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Circular

Using LCA in technology development – the case of structural battery cell technology

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Agenda

- Introduction
- Research goal
- Methodology
- Results
- Conclusion

Session 2.23: Filling the Gaps in Life Cycle Assessments of Upstream Materials for the Sustainable Deployment of Battery Ecosystems (#252)

Introducing the SBC

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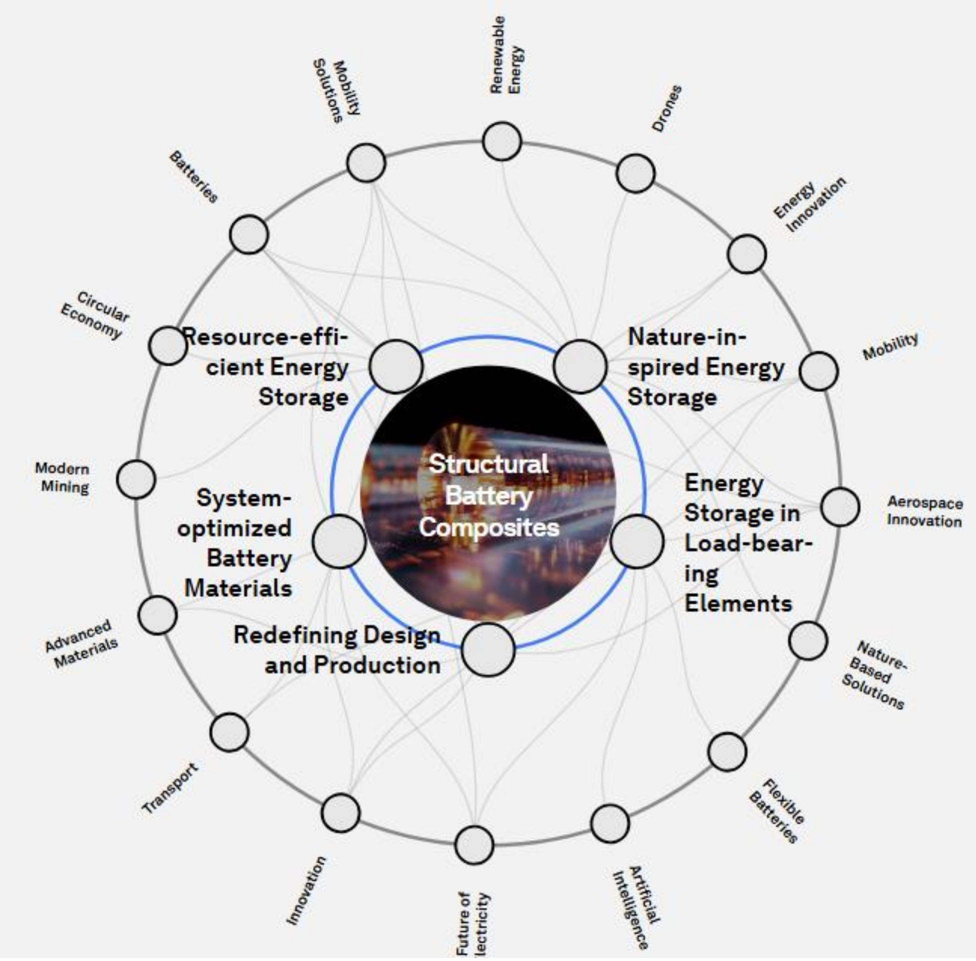
Structural Batteries from Chalmers one of the world's most promising future technologies presented by the World Economic Forum (WEF) Top 10 Emerging Technologies report series of 2025 .

https://intelligence.weforum.org/topics/a1GTG000001IHHx2AO



Introducing the SBC continued

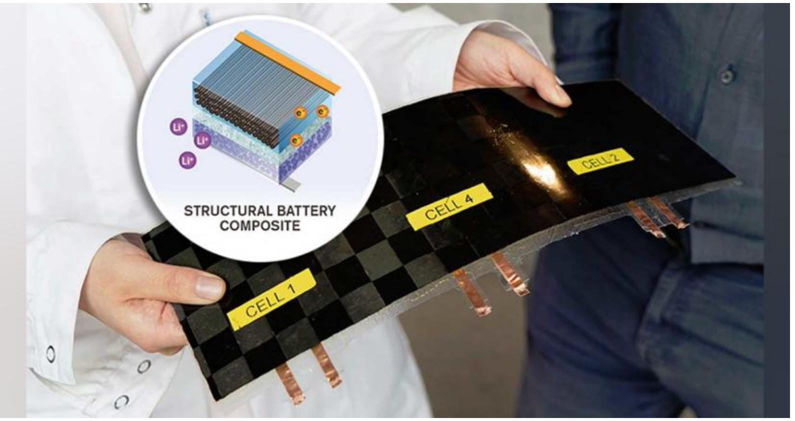
Structural battery composites integrate energy storage into a product's load-bearing materials, enabling lighter, more efficient designs for transportation, aerospace and consumer electronics. By eliminating bulky battery packs and reducing cabling, these composites improve efficiency

Read more

RESEARCH

A structural battery for 'massless' energy storage

Researchers from Chalmers University of Technology in Gothenburg, Sweden, have produced a structural battery that performs ten times better than all previous versions



Research goals

1. Assess potential environmental impacts in early and later stage of development.
2. Support decision making in technology development and production.
3. Evaluate stakeholder participation and the use of scenarios in providing input for technology analyses and planning.

Data collected

- Challenges in the application of prospective LCA have been previously discussed by Thonemann et al., 2020 including challenges in data gaps at early stages.
- In the LCI creation the pedigree matrix and quality of data was used, with insight generated into the production process and the bill of materials (BoM) from the on-site visit.
- Despite limited experimental proof of SBC production achieved when this study was made, the generated LCI facilitated the LCA on assessing conventional non-prospective data with scenarios.
- Potential improvements of higher TRL, MRL considered as scenarios in technology development for 2- 5 years informed by guidance from general rules and regulations e.g.:
  - ✓ on performance criteria of electric vehicle batteries proposal ecodesign regulation;
  - ✓ the battery regulation on batteries and waste batteries (EU 2023/1542);
  - ✓ on carbon footprint rules for electric vehicle batteries (CFB-EV);
  - ✓ Swedish Energy Agency scenarios for electrification;
  - ✓ the EU waste management hierarchy.

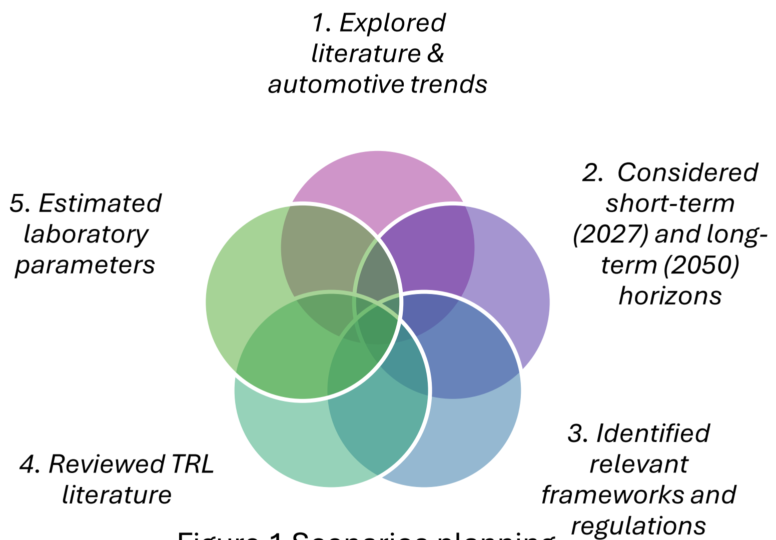


Figure 1 Scenarios planning

Methodology

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Case study developed at TRL3 for benchmarking the SBC technology with prospective LCA of higher Technology Readiness Level (TRL).

- LCA (following ISO 14040/44).
- Primarily collected experimental data, with stakeholder participation using laboratory measurements and observations from visit to the laboratory at Chalmers University of Technology in Sweden.
- Results from ‘cradle to gate’, with EoL.
- Unit of analysis: one (1) SBC unit ≈ the reference flow

Review of literature, technical data, general rules and regulations used in stakeholder engagement, the development of questionnaires, and scenarios.

- TRL review (modified into questionnaire Q1)
- Literature review (key words: co-learning, participatory design, upscaling)
- Scenario planning & scenario analysis
- Developed two questionnaires with TRL discussion points (Q1) and upscaling questions to stakeholders (Q2) used in 2024 participatory workshops.
- Preliminary presentation of the SBC profiles and the characterisation of the SBC designs.

Assess potential environmental impacts in later stage of development.

- Prospective LCA results, also targeted at laboratory environment.
- New LCI data collected via questionnaire (Q3) for future-oriented LCA.

LCA results of lab-scale SBC unit

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Potential impacts	Unit	Reference SBC model	Scenario A: Waste improvements	Scenario B: Scenarios A & CF mix	Scenario C: Scenario B & Dry Room	Scenario B & Additive Manufacturing	Scenario C & Glass fiber- encapsulated (polyester resin)	Scenario A & Energy mix ST (2027)	Scenario A & Energy mix LT (2050)
Climate change	kg CO2-Eq	2.05035	-40%	-0.12%	6.45%	-23.69%	51.77%	59.34%	72.00%
Energy resources: non-renewable, fossil	kg oil-Eq	0.52687	-40%	-0.14%	6.95%	-31.17%	64.29%	72.89%	74.33%
Human toxicity: carcinogenic	kg 1,4-DCB-Eq	0.33198	-6%	0.01%	-3.74%	58.26%	15.51%	50.77%	1.87%
Human toxicity: non-carcinogenic	kg 1,4-DCB-Eq	3.21140	-11%	-0.03%	2.14%	0.29%	16.50%	30.49%	14.02%
Material resources: metals/minerals	kg Cu-Eq	0.03774	-4%	0.00%	-5.71%	46.64%	10.47%	32.92%	-2.25%
Ecotoxicity: freshwater	kg 1,4-DCB-Eq	0.13218	-12%	-0.01%	-3.80%	15.59%	35.28%	67.17%	10.28%
Ecotoxicity: marine	kg 1,4-DCB-Eq	0.17525	-13%	-0.01%	-3.18%	13.42%	34.61%	65.11%	11.43%
Eutrophication: freshwater	kg P-Eq	0.00055	-2%	-0.13%	21.24%	-3.15%	-1.31%	6.92%	23.23%
Water use	m3	0.07919	-8%	-0.03%	3.05%	79.53%	-45.78%	-46.45%	11.04%
Ionising radiation	kBq Co-60-Eq	2.75509	0%	-0.02%	1.76%	95.71%	-12.74%	-36.25%	1.39%
Land use	m2*a crop-Eq	0.13870	-1%	-0.03%	2.02%	100.30%	8.74%	29.40%	2.80%
Acidification: terrestrial	kg SO2-Eq	0.00520	-27%	-0.18%	11.57%	-2.03%	38.62%	50.35%	48.78%
Ecotoxicity: terrestrial	kg 1,4-DCB-Eq	5.51189	-9%	-0.07%	4.31%	28.19%	28.19%	53.07%	13.68%
Eutrophication: marine	kg N-Eq	0.00012	-4%	-0.72%	5.98%	29.42%	-0.48%	-4.61%	10.21%
Ozone depletion	kg CFC-11-Eq	1.97E-06	-2%	-0.03%	2.68%	-34.66%	-31.06%	-27.53%	4.77%
Particulate matter formation	kg PM2.5-Eq	0.00206	-22%	-0.09%	10.58%	0.19%	30.70%	42.10%	39.13%
Photochemical oxidant formation: human health	kg NOx-Eq	0.00363	-27%	-0.07%	7.05%	9.91%	36.27%	47.88%	43.28%
Photochemical oxidant formation: terrestrial ecosystems	kg NOx-Eq	0.00381	-27%	-0.07%	6.40%	7.96%	36.29%	47.81%	42.52%

Discussion

- LCA of SBC emerging technology at early stage of development done at the laboratory scale (TRL 3), where future elements of scaling in prospective LCA are also targeted (laboratory environment).
- Preliminary LCA results identified the battery cell technology as a hotspot, however excluding auxiliaries during production.
- *Assessment* based on a single unit of SBC for $LiFePO_4$ (LFP) battery application: Electricity demand quantified in the SBC production, included testing and conditioning. Auxiliary materials demand measured, and waste management estimated.
- *Results* showed a clear benefit from the avoidance of auxiliaries/ waste reduction and a *tradeoff* amongst foreground system, in the dry room and AM scenarios and background (electricity mix) scenarios.
  - ➢ Potential **reduction in emissions up to 40%** (Climate change) with avoiding auxiliaries and zero waste generated during production.
  - ➢ When dry room scenarios was considered, there was a small decrease or increase in most impacts, due little contribution of electricity demand but argon, and most significance showed in the **material hotspots by electrodes** (CFs and Aluminum foil single side-coated by $LiFePO_4$).
  - ➢ Similarly, in the additive manufacturing (AM) scenario both the battery cell and the structural battery electrolyte were important contributors. However, due to the **significant electricity demand in AM** being higher a significant increase of 50% shown in material resources -100% land use impacts but due to the electricity mix a reduction in Climate Change and Energy resources (20-30%).
  - ➢ The **importance of electricity mix** was also found in the electricity production forecast scenarios where a difference amongst Short-term and Long-term impacts is shown.

Participatory approach with LCA

- To start with, a TRL review of literature was performed as was found is important to guide TRL decisions on a model.
- Hence the prospective analysis of factors is important (A. L. Olechowski et al., 2020; Halicka et al., 2015).
- Two questionnaires were developed for the participatory workshops (Q1: TRL discussion points, Q2: upscaling 19 questions with 4 objectives to aid decision-making in research and development routes.
  - Objective 1: Technology assessment;
  - Objective 2: Environmental assessment;
  - Objective 3: Current situation;
  - Objective 4: Upscaling.

- The TRL analysis of the SBC was discussed in a participatory workshop.
  - In assessing the current situation, respondents agreed TRL3 achieved.
  - Important environmental impacts also identified: Climate change and resource scarcity highlighted and impacts deriving from chemicals used in the structural battery electrolyte, also toxicity.

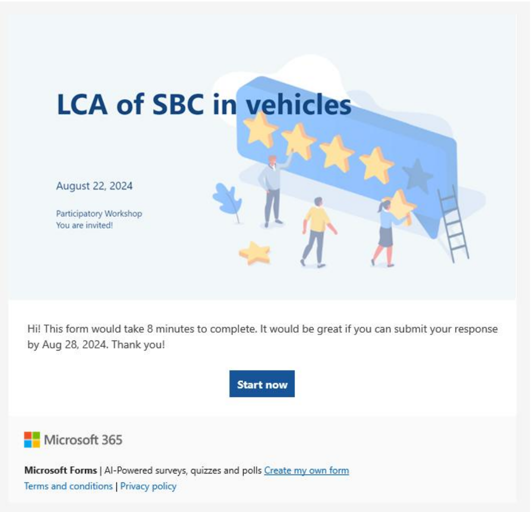
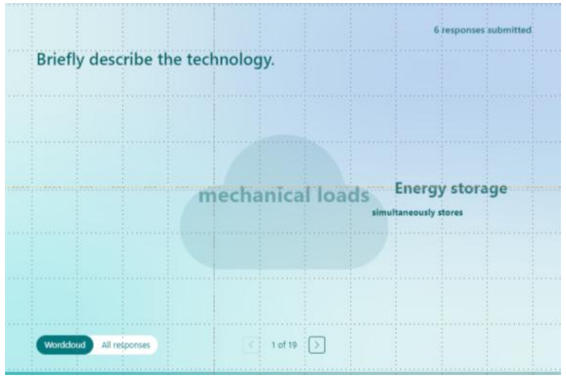
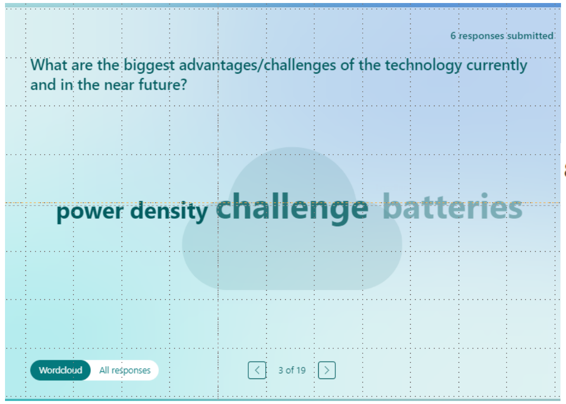


Figure 1 The survey email invite

Participatory workshop responses, extract

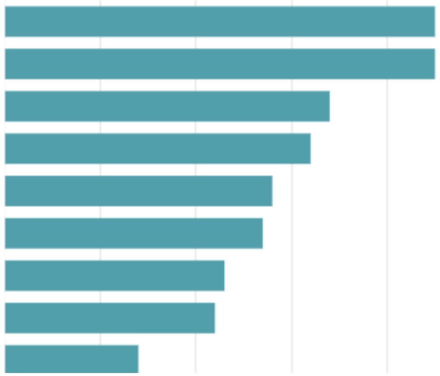




7. Rank the below components from most to least important, for the greatest savings potential considering the main production principes for the lithium-ion structural battery specific design. You can see the average contribution across selected impacts in brackets.

More Details

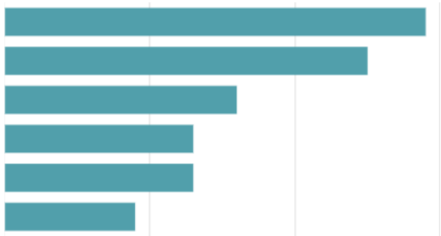
1 Negative electrode (15%) incl. C...
2 Positive electrode (ca. 1%) incl. ...
3 Liquid electrolyte (2%) incl. Lithi...
4 Glass fibre separator (4%)
5 Argon filled-glove box (10%)
6 Electricity mainly for drying, curi...
7 Solid bottom plate (4%)
8 Multilayered pouch (1%)
9 Felt (9%)



14. Rank the below activities based on the main production principles identified for the specific lithium-ion structural battery cell (most to least important).

More Details

1 Materials (e.g. carbon fibre posit...
2 Multifunctional performance (e....
3 Formation and testing procedur...
4 Laboratory procedure (e.g. SBE i...
5 Design fulfills application (e.g. in...
6 Working unit in the laboratory (...



8. Choose the application you have identified as the most relevant for this type of lithium-ion structural battery cell

More Details

Battery Electric Vehicles	2
Hybrid Electric Vehicles	1
Light means of transport	1
Auxiliary or backup purposes st...	2
Other	0

19. In which product characteristics do improvements/disadvantages occur today or can be expected in the future? (multiple answers-max 2)

More Details

Specific energy [Wh/kg]	2
Specific power [W/kg]	3
Elastic Modulus [GPa]	1
Tensile strength [MPa]	0
Other	1

Conclusions

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Overview of challenges
• Difficulties about multifunctionality in comparison to technology alternatives (e.g. commercial LIB batteries, supercapacitors). • Limited stakeholder participation for collecting life cycle perspectives in the sample of technological researchers, technology developers and LCA specialist. • Practically challenging to verify data and quality of available data. • Lack of clarity regarding the influence of the active materials (BoM) and cell design, at the electricity demand from SBC production, including the SBC performance. • Disparities between non-prospective LCI data and on-going technology development to later (temporal) stage, with modifications of the data in constructed preliminary route of development.

Recommendations

Overview of opportunities
• Multifunctionality assessed in prospective LCA at the module-level (SBC) instead of the structural battery cell-level. • The participatory approach enabled a better understanding of the technology assessed in LCA. • LCA usefulness in decision-making support within technology development and production, despite limited prototype tested in the laboratory environment (TRL 3–4) or prototypes demonstrated under relevant environment (TRL 6) previously deemed important (Santos et al., 2023; Halicka et al., 2015). • Results from the participatory workshop emphasized cell improvements expected in technology development the near future. • Therefore, while discussed with the technology experts in the participatory approach, new LCI data collected via questionnaire for the next generation SBC technology (adapted BoM and electrophoretic deposition - EPD Bath technique). • A wider participatory approach across life cycle stages, would enable a better overview in future SBC technology development and future sustainability discussions.

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