VOLKSWAGEN GROUP

Karlsruher Institut für Technologie

Sustainability Assessment of Sodium-Ion Batteries: Benchmarking vs. NMC, LFP, and LMFP across Value Chains

Jonas Sprengelmeyer[a)], Marcel Weil[b),c)], Werner Bauer[d)], Helmut Ehrenberg[d)]

a) Volkswagen AG, Wolfsburg
b) Karlsruhe Institute of Technology (KIT), Institute for Technology Assessment and System Analysis (ITAS), Karlsruhe
c) Helmholtz Institute Ulm for Electrochemical Energy Storage (HIU), Ulm
d) KIT, Institute for Applied Materials (IAM), Eggenstein-Leopoldshafen

1. Motivation and Goal

- The battery cell is a critical component of battery electric vehicles (BEVs), significantly influencing cost, sustainability, performance, and safety.
  Battery cells account for 40-60 % of the total BEV carbon footprint [1].
- Sodium-ion batteries (SIBs) are often highlighted as a more sustainable alternative to lithium-ion batteries (LIBs) [2].
  However, sustainability analysis of SIBs are scarce.
- **Goal of this poster:** Assess the sustainability of SIBs and LIBs across value chains, identify key hotspots, and propose CO_2-reduction strategies to achieve carbon neutrality.

2. Methodology

Life Cycle Assessment (LCA) Framework

Raw Material Extraction and Processing (Global)

Cathode Active Material
- NMF111 ($NaNi_{0.25}Mn_{0.375}Fe_{0.375}O_2$)
- NMF442 ($NaNi_{0.4}Mn_{0.4}Fe_{0.2}O_2$)
- NaPBA ($Na_2Fe[Fe(CN)_6]$)
- NMC811 ($LiNi_{0.83}Mn_{0.1}Co_{0.07}O_2$)
- LFP ($LiFePO_4$)
- LMFP ($LiMn_{0.6}Fe_{0.4}PO_4$)

Anode Active Material
- Hard carbon (petroleum coke based)
- Natural graphite (NG)
- Artifical graphite (AG)

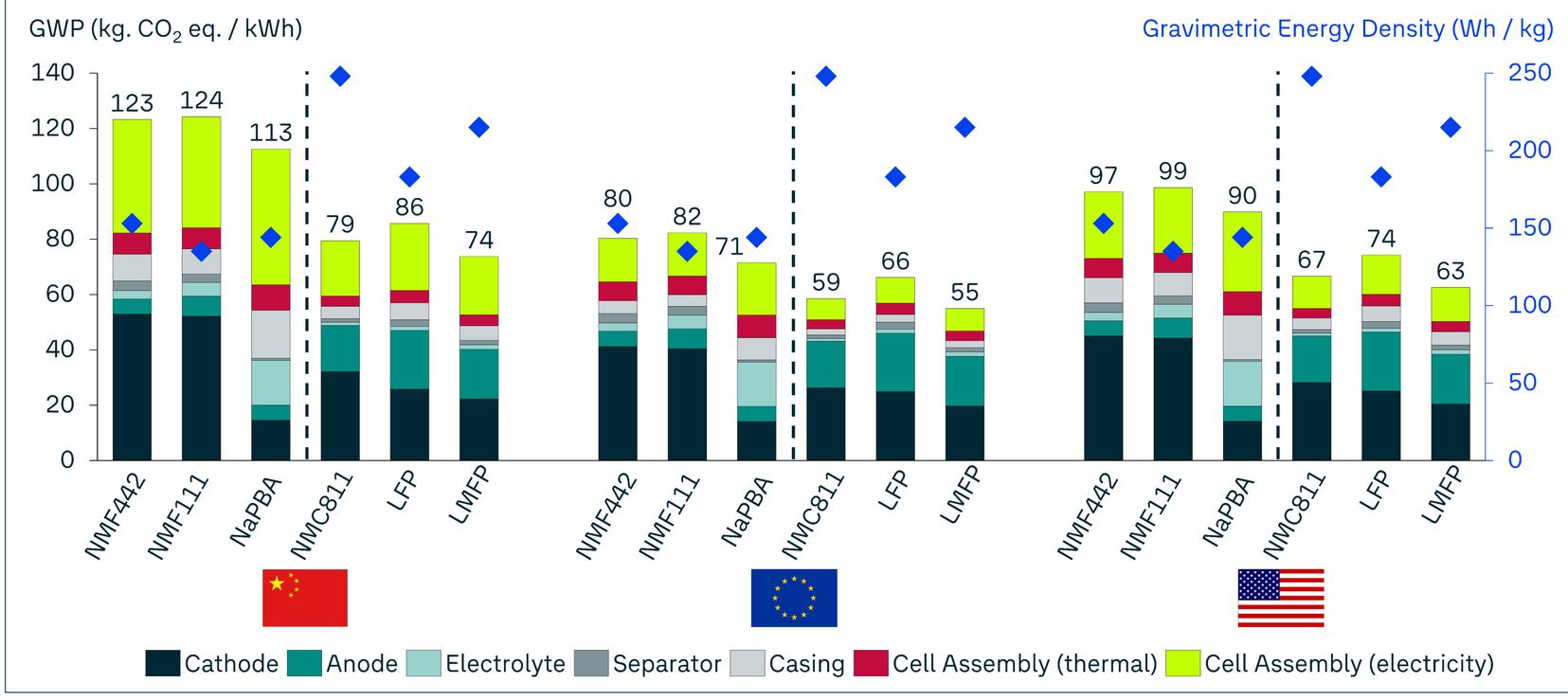
Other Cell Components

Cell Assembly

Global Warming Potential (GWP) in kg CO_2 eq. / kWh

3. Results

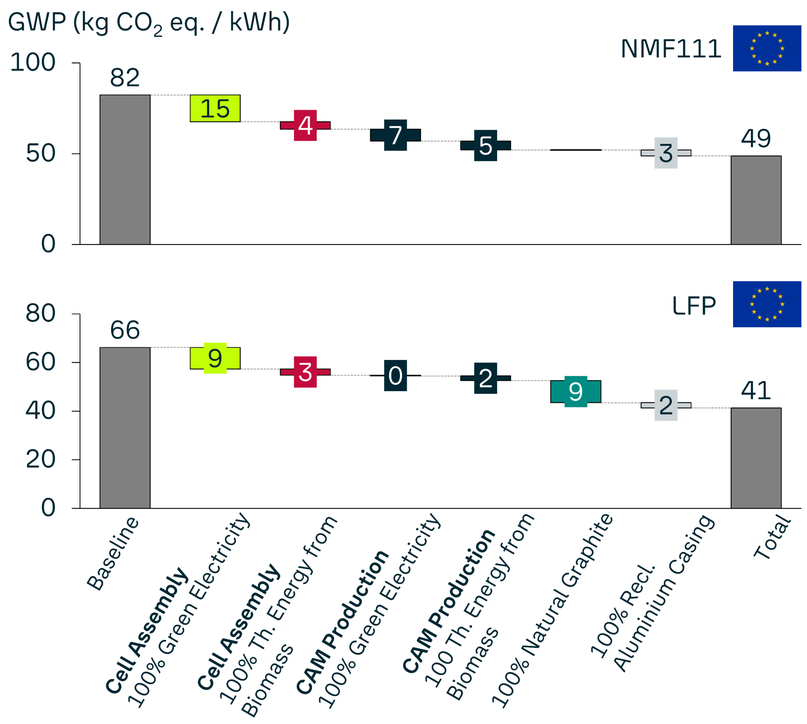
Comparison of the GWP of various Battery Cells across Value Chains (Baseline Scenario*)



- SIBs consistently have 7–40 % higher GWP values than LIBs when produced at industrial scale in the same location.
- NaPBA has the lowest GWP among SIBs, while LMFP ranks lowest across all batteries and value chains.
- Battery cell production in China has the highest GWP, while production in the EU or US lowers it by 14–37 %.

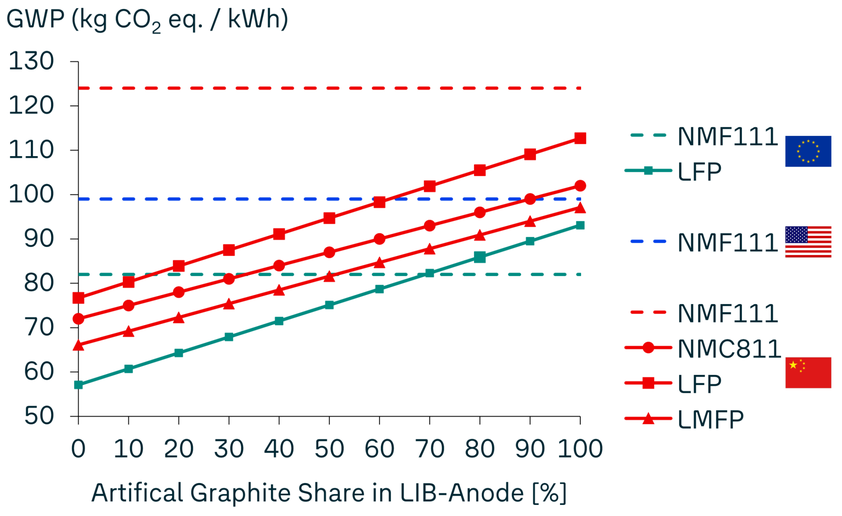
* Baseline scenario assumes LIBs using 25% AG in the anode. Electricity grid mixes for China, the EU, and the US, as well as thermal energy from natural gas, are based on Sphera (GaBi) datasets for the reference year 2020.

CO_2-Reduction Potentials for NMF111 & LFP



- GWP of NMF111 can be reduced by 40 % and LFP by 38 %.
- Largest levers: Green electricity and, for LFP, use of natural graphite.

Sensitivity Analysis of GWP for LIBs with varying Shares of AG in the Anode



- Recent research [3] indicates that the GWP of AG production is 2.3 times higher than previously assumed [4] and about 4 times higher than that of NG [5].
- Consequently, the choice between AG and NG has a substantial impact on the GWP of LIBs.
- SIB NMF111 is more sustainable than LFP when both are produced in the EU and LFP contains over 70 % AG in the anode.

4. Key Messages

- The GWP of battery cell production is a key criterion for site selection. Moving the battery value chain from China to the EU or US could cut CO_2-emissions today by up to 37 %. However, China's lead in renewable energy installations [6] may shift this balance, urging the EU and US to expand renewables to avoid future disadvantages.
- Nickel-based SIBs such as NMF111 can have a lower GWP than state-of-the-art LIBs, even when produced in the same location, challenging previous findings.
- CO_2-reduction strategies for SIBs should prioritize using green electricity in cell assembly. For LFP, the focus should be on green electricity in cell assembly and replacing AG with NG. In the long-term, given NG's limited availability, suppliers should be encouraged to use green energy in AG production or investigate graphite recycling.

References

[1] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[2] K. M. Abraham, "How Comparable Are Sodium-Ion Batteries to Lithium-Ion Counterparts?," ACS Energy Letters, vol. 5, no. 11, 2020
[3] Carrere et al., "Carbon footprint assessment of manufacturing of synthetic graphite battery anode material for electric mobility applications", J. Energy Storage, vol. 94, no. 112356, 2024
[4] Jäger et al., "Carbon, 4. Industrial Carbons. In Ullmann's Encyclopedia of Industrial Chemistry", John Wiley & Sons, Ltd., 2010. DOI: 10.1002/14356007.n05_n03.
[5] Engels et al., "Life cycle assessment of natural graphite production for lithium-ion battery anodes based on industrial primary data", J. Cleaner Production, vol. 336, no. 139474, 2022
[6] https://www.iea.org/reports/renewables-2024/executive-summary