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In Collaboration with Systemiq

WORLD ECONOMIC FORUM

Accelerating Policy Action for Safe and Green Electric Vehicle Battery Recycling

BRIEFING PAPER
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Executive summary

Electric vehicle (EV) battery recycling poses a triple opportunity: 1. potentially cutting about 40% of a battery's lifetime carbon footprint,[1] 2. creating jobs and 3. reducing the reliance on virgin material inputs.

Yet specific challenges need to be overcome to scale EV battery recycling:

- Securing equitable access to sufficient and predictable battery quantities;
- Improving the economics of the recycling of lower-value cell chemistries;
- Further reducing the environmental and social impacts of recycling.

Policy-makers in China, the European Union (EU) and the US have realised the strategic importance of EV batteries and are aiming to scale their recycling through ambitious policy actions, such as the EU Battery Regulation and US Inflation Reduction Act.

Policy-makers need to collaborate to enable a safe and clean transboundary movement and management of end-of-life batteries by:

- Standardizing definitions and transaction triggers;[2]
- Developing and harmonizing standards for black mass composition;[3]
- Increasing information availability through traceability;
- Providing incentives for new recycling technologies that can treat LFP batteries economically;
- Supporting the development of safety measures.

Battery recycling works today but innovation will revolutionize the sector

Between 2020 and 2021, global electric vehicle (EV) sales increased by 50% to 6.6 million vehicles.[4] By 2030, EVs could exceed 50% of total automotive sales,[5] driven by technological advancements and internal combustion engine vehicle phase-out regulations.[6] If options for second-life or echelon use are not viable, batteries must be collected, treated and recycled. In Europe alone, the scaling-up of EVs could result in the recycling of more than 1 million[7] spent batteries by 2030. EV battery recycling poses a triple opportunity, potentially cutting about 40% of a battery's carbon footprint[8] compared to virgin material used, creating jobs and reducing reliance on virgin material inputs. By 2050, recycling could provide 45% to 77%[9] of Europe's supply of battery metals. In the shorter term, the share will be significantly smaller due to a growing EV market and the longer lifetime of EV batteries.

The recycling of batteries aims to recover the raw materials and can be broken down into three steps:[10]

1. Preparation for recycling
2. Pre-treatment
3. Main processing.

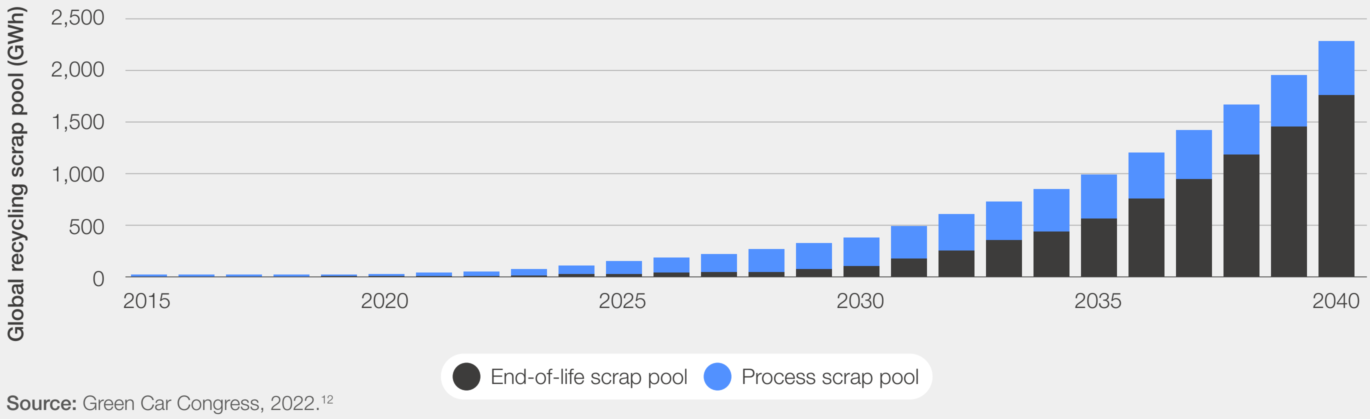
The preparation focuses on discharging and dismantling, while pre-treatment separates battery ingredients so they can be fed into the further industrial processing steps. The product of this step is the so-called black mass, which consists of high amounts of battery metals that can then be extracted and recycled in further processing steps.

The final step comprises two approaches – pyrometallurgy and hydrometallurgy[11] – that are typically combined in industrial battery recycling processes.

- Pyrometallurgy employs high temperatures to conduct smelting and refining operations to extract metals from the black mass.
- Hydrometallurgy dissolves battery materials into acids to recover materials. It involves the leaching of intermediate products followed by further extraction processes to extract the desired metals.

In addition, there are also promising new recycling methods, such as direct recycling, by which cathodes are chemically regenerated to be reused without further processing, or bio-recycling, where specialized micro-organisms are used to extract resources. Both technologies promise to require much lower energy and processing needs but are still in the research or pilot phase and it is unclear if and when they may be commercialized.

FIGURE 1 **Process scraps dominate the global recycling pool until the 2030s**



Source: Green Car Congress, 2022.[12]

The three main EV battery recycling challenges

For policy-makers and the automotive industry, the priority is to scale the safe and clean recycling of batteries globally. To do so, they will have to overcome three key challenges:

1. **Getting access to sufficient battery** quantities – Recently, there has been a rush into battery recycling, with global recycling capacity expected to surge nearly ten times from 2021 to 2025.[13] By 2025, there may be three times more recycling factory space than scrap to feed the plants.[14] Due to batteries' long lifetimes, in 2025, 78% of the available supply is expected to come from manufacturing waste, while only 22% would come from end-of-life vehicles.[15]

   For battery recyclers, the biggest challenge will be to access enough scrap. Cell manufacturers and automakers are particularly well-poised for production scrap since they have direct access. Therefore, recyclers in the EU and the US, in particular, face this issue. For end-of-life scrap, a key challenge is re-collection and preventing leakage of spent batteries into the environment, particularly for smaller handheld batteries, for example from electric scooters.

   China will likely capture a significant percentage of this market early since it has about 50% of the world's battery recycling capacity,[16] putting investments into capacity recycling in Europe and the US at risk.

2. **Improving the economics of the recycling of lower-value cell chemistries** – The economic viability of recycling is heavily dependent on the recovery of high-value transition metals,[17] specifically cobalt and nickel. However, as cobalt in cathodes is reduced and cheaper chemistries such as lithium iron phosphate (LFP) become more popular, current recycling methods will become less economically viable. By 2030, LFP chemistry is expected to account for around 45% of cell demand.[18] One crucial issue will be preventing the irresponsible disposal of lower-value cell chemistries. There are three ways to help support recycling profitability:

   – **Reduce the costs of recycling processes** – The diversity of batteries and the manual nature of the disassembly process challenge the economics of recycling processes.[19] This can be improved by introducing automation and robotics in the disassembly process and battery passports that make information on the battery type, state of health and state of charge easily accessible, thereby increasing the throughput.[20] Automakers can also ease recycling through increased standardization of battery design and design for disassembly, for example by reducing the use of glues to hold components in place. Finally, there is a need for well-developed reverse logistics and dismantling networks to minimize transportation costs, which are one of the biggest recycling cost drivers.[21]

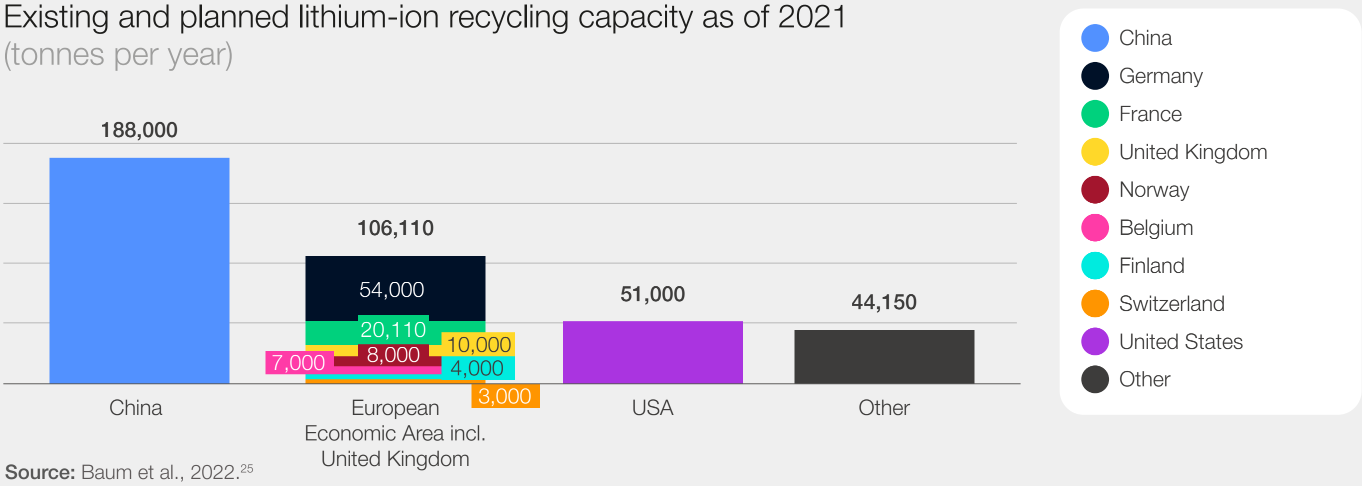
   – **Focusing recycling on countries with a lower cost base** – The recycling of lower-value cell chemistries can also be enabled by focusing on countries with low labour and fixed costs[22] (e.g. energy), such as China or northern Africa. While rising lithium prices have improved the economic attractiveness of LFP recycling, China would currently be best suited for recycling due to its cost structure.

   – **Scaling new recycling technologies** – Unlike pyro- and hydrometallurgy, direct recycling, by which cathodes are chemically regenerated for reuse without further processing, is currently the only recycling technology that can profitably recycle LFP chemistries, spanning almost all geographies.[23] However, this recycling technology is currently not commercialized. It will likely also be limited to production scrap due to the higher homogeneity of this flow and a shorter lead time to market compared to current battery technologies. The commercialization of this technology could enable the recycling of lower-value cell chemistries.

3. **Further reducing the environmental and social impact[24] of recycling** – Environmental issues focus specifically on reducing the greenhouse gas (GHG) footprint of pyro- and hydrometallurgy and reducing the environmental risks of the chemicals used in hydrometallurgical routes. This can be achieved by decarbonizing equipment, inputs and industrial processes, minimizing the use of leachants and solvents and preventing leaching or other forms of environmental pollution. Reducing social impacts focuses on the safe tooling and handling of batteries during disassembly processes and minimizing health risks during hydrometallurgical processes.

FIGURE 2 **Existing and planned lithium-ion battery recycling**

Existing and planned lithium-ion recycling capacity as of 2021
(tonnes per year)



Source: Baum et al., 2022.[25]

TABLE 1 **Synthesis of current EV battery recycling policies**

Circular Cars Initiative (CCI) Policy Levers Framework	China	EU	USA
Create cross-cutting market enablers	Introduced a traceability system for the management of EV battery recycling	EU Battery Regulation introduced Battery Digital Product Passport	
Reshape economic incentives		EU Taxonomy Regulation guides investments into sustainable EV battery manufacturing & recycling	Provides subsidies & tax credits for near-shoring battery recycling; subsidies for recycling infrastructure development
Harmonize & strengthen existing measures	Makes automotive original equipment manufacturers (OEMs) responsible for battery recycling; defines guidelines for battery recycling	EU Battery Regulation introduced material-specific recycling & recycled content standards; producer responsibility for end-of-life batteries	

Key regional actions for EV battery circularity underway

In recent years, China, the EU and the US have passed comprehensive policies to prevent irresponsible disposal, ensure access to critical raw materials and develop domestic recycling infrastructure. Table 1 provides a brief overview of the most relevant battery recycling policies in the three geographies.

China

Since 2016, China has introduced a series of measures to develop a comprehensive policy framework for EV battery recycling. Between 2016 and 2018, Chinese policy-makers focused on laying the foundation before focusing on converging and fully implementing policy from 2019 onwards. These include:

– Interim Measures for the Management of Recycling and Utilization of New Energy Power Vehicle Battery – Makes automakers responsible for EV battery recycling.

– Interim Provisions on the Management of Traceability of Recycling and Utilization of New Energy Vehicles Power Battery – Mandates information on battery recycling at all stages from manufacturers, automakers and recyclers to determine recycling effectiveness.

– Guidelines on Construction and Operation of Power Battery Recycling Service Network for New Energy Vehicles – Narrows definitions for lithium-ion battery recycling facilities.

– Measures for the Administration of Echelon Utilization of Power Batteries in New Energy Vehicles – Standardizes and ensures the quality and recycling of second-life, repurposed and remanufactured batteries.

European Union

The European Union's comprehensive battery policy framework started with the 2006 EU Battery Directive. Given the EU's sustainability ambitions through the EU Green Deal and its Strategic Action Plan for batteries, it reformed its regulatory framework for batteries through the revised 2022 EU Battery Regulation and the EU Taxonomy.

- **2022 EU Battery Regulation**:[26] This regulation aims to facilitate dismantling processes by requiring manufacturers to ensure that batteries are readily removable and replaceable. It also introduces material-specific recycling targets and minimum requirements for recycled content in batteries. This incentivizes high-quality recycling and the recovery and recycling of more valuable materials. For lithium, for example, which is not recovered in large quantities today, the regulation requires recovery and recycling rates of 50% by 2027 and 80% by 2031 and recycled content targets of 6% by 2031 and 12% by 2036. Moreover, the EU Battery Regulation improves data availability throughout the value chain by introducing a digital product passport for EV batteries. Compliance will be a prerequisite for permission to sell into the EU market. This will include critical information on battery type, chemistry, state of health and state of charge. Thus, it will facilitate dismantling and recycling processes. Manufacturers will be responsible for the end-of-life management of all batteries.

- **EU Taxonomy Regulation**:[27] Regulations classify recycling as a sustainable economic activity, thereby strengthening the design for recycling. The EU Taxonomy Regulation incentivizes manufacturers to design recyclable batteries and use recycled materials to attract investments. Recycled materials may cover both production and end-of-life scraps.

United States

The US government is committed to bolstering domestic recycling to near-shore EV battery supply chains and ensuring material availability.

- **Inflation Reduction Act**:[28] The passing of the Inflation Reduction Act means significant tax benefits and other subsidies for localizing supply chains and fuelling EV uptake. Buyers can qualify for a tax credit of up to $7,500 if certain thresholds for the extraction, processing or manufacturing of critical minerals and battery components in the US or in a country with which the US has a free trade agreement are met. For minerals, this threshold is 40% through 2023 and increases to 80% after 2026. For the value of battery components, it is 50% through 2023 and 100% after 2028.

- **Federal Bipartisan Infrastructure Law**:[29] This law dedicated $3 billion to a battery material processing programme and $3 billion for domestic battery manufacturing and recycling.

The review shows that China, the EU and the US aim to improve sustainability performance and ensure the competitiveness of their EV battery value chains. This increasingly leads to competing interests between the three, with the EU and the US aiming to reduce dependencies on China. Even though increased resource regionalization may reduce overall trade in spent EV batteries and recycled materials, China is still expected to dominate EV battery manufacturing, accounting for 69% of global manufacturing capacity in 2027, down from 77% in 2022.[30] As a result, global trade will remain critical to maximizing the deployment of recycled materials in new EV battery production.

Recommendations: Enabling the safe and green management of end-of-life batteries

The challenge for policy-makers in the EU, the US and China will be to develop the framework conditions to enable the safe, green and efficient recycling of EV batteries globally.[31, 32] They could leverage established initiatives such as the ZEV Transition Council to do so.[33] Potential actions should cover the following:

- **Standardizing definitions and transaction triggers**[34] – Align definitions of critical terms such as waste, recycling or recycled material across jurisdictions to ensure harmonized treatment and enable EV battery recycling. In addition, policy-makers can foster circular value creation by harmonizing regulatory frameworks to enable consistent, efficient and transparent product classification. For example, if a contract for recycling is in place, the "product" trigger could be retained and the default "waste" trigger avoided.

- **Developing and harmonizing standards**[35] **for black mass composition** – As the composition of black mass is diverse and differs between battery chemistries and designs, develop standards that specify criteria for what metals are present and in what quantity and quality to facilitate trade. Legislators should prompt the industry to establish standards, with support from academia, to ensure scientific rigour.

- **Increasing information availability through traceability** – Strengthen and harmonize global traceability and transparency requirements to ensure sufficient information availability to enable effective, efficient and sustainable battery recycling. This could, for example, involve the harmonization of digital battery passport requirements to ease battery recycling and the use of recycled materials.

- **Providing incentives for new recycling technologies that can economically treat LFP batteries** – Support the commercialization of new technology, such as direct recycling, through research and development assistance or other public-private partnerships.

- **Supporting the development of safety measures** – Support the development of safe recycling practices globally, for example, by requiring internationally recognized standards in recycling operations.

Contributors

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