BATTERY CARBON FOOTPRINT

BUILDING THE SUSTAINABLE EV: BREAKTHROUGHS IN BATTERY TECH AND CO_2 REDUCTION

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1. Management summary

Electric vehicles (EVs) represent a pivotal solution to addressing climate change and decarbonizing the transport sector. However, the production of EV batteries remains energy-intensive and contributes significantly to the overall carbon footprint of electric vehicles. Earlier analysis indicates that EVs achieved carbon parity with combustion vehicles only after driving 80,000-120,000 km with the current EU electricity mix (40,000-70,000 km with 100% renewables in use phase), depending on battery size and production parameters.

This paper investigates the primary sources of emissions along the battery value chain—from material sourcing and production to recycling—and identifies opportunities for significant reductions. Regulatory frameworks, such as the EU Battery Passport, alongside technical advancements like renewable energy integration, innovative production methods, and enhanced recycling, provide a pathway to achieving substantial decarbonization. By optimizing these processes, **emissions from battery production could decrease from the current ~55 kg CO_2e/kWh to as little as ~20 kg CO_2e/kWh**[1]. Hence, the **break-even for an exemplary EV compared to combustion engine vehicle will be met already after ~50,000 km driving (for current EU electricity mix) or even <30,000 km when charging with 100% renewable energy** instead of ~95,000 km[2]. This will become increasingly relevant in EU from 2028 where cell manufacturers will be legally required to reduce CO_2e emissions below certain thresholds and could become a key differentiator for players along the battery value chain.

[1] Calculation for a 4680 cell with NMC811 cathode and ~10% SiOx in graphite anode produced at 40 GWh production scale.
[2] Calculation for mid-size EV with 80 kWh battery.

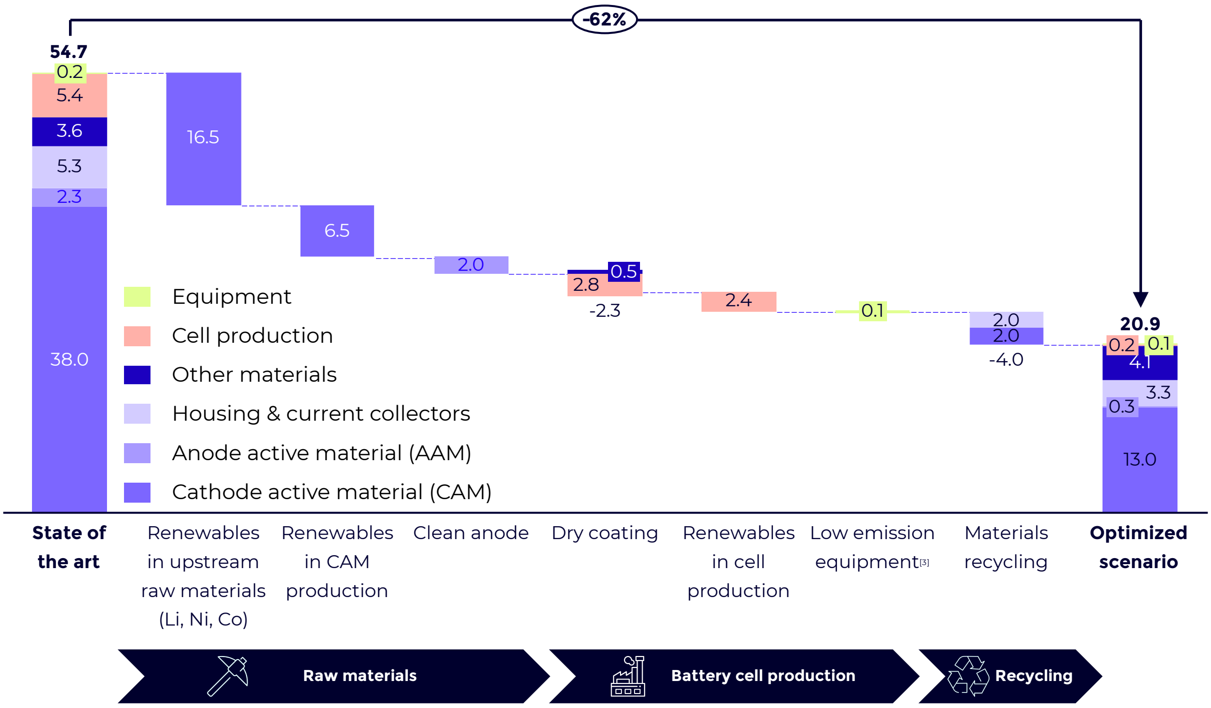

Figure 1: Emission reduction potentials along the battery value chain from raw materials to cell production and materials recycling.

[3] Equipment refers to the machinery used throughout the cell production process.

2. Understanding the challenge: Why EV sustainability matters

The exponential growth of the battery electric vehicle (BEV) market highlights the urgency of addressing the environmental impacts of lithium-ion battery (LIB) production. While BEVs are celebrated for their low-emission use phase, their production generates significant carbon emissions due to energy-intensive processes and material extraction.

The lifecycle emissions of BEVs consist of two main phases: production and use. Figure 1 illustrates the comparative emissions of BEVs and internal combustion vehicles (ICEs). **During production, BEVs have a higher carbon footprint due to battery manufacturing. However, the lower emissions during the use phase enable BEVs to break even with ICEs after covering a certain mileage.**

Several factors influence the emissions associated with battery production:

- **Energy mix in manufacturing regions:** The reliance on fossil fuels versus renewable energy significantly impacts the production footprint.
- **Raw material extraction:** The energy required for mining and processing metals like lithium, nickel, and cobalt contributes heavily to emissions.
- **Recycling practices:** The complex separation, refining processes and high purity requirements exacerbates chemical and energy consumption.

This whitepaper explores how innovations and regulatory frameworks can address these challenges to enhance EV sustainability and reduce their break-even to ICEs.

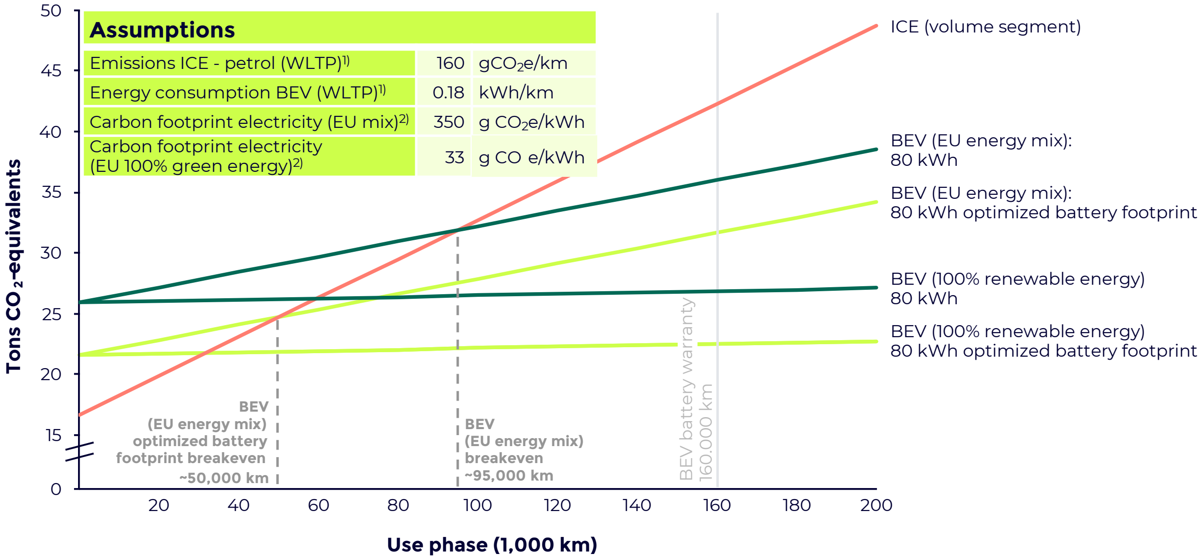

Figure 2: Total cumulated amount of greenhouse gas (GHG) emissions, depending on total kilometers driven, for ICE and BEV incl. materials production and refining, Li-ion battery pack, manufacturing. End-of-life included in in initial emissions.[1)]

[1] volvocars.com/files/cs/v3/assets/blt066aeed1a18c768c/blta7baed3860540bbc/66ea7ba6a603b52352dd3f6e/Volvo_carbonfootprintreport.pdf?branch=prod_alias
[2] evoinvent

3. Building a regulatory framework for sustainability

The European Union has established a robust regulatory and methodological framework to reduce the environmental impact of LIBs, particularly focusing on their GHG emissions. This effort aligns with the overarching goals of the European Green Deal, which seeks to make Europe climate-neutral by 2050 through circular economy principles, sustainable mobility, and cleaner energy systems.

Strengthening EU battery regulations for climate action

In addition to broader climate and energy policies, Europe has implemented specific regulations targeting the GHG footprint of lithium-ion batteries. The EU Batteries Regulation sets sustainability and performance requirements for batteries placed on the market, ensuring compliance with environmental requirements, including GHG reduction targets. Accurate measurement of the GHG footprint of lithium-ion batteries necessitates a standardized methodology for calculating the product carbon footprint. **The Product Environmental Footprint (PEF) Initiative provides a harmonized methodology for calculating a product's carbon footprint, covering the entire lifecycle from raw material extraction to end-of-life disposal with a specific category rule for rechargeable batteries.**

Enhancing transparency with the Battery Passport

The Battery Passport, introduced under the new EU Batteries Regulation, is a digital tool to enhance transparency and traceability of batteries. Serving as a digital identity card, the passport includes critical information on battery type, chemistry, capacity, performance, and environmental characteristics. It tracks the production, usage, and end-of-life stages of batteries, facilitating effective waste management, recycling, and circular economy practices.

Notably, the passport incorporates Product Environmental Footprint calculations with the single impact category climate change, enabling informed decision-making by manufacturers and consumers. **The regulation mandates the use of primary data to calculate GHG footprints for battery components (e.g., anode, cathode, separator) and requires full value chain coverage, from raw material**

acquisition to recycling. This necessitates collaboration among all value chain participants to achieve accurate and comprehensive LCA results.

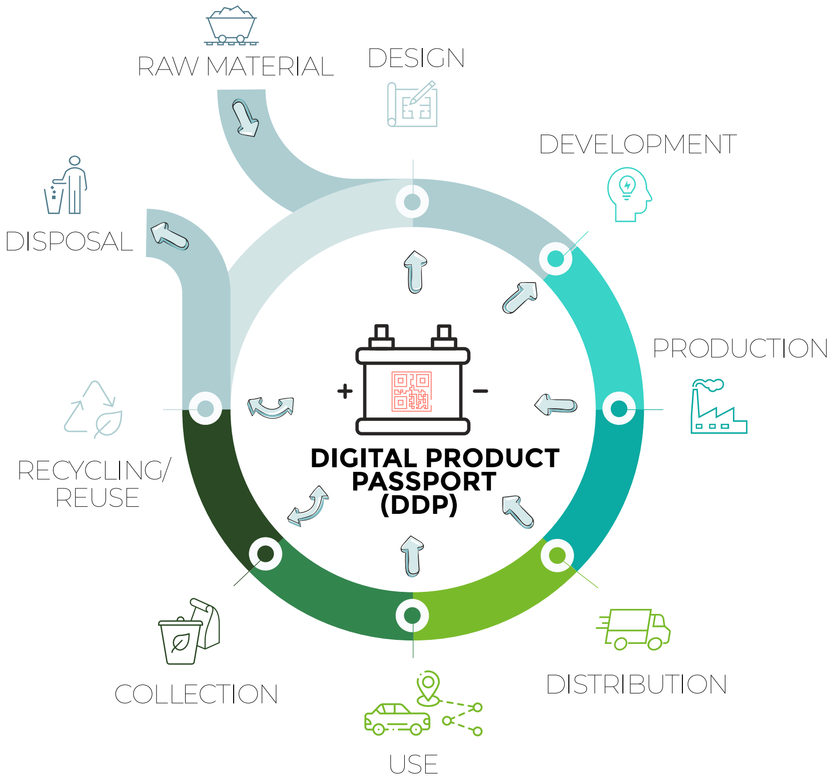

Figure 3: Digital Battery Passport along the value chain

4. Methods: A comprehensive approach to PCF analysis

The Product Carbon Footprint (PCF) is a critical metric for quantifying greenhouse gas (GHG) emissions across a product's entire life cycle. This comprehensive approach evaluates environmental impact from raw material extraction through production, use, and disposal.

The PCF calculation process begins with the **Scope Definition** by defining precise system boundaries and a functional unit that represents the product's core performance. This methodology encompasses all life cycle stages, including raw material extraction, manufacturing, distribution, use phase, and end-of-life treatment (Figure 4).

A rigorous **Life Cycle Inventory Analysis** collects and quantifies environmental inputs and outputs, accounting for energy consumption and raw material use. Data collection is crucial, drawing from both industry databases (secondary data) and supply chain partners (primary data). For complex products like batteries, **primary data is especially critical and is required for specific components by the EU Battery Regulation carbon footprint calculation methodology for EV batteries**.

For the **Impact Assessment** the GHG emissions are calculated using stage-specific emission factors that convert activities into CO_2 equivalents (CO_2e). These scientifically derived factors account for multiple greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The calculation process involves multiplying activity data by corresponding emission factors for each life cycle stage, then aggregating these emissions to determine the total carbon footprint.

The final PCF analysis enables organizations to identify emission hotspots and develop targeted mitigation strategies.

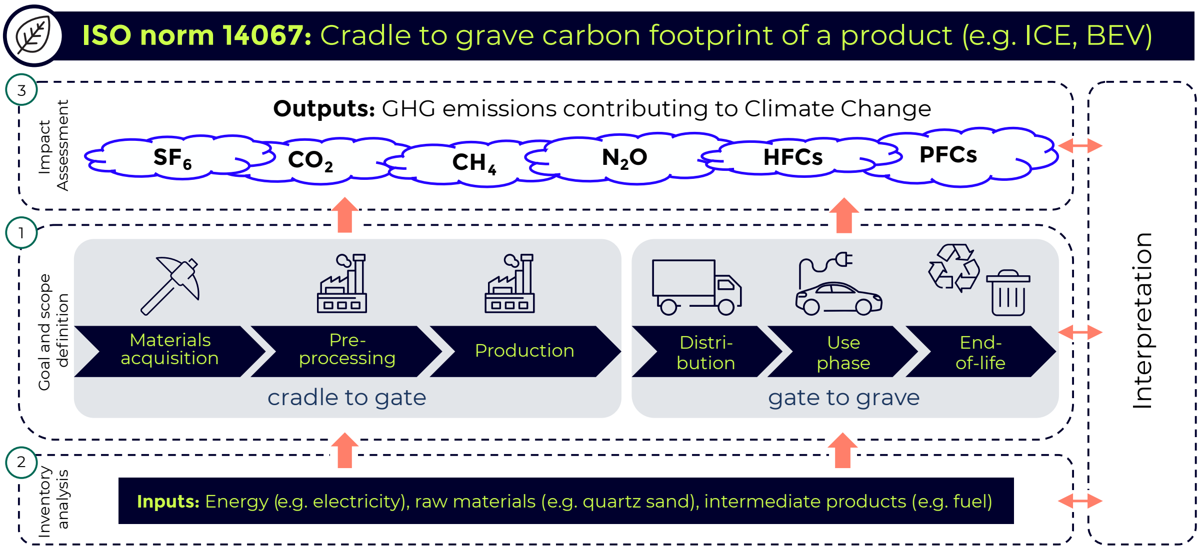

Figure 4: Cradle to gate/grave carbon footprint of a product according to ISO 14067

5. Tackling emissions along the battery value chain

Lowering cathode material footprints: NMC vs. LFP

Cathode active materials (CAMs) represent the largest contribution to a battery's carbon footprint. As such, this chapter focuses on Lithium Iron Phosphate (LFP) and Lithium Nickel Manganese Cobalt Oxide (NMC811), the two most prevalent CAMs in the current battery market. **Although both LFP and NMC811 are essential for battery production, they differ considerably in terms of sustainability and environmental impact.** This chapter examines the entire pathway from raw material extraction to the synthesis of CAMs. The analysis highlights how choices related to raw materials, energy sources, and production methods significantly affect the product carbon footprint (PCF). These findings provide valuable guidance for improving sustainability across the battery value chain.

Two-step calcination as driver for carbon footprint of NMC811 compared to LFP

The production processes for NMC811 and LFP differ in complexity and energy intensity. NMC811 production begins with the preparation of nickel, manganese, and cobalt sulfates, which are mixed in precise ratios to create a precursor (pCAM). This precursor is combined with lithium hydroxide, followed by two calcination steps to enhance electrochemical properties and stability, and concludes with milling and coating. In contrast, LFP production is simpler, involving the mixing of iron phosphate with lithium carbonate and a carbon source. A single calcination step is sufficient, followed by milling and sieving. **The reduced complexity and energy requirements of LFP production contribute to its lower carbon footprint compared to NMC811.**

Premises are key for a reliable and comparable carbon foot-print

The supply chain focuses on raw material extraction and processing locations, as these significantly influence the PCF. The study assumes production in China, a major hub for battery materials, where the energy mix relies heavily on fossil fuels. The supply chains for NMC811 and LFP are modeled using real material sources (Figure 5) and adjusted Ecoinvent datasets, supplemented with P3 machinery consumption data. These adjustments account for regional energy mixes and specific processing methods.

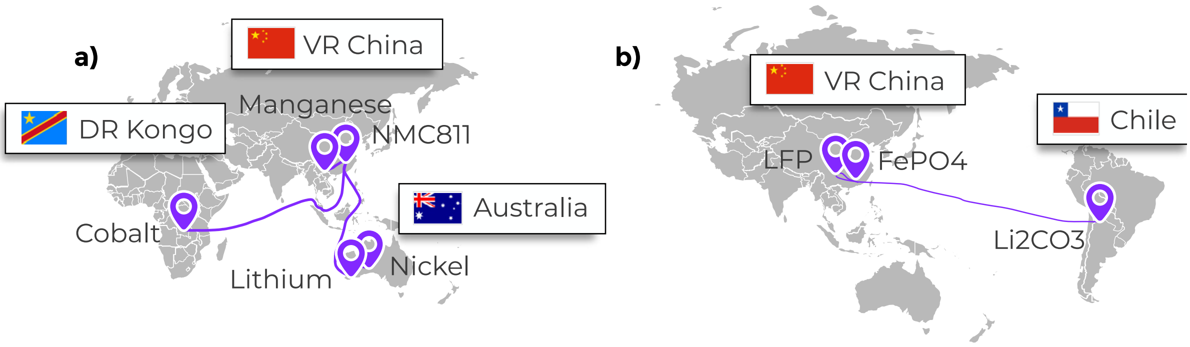

Figure 5: Exemplary supply chains for a) NMC811 and b) LFP

The carbon footprint of the NMC material exceeds those of LFP by far

The PCF of NMC811 is significantly higher than that of LFP. NMC811 has a PCF of 38 kg CO_2e/kWh (29 kg CO_2e/kg), with raw materials accounting for 80% of emissions and energy consumption contributing < 20%. Transition metals (nickel, manganese, cobalt) used in NMC811 production require extensive mining and processing, leading to high emissions. Lithium hydroxide, derived from energy-intensive ore processing, has a higher environmental impact than lithium carbonate, which is used in LFP production. **LFP has a PCF of 15 kg CO_2e/kWh (7.5 kg CO_2e/kg), ~60% lower than NMC811**. Its lower emissions stem from its simpler production process and the use of lithium carbonate, which is extracted from salt lakes using solar energy. Energy consumption for LFP production is also 25% lower than for NMC811. Using 100% renewable energy in CAM production could further reduce the PCF of NMC811[4] by 37% and LFP by 33%, highlighting the importance of clean energy sources in CAM production. 100% renewable energy in NMC811 supply chain further reduces the PCF by 38%.

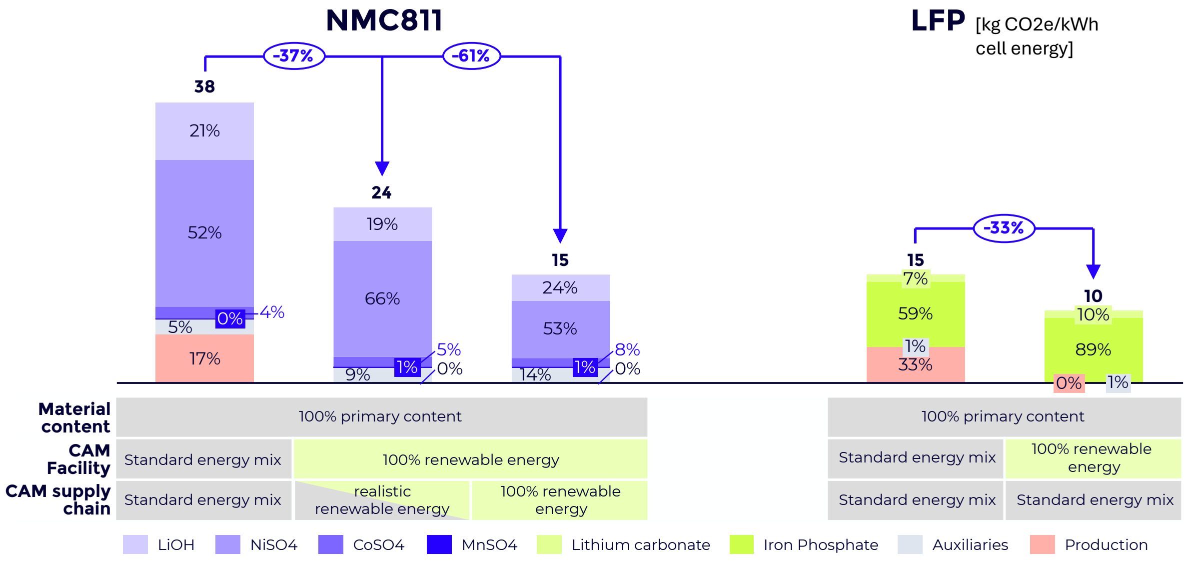

Figure 6: Product carbon footprint of NMC811 and LFP in kgCO2e/kWh cell energy

The carbon footprint of cathode active materials (CAMs) like NMC811 and LFP is profoundly influenced by assumptions regarding energy sources, raw material sources, and regional production setups. Regions with sustainable energy, such as Norway or Sweden, can drastically reduce emissions compared to countries where fossil fuels dominate the energy mix. LFP consistently outperforms NMC811 in this scenario due to its simpler production process and reliance on lithium carbonate compared to the lithium hydroxide used in NMC811. Transition metal sulfates and energy-intensive calcination steps further elevate NMC811's footprint. This discussion highlights the critical need for detailed, scenario-specific analyses to accurately assess the environmental impact of CAMs. Variations of ~25% in published data for NMC811, such as those between Ecoinvent and P3 calculations (29 vs. 38 kg CO_2e/kWh), underscore the importance of aligning PCF assessments with real-world energy mixes and supply chains to guide more sustainable battery

[3] Conversion of NMC811 mass into kWh is based on the factor 1.3 and LFP based on 2.0 kg material per kWh

production. Note that the **higher energy density of NMC811 material reduces the influence of the non-CAM components on cell level**, as their impact is distributed over more stored energy. In contrast to the results on ***material level,*** NMC811 can achieve a lower overall PCF on ***cell level*** than LFP.

6. Emission reduction potentials within battery cell production

Economies of scale as a lever to reduce energy consumption

Despite the materials having the most significant impact on the PCF of a battery, the cell production also takes up a non-negligible share. This chapter explores the energy consumption and emissions associated with battery cell manufacturing, identifies potential improvements, and discusses the significance of alternative technologies like dry coating and renewable energy integration. P3 followed both a top-down and a bottom-up approach to assess the emissions within battery cell production. First-hand data from P3's global Gigafactory data base were combined with literature values to investigate the actual energy consumption of existing battery production facilities. **Energy consumption per watt-hour (Wh) of battery cell energy shows a clear reduction as production volumes increase.** This phenomenon, known from economies of scale as the experience curve, demonstrates an 18% learning rate, where energy consumption declines in a linear manner on a double-logarithmic scale with growing production volumes. This relationship suggests that large-scale production is key to lowering energy intensity in battery manufacturing.

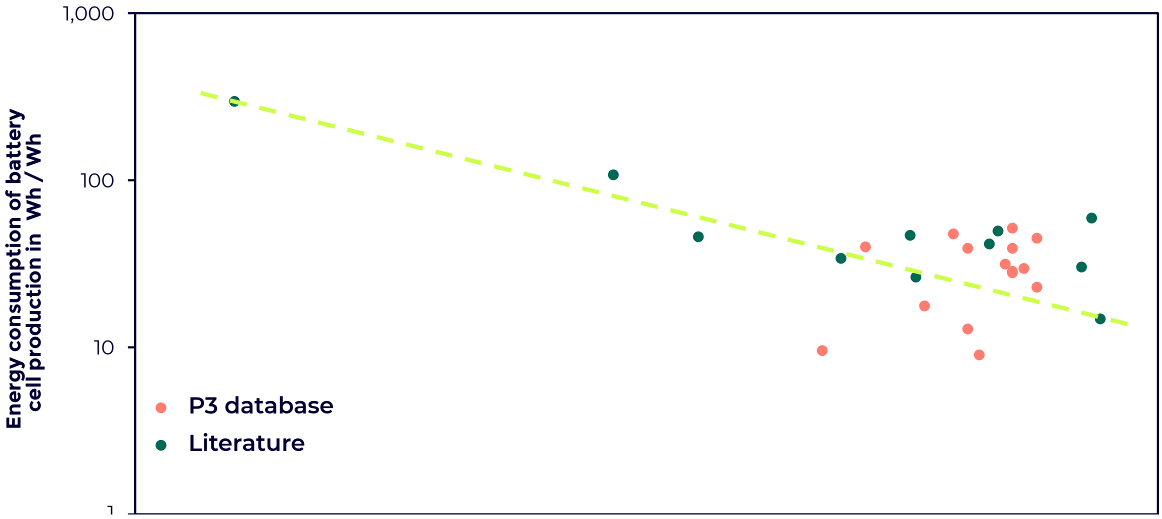

Figure 7: Energy consumption of battery cell production facilities based on literature and P3 database

Dry Coating: A promising emission reduction technology?

Battery cell production involves three major phases: electrode manufacturing, cell assembly, and formation & aging. Traditional wet electrode processes rely heavily on solvents, leading to high energy consumption during drying. Recently, dry coating technology has emerged as a potential solution to reduce energy demand. Tesla, after acquiring Maxwell Technologies in 2019, has already been applying dry coating in its 4680[5] battery manufacturing process. Here, the electrode materials are mixed with binders and additives in a dry form, eliminating the need for solvents. The resulting paste is compressed into electrode films and bonded to the current collector. **According to P3's bottom-up analysis, dry coating can lead to up to ~50% reduction in cell production CO_2e emissions compared to the conventional wet coating process.** This reduction is largely due to the omission of the energy-intensive drying process[6], as well as efficiency improvements in the mixing stage. **However, the overall product carbon footprint of a dry-coated battery cell may be ~5% higher than that of a wet-coated cell**. This discrepancy lies in the binder material, typically Polytetrafluorethylene (PTFE), which provides the necessary cohesion between electrode particles. **Within PTFE production, fluorinated greenhouse gases are released that have a ~12,000x higher global warming potential compared to CO_2**, leading to an overall increase of emissions for the final battery cell. Although PTFE's emission factor is significantly higher than that of conventional binders like PVdF or SBR/CMC, some manufacturers are exploring alternative production methods that capture these emissions, potentially lowering the carbon footprint of PTFE. In such cases, the overall emissions of the battery cell could be reduced, offering a benefit of ~5% (on cell level) in terms of carbon footprint.

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[4] 4680 is a cylindrical battery cell with 46 mm diameter and 80 mm height, as for instance used in the Tesla Model Y.

[5] Other large contributors to energy consumption and CO2e emissions within cell production are dry rooms, as well as vacuum drying and formation. % share depends on drying technology (e.g., steam generated by natural gas) and electricity mix.

Reducing emissions with renewable energy

While process innovations such as dry coating can significantly cut emissions, **the most impactful strategy for reducing the carbon footprint of battery cell manufacturing lies in transitioning to renewable energy sources**. By omitting natural gas and powering facilities with clean electricity only, particularly when combined with energy-efficient technologies like heat pumps, manufacturers can reduce their Scope 2 emissions, which account for energy use within their operations. Furthermore, careful consideration of Scope 3 emissions, including the emissions from upstream suppliers and the production of raw materials, is essential to lowering the overall environmental impact of battery production[7].

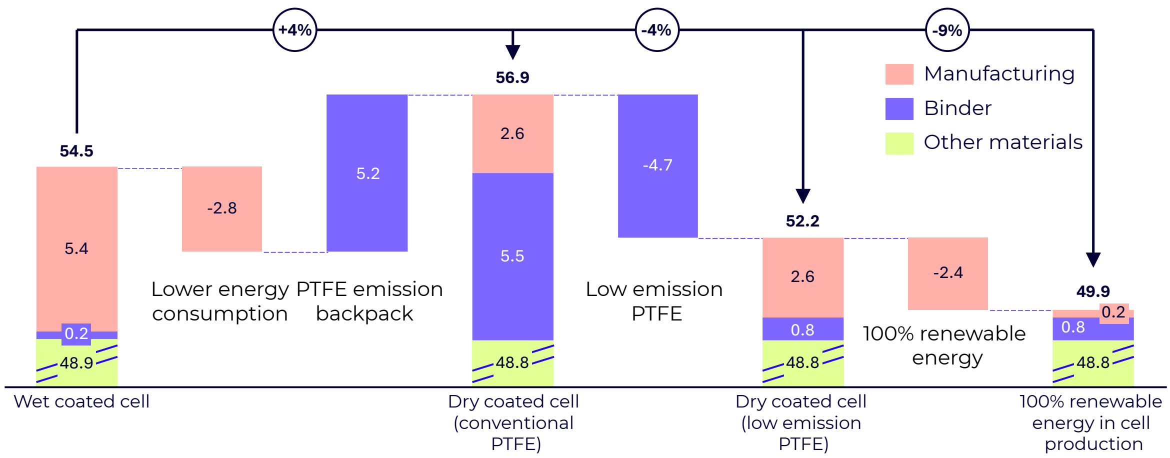

Figure 8: Carbon footprint of a battery cell produced by traditional wet coating vs. dry coating (in kgCO2e/kWh)[8]

Paving the way to zero emission battery production

Battery cell production is a critical stage in the battery value chain, and optimizing energy usage is key to reducing its carbon footprint. Economies of scale, process innovations like dry coating, and the integration of renewable energy sources offer substantial potential for emission reductions. However, challenges remain, particularly regarding the high carbon footprint of materials like PTFE used in dry coating. **Ultimately, a holistic approach that includes both process improvements**

[6] Decarbonization along the battery value chain also needs to consider availability of green electricity in remote locations such as mines and refineries.
[7] Calculation for a 4680 cell with NMC811 cathode and ~10% SiOx in graphite anode for a 40 GWh production

and cleaner energy sourcing is necessary to achieve significant reductions in battery cell manufacturing emissions, contributing to the broader goal of decarbonizing the energy sector and reducing the environmental impact of electric vehicles and energy storage systems.

7. Unveiling the hidden impact of equipment manufacturing

Discovering new insights of the CO_2e footprint in battery manufacturing

Currently, no publications detail the carbon footprint data for the production machinery and facilities used in LIB cell manufacturing. However, given the increasing pressure on automakers and suppliers to enhance CO_2e transparency along the value chain and the potential impact of an extended Carbon Border Adjustment Mechanism on production equipment this analysis is timely. Its goal is to determine whether the CO_2e footprint of manufacturing equipment has been underestimated. Therefore, the CO_2e footprint of the electrode coating & drying system is calculated and analyzed in more detail below, as it is one of the largest and most complex machines in the battery cell production process.

CO_2e footprint analysis of an industrial tandem coating machine

- Case Study: An industrial tandem coating machine (50 m/min, 700 mm width) is analyzed over an 8-year service life.
- Approach: Following ISO 14067, the machine's Bill of Materials (BOM) is reviewed to determine the weight and material type of each component (from large items like rollers, slot dies, housings, and servo motors to smaller elements such as sensors and filters). The CO_2e emissions for each component are calculated by multiplying its weight by material-specific emission factors (sourced internally and validated externally).
- System Boundaries: Only the "production" phase (i.e., the material consumption) is considered, while energy for manufacturing, assembly, transport, use, and recycling is excluded. The same method is applied to all machinery in the LIB cell production process to estimate the total equipment footprint for a single production line (2.2 GWh/year).

The coating equipment comprises several units:

- Unwinding/Rewinding: Dominated by rollers, scaffolds, and supplementary components like electric motors, sensors, and control systems.
- Coating Unit: The primary components here are the slot die, counter roll, and an electronic measurement system.
- Liquid Supply System: Mainly consists of pipes, eccentric screw pumps, tanks, agitators, process filters, and various electronic devices (e.g., pressure gauges).
- Drying Zones: Divided into air heating and foil drying sections, with major contributions from the housing, insulation materials, and additional smaller components (viewing windows, safety switches, LED lights, and air nozzles).

A Pareto (80/20) analysis reveals that electronics, the dryer housing, rollers, the frame (including stairs), and blow nozzles have the greatest impact on the CO_2e footprint. **Notably, electronic components, despite data uncertainties, contribute significantly.**

The rollers (often made of aluminum or chrome-coated steel) also have a high footprint compared to the mainly steel frame. Stainless steel and steel dominate the material consumption, with aluminum also being significant. Using primary raw materials, the CO_2e footprint of the coating equipment is approximately 65 t CO_2e. However, by utilizing secondary materials, that are obtained through recycling, the CO_2e footprint can be reduced by at least 30%.

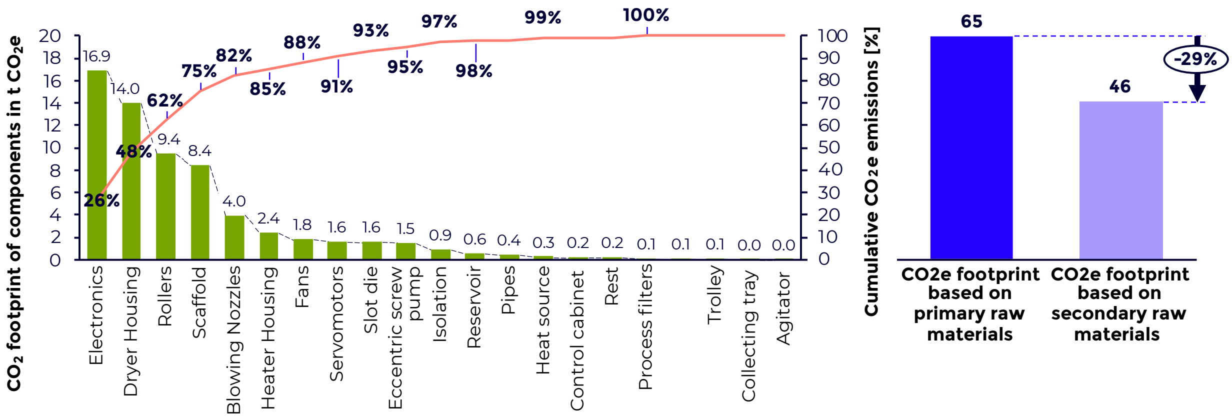

Figure 9: Pareto 80/20 diagram of the CO2e footprint of the various components of the coating machine in t CO2e (left); The CO2e footprint savings by secondary raw materials (right)

Overall, the 2.2 GWh production line totals about 3.7 M t CO_2e, with process steps like notching & stacking/winding (high equipment number), formation (high electronics share), and aging (massive steel use) being the largest contributors.

Advancing CO_2e footprint clarity of battery cell production equipment

In order to assess the impact to a battery cell's footprint, the total CO_2e footprint of the production line (3.7 M t CO_2e) is divided by the 8-year service life and the annual production of the production line (2.2 GWh), which yields a contribution of roughly **0.2 kg CO_2e per kWh for the full production equipment (excl. building). For the PCF of a battery cell, this is relatively minor compared to the CO_2e impact of material use and cell manufacturing**. Therefore, reducing material scrap or using renewable energy along the value chain can have a larger effect.

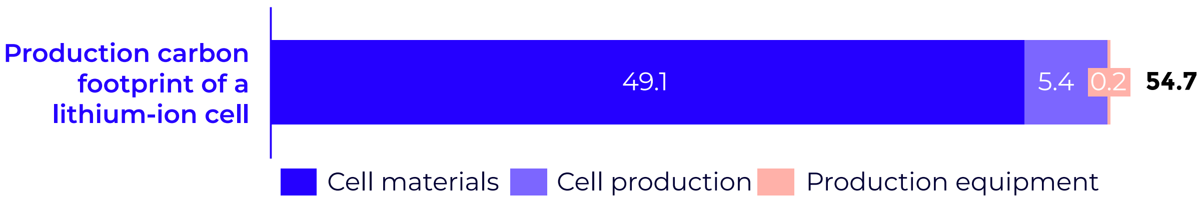

Figure 10: Product carbon footprint of a lithium-ion cell with material, production, and equipment share in kg CO2e per kWh.

For the cell manufacturer's scope 3 emissions and the machine manufacturers, however, the footprint is not negligible. **For example, the CO e footprint for manufacturing the coating machine is comparable to that of manufacturing several mid-range cars**. Scaling up, a cell factory producing 10 GWh/year equates to around 1,000 mid-sized cars, while meeting the 2030 demand of ~5 TWh/year would have a footprint comparable to the production of approximately 550,000 cars—assuming 100% primary raw materials. **With secondary raw materials, a reduction of at least 30% is possible.** Note that the calculation excludes energy for component manufacturing and assembly, packaging, transport, logistics, buildings and land utilization meaning a comprehensive evaluation would yield higher overall emissions.

8. Closing the loop: Advancing battery re-cycling

Battery recycling represents a crucial element in reducing the overall carbon footprint of electric vehicles. **Our analysis demonstrates that the choice of recycling technology significantly impacts both material recovery rates and associated emissions**. As the EV market expands, effective recycling becomes increasingly important for both environmental sustainability and resource security.

Mechanical processing delivers higher recovery rates with lower emissions

Three main approaches dominate today's lithium-ion battery (NMC-based) recycling landscape. Traditional pyrometallurgical processing (smelting) combined with **hydrometallurgical separation shows a relatively high carbon footprint of 12.8 kg CO_2e per kg of recovered material,** with only 25% of overall material recovery. The high emissions stem primarily from direct material burning (40%) and process energy consumption (36%). Modern **mechanical processing with hydrometallurgical separation achieves better results**, with up to 70% of overall material recovery and lower emissions of **3.6 kg CO_2e per kg**. This improved environmental performance comes from eliminating high-temperature smelting, though process energy still accounts for 66% of emissions, with chemical inputs contributing the remaining 34%. **A hybrid approach using pyrolysis represents a middle ground**, recovering 45% of materials while **generating 6.9 kg CO_2e per kg**. This method balances recovery efficiency (eliminating binder and plastic components through pyrolysis) with energy consumption, deriving its emissions from process energy (45%) and controlled thermal decomposition (26%).

exemplary for a module with 80 Ah pouch NMC-811 cells [% mass share]

Material	Mass share	Smelting + Hydromet.	Pyrolysis + Mech. + Hydromet.	Mech. + Hydromet.	
Graphite / Carbon	27%	*Not recovered*	-	+	$
Nickel	17%	--	+	++	$$$
Aluminum	15%	*Not recovered*	o	++	$$
Electrolyte	12%	*Not recovered*			
Copper	6%	--	++	++	$$$
Plastics	4%	*Not recovered*	*Recovered but waste*		
Lithium	2%	*Not recovered*	--	-	$$$$
Cobalt	2%	o	++	++	$$$
Manganese	2%	*Not recovered*	-	+	$

PCF of recycled material compared to raw material from primary source: ***++ significantly lower | + lower | o similar - higher | -- significantly higher***

Figure 11: Comparative analysis of recycling processes, recovered materials with value and associated PCF compared to raw materials from primary source.

Material combustion in high-temperature processes drives carbon footprint

The environmental impact of recycling processes depends primarily on the amount of recovered materials but also the electricity sources, process temperatures, and chemical usage play an important role. Grid electricity composition plays a particularly crucial role in energy-intensive hydrometallurgical processes, while process temperatures significantly affect direct emissions in smelting operations. **Mechanical and hydrometallurgical recycling typically achieves lower carbon footprints than primary production for most materials, particularly for nickel and cobalt.** However, some materials like **lithium carbonate from brine sources still maintain a lower carbon footprint than their recycled counterparts,** highlighting the importance of considering specific material circumstances when evaluating recycling strategies.

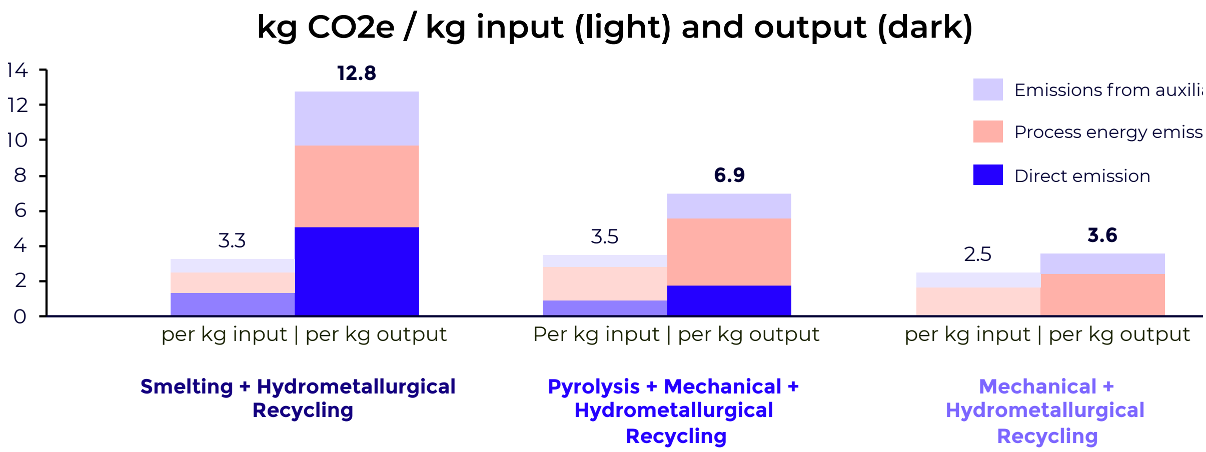

Figure 12: PCF of recycling processes with split of different emission categories and adjustment based on the amount of input or recycled output materials.

Emerging technologies and renewable energy enable circular value chain

Emerging direct recycling technologies promise recovery rates above 90% while potentially reducing energy requirements and chemical usage significantly. These innovative approaches aim to preserve cathode material structure, though they remain in early development stages requiring further technical and commercial validation before commercial implementation. Particullarly, for LFP-based batteries, where conventional hydrometallurgical recycling is challenging from a cost-perspective, novel recycling technologies may be a viable option.

To minimize the carbon footprint of recycling operations, several key strategies have emerged:

- **Transitioning to renewable energy sources** could reduce process emissions by up to 60%
- Implementing **efficient heat recovery systems in hydrometallurgical processes**
- **Scaling operations** to optimize energy efficiency
- **Utilizing "standardized" recycling feedstock** for higher recovery yields

The integration of efficient recycling operations into the broader battery value chain creates significant opportunities for carbon footprint reduction. By providing lower-emission material sources and enabling local supply chains with shorter transportation distances, recycling plays a crucial role in achieving sustainability goals. As the industry matures, the combination of innovative technologies and optimized processes will further reduce environmental impact while securing valuable resources for future battery production.

9. Summary

This whitepaper underscores that EVs, already a strong option for sustainable transport, can become even greener with continuous innovation and a commitment to transparency. To accelerate decarbonization across the battery value chain, stakeholders must:

- **Strengthen supply chain transparency:**

  Full implementation of the Battery Passport allows stakeholders to track and optimize emissions across the entire lifecycle.

- **Adopt renewable energy:**

  Transitioning to renewable energy in upstream materials & battery production and recycling can cut emissions, enabling compliance with stricter regulations.

- **Innovate production methods:**

  Scaling up technologies like dry coating and replacing CO_2e-intensive materials with low-emission alternatives can significantly reduce manufacturing emissions.

- **Invest in sustainable equipment & construction:**

  Designing equipment & buildings with more sustainable materials and optimizing manufacturing processes reduces the embodied emissions of machinery and long-term operational energy consumption.

- **Promote circular economy:**

  Expanding recycling infrastructure, particularly for hydrometallurgical and direct recycling methods, ensures higher recovery rates and lower carbon footprints for materials like lithium and cobalt.

By adopting these strategies, the industry can achieve a fully sustainable battery value chain. Future considerations include assessing the emissions associated with gigafactory construction and evaluating alternative chemistries, such as solid-state and sodium-ion batteries.

List of abbreviations

AAM	Anode active material
BEV	Battery electric vehicle
BOM	Bill Of materials
CAM	Cathode Active Material
CMC	Carboxymethyl cellulose
CO2e	Carbon dioxide equivalent
EV	Electric Vehicle
GHG	Greenhouse Gas
ICE	Internal Combustion Engine Vehicle
LCA	Life Cycle Assessment
LFP	Lithium-Iron-Phosphate
LIB	Lithium-Ion Battery
NMC811	Lithium-Nickel-Manganese-Cobalt-Oxide
pCAM	Precursor
PCF	Product Carbon Footprint
PEF	Product Environmental Footprint
PTFE	Polytetrafluorethylene
PVdF	Polyvinylidene-fluoride
SBR	styrene butadiene rubber
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

Have questions or ideas? Connect with our EV experts!

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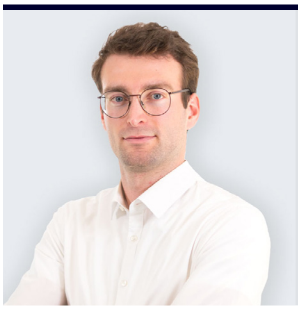

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