Evaluation of Circular Design and Recycling for Traction Batteries

WRITTEN BY

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The impact of lithium-ion batteries on the environment should not be neglected. Recycling and second-life applications of these products built in electric vehicles can significantly improve the life cycle assessment and reduce the environmental impact. With their CycleBat evaluation methodology, FEV enables a differentiated investigation of various factors, for example design for recyclability, second-life application, choice of cell chemistry and generating of costs that are associated with typical recycling pathways.

The aim of developing the FEV's CycleBat evaluation methodology was to visualize and quantify the impact of design-for-circularity approaches on the End of Life (EoL) value of batteries, **FIGURE 1** [1]. New battery designs and improvements in battery sustainability are imperative to meet regulatory targets. Design-for-circularity concepts must be considered in today's vehicle battery development. The evaluation methodology consists of a series of models and has been developed by consolidating the knowledge that was gained in several projects at FEV along the battery value creation chain in recent years.

The CycleBat models consist of two components: the market model and the model about the value creation chain. The market model provides forecasts of supply and demand for EoL batteries across Europe, broken down by cell chemistry, country, producer, and other relevant factors. This model considers not only used batteries, but the entire material flow of the recycling cycles.

In contrast, the value creation chain model provides a detailed breakdown of the costs and CO_2 emissions associated with each step of the value creation chain over time. This enables detailed business case analyses and impact assessments for design-for-circularity approaches.

To assess the impact of design-for-circularity approaches on the cost value of EoL batteries, the introduction of these approaches in the CycleBat value creation chain model was simulated. Then, the resulting changes in costs and CO_2 emissions that are associated with each step of the value creation chain were analyzed and the impact on the overall value of the EoL battery was calculated. These methodologies provide a comprehensive analysis of the impact of design-for-circularity approaches on the value of EoL batteries.

In this article, selected results of the analysis of the impact of design-for-circularity approaches on the value of EoL batteries are discussed. In particular, this includes the choice of the battery cell chemistry and the design of the battery pack. Both approaches play a crucial role in improving the circularity and sustainability of batteries in the automotive industry.

BATTERY CELL CHEMISTRY CHOICE

The right choice of the battery cell chemistry is a crucial aspect in shaping the circular economy in the automotive industry. The analysis focused on the two main chemistries currently under consideration: Nickel Manganese Cobalt (NMC) oxide and Lithium Iron Phosphate (LFP).

On the one hand, NMC offers higher performance than LFP, but at a higher cost, **FIGURE 2**. On the other hand, LFP has a lower power density but is cheaper. In terms of cost the NMC cell has a clear advantage because of the material value. This is because NMC batteries contain valuable metals such as nickel, cobalt and manganese in addition to lithium.

In contrast, LFP batteries mainly contain lithium as a precious metal component; other components of the active cathode material, such as iron or phosphate, are comparatively of low value. This difference in the value of the residual material has an impact on the overall cost effectiveness of the recycling process.

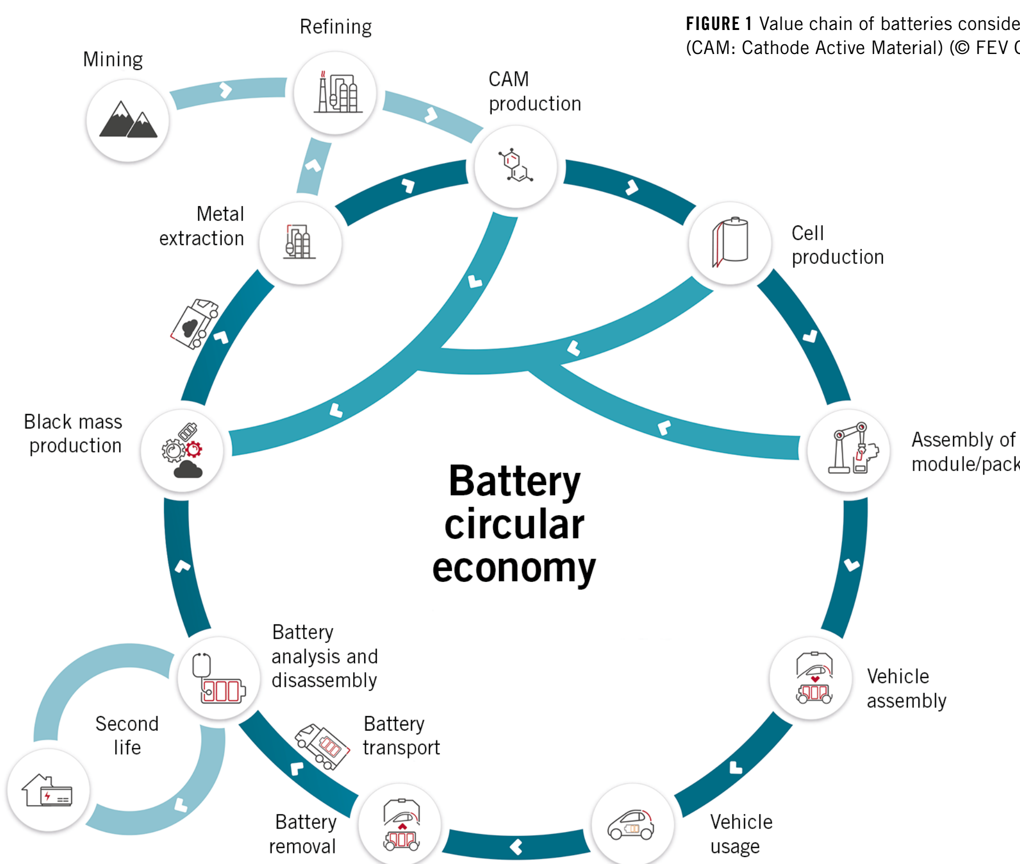

FIGURE 1 Value chain of batteries considering circularity (CAM: Cathode Active Material) (© FEV Consulting GmbH)

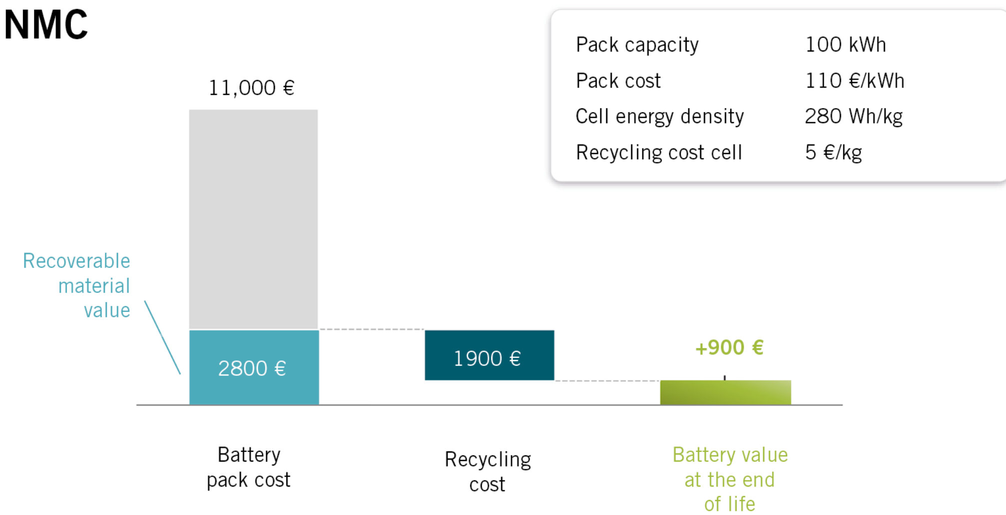

FIGURE 2 Cost value of a Nickel Manganese Cobalt (NMC) battery pack at the end of its life for a typical passenger car in 2040 (raw material prices relate to May 2021, after that, they increased steeply; high-level estimate) (© FEV Consulting GmbH)

Despite the lower complexity of the metal recovery process for LFP, most of the steps in the value creation chain, for example logistics and treatment of the black mass, remain the same, **FIGURE 3**. The recycling costs for LFP batteries can therefore be almost the same as those for NMC batteries (2200 versus 1900 euros). If the recycling costs per kilowatt hour (euros/kWh) are also considered, LFP batteries may even be more expensive due to their lower energy density.

This results in an EoL battery value difference of approximately 1700 euros (+900 versus -800 euros) for a typical battery electric vehicle, which emphasizes the importance of the choice of battery cell chemistry as a design approach for recyclability.

BATTERY PACK DESIGN

The design of the battery pack plays an important role in promoting the circular economy and the sustainable management of batteries at the end of their lifetime. This topic can be further explored by looking at cell-to-pack design versus modular pack design and material mix considerations.

For cell-to-pack design, the battery cells are bonded directly to the pack, often using adhesives or other irreversible joining technologies. This makes disassembly difficult, and if a cell fails, the entire pack may have to be replaced. In contrast, modular pack designs allow individual modules to be replaced, simplifying the repair process. In addition, modular designs allow the recombination of intact modules for reconditioning or reuse. This flexibility not only improves repairability, but also maximizes resource utilization.

When selecting materials for the construction of battery packs, it is important to understand the potential recycling process that the battery will undergo. Some material combinations, for example aluminium with lithium, pose a challenge when it comes to separation even when hydrometallurgical processes are used. To avoid this, it is important to ensure the possibility of material separation during disassembly right from the construction stage. An easier separation increases the value of the resulting black mass, which in turn improves the yield of the metal extraction process and ultimately the value of the EoL battery. In addition, pre-processing steps that increase recycling efficiency, for example an early separation of high-value components like high-voltage parts and electronics, can enable their reuse or dedicated recycling routes. Battery pack design considerations, such as the introduction of modular designs and careful material selection, play an important role in increasing the recyclability and value of EoL batteries.

These selected results so far emphasize the importance of a holistic life cycle approach in the development of batteries for electric vehicles. It is critical for Original Equipment Manufacturers (OEMs) to prioritize EoL battery design and view it as a potential revenue stream or a liability, depending on their business model. Unfortunately, the current trend in the industry is to focus on range and production costs, which often leads to compromises in design when it comes to circulatory capability. An example of this is the increasing adoption of cell-to-pack designs in vehicles, which could hinder future circular economy efforts.

IMPACT ON PROFITABILITY AND COMPETITIVENESS

OEMs need to be aware that design-for-circularity measures can have a significant impact on their profitability, competitiveness, and regulatory compliance. The impacts can extend over several decades after the start of production, and the cost can reach thousands of euros per electric vehicle. Beyond the immediate concerns, the integration of circular design principles offers significant long-term benefits.

Considerations regarding logistics, condition assessment (state of health of the battery) or dismantling costs have a major impact on which batteries are suitable for remanufacturing and reuse. By implementing the principles of the design-for-circularity approaches, OEMs can directly influence these factors, potentially reducing the cost of remanufacturing and increasing the number of batteries that can be considered for a second life [2]. This not only improves the economic and environmental performance of batteries, but also contributes to a more sustainable future. In addition, these approaches offer significant environmental benefits by reducing the need for raw material extraction and minimizing waste throughout the life cycle of batteries.

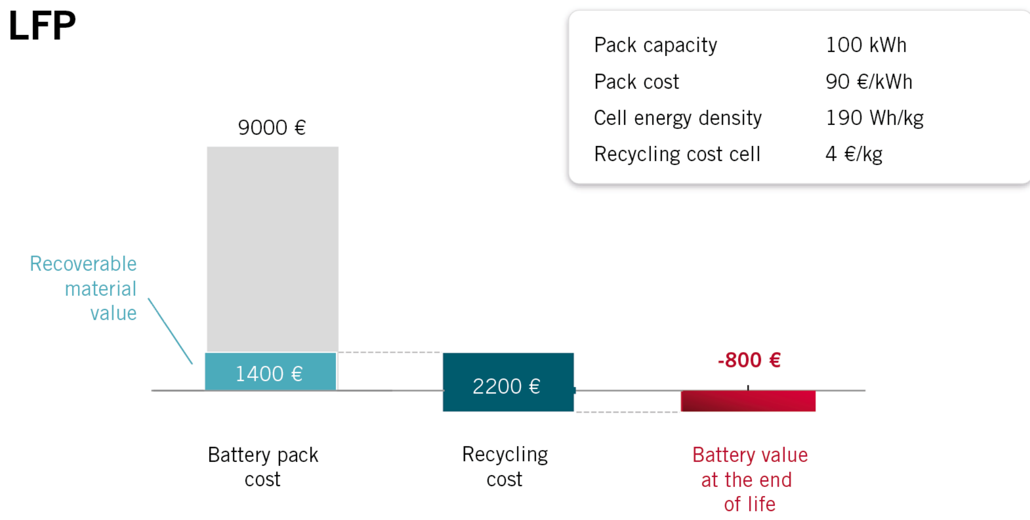

FIGURE 3 Cost value of a Lithium Iron Phosphate (LFP) battery pack at the end of its lifetime for a typical passenger car in 2040 (raw material prices relate to May 2021, after that, they increased steeply; high-level estimate) (© FEV Consulting)

By extending the lifetime of batteries, OEMs can reduce greenhouse gas emissions and minimize the environmental impact that are associated with the battery production.

The implementation of design-for-circularity measures can present challenges and obstacles for OEMs, including technological limitations, economic constraints, and the need for collaboration along the entire value creation chain. Overcoming these obstacles requires proactive collaboration with stakeholders, political decision-makers and technology providers.

Regulations and policies play a crucial role in introducing circular design principles. Extended Producer Responsibility (EPR) frameworks of the EU, eco-design standards and recycling targets can encourage OEMs to prioritize circularity in battery design and facilitate the development of robust collection and recycling infrastructures.

There are successful case studies where OEMs have implemented design-for-circularity measures that show tangible results such as cost savings, improved resource efficiency and enhanced environmental performance. These examples serve as inspiration for the industry and demonstrate the potential of the circular economy to create economic value while reducing the environmental footprint of electric vehicle batteries.

SETTING LONG-TERM GOALS

In summary, it can be said that the FEV CycleBat study shows the crucial importance of applying design-for-circularity principles in the development of electric vehicle batteries and in building an entire European battery ecosystem. OEMs need to align their design decisions with long-term sustainability goals. By doing so, they can improve the economics of batteries today, open up new business opportunities in the future, mitigate risks and contribute to a more sustainable, circular future for the electric mobility industry.

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THANKS

The authors would like to thank all FEV employees who provided valuable insights as part of the CycleBat project work in 2023. In addition, the authors want to thank the industry partners who not only contributed to the work but help building the circular economy of the future.