



GIGABAT

**Life Cycle Assessment in
GIGABAT: supporting eco-design,
production optimisation and
low-impact battery manufacturing**



Funded by
the European Union



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Foundations

The **GIGABAT** LCA work supports the development of more sustainable battery production by identifying environmental hotspots, guiding eco-design choices and conducting a full life cycle assessment of the project's battery production and recycling processes. The work has so far included a screening LCA of the project's reference battery chemistries – NMC811 and LFP, a review of recycling routes, raw material sourcing insights, methodology harmonisation with other European battery projects and preparations for the final full LCA.

The screening LCA based on GIGABAT formulations and available project and literature data showed cradle-to-grave climate change impacts of approximately **120 kg CO₂-eq/kWh battery capacity** for NMC811 batteries and **126 kg CO₂-eq/kWh battery capacity** for LFP batteries. The main hotspots differed by chemistry: for NMC811, cell materials dominated (especially cathode active material), while for LFP, rest-of-pack materials were particularly important.

A key conclusion is that reducing environmental impact requires attention beyond factory energy use. Materials sourcing, cell chemistry, pack design, cell-to-pack ratio, recycling options and battery lifetime all strongly influence the overall environmental performance of battery systems.

Why use LCA in battery production and development?

Life cycle assessment provides a structured and standardised way (ISO 14040/44) to quantify environmental impacts across the battery value chain, from material extraction and manufacturing to distribution, use and recycling. In GIGABAT, it is used to support design and production work from an environmental and eco-design perspective.

The LCA work has three main roles in the project:

- Identify environmental hotspots in battery production, including materials, manufacturing energy, distribution and recycling.

- Provide input to design decisions by showing how different aspects such as cell chemistry, sourcing and gigafactory location affect environmental performance.
- Assessing and evaluating the environmental impacts and effects of the innovations and technical work conducted within the project.
- The work started with a screening LCA and ends with a full LCA of the complete battery production and recycling system at the end of the project.



Key Findings

Screening LCA: Early insights for eco-design

An early-stage screening LCA was conducted for the two reference battery chemistries used in GIGABAT: NMC811 and LFP. The model was based on project-specific anode and cathode formulations available when the study was prepared, complemented with literature data and giga-scale production data from existing LCA literature and databases. The study used one kWh of battery capacity as functional unit. The screening LCA provided intermediate results on environmental performance and was used as input to eco-design discussions within the consortium.

Key results in screening LCA

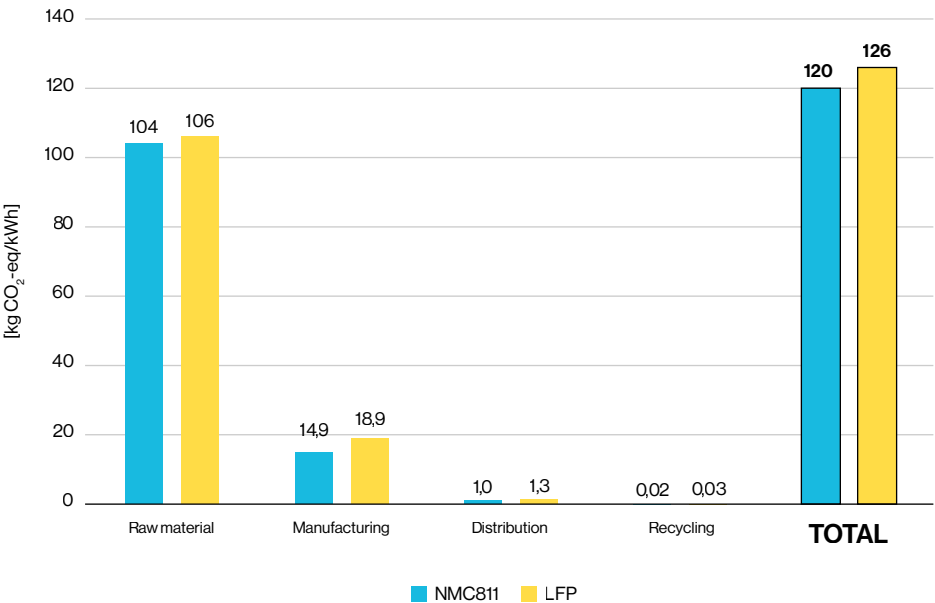
01 **NMC811 & LFP have similar cradle-to-grave climate impacts, but different hotspots**

The screening LCA estimated climate impacts of approximately:

- **NMC811:** 120 kg CO₂-eq/kWh battery capacity
- **LFP:** 126 kg CO₂-eq/kWh battery capacity

Although the total results were similar, the underlying hotspots were slightly different. For NMC811, cell materials were the main contributor, particularly cathode active material. For LFP, rest-of-pack materials had a larger relative influence, partly because lower gravimetric energy density can increase the amount of pack material needed per kWh capacity.

FIGURE 1
Climate impact per kWh of capacity for NMC811 and LFP batteries with GIGABAT formulations, per life cycle stage



02 **Upstream material supply is a major lever for impact reduction**

The screening LCA indicated that raw materials dominate the cradle-to-grave impact for both chemistries. This means that sourcing decisions, production routes, recycled content and supplier-specific environmental data are central to reducing battery carbon footprints.

For NMC811, high-impact materials linked to cathode production are especially important. For LFP, components outside the cell, including pack materials, can play a more prominent role.

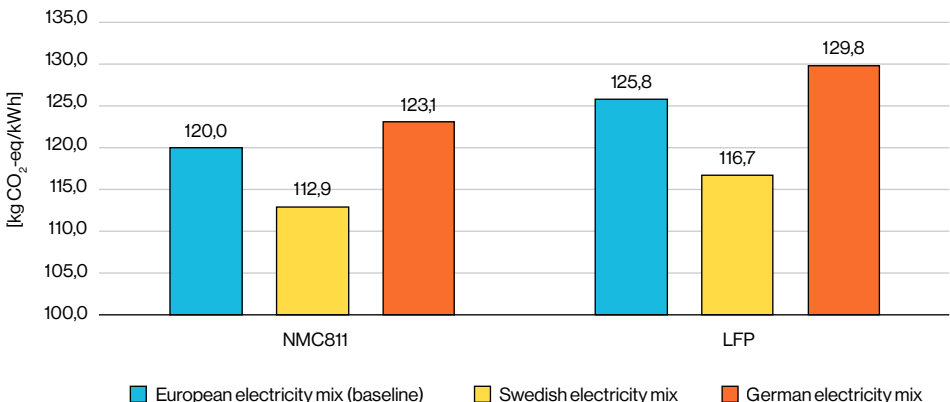
03 **Manufacturing energy matters, but it is not the only priority**

Energy consumption in the gigafactory contributed around 12 to 15% of the total climate impact in the screening LCA when a European average electricity mix was used. A sensitivity analysis showed that using a less carbon-intensive electricity mix, such as a Swedish grid mix with more renewables, can reduce manufacturing-related climate impacts.

However, the results also show that factory energy improvements should be combined with material sourcing and design measures, since upstream material production remains a dominant contributor.

FIGURE 2

Sensitivity analysis of electricity mix for climate impact of GIGABAT NMC811 and LFP batteries



04 **Cell-to-pack ratio is a key design parameter**

The cell-to-pack mass ratio was identified as strongly influencing the results on a battery pack level, particularly for LFP batteries. A higher cell-to-pack ratio reduces the amount of passive pack material required per kWh, thereby lowering climate impact.

At high cell-to-pack ratios, the LFP battery showed lower climate impact than the NMC811 battery in the sensitivity analysis, demonstrating that pack design can significantly influence comparisons between chemistries.

05 **Recycling provides significant opportunities**

The recycling assessment highlighted several opportunities to reduce environmental impacts and increase resource efficiency. Key observations included:

- Recycled materials often have lower environmental impacts than primary materials.
- Designing batteries for efficient disassembly and recycling can improve material recovery.
- Recycling will play an increasingly important role in meeting future requirements under the EU Battery Regulation.

The results emphasise the importance of considering recycling already during battery design and manufacturing development.

06 **Battery lifetime and use phase assumptions are important**

The use-phase scenario showed that cycle life is an important parameter for total life cycle impacts. When a Swedish electricity mix is used for charging, the climate impact from use-phase electricity can be in the same order of magnitude as the battery production impact, while European or global average electricity mixes lead to significantly higher use-phase impacts.

This means that a light, efficient battery with a long service life is desirable when considering full life cycle performance rather than production impacts alone.

Pathway

The role of recycling

Recycling routes were examined in a separate part of the screening LCA work. The review showed that recycling can reduce environmental burdens when secondary materials replace primary materials, but that the benefits depend on recycling technology, recovery efficiency, energy use and material quality.

The work also highlighted that designing batteries for recycling is not only environmentally relevant, but also important for meeting future requirements in the EU Battery Regulation.

Full LCA work

The full LCA builds on the screening LCA and aims to provide a more complete assessment of battery production and recycling processes in GIGABAT.

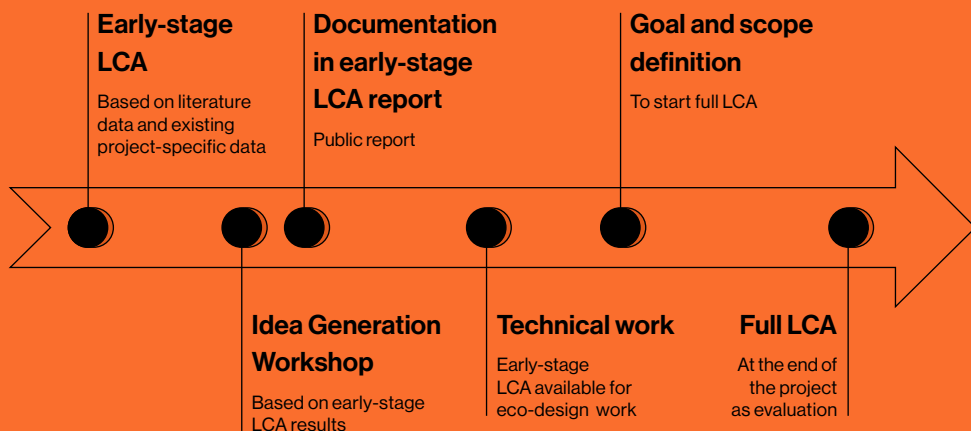
Key ongoing activities include:

- Collecting detailed primary data from project partners using dedicated data collection templates and bilateral collaboration.
- Aligning LCA work with digitalisation activities, with the aim of enabling environmental impact information to be integrated into the digital twin and the battery passport.
- Addressing key methodological choices, recycling scenarios and data gaps.
- Using insights from the screening LCA to prioritise processes and parameters for the full LCA.

The full LCA will enable a deeper analysis of energy and carbon footprints of gigafactory battery production, including sensitivity analyses related to material sourcing and geographical locations with different electricity mixes.

FIGURE 3

Timeline and activities



Knowledge sharing and scientific impact

The LCA work within GIGABAT has contributed to several scientific publications and collaborative initiatives. Highlights include:

- Collaboration with the Battery Heroes Sustainability Working Group to improve harmonisation of battery LCA practices across European projects.
- Research on the environmental implications of battery pack design and cell chemistry selection.
- Presentations at international conferences including SETAC Europe, Battery 2030+, and the International Battery Production Conference (IBPC).
- Development of recommendations to increase consistency and comparability in battery sustainability assessments.

New insights from pack-level LCA research

Following the screening LCA, GIGABAT partners deepened the analysis of pack design and cell chemistry.

This work used detailed teardown data from the A2MAC1 database to derive life cycle inventory data for eight commercially available EV battery packs.

The results showed that pack-level components should not be overlooked in battery LCAs. They also indicated that cell chemistry and pack architecture are closely linked: decisions made at the cell level affect pack-level environmental impacts and should therefore be modelled carefully.

The study also found that LFP packs may be more densely packed than NMC packs, reducing the difference in specific energy at pack level compared with cell level. This finding is important for future LCA studies, since environmental comparisons between chemistries can change depending on whether the analysis focuses on cells or complete packs.

Action Plan

Practical recommendations from the LCA work

Based on the GIGABAT LCA work to date, several practical recommendations can be drawn for battery developers, manufacturers and gigafactory stakeholders:

01 **Prioritise high-impact materials**

Focus sourcing and data collection efforts on materials and components that dominate climate impact, such as cathode active materials, graphite, aluminium and rest-of-pack components.

02 **Use supplier-specific environmental data where possible**

Generic data can support early screening, but supplier-specific data are needed to understand the real influence of production routes, energy mixes and recycled content.

03 **Optimise pack design, not only cell chemistry**

Cell-to-pack ratio, pack mass and passive materials can significantly influence the climate change impacts, especially for chemistries with lower cell-level energy density.

04 **Reduce gigafactory energy demand and use low-carbon electricity**

Manufacturing energy contributes meaningfully to climate impact, and using a low-carbon electricity mix can reduce the footprint of battery production.

05 **Design for recycling from the start**

Battery design should support material recovery, fulfil future regulatory expectations and enable the use of secondary materials where environmental benefits can be verified.

06 **Include lifetime and use-phase considerations**

Energy efficiency, cycle life and charging electricity mix can strongly affect total life cycle impacts, especially when moving beyond cradle-to-gate comparisons.

Conclusions

The GIGABAT LCA work shows that improving the environmental performance of battery production requires a system perspective, benefitting from early integration of life cycle thinking. Material production, pack design, manufacturing energy, recycling and battery lifetime all interact and must be considered together.

The screening LCA has already provided early eco-design guidance to the project, while the ongoing full LCA will provide a more robust basis for evaluating **GIGABAT** developments, identifying improvement opportunities and supporting future low-impact battery manufacturing in Europe.



GIGABAT

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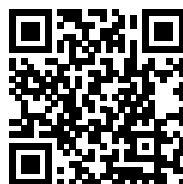
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