in South Korea.
- The Strategy Meeting on the Korean New Deal makes key decisions on overarching sustainability and industrial strategies and is chaired by the President.

Other actors from the private sector with relevance for battery policy include:

- Korean Battery Industry Association (KBIA) – The association consists of battery manufacturers, parts & materials companies, equipment/system companies, and other research institutions. KBIA proposes policies to the government for the interests of member companies and makes efforts to induce government investment in the battery industry.
- Various companies such as LG Energy Solution, Samsung SDI, and SK Innovation have invested in the K-battery-program.

In March 2022, South Korea saw a change of government with the election of Yoon Suk-yeol as president. After the election, the new government announced new strategies to support the battery industry (see next section).

Key strategic documents

- The Korean New Deal [121]
- K-Battery Development Strategy [118]
- Secondary Battery Industry Innovation Strategy [122]
- Post-IRA Public-Private Joint Strategy for Battery Industry Development [120]
- A New National Strategy for Strengthening the Competitiveness of the Secondary Battery Industry [119]

7.1.2. General Policy Objectives with respect to battery development

South Korea has declared that it will move towards carbon neutrality by 2050. The National Determined Contribution target was updated in 2021, and the new mid-term goal is to reduce emissions by 40% from 2018 levels by 2030 [123]. The Korean New Deal is positioned as an additional countermeasure to support the implementation of the NDC.

The Korean New Deal was introduced as a national development strategy to support the country's recovery from the pandemic crisis and to lead global action on structural change. To implement the strategy, strategy meetings are organized at various levels. The strategy consists of three pillars: Digital New Deal, Green New Deal, and Stronger Safety Net for Employment. For the Green New Deal, 73.4 trillion won (42.7 trillion won from the national treasury) will be allocated from 2020 to 2025, and 659,000 jobs will be created [121].

In addition, circular economy is increasingly becoming the subject of strategic documents. In 2021, the government announced an action plan towards circular economy, namely, the K-Circular Economy Implementation Plan for Carbon Neutrality. This includes several measures to improve the circularity of batteries, such as the establishment of a cluster to develop and demonstrate recycling technologies for used batteries by 2025 [124].

Regarding the supply of critical resources, a Top 100 Rare Metal Companies Support Scheme has been established to identify the businesses involved in recycling of minerals used in rechargeable batteries and offer comprehensive support for them [118].

Figure 13: Policy timeline and strategic objectives of South Korea.

POLICY TIMELINE

2020: The Korean New Deal
2021: 2030 K-Battery Development Strategy
2022: Secondary Battery Industry Innovation Strategy
2023:

- Post-IRA Public‐Private Joint Strategy for Battery Industry Development (MOTIE)
- a new national strategy for strengthening the competitiveness of the secondary battery industry (MOTIE)

POLICY GOALS

Goals by 2025

- 1.13 million of EVs along with the installation of 15,000 rapid chargers and 30,000 slow chargers (Korean Green Deal)
- Commercialization of lithium-sulfur batteries (K-Battery Strategy)

Goals by 2027

- Commercialization of solid-state batteries (K-Battery Strategy)

Goals by 2028

- Commercialization of lithium-metal batteries (K-Battery Strategy)
- Quadruple domestic production capacity of cathode materials and to triple exports of battery production-related equipment with the investment (MOTIE, 2023)

Goals by 2030

- To become No.1 battery powerhouse, with increasing battery sales (40 % of the global market) and material/parts/equipment (20 % of the global market)(K-Battery Strategy)
- To establish an environment that allows 100 percent of all secondary batteries to be recycled (MOTIE, 2023)

Table 34: Overview of the public battery strategies and main characteristics in South Korea with a focus on t he main actors.

Aspects	Description
Overall strategic goals	To become the world's No. 1 battery powerhouse by 2030 [118].
Current R&D performance (publication and patent) [2]	■ 12.6 % global patent share (2016-2020) – Strength in Li-Sulfur (26 %, second highest) and Li-Air (21 %, third highest) batteries ■ 7.3 % global share of publications (2017-2021) – Relatively strong in Li-Air (13%) batteries, ranking 4th
Current market status (raw materials, components, cells)	Component production: 7 % global share of anode, 14 % of cathode, 11 % of electrolyte, 14 % of separator (2023). Cell production: 97.5 GWh (22 % share) of EV battery cell sales in 2022.
Technological focus/targets	SSBs, Li-S batteries, and Li-metal batteries are targeted for early commercialization by 2027, 2025, and 2028, respectively, and technical KPIs are set for these battery chemistries [118]. To develop NCM batteries with a driving range of over 800 km by 2030 (Innovation Strategy on Secondary Battery Industry).
Production focus/targets	To increase battery sales to 166 trillion won (40 % of the global market), materials/parts/equipment sales to 60 trillion won (20 % of the global market), and battery exports to 20 billion dollar [118]. To quadruple the domestic production capacity of cathode materials and triple the export of battery production-related equipment over the next five years [119].
Recycling focus/targets	To establish 100 % domestic secondary battery closed-loop by 2030 [119].
Reaction to the IRA	Post-IRA Public-Private Joint Strategy for Battery Industry Development (2023), including support for battery firms' and material suppliers' investments in facilities in North America (7 trillion won), LFP projects to help companies enter overseas markets, change in tax credit rate, R&D for next-generation battery, etc. [120]
Major instruments	■ The Korean New Deal project "Eco-friendly Mobility Future" (2020-2025) with 13.1 trillion won from the national treasury [121]. ■ Under the K-Battery Industry Strategy [118]: – Several large-scale R&D projects worth over 500 billion won for early commercialization of next-generation batteries. – 80 billion won Public-Private R&D Innovation Fund, including 30 billion won MOTIE funding. – K-Battery Incentive Program by the Export-Import Bank of Korea with 1.5 trillion won. – 40.6 trillion won is expected to be invested by the private sector by 2030. ■ The Secondary Battery Industry Innovation Strategy announced that the government will provide 1 trillion won in R&D funding [122]. ■ Under the Post-IRA Public-Private Joint Strategy for Batteries [120]: – The Export-Import Bank of Korea and Korea Trade Insurance Corporation will provide 7 trillion won of support over five years. – The government will launch new projects on LFP batteries with about 50 billion won. – 150 billion won for next-generation battery R&D pre-feasibility study. – Three major battery manufacturers (private) plan to invest 1.6 trillion won in next-generation batteries over the next five years. ■ Under the new national strategy for strengthening competitiveness of the secondary battery [119]: – Public-private joint R&D investment of 20 trillion won by 2030 for the development of technology to commercialize the world's first all solid-state battery for EVs. – R&D investment of 150 billion won for 5 years for NCM battery, 50 billion won for LFP battery, and 150 billion won for ESS. *In South Korea, subsidies or investments are often made on a very large scale as the large corporations (conglomerates) co-finance the investments.

7.2. Funding strategy for batteries

7.2.1. Past and current funding strategies

In the past, there have been many programs for battery technology, for example, the "Green Industry Leading Secondary Battery" was funded by KEIT from 2011-2018. The program was derived from the government's initiative of "Measures to Strengthen the Competitiveness of Secondary Batteries", which was announced in 2011 to achieve the No. 1 global market share for medium-size secondary battery, taking into account climate change and environmental issues. As of 2011, R&D focus was more on lithium-ion battery and material development[10]. In 2011, the government funded 38.53 million euros for battery research, with 76 % of the budget invested in lithium-ion battery, focusing on material research and optimized electrodes. From 2009 to 2014, the government allocated about 340 million euros to battery research [14].

In July 2021, Korea's comprehensive battery strategy, the K-Battery Development Strategy, was released with the goal of becoming the undisputed No. 1 country for batteries by 2030 [118]. The expected economic outcomes of the strategy by 2030 are to increase battery sales to 166 trillion won (40 % of the global market), materials/parts/equipment sales to 60 trillion won (20 % of the global market), and battery exports 20 billion dollar [118].

After the change of government, under the Yoon administration, MOTIE announced a new industry strategy called Secondary Battery Industry Innovation Strategy in November 2022. The new strategy still holds the vision of "becoming the No. 1 country in battery by 2030", but with a strong focus on resilient supply chain after the announcement of the IRA. In particular, the government supported the establishment of the "Battery Alliance" to secure key battery materials [122].

Since the passage of the IRA in the U.S., South Korea has increasingly recognized the importance of supporting domestic material suppliers. For this aim, in April 2023, MOTIE announced the Post-IRA Public-Private Joint Strategy for Battery Industry Development [120]. Furthermore, just two weeks after the announcement of the Post-IRA strategy, MOTIE released a new National Strategy for Strengthening the Competitiveness of the Secondary Battery Industry, with 20 trillion won of public-private investment [119].

7.2.2. Funding priorities and instruments

Among all the Korean New Deal projects, 10 key projects were selected that could significantly contribute to the creation of jobs and new industries as well as a balanced form of regional development. One of the projects, "Eco-friendly Mobility of the Future" aims to accelerate the transition from old diesel cars through the provision of EVs and HVs, investing 20.3 trillion won (including 13.1 trillion won from the national treasury) by 2025 to create 151,000 jobs. The project will support the provision of 1.13 million EVs, including passenger cars, buses, and freight vehicles by 2025 and the installation of 15,000 fast chargers and 30,000 slow chargers [121].

The K-Battery Development Strategy was released with President Moon Jae-in's remark, but related funding measures are assigned to different ministries, such as MOTIE and MSIT. The strategy offers a policy mix that includes the R&D programs, tax incentives, infrastructures, demand-side policies, and other funding instruments. The document describes not only the tasks of the government, but also the expected cooperation of the private sector.

The K-Battery strategy is based on three pillars: securing top-notch technology by promoting large-scale public-private partnerships in R&D; building the world's leading production base by establishing a connected and collaborative ecosystem; and expanding the battery market by creating public and private market demands.

With regard to large-scale R&D activities, funding priorities (Table 35) are set on early commercialization of next-generation batteries, securing key technologies on materials/parts/equipment, and improving existing lithium-ion batteries [118].

In addition, as part of the K-Battery Development Strategy, investment incentives to foster the growth of key materials/parts/equipment suppliers for batteries will be introduced [118]:

- Key battery technology will be added to the list of "National Strategic Technologies" eligible for tax incentives. R&D expenditures will be able to receive a tax credit of up to 40-50 percent, and facility (machines, infrastructure, laboratories etc.) expenditures a tax credit of up to 20 percent.
- Companies making facility expenditures in the high-tech industry or in the technology that is in line with the Notice on the Designation of National Strategic Technologies are exempted from the requirement to close or reduce their overseas operations to qualify for reshoring subsidies.
- Other investment incentives include the possible designation of High-Tech Investment Zones, a new K-Battery Incentive Program by the Export-Import Bank of Korea worth 1.5 trillion won, and a program to advance industrial structure by the Korea Development Bank.

[10] Fraunhofer Representative Office of South Korea

Table 35: Funding programs and instruments mentioned in the K-Battery Development Strategy.

Program title	Focus
A Study on the Development of Original Breakthrough Technology for Rechargeable Batteries added to a preliminary feasibility study on the 'Development of Carbon-Neutral Innovations' (2023 to 2030, Ministry of Science and ICT (MSIT)	Next-generation rechargeable battery manufacturing (solid-state battery, lithium-sulfur battery, lithium-metal battery)
Development of lithium-based next-generation battery technology (2020 to 2024, MOTIE)	Next-generation material/parts/equipment
Development of original core technology for next-generation lithium-metal rechargeable batteries for EVs (2018 to 2023, MSIT)	Next-generation material/parts/equipment
Review of innovative research funding for Disruptive Innovation Projects (2021, MSIT)	Next-generation material/parts/equipment
Establishment of the Support Center for Commercialization of Next-Generation Batteries (2022-2026, MOTIE)	R&D infrastructure
Development of high-reliability next-generation nickel-based cathode materials (2021 to 2023, MOTIE)	Enhanced performance (existing lithium-ion battery)
Development of high-performance silicon-based anode materials for rechargeable batteries and their manufacturing equipment (2021 to 2023, MOTIE)	Enhanced performance (existing lithium-ion battery)
Development of Safe Module Materials and Applications' with a fire extinguishing patch embedded in the module (2021 to 2024, MOTIE)	Improved safety (existing lithium-ion battery)
A preliminary feasibility study on the 'Development of Smart Battery Technology' with self-detection, self-control and self-healing properties (2024 to 2028, MOTIE)	Improved safety (existing lithium-ion battery)
Development of manufacturing innovations for medium to large sized rechargeable batteries to reduce carbon emissions (2022 to 2025, MOTIE)	Greater productivity (existing lithium-ion battery)

The Secondary Battery Industry Innovation Strategy under the new regime set three goals: securing a stable battery supply chain, building a high-tech innovation hub, and creating a healthy industrial ecosystem. To achieve these goals, the strategy outlined the following key tasks for the government [125]:

- Building a public-private joint "Battery Alliance" to secure key minerals with various projects to secure core minerals and a financial support plan to provide loans and guarantees.
- Government investment to develop key battery technologies and cutting-edge production bases. To promote R&D, 20.5 trillion won (1 trillion from the government and 19.5 trillion from private companies) will be invested by 2030.
- Financial support to companies making battery-related domestic investments (e.g. loans and guarantees, investment fund, tax benefits).
- The government and companies will jointly train a total of 16,000 people to meet the demand for key talents.

The Post-IRA Public-Private Joint Strategy for Battery Industry Development will implement support for domestic material suppliers, including investment in facilities in North America, market penetration schemes for lithium iron phosphate (LFP) batteries, tax incentives for material and mineral processing companies, next-generation battery R&D prefeasibility study, etc. [120]. With the New National Strategy for Strengthening the Competitiveness of the Secondary Battery Industry, Korea is striving to ensure global competitiveness and a stable supply chain of critical minerals and materials. Specifically, the government aims to quadruple the domestic production capacity of cathode materials and triple exports of battery production-related equipment over the next five years. The strategy continues to hold a vision to secure advanced technology for the production of solid-state, lithium-metal and lithium-sulfur batteries. In addition, it mentions the development of NCM batteries, LFP batteries and ESS [119].

Recycling is also mentioned in the announced battery strategies. The K-Battery Development Strategy includes the objectives related to recycling. Furthermore, the new battery strategy released in 2023 sets an ambitious goal: to establish 100% domestic secondary battery closed-loop by 2030 [119].

7.2.3. Funding budgets

- 20.3 trillion won (approx. 14 billion euros), including 13.1 trillion won (appeox. 9.1 billion euros from the national treasury) will be invested in "Eco-friendly Mobility Future", the Korean New Deal project (2020-2025) for the green transition from old diesel cars and vessels.

- Under the K-Battery Development Strategy:
  - Several large-scale R&D projects worth over 500 billion won (approx. 348 million euros) will be carried out for early commercialization of next-generation batteries [126].
  - A Public-Private R&D Innovation Fund worth 80 billion won (approx. 56 million euros), including 30 billion from MOTIE, 20 billion from three major battery manufacturers (LG Energy Solution, Samsung SDI, and SK Innovation), and 30 billion from the private investment sector through an asset management company, will be created to support R&D activities of SMEs and startups specializing in materials/parts/equipment for batteries.
  - Financial support including 1.5 trillion won (approx. 1.0 billion euros) K-Battery Incentive Program by the Export-Import Bank of Korea will be prepared.
  - In South Korea, subsidies or investments are often made on a very large scale, as the large corporations (conglomerates) co-finance the investments [127, 14]. In fact, the K-Battery Development Strategy also states that 40.6 trillion won (approx. 28 billion euros) is expected to be invested by the private sector by 2030.

- Under the Innovation Strategy on Secondary Battery Industry, the new government will provide 1 trillion won (approx. 696 million euros) in R&D funding by 2030 to develop super-gap technology [122].
- The post-IRA public-private joint strategy for batteries includes the following topics [120]:
  - The Export-Import Bank of Korea and the Korea Trade Insurance Corporation will support battery firms' and material suppliers' investments in facilities within North America with 7 trillion won (approx. 4.9 billion euros) in loans and guarantees over the next five years, as well as higher credit lines, interest rate reductions, lower insurance premiums and other financial incentives.
  - The government also plans to launch 50 billion won (approx. 35 million euros) plus LFP battery projects to help companies enter overseas markets.
  - The tax credit rate for investment related to national strategic technologies will be increased, providing larger investment incentives for materials and mineral processing companies.
  - The government will promote a 150 billion won next-generation battery R&D prefeasibility study as part of an investment to secure cutting-edge technology.
  - Three major battery manufactures plan to invest 1.6 trillion won in next-generation batteries over the next five years and build an all-solid state battery pilot line in Korea.

- MOTIE announced a new national strategy for strengthening the competitiveness of the secondary battery industry, on 20 April in 2023. According to the strategy, South Korea will invest 20 trillion won (approx. 14 billion euros) by 2030, jointly by public and private actors, to widen the technology gap with global competitors. Specifically [119],
  - The government and private sector plan to invest more than 350 billion won (approx. 244 million euros) to develop the technologies of NCM batteries, LFP batteries and ESS.
  - The government will establish a 500 billion won (approx. 348 million euros) fund to support materials, parts and equipment companies.

7.3. Strategic technical objectives with respect to battery development

7.3.1. Specific technological focus of funding programs and strategies

The K-Battery Development Strategy emphasizes the technological focus on three types of "next-generation batteries", i.e. solid-state batteries, lithium-sulfur batteries, and lithium-metal batteries. The strategy aims for early commercialization of those technologies by 2027, 2025 and 2028, respectively. To achieve this goal, the private sector is expected to invest 20.1 trillion won in R&D by 2030, and the government plans to deliver tailored support for large-scale R&D projects targeting core product applications.

The strategy also includes the development of key materials/parts/equipment for batteries in various relevant areas, such as electrode materials, solid-state electrolytes, and manufacturing equipment, to enable commercial applications. In addition, a Next-Generation Battery Park will be established to provide comprehensive support for research and demonstration evaluation of next-generation battery technologies, with support of MOTIE.

With regard to existing lithium-ion battery technology, the government will also provide support to improve battery performance, safety and productivity [118].

For lithium-ion-batteries

According to the K-Battery Development Strategy, the R&D focus for existing lithium-based batteries is to improve 1) performance, 2) safety, and 3) manufacturing productivity [118];

1) For performance improvement, investment will be made in material development for cathode materials with high-nickel and low-cobalt content, as well as surface treatment technology and equipment to improve reliability at high operating temperatures, high-capacity silicon-based anode materials with equipment to enable massive synthesis and continuous manufacturing, and single-walled carbon nanotube and homogeneous dispersion technology to improve electrode conductivity and durability.

2) To improve battery safety, battery technologies will be developed that not only enable delayed explosion, but also provide self-diagnosis and self-healing capabilities.

3) Manufacturing productivity will be enhanced through low-carbon processes, digitalization, and smart technologies. Specifically, the development of equipment to improve the efficiency of an energy-intensive drying process, as well as a dry coating process without electrode drying will lead to manufacturing with higher productivity and a lower carbon footprint. In addition, innovative manufacturing processes will be introduced to make the best use of the latest technologies, such as artificial intelligence or a digital twin.

According to the new strategy under the Yoon administration, the government and the private sector will invest more to develop the technologies of NCM batteries, LFP batteries and ESS [119].

For solid-state batteries

Solid-state battery R&D focuses on technologies tailored to a range of market segments, including lightweight sulfide-based solid-state batteries for EVs, military and space applications, and oxide-based solid-state batteries that are safe for use at high temperatures for ESS applications. The solid-state electrolyte will be selected as one of the seven next-generation materials and added to the list of "Future-Leading Items" to expand support for the development of original technologies [118].

For alternative battery technologies [118]

The R&D focus for lithium-sulfur batteries is to create new markets, such as lightweight batteries for aircraft and drones, and flexible batteries for textiles and electronics, by making the batteries lighter and smaller. In addition, lithium-sulfur cathode materials will be selected as one of the seven next-generation materials.

On the other hand, the R&D focus for the lithium-metal battery is the use of lithium-metal anode materials in solid-state batteries for EV applications to maximize energy density and safety. Lithium-metal anode materials will be selected as one of the seven next-generation materials.

In addition to the two types of batteries, other new technologies will be developed. For this aim, innovative research funding for MIST's Disruptive Innovation Projects by will be reviewed. Next-generation batteries, including lithium-metal-air battery and multivalent ion battery technologies, will be developed, as well as advanced batteries based on organic materials. In addition, lithium-air cathode materials, dual/

multivalent ion materials, redox couples, and sodium-ion cathode materials will be added to the list of the seven next-generation materials.

A new preliminary feasibility study is planned on the "Development of High-Performance Next-Generation Battery Technology" (2023 to 2028, MOTIE) to support rational decision-making on financial execution by presenting the results of an objective and neutral investigation on a large-scale funding program before implementation.

7.3.2. Technical objectives and milestones (KPIs)

KPIs for lithium-ion batteries (until 2025/until 2030)

The K-Battery Development Strategy does not specifically mention the time period, but seeks to achieve the following targets by improving the performance of existing lithium-based batteries, so the time horizon for these KPIs likely to be short-term [118].

To contribute to these objectives, MOTIE will organize two programs (Development of high-reliability next-generation nickel-based cathode materials and development of high-performance silicon-based anode materials for rechargeable batteries and their manufacturing equipment) from 2021 to 2023.

According to the newest strategy published by the Korean government, they will aim to develop NCM batteries that have a driving distance of over 800 km by 2030 [119].

KPIs for solid-state batteries (until 2025/until 2030)

K-Battery Development Strategy describes the roadmap for commercialization of the solid-state batteries as below [118] (Table 38).

KPIs for alternative battery technologies (until 2025)

K-Battery Development Strategy describes the roadmap for commercialization of the lithium-sulfur batteries and lithium-metal batteries as below [118] (Table 40).

Table 36: Korean KPIs for LIBs until 2025.

KPIs until 2025 (for LIBs)	KPI (KR)	Technological feasibility assessment
Electric driving range	450 - > 600 km	**Realistic** – while the average driving range of full electric vehicles lies at around 300 km with usable battery energy content of around 60 kWh, driving ranges beyond 600 km are already realized today for premium EVs and might be further pushed with energy-optimized LIBs [128].
Cycle life	500 - > over 1,000	**Realistic** – for vehicles with larger batteries and driving ranges, a battery cycle life below 1,000 deep cycles (0-100 % state of charge) is sufficient to cover the lifetime of the vehicle (e.g., 500 cycles x 600 km range = 300,000 km in total). Entry-level EVs with smaller batteries will require more durable batteries to achieve the same accumulated driving range e.g., 1,000 cycles x 300 km range = 300,000 km in total).
Battery safety / temperature	High temperature reliability (>45° C)	**Realistic** – high-temperatures due to climate or fast charging must not impact battery performance. Battery cooling is however recommended to prevent excessive thermally-induced battery aging.

Table 37: Korean KPIs for LIBs until 2030.

KPIs until 2030 (for NCM batteries)	KPI (KR)	Technological feasibility assessment
Electric driving distance	>800 km	**Realistic** – may be achieved through multiple or a combination of measures (larger battery pack, improved cells, better integration, lighter vehicle chassis)

Table 38: Korean KPIs for solid-state batteries until 2030.

KPIs until 2030 (for SSB)	KPI (KR)	Technological feasibility assessment
Specific energy	400 Wh/kg (2025-2028; commercial technology)	**Ambitious** – The specific energy target of 400 Wh/kg at the cell level will require a Li-metal or anode-free cell setup. Commercialization is not expected until the late 2020s.
Demonstration projects	Automotive demonstration (2030)	**Realistic** – SSBs for EV applications could be realized by 2030, if this technology can be successfully scaled to larger cell formats.

Table 39: Korean KPIs for alternative batteries until 2030.

KPIs until 2030 (li-sulfur, li-metal)	KPI (KR)	Technological feasibility assessment
Applications for lithium-sulfur batteries	– Small/flexible battery development (2025-2028) – Commercial technology for UAVs (2025-2028) – Aerial vehicles application (2030)	**Realistic** – Due to their favorable specific energy content exceeding 300 Wh/kg and thus outperforming Li-ion batteries, Li/S batteries are best suited for weight-critical applications such as drones, aviation or space [129].
Specific energy (lithium-metal battery)	400 Wh/kg (2025-2028; commercial technology)	**Ambitious** – The specific energy target of 400 Wh/kg at the cell level will require a Li-metal or anode-free cell setup. Commercialization before the late 2020s has little probability.
Demonstration projects (lithium-metal battery)	Automotive demonstration (2030)	**Realistic** – SSBs for EV applications could be realized by 2030 if this technology can be successfully scaled to larger cell formats.

8. Public battery strategy of China

8.1. Political objectives and strategies[12]

8.1.1. Main Actors and initiatives

The Central Committee is a political body that comprises the top leaders of the Chinese Communist Party (CCP) and carries out the decisions of the National Congress, leading the work of the Party, and representing the Party internationally [130][13]. The State Council is the chief administrative organ of the People's Republic of China. It is the functional center of state power and clearinghouse for government initiatives at all levels[14] [131]. These ministries and institutions play an important role in the operational implementation of the political objectives for battery technology:

- MIIT (Ministry of Industry and Information Technology) is a ministry under the State Council. It is responsible for the administration of industrial sectors and information industry.

- NDRC (National Development and Reform Commission) is a ministry under the State Council. It implements the policies and decisions of the Central Committee on development and reform.

- NMSAC (National Manufacturing Strategy Advisory Committee) is a strategic decision-making advisory platform and high-level think tank with members from ministries and other policy makers to promote the transformation of the manufacturing sector [132].

- MoST (Ministry of Science and Technology) is a ministry under the State Council. It takes the lead in establishing a unified national platform for science and technology (S&T) management and a mechanism for fund allocation, evaluation and supervision of research projects.

- MoF (Ministry of Finance) is a ministry under the State Council. It implements the decisions and policies of the Central Committee on public finance and adheres to the centralized and unified leadership of the CCP on fiscal work.

- TAX (State Taxation Administration) is an agency directly under the State Council. It is responsible for drafting tax laws, regulations and implementation rules, and making tax policy recommendations.

- CSAE (China Society of Automotive Engineers) is an important force for popularizing new ideas, technologies and notions in China's automotive industry, and acts as a bridge to promote exchanges between the domestic and international automotive industries. CSAE is a national academic legal entity voluntarily formed by Chinese automotive scientists and technicians and is part of the China Association for Science and Technology, a non-profit social organization. [133]

- CATARC (China Automotive Technology Research Center) is a comprehensive technical service enterprise group under the State-owned Assets Supervision and Administration Commission of the State Council (SASAC)[15]. Its activities cover 10 major areas such as standardization, industry think tank, experimentation, engineering technology R&D services, digitization, engineering design, consulting services, certification business and strategic emerging business, testing and evaluation [134].

- China EV100- The China Electric Vehicle Association was established in 2014 as a non-profit, third-party think tank platform and intermediary organization to promote modernizations of automobiles and realize the coordinated development of automobile, energy, information, transportation revolution and smart city [135]. They published a report on how to achieve carbon neutrality in automobile, transportation, and energy sectors.

- CIAPS (Chinese Industry Association of Power Sources) is a national, industrial, non-profit social organization voluntarily formed by the battery industry enterprises. [136] It recently decided to set up a working group to work on CO2-emission standards in the battery industry[16].

- CAAM (Chinese Association of Automobile Manufacturers) is composed of enterprises and institutions as well as organizations in the production of automobiles and its parts (vehicle related industries)[17]. CAAM is a self-disciplined and non-profit social organization and plays its role in providing services, reflecting demands, standardizing behaviors and building platforms [137].

While ChinaEV1000, CIAPs and CAAM are both private organizations, CATARC is state-owned.

[12] In this chapter, we use the exchange rate 1EUR = 7.90 CNY referring to the ECB rate on 30/06/23

[13] translated from homepage

[14] translated from homepage

[15] translated from homepage

[16] www.ciaps.org.cn/news/show-htm-itemid-39253.html

[17] Brief introduction – China Association of Automobile Manufacturers(CAAM)

Table 40: List of key documents.

Key Strategic Documents	Publish Date	Authorship
2021 National Key R&D Program	05/2021	MoST
Energy Saving and New Energy Vehicle Technology Roadmap 2.0	10/2020	CSAE
Action Plan towards the Development of Automotive Power Battery Industry	02/2017	MIIT, NDRC, MoST, MoF
"Made in China 2025" Technology Roadmap in Key Areas	10/2015	NMSAC
Made in China 2025	05/2015	The State Council
14th 5-Year industrial green development plan	11/2021	MITT

8.1.2. General Policy Objectives with respect to battery development

China is determined to tackle climate change in the next decades and has set a binding target of reducing CO_2 emissions per unit of GDP by 18 % in 2025 compared to 2020, and reducing energy consumption per unit of GDP by 13.5 %. As a milestone in 2030, CO_2 emissions per unit of GDP should decrease by 65 % from 2005 levels, with total emissions peaking by then and gradually declining until 2060, when carbon neutrality should be finally achieved [138, 139].

As the world's largest automobile market, China's road transport contributed about 800 million tons of CO_2 emissions in 2019, accounting for 8 % of the country's total emissions. In 2020, the CO_2 emission from passenger cars alone has reached about 500 million tons [140]. In order to achieve the emission reduction target, electrification of the transportation sector is regarded to play a central role. As early as 2015, the development of energy-saving and new energy vehicles (NEV) was set as one of the strategic tasks and priorities in Made in China 2025 [141]. According to the NEV Industry Development Plan (2021-2035), by 2025, NEV sales shall account for about 20 % of total new vehicle sales [142]. By 2030, the retaining volume is estimated to reach 10 million units [143]. By 2035, NEV shall account for more than 50 % of total vehicle sales, with pure electric vehicles accounting for more than 95 % of NEV and public sector vehicles fully electrified. Total carbon emissions from the automobile industry will peak ahead of the national carbon emission reduction commitment around 2028, and in 2035, decrease by more than 20 % from the peak [142, 144].

In addition to curbing CO_2 emissions, strengthening the industrial base, establishing China as an international technology leader in new propulsion technologies, and ensuring energy security are strategic goals of the government [141, 139]. An important focus of the NEV development plan is to strengthen innovation in the battery sector [142, 145]. In recent years, China has intensively promoted battery technology from both the supply and demand sides. The government's comprehensive package of measures ranges from massive research funding, production and settlement support to subsidies and tax benefits for purchases. Extensive tax incentives for electric vehicles, and more generally, for technologies that incorporate high-performance batteries, were used intensively to drive sales and adoption of these technologies in the past [146].

China is very active in battery technology development and will continue to strengthen fundamental research on new power battery systems. It aims to achieve technological transformation and benchmark tests in 2025. By then, the breakthrough of the new power battery system, e.g. lithium-sulfur batteries, metal-air batteries and solid-state batteries, is supposed to be achieved, with the energy density at the cell level reaching 500 Wh/kg [146]. Meanwhile, China also emphasizes the balanced and coordinated development of the entire value chain. By 2025, power batteries and driving electric motors are expected to be exported in large quantities [147]. By 2035, power battery technology is expected to be in an international leading position with a complete, independent and controllable industry chain, including but not limited to key materials, system integration technologies, automation equipment and processes, recycling system, etc. [144, 145, 146].

Made in China 2025 has set the green development index of comprehensive utilization rate of industrial solid waste to reach 79 % [141]. In addition to efforts to transfer technology and improve product performance, China is also addressing the secondary use of batteries in energy storage, charging and swapping, etc. and the recycling of valuable materials [142, 146]. As stated in the Mid- and Long-term Development Plan for Automotive Industry, the actual recycling rate of vehicles should reach internationally advanced levels by 2025 [145]. As for batteries, it is required that the recovery rate of nickel, cobalt, manganese should reach at least 98 %, that of lithium at least 85 %, of rare earths and other major valuable metals at least 97 %. In terms of material restoration process, the material recovery rate should reach at least 90 % [148].

Regulation and Industry specifications with regards to batteries or their applications

- Lithium-ion Battery Industry Specification Terms and Conditions (2021 Edition) – Ministry of Industry and Information Technology (10.12.2021) [149] aims to encourage and guide the technical progress and standard development of the industry in terms of industrial layout and project establishment, process technology and quality management, product performance, safety management, and comprehensive utilization of resources and environmental protection.

- Management Measures for Secondary Utilization of NEV Power Battery – Ministry of Industry and Information Technology, Ministry of Science and Technology, Ministry of Ecology and Environment, Ministry of Commerce, State Administration for Market Regulation (19.08.2021) [150] have specified the requirements for involved enterprises, recycled/reused products, recycling processes, and aim to strengthen the management of secondary utilization of NEV power battery, enhance the comprehensive utilization of resources, ensure the quality of secondary battery products and protect the ecological environment.

- Technical Specifications for Pollution Control of Waste Lithium-ion Power Battery Treatment (draft) (HJ 1186-2021) – Ministry of Ecology and Environment (07.08.2021) [151] specifies the general requirements for the treatment of waste lithium-ion power batteries, the technical requirements for pollution control of the treatment process, the requirements for pollutant emission control, and the requirements for environmental monitoring and operational environmental management.

- EV Traction Battery Safety Requirements (GB 38031-2020) – Ministry of Industry and Information Technology (12.05.2020) [152] focuses on thermal, mechanical, electrical and functional safety requirements.

- Comprehensive Utilization of NEV Waste Power Battery Specification Terms and Conditions (2019 Edition) – Ministry of Industry and Information Technology (02.01.2020) [148] refers to the multi-level and multi-purpose proper utilization process of the retired power battery, mainly including secondary utilization and recycling. The targets for the recovery rate of nickel, cobalt, manganese are ≥98 %, for lithium ≥85 %, and for rare earths and other major valuable metals ≥97 %.

- Interim Measures for the Management of NEV Power Battery Recycling – Ministry of Industry and Information Technology, Ministry of Science and Technology, Ministry of Ecology and Environment, Ministry of Transport, Ministry of Commerce, General Administration of Quality Supervision, Inspection and Quarantine, National Energy Administration (26.01.2018) [153] specifies the requirements for recycling batteries retired/scrapped from production, utilization, storage and transportation. It addresses the implementation of the extended producer responsibility system, which means that automobile manufacturers take the main responsibility, and other related enterprises fulfill corresponding responsibilities in the recycling process. The aim is to promote cooperation between all market players to form an efficient recycling network.

The 14th 5-Year industrial green development plan by MIIT (2021) seeks to improve power battery recycling regulations and systems, explore the promotion of "Internet + recycling" and other new business models, strengthen traceability management, encourage upstream and downstream enterprises in the industrial chain to build common recycling channels, and build a number of centralized recycling service outlets. It also aims to promote the large-scale gradient application of waste power batteries in the fields of energy storage, power backup, power charging and replacement, and build a number of secondary utilization and recycling projects. By 2025, a more complete power battery recycling system should be established.

Public policy as incentives for e-mobility and battery development

As stated in the guidelines to achieve carbon neutrality, financial and taxation price policies, such as NEV and clean energy vehicles and vessels tax incentives, are recommended to promote low-carbon industrial development, technology research and development [138]. In fact, pure electric and fuel cell passenger cars has been exempted from vehicle and vessel tax since July 2018 [154].

In addition, NEVs including pure electric vehicles, plug-in hybrid vehicles (including range extenders) and fuel cell vehicles, are also exempted from purchase tax in 2020 and 2021 [155].

Meanwhile, premiums are obtained when purchasing either electric cars, buses or trucks, the amount of which depends on the range, energy consumption per unit load mass, and installed battery capacity, respectively [156]. It should be noted that the premium is gradually decreasing with EV rollout [157].

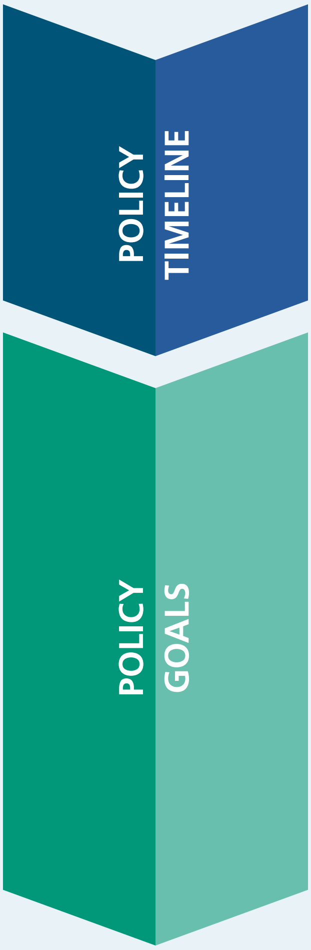
The Action Plan also proposes other tax incentives, such as power battery products eligible for consumption tax exemption, power battery enterprises eligible to enjoy high-tech enterprises, technology transfer, technology development, and other preferential tax policies in accordance with regulations [146].

In total, China plans to spend more than 38.4 billion yuan (approx. 4.9 billion euros) on subsidies to promote NEVs in 2022 [158]. This is a slight increase from 37.5 billion yuan (approx. 4.7 billion euros) in 2021 [159] and 31.3 billion yuan (approx. 4.0 billion euros) in 2020 [160].

Table 41: Overview of the public battery and main characteristics in China with a focus on the main actors.

Aspects	Description
Overall strategic goals	Development and production of batteries and EVs in China (autonomy) Further expand capacities along the value chain
Current R&D performance (publication and patent) [2]	16.3 % global share of patents (2016-2020), the third strongest performance among the six major countries/area. – Strength in Na-sulfur (22 %), Al-ion (21 %) and Na-ion (24 %) batteries, all of them show the second highest number – Weakness in Redox-Flow and Li-air batteries with the smallest share 57.4 % global share of the publication (2017-2021) the strongest performance among the six major countries/area. – Particularly strong in Zn-ion (70 %), metal-sulfur (72 %), Li-sulfur (73 %), metal-air (70 %) and Zn-air (79 %) batteries
Current market status (raw materials, components, cells)	Raw materials: produce 17 % of lithium,1.7 % of cobalt, 4.8 % of nickel and 62 % of natural graphite (2020) Component production: 79 % global share of anodes, 67 % of cathodes, 75 % of electrolytes and 62 % of separators (2023) Cell production: 265 GWh (66 % share) of EV battery cell sales in 2022 xEV sales market: 3,67 million vehicles in 2021
Technological focus/targets	A number of KPIs for LIBs, SSBs and alternative (metal-sulfur and Li-sulfur) batteries are mentioned in roadmaps, funding guidelines, etc. By 2025, a breakthrough of the new power battery system, e.g. lithium-sulfur batteries, metal-air batteries, and solid-state batteries, is supposed to be achieved, with energy density on cell level reaching 500 Wh/kg (Action Plan towards the Development of Automotive Power Battery Industry (MIIT, MoST, NRDC, MoF)).
Production focus/targets	By 2035, NEV shall account for more than 50 % of total vehicle sales, with pure electric vehicles accounting for more than 95 % of NEVs and vehicles in public sector will be fully electrified (NEV Industry Development Plan).
Recycling focus/targets	The actual recycling rate of vehicles should reach the international advanced level by 2025 (MIIT, NDRC, MoST 2017). The recovery rate of Ni, Co, Mn should reach at least 98 %, that of Li at least 85 %, that of rare earths and other major valuable metals at least 97 %. Also, the material recovery rate should reach at least 90 % (MIIT 2020).
Reaction to the IRA	No official information was found
Major instruments	R&D support mainly through the National Key R&D Programs by the MoST, but also the investment by the NSFC/CAS. Massive subsidies to promote NEVs (tax incentives for EV manufacturers, tax exemption on purchase of NEVs) have been made.

Figure 14: Policy timeline and strategic objectives of China.



2015: Made in China 2025 and its Technology Roadmap in Key Areas
2016: The 13th Five-Year Plan -> National Key R&D Program (MoST)
2017: Mid- and Long-term Development Plan for Automotive Industry (MIIT, NDRC, MoST) and Action Plan towards the Development of Automotive Power Battery Industry (MIIT, NDRC, MoST and MoF)
2020: Energy Saving and New Energy Vehicle Technology Roadmap (CSAE), NEV Industry Development Plan (The State Council)
2021: The 14th Five-Year Plan -> National Key R&D Program (MoST), Industrial Green Development Plan (MITT)
2023: decided to extend a tax exemption on purchases of NEVs until 2027

Goals by 2025

- Power batteries and driving motors are expected to be exported in bulk (Made in China 2025)
- A breakthrough of the new power battery system, e.g., lithium-sulfur batteries, metal-air batteries and solid-state batteries, with energy density on cell level reaching 500 Wh/kg (Action Plan towards the Development of Automotive Power Battery Industry)
- The actual recycling rate of vehicles should reach international advanced levels (Mid- and Long-term Development Plan for Automotive Industry)
- EV sales shall account for about 20 % of total new vehicle sales (NEV Industry Development Plan)

Goals by 2035

- NEV shall account for more than 50 % of total vehicle sales, with pure electric accounting for more than 95 % of NEV and vehicles in public sector fully electrified (NEV Industry Development Plan)
- Power battery technology is expected to be in an international leading position with complete, independent and controllable industry chain

8.2. Funding strategy for batteries

8.2.1. Past and current Funding Strategy

Initially, China did not have a dedicated battery strategy and programs - it was rather seen as part of its very ambitious New Energy Vehicle (NEV) strategy, which was introduced with industry support in the early 1990s. For a long time, the focus was very much on demand-side policies, such as tax incentives, exemptions, or consumer subsidy programs to promote NEVs [161]. At first, China's battery policy was very technology-oriented and aimed at catching-up with the leading countries at the time (Japan and South Korea). There was a massive subsidy policy to create a market for NEVs and domestically produced lithium-ion phosphate batteries [161]. Since 2017, China has been reducing its subsidies constantly - because the goal of creating a market was already achieved. Now China is adopting a more technology-open approach and letting the market decide which technology will succeed.

The Chinese strategy is becoming more comprehensive, including specific supply-side measures (e.g. infrastructure building or research on battery safety issues) to address specific market failures. Previously, China much more focused on performance parameters and power density, but now they also have more "qualitative" objectives regarding safety and recycling. There is also an industry-led initiative to orient themselves more toward a lower carbon footprint of batteries because they want to export to the EU, where the Batteries Regulation is being updated.

In general, China is trying to attract private capital into the battery sector by making public investments in technology development [146]. Public funding are allocated into three categories:

- Research: national science and technology funding programs (dedicated projects, R&D funds) and other coordinated support for core technology research and development.

- Technology transfer: industrial transformation and upgrading, technological transformation, high-tech industry development dedicated projects, smart manufacturing dedicated projects, advanced manufacturing industry investment funds and other funding channels, focusing on supporting the leading enterprises in frontier fundamental research, battery products and key components, manufacturing equipment, recycling and other areas.

- Tax incentives: for example, power battery products eligible for consumption tax exemption, power battery enterprises eligible to enjoy high-tech enterprises, technology transfer, technology development and other preferential tax policies in accordance with regulations.

The amount of government subsidies to electric vehicle manufacturers is estimated to be around 39 billion euros between 2009 and 2020 [162]. In this context, government subsidies are an important driver of electric mobility and have led to China becoming not only the world's largest supplier, but also the largest sales market for electric vehicles and batteries.

The subsidy policy is being systematically adapted to the new circumstances. For example, subsidies have been steadily reduced in recent years. The protection of domestic producers through the so-called "white list" has also been abolished in 2019 [163]. However, the subsidy freeze planned until 2021 was suspended due to the Corona pandemic and falling sales figures, and the payment of subsidies and purchase premiums for new electric vehicles was initially extended until 2022 [164, 165]. In addition, in June 2023, the Chinese government announced that it would continue a tax exemption on purchases of NEVs until the end of 2027 with 520 billion yuan, trying to stimulate slower car sales growth [166].

With the help of a comprehensive government subsidy program, a complete value chain has been established in China. This ranges from the procurement of raw materials to battery manufacturing and the production of electric vehicles [162]. Many of the battery manufacturers have already achieved a dominant position in the market and are further strengthening their dominance by investing in production capacity and R&D. Government support for foreign investment in resource-rich regions can also ensure a stable supply of critical raw materials. China's mastery of the entire value chain currently represents a significant competitive advantage over global rivals.

The government is paying special attention to the development of charging infrastructure. In this context, the development of charging infrastructure is mainly carried out through public-private partnerships between state-owned energy companies, vehicle manufacturers and charging infrastructure operators [164]. In addition to charging stations, the MIIT plans to build over 10,000 new swap stations to facilitate battery swapping [167].

8.2.2. Funding priorities and instruments

As specified in the 2021 National Key R&D Programs, these are the following priorities for China's battery funding policies with regards to technological features:

- High capacity, high energy density solid-state LIB for EV application

- High energy density lithium metal-based secondary batteries for both EV and energy storage applications

- High safety, long cycle life, low-cost LIB, solid-state LIB as well as metal-sulfur based batteries for energy storage and smart grid

8.2.3. Funding Budgets

Li et al. estimate that during the 13th Five-Year Plan (2016-2020), a total of 1.844 billion yuan (approx. 233 million euros) was invested by national funds in R&D activities, with the following breakdown [168]:

- MoST formulated 27 projects on advanced batteries through six National Key R&D Programs, including
  - 13 projects for "New Energy Vehicles" with 750 million yuan, to support R&D on vehicle batteries and the large-scale industrialization.
  - 5 projects for "Smart Grid Technology and Equipment" with 294 million yuan, to support R&D on advanced batteries for large-scale energy storage in grid.
  - 9 projects for "Nanotechnology", "Deep Sea Key Technology" and "Key Technology and Supporting Platform of Material Genome Engineering" with 150 million yuan.
- National Natural Science Foundation of China invested approximately 50 million yuan in the basic research related to batteries
- Chinese Academy of Sciences' Strategic Priority Research Program invested 290 million yuan in advancing automotive batteries and 160 million yuan in developing energy storage batteries

During the 14th Five-Year-Plan period (2021-2025), R&D on battery-related topics continues to be supported, under the National Key R&D Program. Below are the three National Key R&D Programs released in 2021 that focus on battery technology (Table 42) [169, 170, 171], which we have identifie d as the programs with priorities for battery projects, with one open callfor proposals [172]. The research funding in different programs related to battery technology amounts to 227 million yuan (approx. 29 million euros) in 2021.

Table 42: Battery-related topics in 2021 National Key R&D Program in China.

2021 National Key R&D Program	Total Program Budget	Funding Priorities (budget breakdown to battery projects)
New Energy Vehicles	5 years duration, 6 key technology tracks, 18 projects 0.86 billion yuan funding	all solid-state LIB technology, approx. 47.8 million yuan funding
New Energy Vehicles Open Call for High-safety, All-climate Power Battery System Technology	3 years duration, milestone evaluation takes place 1 year after official launch. 1 project, 60 million ¥ funding	high safety, all-climate conditions application, 60 million ¥ funding
High-end Functional and Smart Materials	4 years duration, 6 key technology tracks, 35 projects, 0.659 billion ¥ funding	high energy density lithium metal-based secondary batteries, approx. 18.8 million ¥ funding
Energy Storage and Smart Grid	4 years duration, 6 key technology tracks, 20 projects, 0.667 billion ¥ funding	– GWh LIB energy storage system – MWh intrinsically safe solid-state battery for energy storage – metal-sulfur based battery for energy storage approx. 100 million ¥ funding

8.3. Strategic technical objectives with respect to battery development

8.3.1. Specific technological focus of funding programs and strategies

For lithium-ion batteries

Regarding the technological objectives for lithium-ion batteries, the following can be inferred from the Action Plan [146], the Roadmap(s) [143, 144] and the 2018 National Key R&D Program [173]:

- R&D focus: Significant improvement of product performance (high energy density, wide temperature adaptivity), high safety, long cycle life, low cost

- Value chain focus: Large-scale automated production and application, secondary use and recycling, promote the development and industrialization of new lithium-ion power batteries, achieve large-scale applications in 2020

- Application focus: EVs at all levels, large-scale energy storage

The previous subsidy policy had a clear technology orientation, especially battery capacity, energy density, etc. were set as the key evaluation index of the subsidy amount. In the latest specification, the product performance requirements are lifted [149]. Although lithium-iron-phosphate (LFP) batteries are cost-effective, China is rapidly transitioning from LFP to high energy density lithium nickel manganese cobalt oxide (NMC) batteries [174].

The key objective is to significantly improve product performance parameters:

- by 2020, a single cell should fulfil the following criteria: energy density of ≥300 Wh/kg, of system ~260 Wh/kg, cost ≤1 ¥/Wh (≤127 €/kWh), operational temperature -30 °C ~55 °C, capable of 3C charging

- by 2025, breakthrough of the new power battery system technology, energy density of single cell ~500 Wh/kg)

- by 2020, the total production capacity of the industry has amounted to ≥100 GWh/a, promote leading enterprises of international competence with production and sales scale ≥40 GWh

The following additional KPIs are defined in funding guidelines of the National Key R&D Program and expected to be achieved by the projects:

Topic: High Energy Density Lithium Metal-based Secondary Batteries (from "High-end Functional and Smart Materials")

- lithium metal-based composite negative electrode specific capacity ≥2000 mAh/g
- solid electrolyte film surface resistance ≤10 $\Omega \cdot cm^2$, separator thickness ≤20 µm, electrochemical potential window ≥4.8 V
- cathode material specific capacity ≥215 mAh/g, capacity retention rate ≥80 % after 2500 reversible cycles
- energy density ≥350 Wh/kg
- cycle life ≥2000 cycles
- above 10 Ah at 100 % SOC withstands the nail penetration test (no fire, no explosion) and meets the current national safety standard

Topic: GWh Lithium-ion Battery Energy Storage System (from "Energy Storage and Smart Grid")

- cycle life of storage unit at 25 °C, 100 % depth of discharge with 0.5C charge or discharge ≥15,000 cycles
- capable of 2 hours storage with ≥0.5C discharge
- high-voltage battery system unit insulation tolerance level ≥35 kV (DC)
- system energy conversion efficiency ≥90 % (including the main circuit and auxiliary circuit power consumption, AC low-voltage side efficiency)
- rated power ≥rated power at 1C charge and discharge
- 1 minute sustained peak power ≥rated power at 2C charge and discharge
- expected service life ≥25 years
- output scale ≥1 GWh
- equivalent cost of electricity ≤0.1 ¥/kWh

For solid-state batteries

For solid-state batteries, the technology focus is stated in the Action Plan [146] and the Industry Development Report [175]:

- R&D-focus: Breakthroughs in key materials and components, high capacity and high energy density, high safety, long cycle life
- Value chain focus: Technological transformation and benchmark test in 2025, commercialization in 2030
- Application focus: EV at all levels, large-scale energy storage

The following additional KPIs are defined in funding guidelines of the National Key R&D Program and expected to be achieved by the projects:

Topic: All Solid State Lithium-ion Battery Technology (from "New Energy Vehicles")

- solid state composite positive electrode specific capacity >400 mAh/g (see assessment, regarded as very ambitions even for Li/Mn rich cathodes)
- composite metal lithium negative electrode specific capacity >1,500 mAh/g
- solid electrolyte thickness <15 µm
- conductivity under room temperature >1 mS/cm
- lithium-ion transference number >0.8
- capacity >10 Ah
- energy density >600 Wh/kg
- cycle life >500 cycles

Topic: MWh Intrinsically Safe Solid-State Lithium-ion Energy Storage Battery (from "Energy Storage and Smart Grid")

- liquid electrolyte content in the single cell ≤5 wt% of the cell mass
- cycle life ≥15,000 cycles (1C charge/discharge, 25 °C, 100 % depth of discharge)
- 10 MWh solid-state energy storage lithium-ion battery system, module level efficiency ≥90 %, battery cabinet level efficiency ≥80 %, 40-foot container storage capacity ≥5 MWh
- cycle life of storage unit at 25 °C, 100 % depth of discharge with 0.5C charge/discharge ≥12,000 cycles
- response time ≤200 ms
- system energy conversion efficiency ≥90 % (including the main circuit and auxiliary circuit power consumption, AC low voltage side efficiency)
- equivalent cost of electricity ≤0.2 ¥/kWh
- no fire, no explosion under extreme use case

For alternative battery technologies

For alternative battery technologies, the Chinese government's R&D focus is on performance parameters such as long cycle life, high efficiency, and low cost [171, 170].

The value chain focus is on creating large-scale energy storage with low resource dependency. The application focus is on energy storage and probably low range EVs.

For metal-sulfur based energy storage batteries, the objectives are the following:

- cycle life of ≥15,000 cycles (room temperature, charge/ discharge rate ≥0.5C, 80 % depth of discharge)
- average Coulombic efficiency of 500 cycles 99.99 % (current density of negative electrode = 3 mA/cm^2, areal capacity = 6 mAh/cm^2).
- 100 kWh metal-sulfur-based energy storage battery system, 0.5C charge / discharge, system energy conversion efficiency ≥80 % at 25 °C, cycle life ≥12,000 cycles, capacity retention rate ≥80 % below -20 °C operation condition
- system cost ≤0.6/Wh (≤83 €/kWh)

8.3.2. Technical objectives and milestones (KPIs)

Some more general KPI targets, focused on different applications and performance parameters then towards specific technologies, are specified in the Energy Saving and New Energy Vehicle Technology Roadmap 2.0 (Table 43) [144]:

Production capacity

The battery production capacity (type of battery not specified) in China is expected to reach 400 GWh in 2025 [176] and 800 GWh in 2030 [177].

The mass production capacity of solid-state batteries is estimated to reach 25 GWh in 2025 and 250 GWh in 2030 [178]. Some examples of announced manufact uring projects in mainland China are listed in Table 44 [179].

Table 43: Technological roadmap of batteries by type of batteries and application areas (China SAE).

Type	Application Scope	KPI	2025	2030	2035
High energy density battery	Low end	Specific energy (Wh/kg) on cell level	>200	>250	>300
		Cycle/service life	>3,000/12 years	>3,000/12 years	>3,000/12 years
		Cost (¥/Wh)	<0.35	<0.32	<0.30
	Commercial	Energy density (Wh/kg) on cell level	>200	>225	>250
		Cycle/service life	>6000/8 years	>6000/8 years	>6000/8 years
		Cost (¥/Wh)	<0.45	<0.40	<0.35
	High end	Specific energy (Wh/kg) on cell level	>350	>400	>500
		Cycle/service life	>1,500/12 years	>1,500/12 years	>1,500/12 years
		Cost (¥/Wh)	<0.50	<0.45	<0.40
Intermediate battery	ordinary	Energy density (Wh/kg) on cell level	>250	>300	>325
		Cycle/service life	>1,500/12 years	>1,500/12 years	>1,500/12 years
		Cost (¥/Wh)	<0.60	<0.55	<0.50
	fast charging	Energy density (Wh/kg) on cell level	>225	>250	>275
		cycle/service life	>3,000/10 years	>3,000/10 years	<0.60
		cost (¥/Wh)	<0.70	<0.65	<0.60
		charging time (min)	<15	<12	<10
High power density battery	high power	Energy density (Wh/kg) on cell level	>80	>100	>120
		cycle/service life	>3*10^5/12 years	>3*10^5/12 years	>3*10^5/12 years
		cost (¥/Wh)	<1.20	<1.00	<0.80

Table 44: Announced production for SSB announced in China [179].

Company	Annual production capacity
ProLogium TM	50 GWh (2026)
QingTao (Kunshan) Energy Development	10 GWh (2024)
Star Energy	2 GWh (2024)
Solid State Lion (WELION)	1 GWh (2022), 20 GWh (2026)
Ganfeng Lithium	2 GWh (in production)

KPIs for lithium-ion-batteries (until 2025/until 2030/beyond 2030)

The KPIs from the Chinese Government for lithium-ion batteries until 2025 are as follows:

Table 45: Chinese KPIs for LIBs until 2025.

KPIs until 2025 (for LIBs)	KPI (CN)	Technological feasibility assessment
Specific energy (for semi-solid-state Li-ion and Ni rich Mn based Li-ion cells)	400 Wh/kg (cell level) [175]	**Ambitious** – Cell-level specific energy of >350 Wh/kg is unlikely to be achieved with conventional (non Li-metal) Li-ion technology based on intercalation/insertion type active materials.
Specific power	≥1,300 W/kg [175]	-
Charging rate (for fast charging type)	<15 min [144]	**Ambitious** – Charging rates >4C are feasible for high-power batteries, but challenging to implement in high-energy cells and likely to lower cycle life and result in lower charging efficiency due to resistive losses (accompanied by heat generation).
Cycle life	≥2,000 cycles [175]	**Realistic** – High cycle numbers >2000 cycles are possible with LIBs, but may not be required for EV applications. However, stationary energy storage systems (ESS) or heavy duty electric vehicles (i.e. trucks) require these high cycle numbers.
Calendar lifetime	≥10 years [143]	**Realistic** – The warranty on most EV batteries is 8 years. Longer calendar life is desirable in ESS applications.
Battery cost (cell level)	≤0.6 ¥/Wh (≤76 €/kWh) [175]	**Realistic** – Cell level costs below 86 €/kWh will be challenging to realize on the short-term, as battery raw material prices are currently surging. Given the strong battery value chain and raw material availability in China, this mid-term target is realistic, especially for Ni, Co-free cell chemistries.
Battery safety	In the EV Traction Battery Safety Requirements (GB 38031-2020) [152], in case of cell thermal runaway, the system should operate without fire and explosion for 5 min, leaving time for occupants to escape safely.	**Ambitious** – Conventional high-energy batteries contain combustible liquid electrolyte, which makes them prone to fire in the event of misuse (physical damage or short circuit). The goal should lie in stopping the spread of fire and prevent explosive events.
Recycling recovery rate	recovery rate of Nickel, Cobalt, Manganese ≥98 %, of Lithium ≥85 %, of rare earths and other major valuable metals ≥97 % [148]	**Ambitious** – The material recovery rates are very high, especially for lithium. For reference, the EU Battery Directive Proposal targets a recovery rate of 90 % for Cu, Co and Ni, while 35 % for Li by 2025 (or 2030).
Material recovery rate	in case of material restoration process, the material recovery rate ≥90 %.	**Ambitious** – For reference, the EU Battery Regulation proposes a 65 % recycling efficiency for 2025 and 70 % by 2030.

Regarding battery safety, according to the National Key R&D Program New Energy Vehicles Open Call for High-safety, All-climate Power Battery System Technology [172] the targets for high-safety, all-climate battery system integration technology are as follows:

- module efficiency ≥80 %
- safety risk prediction and early alert model ≥3
- abnormal cell identification rate ≥95 %
- short circuit fault diagnosis accuracy ≥90 %
- in case of thermal dispersion, no fire and explosion within 90 min (after the thermal runaway signal)
- no fire and explosion under 200 kN extrusion

The KPIs for lithium-ion batteries from the Government until 2030 and beyond 2030 are the following (Table 46 and 47, respectively).

Table 46: Chinese KPIs for LIBs until 2030.

KPIs until 2030 (for LIBs)	KPI (CN)	Technological feasibility assessment
Specific energy (cell level)	>400 Wh/kg (high energy LIB) [144]	**Ambitious** – Due to physicochemical limitations, advanced lithium-ion batteries based on intercalation/insertion type active materials are not likely to exceed specific energy contents much above 400 Wh/kg.
Power density and charging rate	≥1,300 W/kg [175] For fast charging type <12 min [144]	**Ambitious** – Charging rates >4-5 C are feasible for high-power batteries, but are challenging to implement in high-energy cells and are likely to lower cycle life and result in lower charging efficiency due to resistive losses (accompanied by heat generation).
Cycle life	≥2,000 cycles [175]	**Realistic** – High cycle numbers >2,000 cycles are possible with LIBs, but may not be required for EV applications. However, stationary energy storage systems (ESS) or heavy duty electric vehicles (i.e. trucks) require these high cycle numbers.
Cost	cell ≤0.6 ¥/Wh (≤76 €/kWh) [175]	**Realistic** – Cell-level costs below 86 €/kWh are realistic if a cost-competitive LIB recycling loop is established by the end of the decade.

Table 47: Chinese KPIs for LIBs beyond 2030.

KPIs beyond 2030 (for LIBs)	KPI (CN)	Technological feasibility assessment
Specific energy (cell level)	≥500 Wh/kg [175]	**Ambitious** – Cell-level specific energy >400 Wh/kg is unlikely to be achieved with conventional (non Li-metal) Li-ion technology based on intercalation/insertion-type active materials.
Specific power	≥1,500 W/kg [175]	**Ambitious** – Charging rates >3C are feasible for high-power batteries, but challenging to implement in high-energy cells and are likely to reduce cycle life and result in lower charging efficiency due to resistive losses (accompanied by heat generation).
Cycle life	≥2,000 cycles [175]	**Realistic** – High cycle numbers >2,000 cycles are possible with LIBs, but may not be required for EV applications. However, stationary energy storage systems (ESS) or heavy duty electric vehicles (i.e. trucks) require these high cycle numbers.
Cost (cell level)	≤0.6 ¥/Wh (≤76 €/kWh) (inferred) [175]	**Realistic** – Cell-level costs below 86 €/kWh are realistic if a cost-competitive LIB recycling loop is established by 2030+ and/or for low-cost cathode chemistries (e.g., lithium iron phosphate).

KPIs for solid-state batteries (until 2025/until 2030/beyond 2030)

The KPIs for solid-state batteries from the Government u-ntil 2025, 2030 and beyond 2030 are summarized in the following tables (Table 48, 49 and 50, respectively).

Table 48: Chinese KPIs for solid-state batteries until 2025.

KPIs until 2025 (for SSB)	KPI (CN)	Technological feasibility assessment
Specific energy	Cell level ≥500 Wh/kg [146] For semi-solid-state with Ni-rich cathode (cell ≥400 Wh/kg [175])	**Realistic** – This specific energy target is achievable with lithium-metal based SSBs.
Cycle life	≥5,000 cycles/ 12 years [175]	**Ambitious** – Achieving high cycle numbers will be challenging for SSBs.
Battery cost (cell level)	≤1.5 ¥/Wh (≤190 €/kWh) [175]	**Realistic** – The target battery cost for SSBs is high (in contrast to roadmap targets in other world regions). However, this cost target seems realistic given the expensive raw materials (Li metal and solid electrolyte), novel processing routes, and more demanding processing environments (dry atmosphere) [180].

Table 49: Chinese KPIs for solid-state batteries until 2030.

KPIs until 2030 (for SSBs)	KPI (CN)	Technological feasibility assessment
Specific energy	≥500 Wh/kg (cell) ≥400 Wh/kg (pack/ module) [175]	**Realistic** – For Li-metal-based or anode-free SSBs, this energy content target is realistic.
Cycle life	≥6,000 cycles/ 15 years [175]	**Ambitious** – Achieving high cycle numbers will be challenging for Li-metal based SSBs due to potential immobilization of electrochemically active lithium and resistance build-up due to chemomechanics of the solid-solid interfaces.
Cost	≤1.1 ¥/Wh (≤139 €/kWh on cell level) [175]	**Realistic** – With ongoing ramp-up (economies of scale) and improving technological maturity of SSBs, this cost target for 2030 seems realistic.

Table 50: Chinese KPIs for solid-state batteries until 2030.

KPIs until 2030 (for SSBs)	KPI (CN)	Technological feasibility assessment
Specific energy (cell level)	≥500 Wh/kg, pack/module ≥450 Wh/kg [175]	**Realistic** – For Li-metal-based or anode-free SSBs, this energy content target is realistic.
Cycle life Calendar life	≥10,000 cycles 20 years [175]	**Ambitious** – Achieving high cycle numbers will be challenging for Li-metal based SSBs due to potential dendrite formation and ongoing immobilization of electrochemically active lithium.
Cost (cell level)	≤0.7 ¥/Wh (≤89 €/kWh) [175]	**Ambitious** – This ambitious cost target may be achieved for "anode-free" SSBs without the need for lithium-metal processing in conjunction with scaled and matured solid electrolyte production at lower costs beyond 2030.

KPIs for alternative battery technologies (until 2030/beyond 2030)

The KPIs below are probably targeted towards metal-sulfur-batteries, as described for this timeframe in the R&D-Focus (see 9.2.1.).

Concerning the meaning of alternative batteries for China, there is not much information for Na-ion / Li-F in the officially released documents. The energy density and cycle life KPIs for Li-S are mainly extracted from the key R&D Program Energy storage & Smart Grid.

Table 51: Chinese KPIs for LIBs beyond 2030.

KPIs until 2030 (for alternative)	KPI (CN)	Technological feasibility assessment
Specific energy (cell level)	≥500 Wh/kg (inferred) [181]	**Realistic** – This specific energy target has already been achieved in prototype cells. Li/S cells are known for their high specific energy [Wh/kg] with low excess of electrolyte.
Cycle life (for energy storage applications)	≥15,000 cycles (room temperature, ≥0.5C, 80 % depth of discharge) [171]	**Ambitious** – Achieving high cycle life (>1,000 cycles) is a major challenge for Li/S batteries due to the solubility of polysulfides in the electrolyte, which induces self-discharge.
Cost (system level)	≤0.6 ¥/Wh (≤76 €/kWh) [171]	**Realistic** – Given the very low cost of the cathode active material (sulfur), the use of lithium metal is the major cost contributor, which could put this realistic target at risk.

Table 52: Chinese KPIs for alternative batteries beyond 2030.

KPIs beyond 2030 (alternative)	KPI (CN)	Technological feasibility assessment
Specific energy (cell level)	≥500 Wh/kg [171]	**Realistic** – This specific energy target has already been achieved in prototype cells. Li/S cells are known for their high specific energy [Wh/kg] with low excess of electrolyte.
Specific power	≥1,500 W/kg (inferred) [175]	**Ambitious** – Li/S batteries are typically not high-rate batteries, as the kinetics of conversion-type cathodes such as sulfur are slow.
Cycle life	≥2,000 cycles (inferred) [175]	**Ambitious** – Achieving high cycle life (>1,000 cycles) is a major challenge for Li/S batteries due to the solubility of polysulfides in the electrolyte, which induces self-discharge.
Cost (cell level)	≤0.6 ¥/Wh (≤76 €/kWh) (inferred)	**Realistic** – Given the very low cost of the cathode active material (sulfur), the use of lithium metal is the major cost contributor, which could put this realistic target at risk.

9. Overview on battery-related policy objectives of other countries

9.1. UK

The UK's Climate Change Act, updated in 2019, declared that it is the duty of the Secretary of State to ensure that the UK's net carbon account in 2050 is at least 100% lower than the 1990 baseline [182]. This act made the country the first major economy to adopt a legally binding obligation to achieve net zero emission by 2050.

To achieve this goal with economic success at the same time, the government formulated a Ten Point Plan to mobilize £12 billion to create green jobs. Of the ten points, Point 4 is about accelerating the shift to zero emission vehicles. The government will take action to end the sale of new petrol and diesel cars and vans by 2030, with all vehicles required to have significant zero emission capability (e.g. plug-in and full hybrid) by 2030 and 100 % zero emissions by 2035 [183].

Under the Ten Point Plan, the UK government has committed up to £ 1 billion to support the electrification of UK vehicles and their supply chains, including the development of "gigafactories" in the UK to produce the batteries needed at scale (Automotive Transformation Fund). On the demand-side, £ 1.3 billion will be invested to accelerate the roll-out of charging infrastructure and £ 582 million to extend the Plug-in Car, Van, Taxi, and Motorcycle grants to 2022-23 to reduce their sticker price for the consumers.

As a means of R&D funding for battery technologies, UK Research and Innovation has organized the Faraday Battery Challenge, which has invested up to £ 330 million in research and innovation projects and facilities between 2017 and 2022. The Challenge provided £ 108 million to the UK's independent institute (the Faraday Institution) for electrochemical energy storage research, skills development, market analysis, and early-stage commercialization. In addition, more than £ 90 million of funding has been made available by Innovate UK to lead feasibility studies and collaborative research and development projects. Furthermore, over £ 120 million has been invested in the UK Battery Industrialization Center to help companies rapidly develop their capabilities to manufacture batteries, scale-up, and expand into global markets. [184]. In October 2022, it was announced that the Faraday Battery Challenge would be extended to March 2025, with an additional £ 211 million [185].

KPIs for battery performance were not found in the strategic documents published by the UK government. However, the Advanced Propulsion Center UK, a non-profit organization that organizes the Automotive Transformation Fund collaborating with the UK government, published the Electrical Energy Storage Roadmap 2020 with the Automotive Council UK. The roadmap shows technology indicators (transient discharge power density, gravimetric energy density, volumetric energy density and cost) to be achieved by 2035 at cell and pack level [186].

9.2. France

France has set the goal of reducing its emissions by 40 % in 2030 compared to 1990 and achieving carbon neutrality throughout the country by 2050, without the use of carbon offsetting. In order to achieve this goal, as for the mobility sector, France will end the sale of new private and light commercial vehicles powered by fossil fuels by 2040 [187].

Bpifrance (a French public investment bank) has launched a series of initiatives since 2018, leading to the emergence of battery factory projects for the automotive sector. In 2021, Bpifrance launched a call for proposals for "solutions et technologies innovantes pour les batteries", as part of the Investments for the Future 4 (PIA4) and the National Recovery and Resilience Plan. This program provides a grant and a recoverable advance to the selected projects led by French companies to support R&D on batteries [188]. In addition, France has joined the Important Project of Common European Interests (IPCEI) Batteries.

9.3. Israel

Israel's Nationally Determined Contribution under the Paris Agreement, submitted to the UNFCCC in July 2021, includes an unconditional absolute GHG emission reduction target for 2030 and 2050, relative to 2015, of 27 % and 85 %, respectively [189]. In 2022, Israel's Ministerial Committee for Legislation approved the Climate Law with the more ambitious goal of achieving a zero-emissions economy by 2050 [190].

Before setting the ambitious goal of carbon neutrality, Israel had already set the objectives to regulate gasoline-fueled automobiles in the Energy Economy Objectives for the Year 2030. According to the document, Israel will prohibit the entry of gasoline- or diesel-fueled automobiles starting in 2030. Furthermore, the following interim targets were defined: 5 % of sales in 2022, 23 % of sales in 2025, and 61 % of sales in 2028 [191].

To increase the rate of electric mobility, Israel has taken steps to facilitate the entry of electric vehicles into the Israeli market through various measures, such as setting regulations, increasing charging infrastructure, providing economic incentives, establishing electric vehicle sharing systems, introducing electric vehicles in public transportation and government use [192]. Recently, Israel has been eager to promote climate-tech innovation, and the government approved an innovation program for climate technology that will allocate 3 billion shekels (approx. 859 million euros) by 2026 [193].

9.4. Canada

Canada's most recent Nationally Determined Contribution under the Paris Agreement promises to reduce emissions by 40-45 % below 2005 levels by 2030 and to net-zero by 2050 [194]. Toward this goal, the Government of Canada is seeking to accelerate a mandatory target for all new light-duty car and passenger truck sales to be zero-emission by 2035 through a combination of investments and regulations [195].

In terms of incentives to promote zero-emission vehicles, the Zero-Emission Vehicles (iZEV) program will invest an additional $ 287 million over two years starting in 2020-21, continuing until March 2022. The program provides a rebate of up to $ 5,000 for a zero-emission light-duty vehicle. An additional $ 150 million will also be invested in charging and refueling stations across Canada over three years [196].

Canada analyzes that its competitiveness in a battery market is based on secure supply chains for critical minerals. In the Healthy Environment Healthy Economy Plan, the government noted that Canada is one of the only jurisdiction in the western hemisphere that has reserves of all the minerals required to produce advanced batteries for electric vehicles. The government will leverage Canada's competitive advantage in mining to build Canada's battery and critical mineral supply chains and support the broader transition to clean energy [196].

With regard to innovation policy, the Net Zero Accelerator provides funding as part of the Strategic Innovation Fund, organized by the Innovation, Science, and Economic Development Canada program. This program will provide up to $ 8 billion to support projects that will enable Canada to reduce its domestic greenhouse gas emissions, including the development of a Canadian battery innovation and industrial ecosystem. Examples of eligible project topics include, but are not limited to, cathode manufacturing, anode manufacturing, battery cell manufacturing, and electric vehicles [197].

9.5. Taiwan

Taiwan's Greenhouse Gas Reduction and Management Act, released in July 2015, outlines the country's long-term national goal of reducing GHG emissions to no more than 50 % of 2005 GHG emissions by 2050 [198]. More recently, in March 2022, the government of Taiwan released a roadmap to an even more ambitious goal, "Taiwan's Pathway to Net-Zero Emissions in 2050". Regarding the mobility sector, the document states that by 2030, Taiwan aims to make all urban public buses and official cars, 30 % of car sales and 35 % of scooter sales be electric, and by 2040, to make 100 % of car and scooter sales be electric. To achieve this goal, NT $168.3 billion will be allocated for electrification of transportation vehicles sector by 2030 [199].

Taiwan released the National Development Plan (2021-2024) in July 2021, which mentions vehicle batteries in the "strategic stockpile industries" section as one of the examples of major industrial key materials to be developed for domestic supply and technical autonomy. And the technology and uniqueness of vehicle batteries will be enhanced and the needs for various applications in the market will be strategically expanded [200].

9.6. India

At the COP 26 Climate Meeting in 2021, India pledged to achieve net-zero carbon emissions by 2070 [201].

Since 2015, the Ministry of Heavy Industries in India has been promoting the faster adoption and manufacturing of hybrid and electric vehicles under the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME India) scheme. The first phase of FAME had been extended from time to time, until it was finally completed in March 2019. FAME II was launched in April 2019 with a total budget of Rs.10,000 Crore, of which around 86 % has been allocated for demand incentives. Notably, the FAME II notification indicated that since battery cost is one of the main factors of the price difference between xEVs and internal combustion vehicles, the demand incentives would be based on the battery capacity and would only be provided if the vehicle is equipped with advanced batteries that meet certain performance [202]. FAME II was originally scheduled to end at the end of March 2022, but it was announced that the period would be extended to the end of March 2024 [203].

In addition, to expand battery production capacity, in May 2021, the Cabinet of India approved the production-linked incentive scheme, "National Program on Advanced Chemistry Cell (ACC[18]) Battery Storage" to achieve manufacturing capacity of 50 GWh of ACC and 5 GWh of "Niche" ACC with an outlay of Rs. 18,100 Crore (approximately 212 million euros) [204].

[18] ACC battery is defined as the new generation of advanced storage technologies that can store electrical energy either as electrochemical or chemical energy and convert it back into electrical energy.

10. Cross-Country-Analysis

In the following, we compare the characteristics of the different country's battery strategies according to the dimensions of analysis in the country reports (chapters 3 to 8).

As a disclaimer for the interpretation of the cross-country analysis, it should be noted that the KPIs can vary in their status as official and high-level objectives, depending on the country's contexts and political system. Also, some KPIs are based on an overall and coherent national battery strategy (e.g. Blueprint in the U.S., K-Battery Development Strategy in South Korea, Green Growth Strategy in Japan), while others come from specific ongoing funding programs (e.g. Battery 500 in the U.S., NEDO's programs in Japan, National Key R&D Program in China) and are focused towards specific individual project levels.

10.1. Comparison of R&D outputs of the major countries

Before comparing the collected KPIs, this section illustrates the results of our bibliometric and patent analyses in order to set the context in terms of R&D outputs and capacities of the international players. In particular, publication activities can be relate to the public funding measures of countries and reflect their technology focus.

The following figures show the recent global share of publications and patents for different types of battery technologies for the six major countries or regions. The publication analyses were based on peer-reviewed publications in Web of Science. Different keyword-based search strategies were used to identify the respective key publications. The patent analyses were conducted using mixed IPC class (International Patent Classification) and keyword-based search strategies in the Derwent Worlds Patents Index (WPI) database hosted by the Scientific & Technical Information Network. This analysis considers patents filed in 2016-2020, and publications published in 2017-2021. In general, Japan dominates for patents, and China for publications.

Publications

China's share of publications is well above 30 % for all the battery technologies that we have examined. Furthermore, the share exceeds 50 % for LIB and most of the alternative battery technologies. The EU28 and the U.S. show a similar level of publications and account for approx. 10-20 % global share, depending on the battery type. The U.S. has more than 20 % of the share for SSBs (22 %), Redox-Flow batteries (23 %) and Na-Sulfur (21 %) while the EU28 has a higher share for Redox-Flow batteries (25 %).

Germany, South Korea and Japan have smaller global shares, typically less than 10 %. Germany ranks 4th for SSBs (9 %), Na-Sulfur (5 %) and Al-ion (7 %) batteries, while South Korea does for the other 8 battery types, including Redox-Flow batteries (9 %) and Li-Air batteries (13 %). Japan has the lowest share of publications for 9 out of the 11 battery types examined.

Patents

In contrast, Japan has the highest patent share (especially for Li and Al-ion batteries as well as SSB, where the figures exceed 40 %), except for Li-air, Na-sulfur and Li-sulfur batteries. For these three battery types, the U.S. has the largest share of patents. The U.S. also accounts for more than 20 % of patents for SSB, Na-ion, Zn-ion, Mg-ion, and Redox-Flow batteries.

China has the second largest share of patents for Na-sulfur (22 %), Al-ion (21 %) and Na-ion (24 %) batteries, and the smallest for Redox-Flow and Li-air batteries. On the other hand, the EU has its strength in Redox-Flow (25 %, second largest share) and Zn-air (17 %, second largest share).

South Korea is strong in specific types of technologies. The country accounts for 26 % of Li-sulfur, 21 % of Li-air (second largest) patents. For SSB, South Korea ranks 3rd with over 15 % share (ahead of the EU28 with 14 % share). Germany ranks 4th for Redox-Flow batteries (14 %) and 5th for Li-air batteries (8 %), but 6th for other technologies.

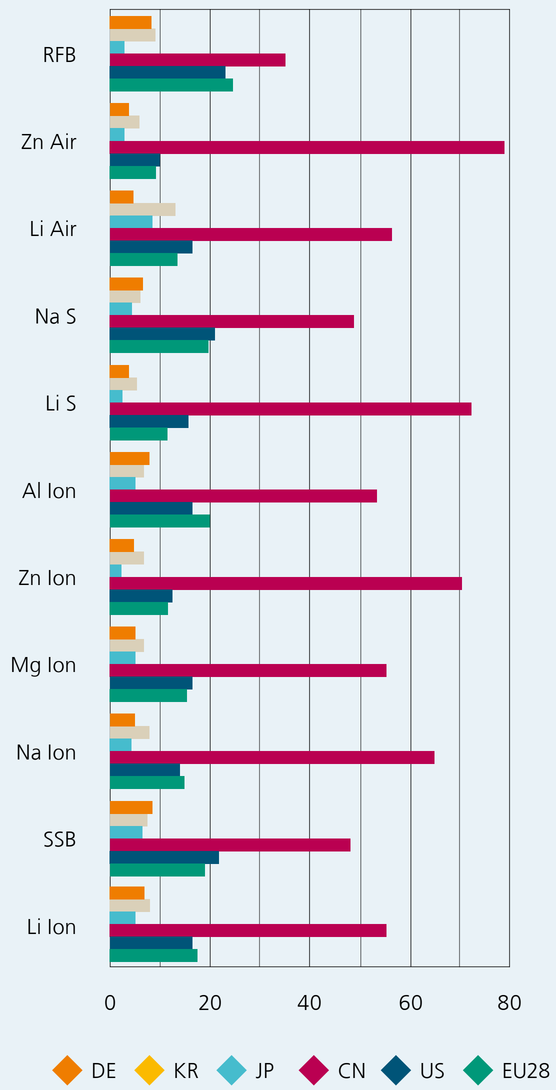


Figure 15: Share of global peer-reviewed publications for alternative battery technologies by country and world region (2017-2021).

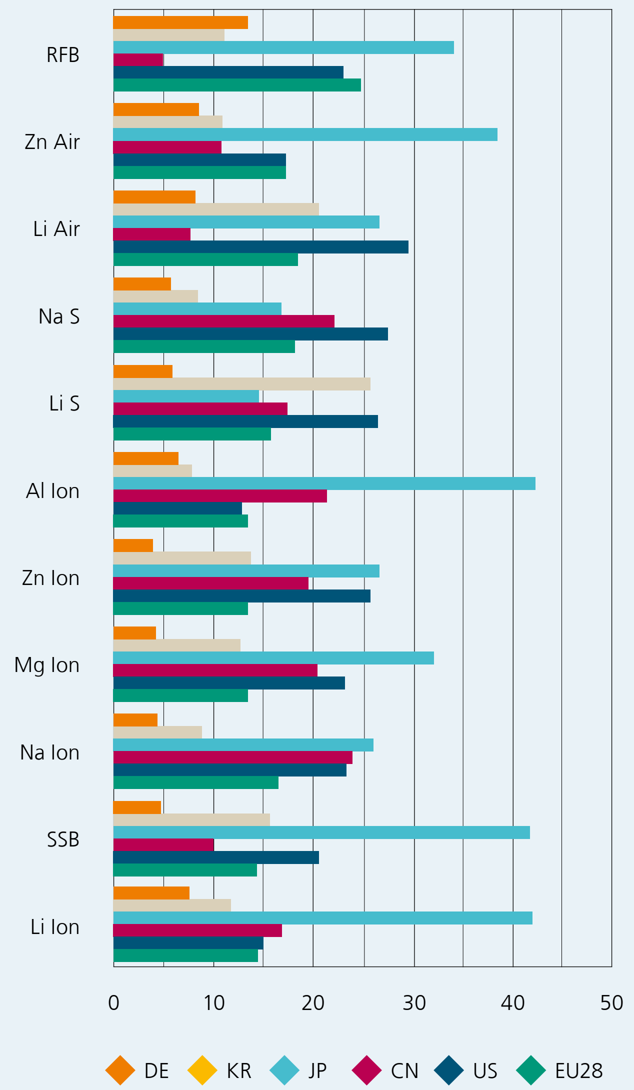


Figure 16: Share of global transnational patent applications for alternative battery technologies by country and world region (2016-2020).

Discussion

This comparison reveals that three major players in the battery industry (China, South Korea and Japan) demonstrate very different and unique S&T performances.

China has by far the strongest scientific capacity in terms of publications in these years, but still moderate in terms of transnational patents. Although China is the world's largest supplier of liquid electrolyte-based lithium-ion batteries, its share of Li-ion battery patents is 17 %, less than half that of Japan and comparable to the U.S. (15 %) and the EU28 (15 %).

South Korea, which has the second largest industrial share of batteries in the global market, shows a low to moderate performance in patents and publications. One of the country's strategic objectives is set on lithium-sulfur batteries (aims to commercialize by 2025), which can be confirmed by its strength in patenting.

Japan has the lowest share of publications but the highest share of patents. In 2001, the country's share of lithium-ion battery publications was more than 26 %, but it has been steadily decreasing, finally reaching less than 3 % in 2021, while the patent share has been fluctuating around 40-55 % from 2001 to 2019.

Based on the result, the relationship between bibliometric indicators and industrial share is not simple. To understand the background of industrial competitiveness, S&T capacity has to be considered as only one of the relevant factors. In particular, in terms of ensuring production capacity, there are other important aspects to be taken into account. For example, the availability of raw materials, access to materials and components, the price of energy, skilled workforce as well as securing battery demand are influential factors.

10.2. Comparison of political objectives and strategies

10.2.1. Central actors, official strategies and their background

All countries have rather recent strategies – and there are constantly further updates, such as the Dachkonzept (BMBF, DE 2023), the Battery Industry Strategy (METI, JP 2023) and the National Strategy for Strengthening the Competitiveness of the Secondary Battery Industry (MOTIE, KR 2023). An update of the SRIA is also planned in 2023/2024. This is surely due to the "critical phase" of the market ramp-up and diffusion between 2020 and 2030, establishing battery ecosystems globally, and the current geopolitical situations and according attempts to maintain or achieve sovereignty.

In terms of central actors, in general, there are always the ministries for research, but also for economy is very much involved in strategy and program formulation. However, policy makers also involve non-public bodies, such as research institutions, networks and industry groups in their decisions. There are some differences when it comes to the degree of centralized power of public bodies, and especially in China, almost everything is determined by the different public actors (ministries), but intermediary organizations take the leading role in coordinating processes. In Japan, too, the ministries play a leading role, but they include industrial actors in the public-private council to discuss strategy. In the U.S. there is a wide range of public and private actors cooperating to determine the battery strategy. In South Korea, the EU and Germany, public-private partnerships also play an important role.

All countries aims to be climate neutral by 2050 or earlier (Germany in 2045), except China (10 years later). In addition to the general awareness of the need for electrification (especially of the mobility sector), each strategy reflects the current and past market position of each country in battery technology and/or the automotive industry in its transition to EVs. For the three Asian countries, the goal of (securing) global market share is increasingly an issue, while Germany and the U.S. focus rather on securing a future value chain. The EU has a strong focus on the development of sustainable battery technologies and production in line with its overarching climate goals.

10.2.2. Strategic objectives

All countries want to maintain or thrive to a leading position in the battery market and strengthen their (domestic) value chain. Economic motivation is a common driver for all of the policies. Exceptionally, China gives an explicit timeline for the achievement of their overarching goals related to batteries and EVs.

Table 53: Overview on different dimension of strategic objectives.

Technology sovereignty/ independence from international supply chains	All the countries have goals directly related to the development of a complete value chain for batteries and becoming less dependent on international supply chains.
Targets related to electrification of vehicles	All the countries have set goals regarding the electrification of mobility, most often using the share of sales of EVs. Battery technology and production plays a role in achieving this. However, the specific target for electrification varies from country to country. For example, the U.S. sets the target for ZEV, while JP considers EV/FCV/HV/PHEV and has high targets for the share and export of EVs.
Goals related to sustainability and circularity aspects	All countries want to be climate neutral by 2050 or before (Germany in 2045), except China (10 years later). The specific objectives regarding sustainability and circularity (recycling of batteries) vary greatly between the different regions of the world: In Germany, the EU and Japan, there are specific KPIs for the development of recycling technology, but the U.S. and South Korea also have dedicated policies. China is now also focusing more on improving the circularity of batteries.
Application fields and markets	All the countries are focused on the EV-market, some have also included other application fields (stationary storage, air-transport/drones, military use). For example, the U.S. (military, power sector/ large-scale grid storage, electric ferries).

10.2.3. Type of funding policies and measures

Current Funding programs and initiatives

All programs are very complex and idiosyncratic – that is, they have developed their programs for different reasons and have different backgrounds, so it is very difficult to compare them. However, all countries have R&D funding programs with specific calls for projects that are either technology-focused (e.g. a particular type of battery) or technology-open and more mission-oriented (e.g. to achieve a particular goal). In Germany, the EU and U.S., funding programs are also accompanied by a strong focus on building a network of relevant actors in consortia, platforms or similar aggregations to form "clusters of experts" around specific topics and bundle competencies.

Relevance of demand side policies

All countries make use of demand-side policies, some started earlier than others (China) and some focus on tax purchase premiums and tax incentives for EVs (Germany and U.S., especially with the IRA).

Nature of funding policies

There is a focus on classical supply side measures in Japan, South Korea, the EU and Germany. For the EU and Germany the only demand side measures are rather for the end of the value chain (for EVs). South Korea often provides direct support to its battery manufacturers, for example, through large tax credit. The announcement of its national strategy also discloses the planned contribution of private conglomerates. For China we can observe massive interventions from both demand- and supply side, whereas batteries were for a long time rather seen as an element of the EV-policy (now there is a shift towards more targeted supply-side-measures for batteries). In the U.S. there is a balanced composition of supply- and demand side measures.

Degree of technology-openness

China, South Korea and Japan had for a long time a strong focus on specific types of cell chemistry, while Germany and the U.S. took a more technology-open strategy. However, since the development of the battery market has been accelerated in the last years, also the Asian Players seem to integrate more "technology-open" formulation in their policies (with respect to alternative technologies) and focus more on the achievement of functional parameters, even if they still mentioning specific technologies. These are, especially in the case of Japan, often technologies, where they have invested a lot and some sort of comparative advantage due to their leadership in research. Also China has shifted to a rather technology-open strategy recently.

10.2.4. Funding budgets

With regards to the funding budgets of the analyzed states, some disclaimers have to be made before the interpretation of these numbers is suitable.

First, it might be, that especially for the case of China and South Korea - not all funding sums are made public or explicit. Often much of the funding for batteries is more indirect through demand side policies - that is to say tax incentives or exemptions and other subsidies. The amount of these indirect investments is difficult to capture without the direct internal data from the governments, although we integrated some data that was available. Furthermore, the information gathered on funding budgets sometimes cannot really be assigned to years and exact funding purposes. This is another reason, why it is not easy to simply compare the sum of the funding budgets.

Because of these challenges, we compare only direct R&D funding, mainly focusing on specific public funding bodies (U.S.: DOE, DE: BMBF, JP: NEDO, KR: MOTIE and CN: MoST). Considering the limited availability of information on a yearly base (especially for DE, KR and CN), we compare the budget per year including estimated figures based on several assumptions (see the footnote[19]).

The Figure 17 compares estimated annual funding on battery R&D from 2014 to 2022.

For the U.S. the DOE EERE Vehicle Technology Office has increased its battery R&D budget slightly but steadily until 2020. Recently, the EERE was appropriated funds through the Infrastructure Investment and Jobs Act, adding 110 million dollars in 2022 [205] and is expected to sharply increase its total budget on battery-related topics with the following programs:

- Lithium-Ion Battery Recycling Prize Competition (10 million dollars)

[19] Data source for estimation: For 2014 [218], For 2016 [217], For 2018 [7] and [216], US: DOE Annual Progress Report [89], JP: NEDO project budget for RISING-2 [219] RISING-3 [220] and SOLiD-EV [221], DE: [15], CN: budget allocation under the funding guideline in 2021 in National Key R&D Program [169, 172, 170, 171]
For 2022: US, funds through the Infrastructure Investment and Jobs Act [205] plus estimation for Battery R&D budget based on the previous annual report, JP NEDO project budget for RISING-3/SOLiD-EV plus annual average of Green Innovation Funds [101], SK annual average of the R&D investment under the Secondary Battery Innovation Strategy [122].
For the US and JP, the annual average ECB rate of 2018, 2020, 2022 was utilised for calculation for each year.

- Battery and Critical Mineral Recycling (60 million dollars)
- Electric Drive Vehicle Battery Recycling and Second-Life Applications Program (40 million dollars)

As explained in our 2018 monitoring report, the BMBF in Germany had also gradually increased its R&D budget around 35 million euros per year, until 2017. Recently, the BMBF has expanded its budget much rapidly - according to the document from the Deutscher Bundestag, battery research was funded by the BMBF with 29.5 million euros in 2015, reaching almost 60 million euros in 2019, and was expected to be funded with more than 111 million euros in 2020 [206]. Also, the updated roof concept (2023) mentioned that the BMBF has funded ca. 800 million euros in a decade (the simple annual average is ca. 80 million euros).

It should be noted that as this analysis focuses on specific funding organizations, we have excluded the German contribution to the IPCEIs. The BMWK (formerly BMWi) has invested around 1.5 billion euros in two IPCEIs [6], which support R&D&I and also first industrial deployment, targeting at higher TRLs than the usual BMBF funding programs.

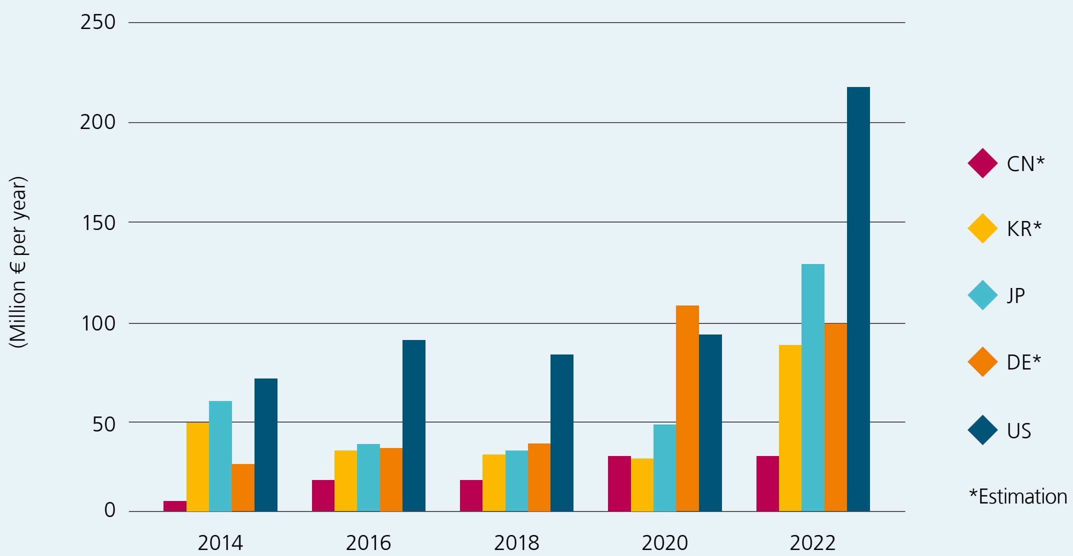
Our past monitoring reports revealed that both South Korea and Japan had decreased their public R&D budget until 2017, but the latest data indicates that they are trying to increase it again. Although there is no official announcement about the annual budget of the MOTIE in South Korea annually, 1 trillion won (ca. 697 million euros) of R&D investment by the government by 2030, announced in the Secondary Battery Innovation Strategy (2022), seems tremendous compared to the past funding strategy.

The battery R&D budget of NEDO in Japan did not jump so dramatically as of 2020, but in 2022, the organization started a new instrument, the Green Innovation Fund with 120.5 billion yen being allocated on battery topics by 2030 (ca. 772 million euros in total, annually ca. 86 million euros) mainly as a subsidy for the companies that are trying innovative R&D. Although the characteristics of the new instrument is different from other NEDO projects as funding for commissioned research, we could say that the NEDO will become much more active in this area with this new funding source.

The public funding on battery R&D in China has slightly risen from 2014 based on our estimation. The project budget under the guideline of National Key R&D Funding in 2021 was ca. 29 million euros. It is worth noting that the R&D funding program in China often does not count personnel cost support and it is difficult to compare with other countries in the same condition. The real public funding is estimated to be much higher and notice should be given rather to the changes in funding over time.

In conclusion, all the major countries have strengthened public R&D funding since 2014. Especially since around 2020, many of the countries have experienced a rapid expansion reflecting on new strategies (U.S.: Bipartisan Infrastructure Act, JP: Green Growth Strategy, KR: Secondary Battery Innovation Strategy) and strategic programs (DE: Roof Concept of Battery Research in 2023, formerly Roof Concept of Research Factory in 2019). The funding has doubled and partly tripled for all countries compared to the level of funding before 2020.

Figure 17: Trend of the public R&D funding in the major countries.



10.3. Comparison of the strategic technological objectives

In this section, we compare the most important KPIs (energy density (gravimetric/volumetric), cost and cycle life) identified in the officially available strategic documents. Again a detailed list of the KPIs with explanations of their background and a technological assessment can be found in the country analysis chapters 3-8. Since each country's strategy defines their KPIs differently (different timeframes and dimensions of performance), it is often not possible to compare all countries' data in each graph.

For this comparison, the availability of the data for the most important KPIs is as follows (Table 54). In the following we will make a short analysis to compare the strategic technological objectives of the chosen states/countries.

Table 54: Available KPIs for comparison analysis in the major countries.

Country	By 2025	By 2030	Beyond 2030
DE	–	Solid-state (energy density, cycle life) Alternative (energy density, cycle life)	–
EU	Lithium-based (energy density, cost, cycle life)	Lithium-based (energy density, cost, cycle life) Solid-state (energy density, cost, cycle life)	Alternative (energy density, cost, cycle life)
U.S.	Lithium-based (energy density, cost, cycle life)	Lithium-based (energy density, cost) Solid-state (energy density, cost)	–
JP	Alternative (energy density)	Lithium-based (cost) Tech-open (energy density)	Alternative (energy density, cost, cycle life)
KR	Lithium-based (cycle life)	Solid-state (energy density) Alternative (energy density)	–
CN	Lithium-based (energy density, cost, cycle life) Solid-state (energy density, cost, cycle life)	Lithium-based (energy density, cost, cycle life) Solid-state (energy density, cost, cycle life) Alternative (energy density, cost, cycle life)	Lithium-based (energy density, cost, cycle life) Solid-state (energy density, cost, cycle life) Alternative (energy density, cost, cycle life)

10.3.1. Technological focus

The focus for the targeted technologies and cell chemistries of each country is the following:

- China: LIBs, SSBs, metal-sulfur, esp. Li-sulfur.
- South Korea: LIBs, SSBs, next-generation batteries (not specified), but mentions Li-sulfur and Li-metal batteries as alternative battery type
- Japan: LIBs, SSBs and alternatives types (fluoride shuttle and zinc-anode batteries)
- U.S.: technology-open approach, but a lot of research regarding SSBs and alternative battery types funded by DOE/ARPA-E
- EU: lithium-ion (Gen.3a +Gen.3b), solid-state and alternative types such as redox-flow, metal-air and sodium
- DE: LIBs, SSBs, sodium-ion batteries and other alternative batteries

Interestingly, all of the public strategies do not merely focus on one specific technology type, but instead try to diversify and all of them include SSBs and alternative types besides the more conventional lithium-ion-batteries. However, some countries are already very specific regarding the type of technology (e.g. JP, CN), while others chose a more technology open approach (U.S., EU).

10.3.2. KPIs in gravimetric energy density for the different battery types

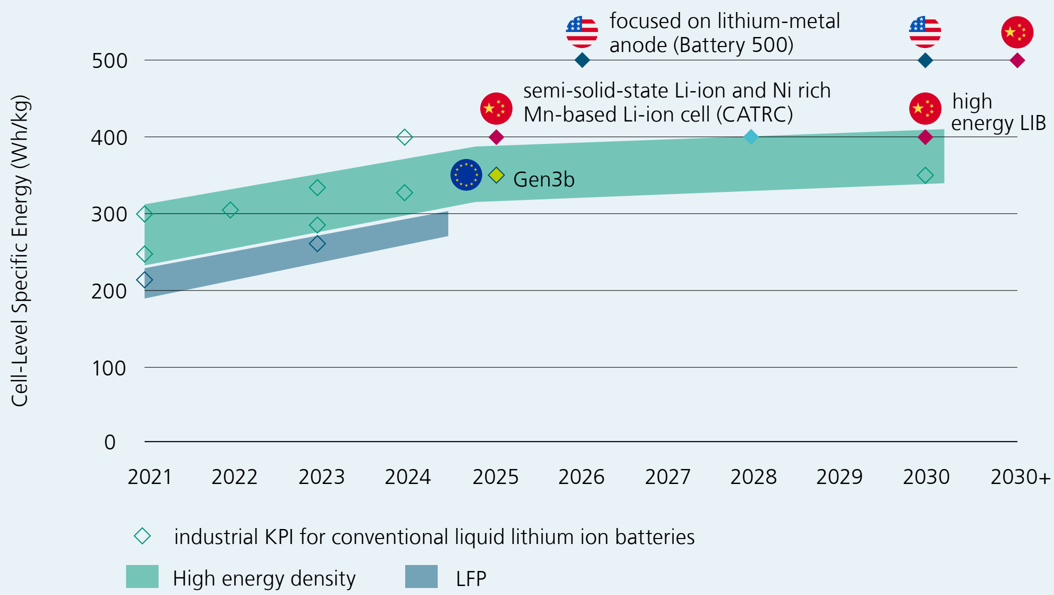
KPIs for LIBs (cell level)

For lithium-ion batteries, China has a more ambitious target than the EU in the short-term (until 2025). In addition, the Battery500 consortium in the U.S., whose second project phase runs until 2026, is pursuing a concept using a conventional layered oxide cathode, a lithium metal anode and a liquid electrolyte to achieve an ambitious target of 500 Wh/kg.

The U.S. mid-term target (until 2030) defined in the National Blueprint is the same as the target of the Battery 500 consortium, and still higher than the Chinese KPI. It is worth noting that the ambitious target set by the U.S. is not well specified in the Blueprint (to be achieved through "revolutionary battery technologies"), and the document mentions solid-state and Li-metal as examples. Therefore, we have categorized the Blueprint KPI as both lithium-ion batteries and solid-state batteries in the following graphs.

The Chinese KPI beyond 2030 is comparable to the U.S. KPI by 2030 mentioned in the Blueprint. In this graph, the KPIs for Germany, South Korea and Japan could not be included due to missing data for the lithium-ion batteries KPIs.

Figure 18: Roadmaps for the gravimetric energy density of LIBs compared with KPIs of established battery cells (source: own representation based on official documents and market reports).



KPIs for SSBs (cell level)

China is the only country which has the KPI for SSBs by 2025, with very ambitious number (500 Wh/kg). Regarding the targets until or beyond 2030, China is still most ambitious, as well as the U.S. and the EU (Gen 4b/c), followed by the EU (Gen 4a) and South Korea. In this graph, the KPIs in Japan are not included. It is because, although NEDO's document includes an example of target specifications for commercialization (At the pack level, 300 Wh/kg around 2025, 400 Wh/kg around 2030), it is unclear whether the project is actually committed to achieving these KPIs.

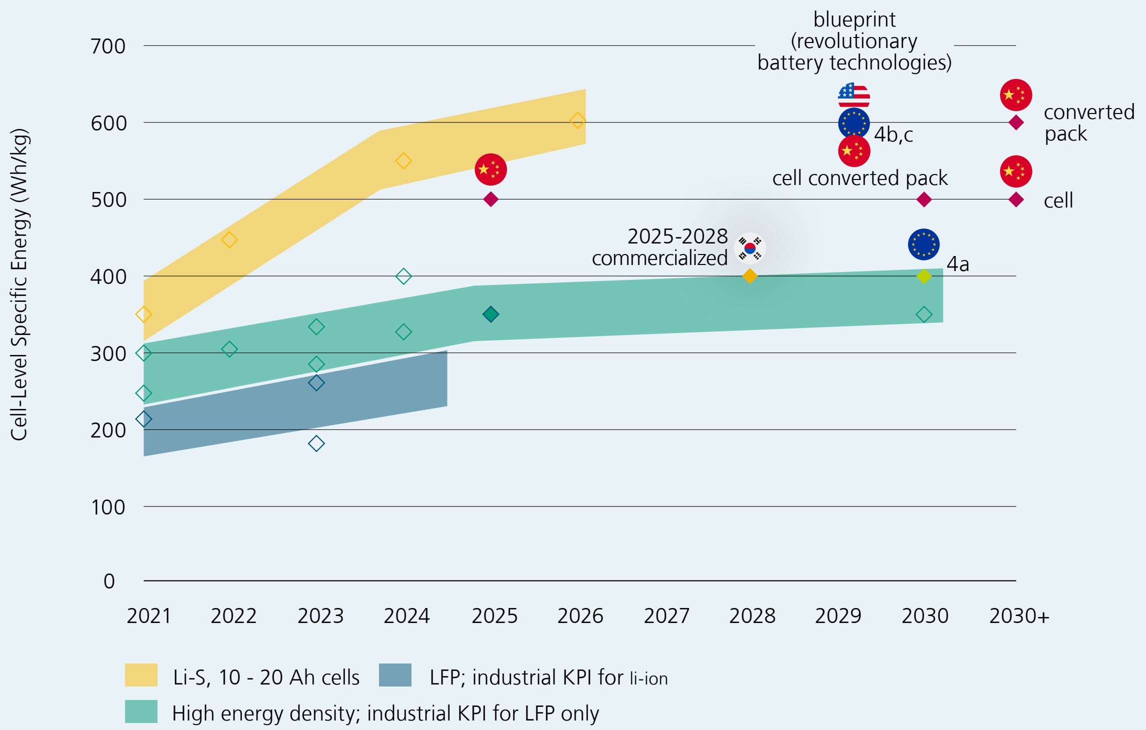
It should be noted that all-solid-state batteries are still in an early stage of development (TRL 1-4) [207] and mostly being reported at laboratory-scale. [208] Recently, the solid-state battery model SolidPAC (Solid-State Battery Performance Analyzer and Calculator) has been developed by researchers from Oak Ridge National Laboratory as an interactive battery-on-demand energy density estimator [209]. Larger sulfide-based SSBs from start-up companies such as Solid Power, have reported cell-level energy density of 440 Wh/kg and 930 Wh/l on cell level for 1,000 cycles based on NMC||Li metal-chemistry and a sulfide-based solid electrolyte (cell size not reported). [210] The term SSB is very broad and includes a wide range of solid electrolyte (sulfidic, oxidic, polymer, hybrid) and active chemistries (Li-metal, anode-free, Si-anode, graphite, etc.).

KPIs for alternative battery types (cell level)

Japan is the only country with KPIs for alternative battery types by 2025, but these are for prototype projects. Only South Korea has the KPI for lithium-metal batteries before 2030 (2025-2028), reflecting its focus on early commercialization of the technology. China's KPIs are not so well specified the type of battery to be pursued, but seem very ambitious compared to the other countries. The EU has a very ambitious target for post-lithium batteries by 2030, which is as high as for China. The other KPIs for alternative battery types by 2030 or beyond (sodium, redox-flow and metal-air) are all for stationary storage applications and are below the targets of Japan and China. Germany's KPI for sodium-ion batteries is very similar to the EU's. Japan has two other KPIs for fluoride batteries and zinc-anode batteries at the pack level, to be achieved after 2030 (2033), but the KPI for zinc-anode batteries is not as ambitious as the Chinese and EU ones (except for stationary applications). The U.S. target for next generation batteries is ambitious (500 Wh/kg at the cell level) but not well specified (they include solid-state, Li-metal in the Blueprint) and is therefore removed from the graph.

China is focused on lithium-sulfur and metal-sulfur, while Japan wants to develop fluoride-shuttle and zinc-anode batteries. The EU has objectives for metal-air, sodium and redox-flow batteries.

Figure 19: Roadmaps for the cell-level specific energy of SSBs compared with KPIs of established battery cells (source: own representation based on official documents and market reports).



The comparison of the KPIs for energy density (Wh/kg on cell level) until 2025 shows that overall the countries seem to have different foci. Whilst the U.S. is most ambitious concerning liquid electrolyte-based LIBs, China is most ambitious when concerning the target for solid-state battery cells. Japan has also a target for prototypes of the fluoride shuttle/zinc anode battery.

10.3.3. Comparison on the different KPI dimensions

In the following we will compare the KPIs of the countries for different dimensions and years using bar charts. For each bar, the type of battery type and the actor/strategy from which the KPI originates are noted.

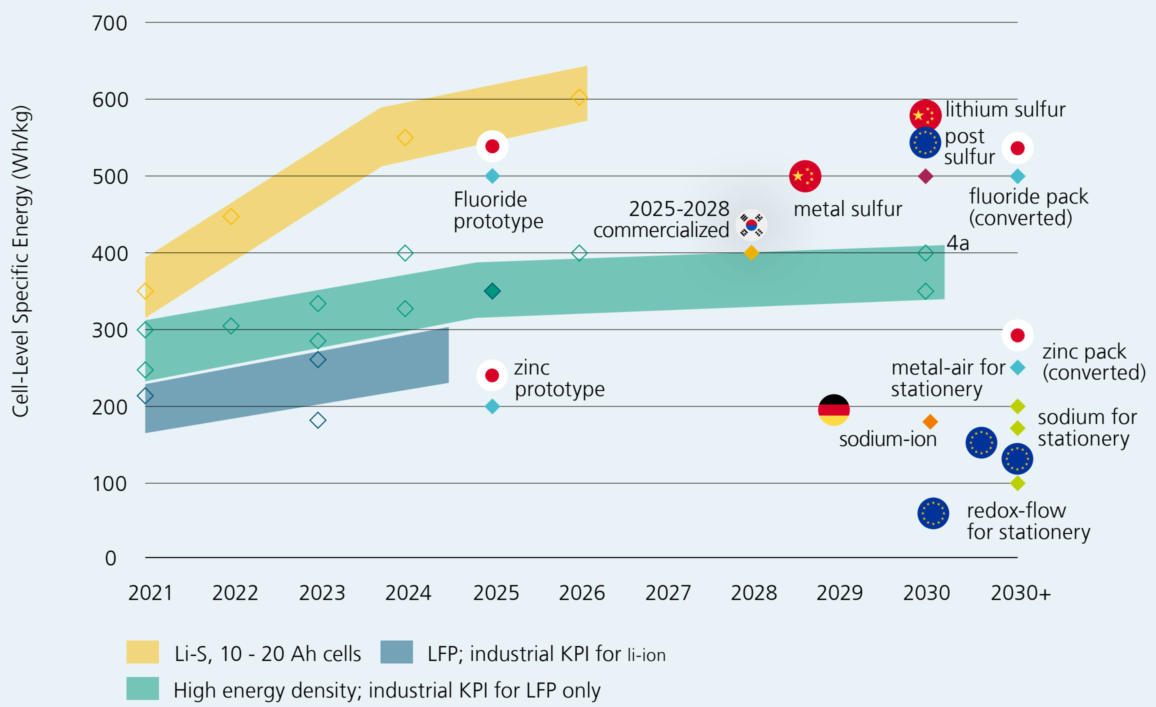
Comparison of the volumetric energy density targets

Volumetric energy density KPIs are given only by DE, EU and JP. The KPIs for liquid electrolyte-based LIBs are only given by the EU; 750-1,000 Wh/l for Gen3b by 2025 and 500 Wh/l for utility-scale by 2030.

For SSBs, Germany, the EU and Japan have defined relevant KPIs (note that Japan's KPIs are defined for "advanced batteries" for high energy use, and SSB is mentioned as one of the examples of possible technologies). The EU target for Gen 4b/c by 2030 is the most ambitious. The EU's target for Gen 4a by 2030 [21], the German one for SSBs by 2026, and the Japanese one for advanced batteries by 2030 are similar. Japan has set a lower KPI for high power use, with a high specific power target (2,000-2,500 W/kg).

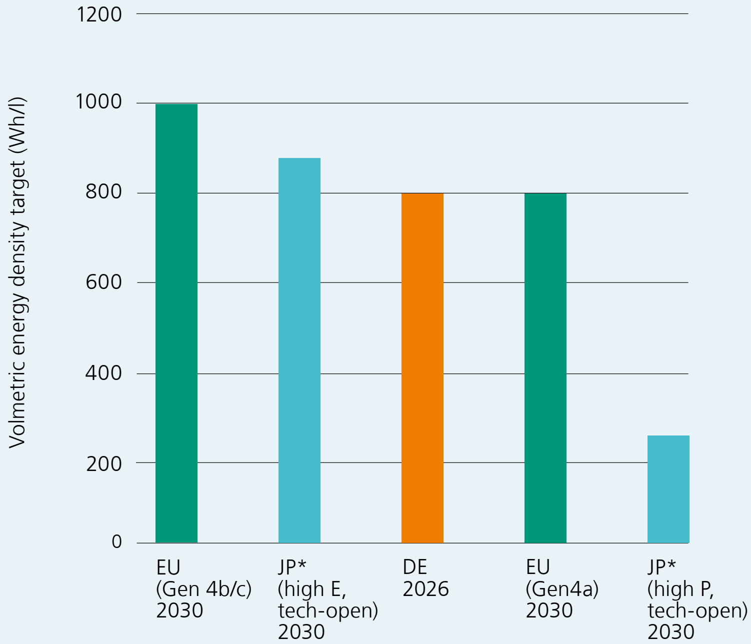
For alternative batteries, the EU and Japan have defined volumetric energy density KPIs for different types of batteries (EU: Gen 5, specifically for metal-air batteries, for stationary batteries and for redox-flow batteries, Japan: for fluoride and zinc-anode batteries for mobility applications), ranging from 1,000 Wh/l to 50 Wh/l, depending on the characteristics of their cell chemistry and potential applications. Japan also has KPIs by 2025 for these two types of batteries, but only at the test cell level (1000 Wh/l for a 2Ah level cell for fluoride batteries, 500 Wh/l for a 5Ah level cell for zinc-anode batteries).

Figure 20: Roadmaps for the cell-level specific energy of alternative batteries compared with KPIs of established battery cells (source: own representation based on official documents and market reports).



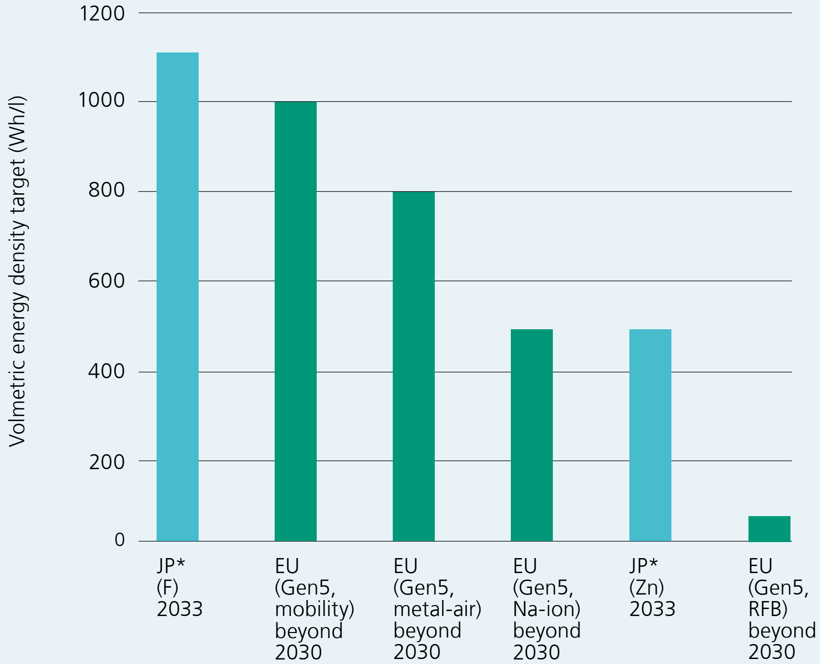
[21] Japan's KPI for high energy use is described as "700-800 Wh/l" at the pack level

Figure 21: Volumetric energy density target KPIs for solid-state-batteries (source: own representation on the basis of official documents).



*converted from pack to cell with coefficient 0.8

Figure 22: Volmetric energy density target KPIs for alternative batteries (source: own representation on the basis of official documents).



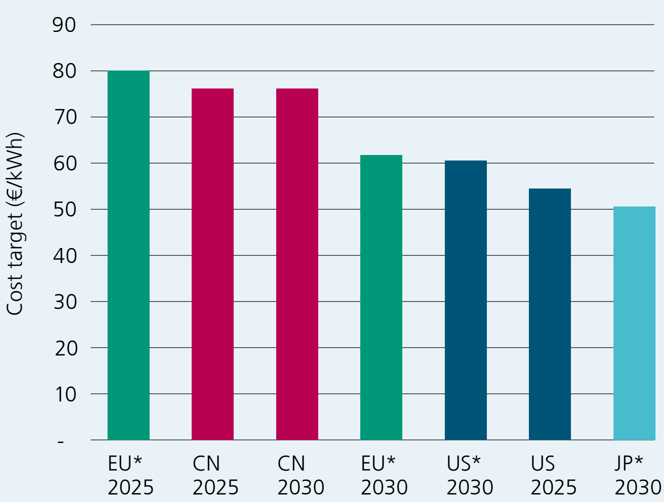
*converted from pack to cell with coefficient 0.8

Comparison of battery cost targets

Regarding cost, all countries except KR have set KPIs. For comparison, we have converted the pack cost KPIs into ones at a cell level with a specific coefficient (0.8), considering that the pack manufacturing cost accounting for about 20 % of total battery cost, based on the estimate in 2022 [211]. In addition, we used the ECB exchange rate on 30/06/23 to calculate the cost target at EUR level for U.S., JP and CN data (1EUR=1.087 U.S.D, 157 JPY and 7.90 CNY).

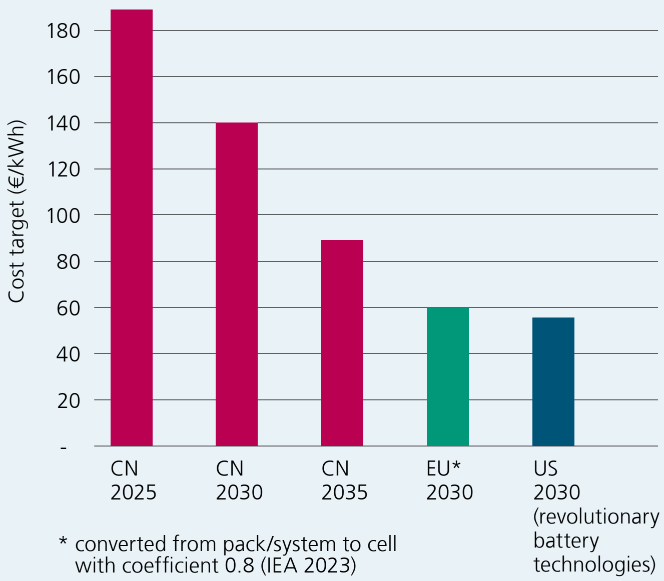
Comparing the cost targets for LIBs, the EU (100 €/kWh at pack level) and China (approx. 76 €/kWh at cell level) have very similar targets for 2025, as do the EU (75 €/kWh at pack level) and the U.S. (74 €/kWh at pack level). Japan's target for 2030 (64 €/kWh on pack level) seems slightly more ambitious, but given the rapid depreciation of the yen in these two years (1 EUR = 130 JPY in 2021), the target is probably intended not to be stand out. As LIB is a relatively mature technology, major countries have set similar and realistic cost targets.

Figure 23: Cost target KPIs for lithium-ion-batteries (source: own representation on the basis of official documents).



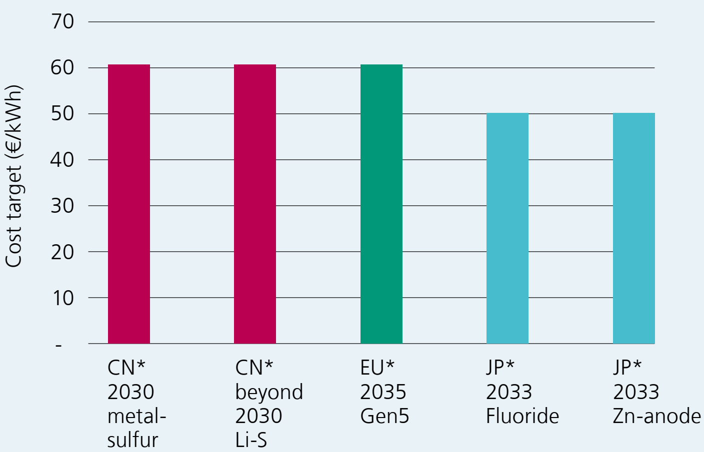
* converted from pack/system to cell with coefficient 0.8 (IEA 2023)

Figure 24: Cost target KPIs for solid-state-batteries (source: own representation on the basis of official documents).



* converted from pack/system to cell with coefficient 0.8 (IEA 2023)

Figure 25: Cost target KPIs for alternative batteries (source: own representation on the basis of official documents).



* converted from pack/system to cell with coefficient 0.8 (IEA 2023)

For Gen.4 and 4 types of batteries, the U.S. has the lowest cost target of approx. 55 €/kWh[22], and the EU has a similar one (75 €/kWh on pack level), while the Chinese target for Gen.4 seems very high (realistic) compared to them. China's roadmap shows the steady decrease of its cost target for SSBs, reaching ca. 89 €/kWh by 2035, which is still higher than the EU and the U.S. targets by 2030.

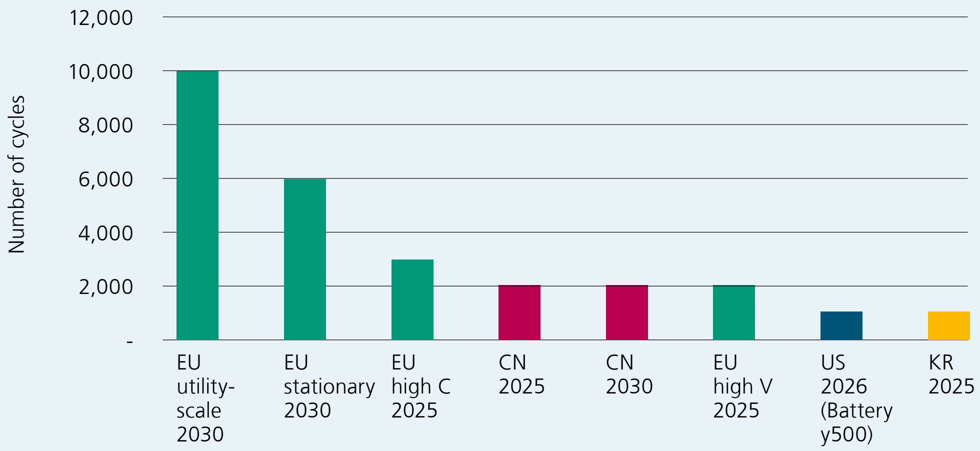
It is difficult to simply compare the cost targets for alternative batteries with different cell types and chemistries. However, all the targets show similar values of 50-60 €/kWh from 2030 to 2035. These targets are comparable to those for LIBs by 2030, possibly because these alternative batteries need to be sufficiently competitive in the market with existing technology and LIBs are regarded as a benchmark.

General assessment of cost KPIs

While battery costs have fallen by 90 % over the past decade due to economies of scale (gigafactories), they have recently been rising rapidly (since late 2021) due to raw material shortages and supply chain issues. As costs rise, batteries with low content of critical raw materials may gain importance in the long-term. Therefore, even battery chemistries with lower specific energy might be targeted in order to secure the supply of raw materials for battery production and to be less dependent on international value chains. In particular, this could be the case for the KPIs regarding fluoride and zinc battery cells from NEDO (JP).

More generally, in the current unstable and fluid situation of international crisis, it is very difficult to assess and envision future battery costs. The dependence on international supply chains and availability of critical resources is very high, as the share of advanced materials in battery production cost is 60 % [212].

Figure 26: Comparison of targeted life cycles for liquid-electrolyte based lithium-ion batteries (source: own representation on the basis of official documents).



[22] The U.S. target is set for "revolutionary battery technologies", including SSBs and Li-metal batteries.

Figure 27: Comparison of targeted cycles for solid-state batteries (source: own representation on the basis of official documents).

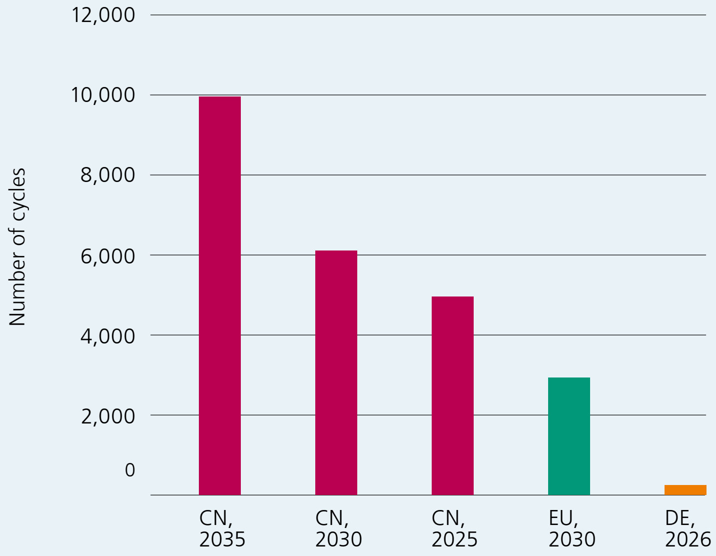
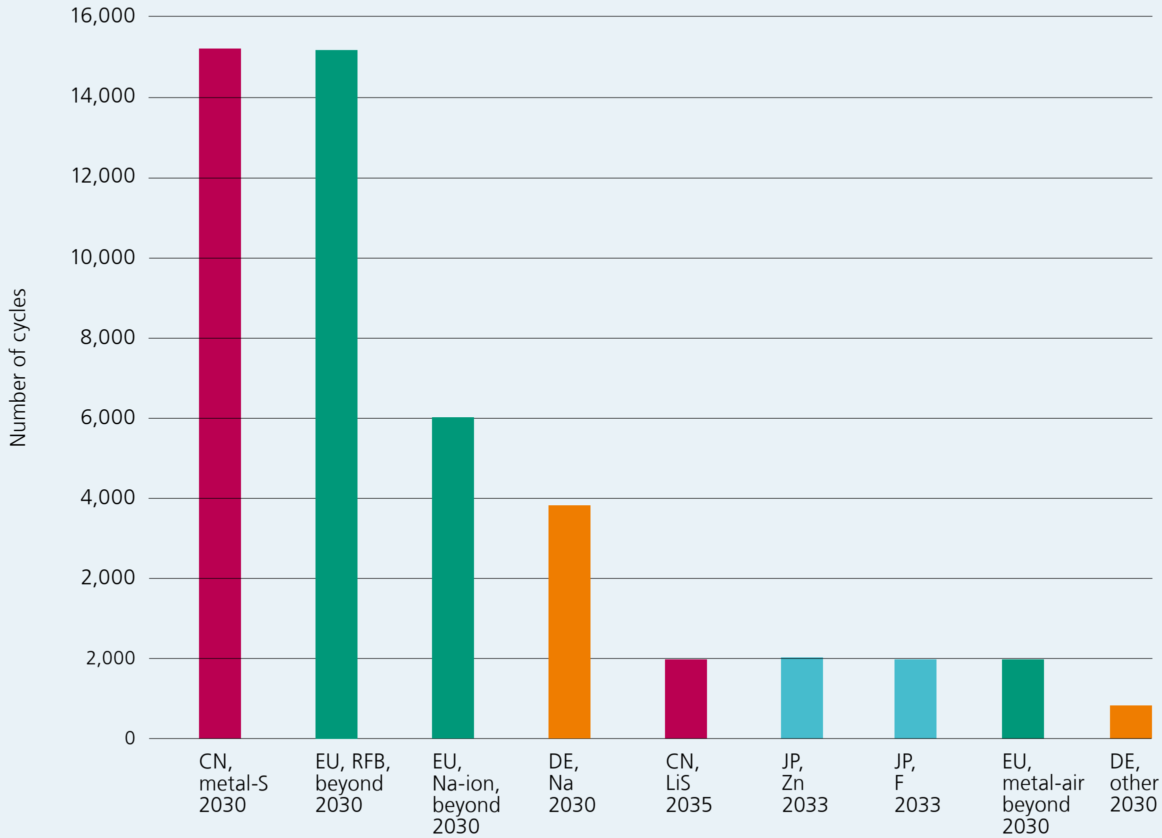


Figure 28: Comparison of targeted cycles for alternative batteries (source: own representation on the basis of official documents).



[23] The EU's cycle life target for metal-air batteries are described as "2,000-5,000 cycles".

[24] Zn, Al, Fe, Ca and Mg-based systems are mentioned

Comparison regarding cycle life/number of cycles

When comparing cycle life targets, we need to consider the application of the batteries. In general, stationary applications require higher cycle life but lower energy density. For example, the U.S. Battery 500 targets 500 Wh/kg using lithium-metal anodes, which makes it difficult to achieve a higher cycle life number.

Excluding the targets for high-capacity applications (including utility-scale and stationary), the EU, China, the U.S. and South Korea have similar cycle life targets for LIBs of 1,000 cycles to 2,000 cycles, with the EU and China being more ambitious than the U.S. and KR.

In terms of target cycles for SSBs, China has by far the most ambitious target than the EU and Germany, assuming that performance could be steadily improved over time. The EU's target by 2030 is almost half of China's target for the same year. Germany's KPI for cycle life (>200 cycles) is less than a tenth of the EU's. However, Germany aims to develop a rechargeable, multi-layer cell with both more than 200 cycles and a high energy density (>800 Wh/l) at the same time, which is assessed as ambitious.

KPIs for alternative batteries also vary by application and cell chemistry. The highest targets are the Chinese KPI for metal-sulfur batteries by 2030 and the EU's for redox-flow batteries (stationary use) beyond 2030, targeting at 15,000 cycles. The EU's Gen5 target for stationary use is the next highest at 6,000 cycles.

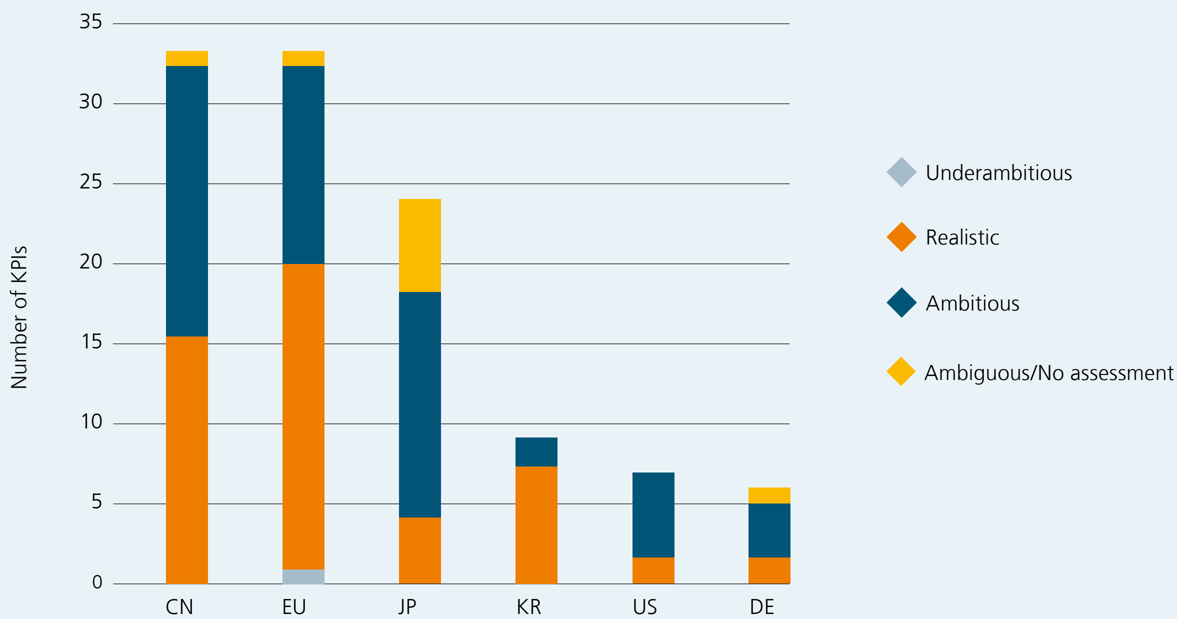
Three countries set a cycle life target for alternative batteries beyond 2030, for different types of batteries (Japan for zinc-anode and fluoride batteries (EVs/PHEVs use) and the EU for metal-air batteries, China's KPI did not specify the type of battery), but with the same value (at least 2,000 cycles[23]).

Germany has set two KPIs to be achieved by 2030, one for sodium-ion batteries (3,500 cycles) and the other for other alternative batteries[24] (1,000 cycles).

10.3.4. Technological feasibility of the political KPIs

In Chapters 3-8, we have listed all relevant KPIs and assessed their technological feasibility on the basis of the state-of-the-art scientific literature. When it comes to comparing the different KPIs on this dimension of how realistic or ambitious they are, some disclaimers have to be made in advance. First of all, some countries have only few KPIs that are more general and not specific to a technology type (e.g. the U.S.), making it more difficult to assess. Secondly, only because one country has many different KPIs for the identified time horizons, this does

Figure 29: Comparison of the number of identified KPIs and the results of their technological feasibility (source: own representation on the basis of official documents).



not necessarily mean that it is more ambitious than the others. Finally, due to the availability of information, some countries (e.g., South Korea) might be underestimated, in terms of the number of KPIs.

However, if we sum up the number of KPIs identified in our research with the results of assessment (realistic, ambitious, under ambitious and ambiguous) for each country, the following graph shows the differences between them (Figure 29).

Overall, China, the EU, and Japan tend to set a lot of KPIs to promote R&D activities.

China's KPIs can be found in various documents. Among them, the most important are the two technology roadmaps announced by CATARC and China SAE, respectively. These two organizations are known as key intermediaries in battery policy formulation, coordinating the policy discussion among different stakeholders and experts [213]. In addition, the funding guidelines of national key R&D programs also include specific KPIs to be achieved.

In the EU, KPIs are mostly articulated in the Strategic Research and Innovation Agenda (SRIA). As the SRIA is discussed in a public-private partnership with many technical experts and is used as input to specify the objectives of Horizon Europe calls, the EU KPIs tend to be realistic. In addition, the EU Battery Regulation has recently introduced recycling targets.

In Japan, most KPIs are included in NEDO's basic plan for its projects and/or funding guidelines. Interestingly, the country has a higher number of "ambiguous" KPIs, meaning that they are difficult to assess due to the higher uncertainty of alternative battery technologies. NEDO has two types of KPIs for alternative batteries: one is to be achieved within a project period (KPIs for a test cell), and another shows a future vision when the technology is commercialized (e.g., targets in 2033). On the other hand, the newly launched Green Innovation Fund provided a limited number of KPIs with a technology-open approach (the KPIs are expected to be achieved by "advanced batteries", including SSBs), as in the U.S..

In contrast to these three countries, the U.S. focuses on a smaller number of core KPIs. For example, the mid-term goal of the Battery Blueprint is to demonstrate battery technologies that achieve a production cost of less than $ 60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free. Another important feature is a technology-open approach - the above KPIs will be achieved by "revolutionary battery technologies", including solid-state and Li-metal batteries.

South Korea's KPIs are mostly derived from the K-Battery Development Strategy. The main KPIs reflect the strategic goal of the strategy, "commercializing SSB, lithium-sulfur, and lithium-metal batteries by 2027, 2025, and 2028, respectively". As the country focuses on the early commercialization of these new technologies by industrial actors, the K-Battery Strategy includes qualitative targets (e.g. application) and numerical indicators for SSBs and alternative batteries are limited to energy density.

Germany did not have any KPIs until the roof concept was updated. While the previous roof concept emphasized the transfer of technology from research to industry and the strengthening of production technology, the updated version also highlights an aspect of technological sovereignty. Thus, one of the five action areas of the new strategy is the development of promising future technology variants, with specific targets for the development of SSBs, sodium-ion batteries and other alternative batteries.

Here we could observe that each country sets and uses its technical KPIs differently. Especially in the three countries with a higher number of KPIs, we found the KPIs also in the funding guidelines specifying the technical KPIs to be achieved with the support by the program. Although setting a number of KPIs would be helpful to align R&D efforts, some scientific researchers criticize that setting a lot of KPIs in different aspects (e.g., gravimetric/volumetric energy density, cycle life, calendar life) and achieving them at once is too challenging because some KPIs have a trade-off relationship. In particular, from the perspective of the technology assessment of these KPIs, it is to say for alternative battery technologies, that finding a battery technology that meets all KPIs will be challenging. It is likely that the market will diversify: SIBs could serve as a low-cost battery with intermediate energy content (potentially as a replacement of lead acid batteries), Li-S could be applied in weight-critical applications (e.g., drones, eVTOLs) and Li-O_2 in volume-critical fields of applications with high energy demand.

Therefore, we will not claim "a sufficient number of KPIs" for efficient R&D based on our analysis. Instead, it is recommended to clarify what are the core KPIs for the country considering trade-off features and how the KPIs should be interpreted in the actual R&D activities (strict mandate to achieve or just a future vision).

11. Conclusion

11.1. Summary on the battery strategies by region

Germany has historically pursued an open technology strategy for battery technology with many different measures, but did not publish a specific strategy on performance parameters until recently. Under the comprehensive strategy "Battery Research Roof Concept" (German: Dachkonzept Batterieforschung) updated in January 2023, several supply-side measures were introduced, the development of production processes at larger scales particularly were prioritized to address the lack of production capacity. Also, project activities and funding under the framework of the IPCEIs (Important Projects of Common European Interest) together with the European industry are aimed at aligning with the EU policy on cross-cutting issues such as sustainability, recycling and digitalization of batteries.

The **EU** is pushing forward the development of a competitive and sustainable battery value chain using several activities and initiatives, such as public-private partnerships and the aforementioned instrument of IPCEIs. The overall battery policy can be described as supply side, but has some demand-side elements for the end of the value chain (with respect to Electric Vehicle purchasing). Under initiatives like Batteries Europe and the Batteries Europe Partnership Association (BEPA) Strategic Research and Innovation Agendas (SRIAs) have been published, which describe a clear technological roadmap and specific performance parameters for the battery cell chemistries. Since the EU's main priority is tackling environmental problems, the EU sets ambitious and concrete goals for the sustainability and recycling of batteries. The new Batteries Regulation to introduce circular economy principles and mandatory sustainability requirements has also been adopted.

Under the Biden Administration, the **U.S.** is trying to establish a sustainable and competitive battery value chain for a variety of reasons: to fight against climate change, create new employment, support technology sovereignty and for national defense. Therefore, the U.S. has invested in both supply- and demand-side policies in a well-balanced way. As for innovation policies, the US has taken rather a technology-open strategy in their R&D funding programs, but the newly published national blueprint sets performance parameters, not only for single technical parameters but for other important aspects, such as the cost and sustainability of batteries as well. With the Inflation Reduction Act 2022, the U.S. wants to stimulate its economy and to increase its resilience. This program intends to provide a strong response to China's economic and technological leadership or dominance and provides enormous incentives and, in some cases, imposes obligations to relocate production to the U.S.

Japan has traditionally strongly focused on the supply-side mechanism, especially the development of solid-state batteries and specific types of alternative batteries through NEDO funding setting a lot of KPIs. However, as Japan recognized that it was steadily losing ground in market competition and that the era of conventional lithium-ion batteries will continue for the time being, the priority has recently been given to increasing production capacity and ensuring the domestic and global market in lithium-ion batteries, for example within a Battery Industry Strategy formulated in 2022.

South Korea aims to be the international undisputed No.1 country in the battery industry. The comprehensive Korean-battery strategy from 2021 shows a clear R&D focus on commercializing three types of advanced batteries (lithium-sulfur, lithium-metal and solid-state batteries). South Korea supports not only the promotion of its Electric Vehicle-industry, but also provides direct support for its battery manufacturers (for example by giving large tax credits). As a unique feature of the national strategy, three large private companies are going to invest a large amount (about 30 billion euros) with the government. After the regime change, the government newly announced strategies to strengthen the battery industry, including countermeasures to the U.S.'s Inflation Reduction Act.

While **China** for a long time has massively relied on demand-side policies and has treated battery technology as an element of its New Energy Vehicle strategy for the huge domestic market, it is now shifting more and more toward a targeted battery strategy with increasing supply-side measures. As of 2022, China has the largest market share in the battery industry and is continuously trying to strengthen its global market position. Whereas for a long time, China had focused on performance parameters such as energy density, it is now increasingly including qualitative parameters such as safety. The government in particular has very specific goals about sustainability, for example with regard to positioning in the EU market. A lot of key performance parameters are set not only by ministries (such as in the Industrial Development Plan for Electric Vehicles 2021-2035) but also by the associations which are not completely governmental but have a strong influence on the government.

11.2. Outlook and recommendations

Strategies are constantly being developed

All countries have rather recent strategies - and there are constantly further updates such as Dachkonzept (BMBF, DE 2023), Battery Industry Strategy (METI, JP 2023) and national strategy for strengthening the competitiveness of the secondary battery industry (MOTIE, KR 2023). Also, an update of the EU SRIA is planned in 2023/2024. This is surely due to the "critical phase" of market ramp-up and diffusion between 2020 and 2030, establishing battery ecosystems globally and the current geo-political situations and according attempts to maintain or reach sovereignty.

However, surprisingly the strategies are often not available in English language, in case of KR and CN it was difficult to find information and professional translation support was needed. More importantly, during the course of the projects, major countries have continuously released and/or updated their battery strategies and policies (see the policy timeline in Chapter1), making it difficult (or better impossible) to complete our work. Given the rapidly changing global policy climate, the government needs to be more responsive to the external environment. For example, the enactment of the Inflation Reduction Act has large impact on other countries and the EU and South Korea announced their new strategies as a countermeasure.

Strategies are becoming more market- and industry-oriented as battery and EV markets develop

All countries and states have specific strategies for the development of battery technology and in the last years there seems to have been a shift toward higher TRL-innovation, industrial policies and value chain support as well as demand-side policies for EV-uptake.

Strategies are breathing the spirit of technology sovereignty amid geo-political tensions

The external factors (pandemic, climate crisis, wars) and the unstable political environment reinforce the momentum of competition between the largest international battery players and their quest for more autonomous battery production. The transition toward electric mobility and renewable energies has been accelerated by the climate crisis and the Russian attack on the Ukraine (especially for the Western states U.S./EU/DE but also JP/KR). The aspiration for more technology sovereignty was being expressed in all of the strategies well before 2022, and the pandemic with the resulting disruptions in global value chains seems to have played a big role here. The economic war between China and the U.S. is also evident in their strategies and funding budgets for battery technology.

Strategies increasingly combine supply and demand side measures for the development of circular ecosystems

There doesn't seem to be one right way to support battery technology development: while some are focusing more on research and supply side measures, others use a lot of demand-side-measures. In the case of China, this broad strategy with special emphasis on demand side measures for EVs has been successful in building a robust, internationally competitive battery value chain in the country. Other countries now seem to be following this lead. The stricter regulation and focus on sustainability and circularity of batteries in the EU (and to some extent the U.S.) also seem to have an effect on the other countries – the "higher standard" principle for countries which are aiming to penetrate foreign markets.

Strategies increasingly consider the development of alternative battery technologies

Different countries are placing varying emphasis on some of the emerging battery technologies. However, it can be seen that basically all international strategies refer to lithium-ion batteries as a benchmark, solid-state batteries as a future technology currently under consideration, and alternative battery technologies to potentially increase technology sovereignty and achieve better sustainability. The strategic goals target the years 2025 to 2030 and beyond.

Strategies are relying more on key performance indicators (KPIs) facilitate a more detailed monitoring

The relationship between bibliometric and patent indicators and industrial share is not simple. To understand the background of industrial competitiveness, R&D capacity has to be considered as only one of the relevant factors, alongside production, other economic factors and e.g. a skilled workforce.

All major countries have increased public R&D funding in recent years. Especially since around 2020, many of the countries have experienced a rapid expansion, reflecting new strategies. However, there are no clear budgets with distribution of funds per year (often not very transparent depending on the country, sometimes the numbers are really general and include various expenditures in the field of energy and mobility.

Each country has defined a different number of KPIs with different degrees of feasibility. Although setting a number of KPIs would be useful to align R&D efforts, some scientific researchers criticized that setting a lot of KPIs in different aspects and achieving them at once is too ambitious because some KPIs show a trade-off relationship.

Recommendations

The renewal or updating of strategies, market and industry orientation, and attempts to develop sustainable battery ecosystems are regarded as positive directions and provide orientation. The context and aim of the strategies can vary of course (e.g. depending on the country´s political positioning, funding strategies, R&D strategies, industry policy, sustainability goals etc.) but strategies should be renewed in a specific and defined timeframe (not too often) and with a mandate from the organization (the body publishing the strategy must demonstrate a clear understanding of the role and liability of the strategic goals).

Therefore, it would also be beneficial to clarify or understand what the core KPIs are for each individual country, taking into account trade-off features between different KPIs, and how the KPIs should be interpreted in the actual R&D activities (i.e., a strict mandate to achieve or just a future vision).

In all the countries and regions, there is evidence that more effort is being devoted not only to formulating strategic goals, but also on monitoring the status quo and the development of the global situation so that the governments, as well as other key stakeholders, can reflect on their own policies and strategies (or even align international strategies) well in advance. Monitoring can help assess different technological, economic, and sustainable pathways, including the progress of alternative technologies. Policies and strategies can thus be underpinned by a more substantiated and reliable (data)base. However, neutrality should be ensured, and a holistic assessment framework should ideally provide more transparency and be coordinated with the key stakeholders and interest groups.

List of Abbreviations

Abbreviation	Description
ARPA-E	Advanced Research Projects Agency (U.S. DOE)
BEPA	Batteries European Partnership Association
BEV	Battery Electric Vehicle
BMBF	Federal Ministry for Education and Research (Germany)
BMVI	Federal Ministry of Transport and Digital Infrastructure (Germany; currently Federal Ministry for Digital and Transport (BMDV))
BMWK	Federal Ministry for Economic Affairs and Climate Action (Germany)
CATARC	China Automotive Technology & Research Center Co., Ltd
CATL	Contemporary Amperex Technology Co., Limited
CCP	Chinese Communist Party
China SAE	China Society of Automotive Engineers
CN	China
DE	Germany
DOE	Department of Energy (U.S.)
EERE	Office of Energy Efficiency & Renewable Energy (U.S. DOE)
ESS	Energy Storage System
ETIP	European Technology and Innovation Platform
EU	European Union
EC	European Commission
EV	Electric Vehicle
FCAB	Federal Consortium for Advanced Batteries (U.S.)
FY	Fiscal Year
GHG	Greenhouse Gas
HV	Hybrid Vehicle
ICE	Internal Combustion Engine
IPCEI	Important Project of Common European Interest
IRA	Inflation Reduction Act (U.S.)
JP	Japan
KEIT	Korea Evaluation Institute of Industrial Technology

List of Abbreviations

Abbreviation	Description
KPI	Key Performance Indicator
KR	The Republic of Korea (South Korea)
LDV	Light Duty Vehicle
LFP	Lithium iron phosphate ($LiFePO_4$)
LIB	Lithium Ion Batter
LIBTEC	Consortium for Lithium Ion Battery Technology and Evaluation Center (Japan)
METI	Ministry of Ecnomy, Trade and Industry (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MoF	Ministry of Finance (China)
MoST	Ministry of Science and Technology (China)
MOTIE	Ministry of Trade, Industry and Energy (South Korea)
MSIT	Ministry of Science and ICT (South Korea)
NCM	Lithium Nickel Manganese Cobalt Oxides
NDRC	National Development and Reform Commission (NDRC)
NEDO	New Energy and Industrial Technology Development Organization (Japan)
NEV	New Energy Vehicle
NMSAC	National Manufacturing Strategy Advisory Committee (China)
OEM	Original Equipment Manufacturing
PHEV	Plug-in Hybrid Electric Vehicle
SIB	Sodium Ion Battery
SOC	State of Change
SRA	Strategic Research Agenda (EU)
SRIA	Strategic Research and Innovation Agenda (EU)
SSB	Solid State Battery
TRL	Technology Readiness Level
UNFCCC	United Nations Framework Convention on Climate Change
VTO	Vehicle Technologies Office (U.S. DOE)
ZEV	Zero Emission Vehicle

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Project Executing Organization
Projektträger Jülich (PtJ)
Neue Materialien und Chemie
Werkstofftechnologie für Energie und Mobilität (NMT 1)
52425 Jülich

Project Lead
Dr. Axel Thielmann
Head of Competence Center – Emerging Technologies
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Strasse 48
76139 Karlsruhe, Germany
Phone +49 721 6809-299
axel.thielmann@isi.fraunhofer.de

Scientific Coordination
Chie Endo (Ode)
Competence Center – Emerging Technologies
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Strasse 48, 76139 Karlsruhe, Germany
Phone +49 721 6809-311
chie.endo@isi.fraunhofer.de

Authors
Chie Endo (Ode)
Tanja Kaufmann
Dr. Richard Schmuch*
Dr. Axel Thielmann

*Fraunhofer Research Institution for
Battery Cell Production FFB / University of Münster,
MEET Battery Research Center

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Contact

Dr. Axel Thielmann (Project Lead)
Head of Competence Center – Emerging Technologies
Phone +49 721 6809-299
axel.thielmann@isi.fraunhofer.de

Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48
76139 Karlsruhe, Germany
www.isi.fraunhofer.de