Structural batteries in electric road vehicles -When is it a good idea?

Frida Hermansson[1], Fredrik Edgren[2], Johanna Xu[3], Leif E. Asp[3], Matty Janssen[1], Magdalena Svanström[1]*

[1]Environmental Systems Analysis, Chalmers University of Technology, 412 96 Gothenburg, Sweden

[2]Body Technology, Volvo Cars, 405 31 Gothenburg, Sweden

[3]Material and Computational Mechanics, Chalmers University of Technology, 412 96 Gothenburg, Sweden

**Corresponding author. Email: frida.hermansson@chalmers.se*

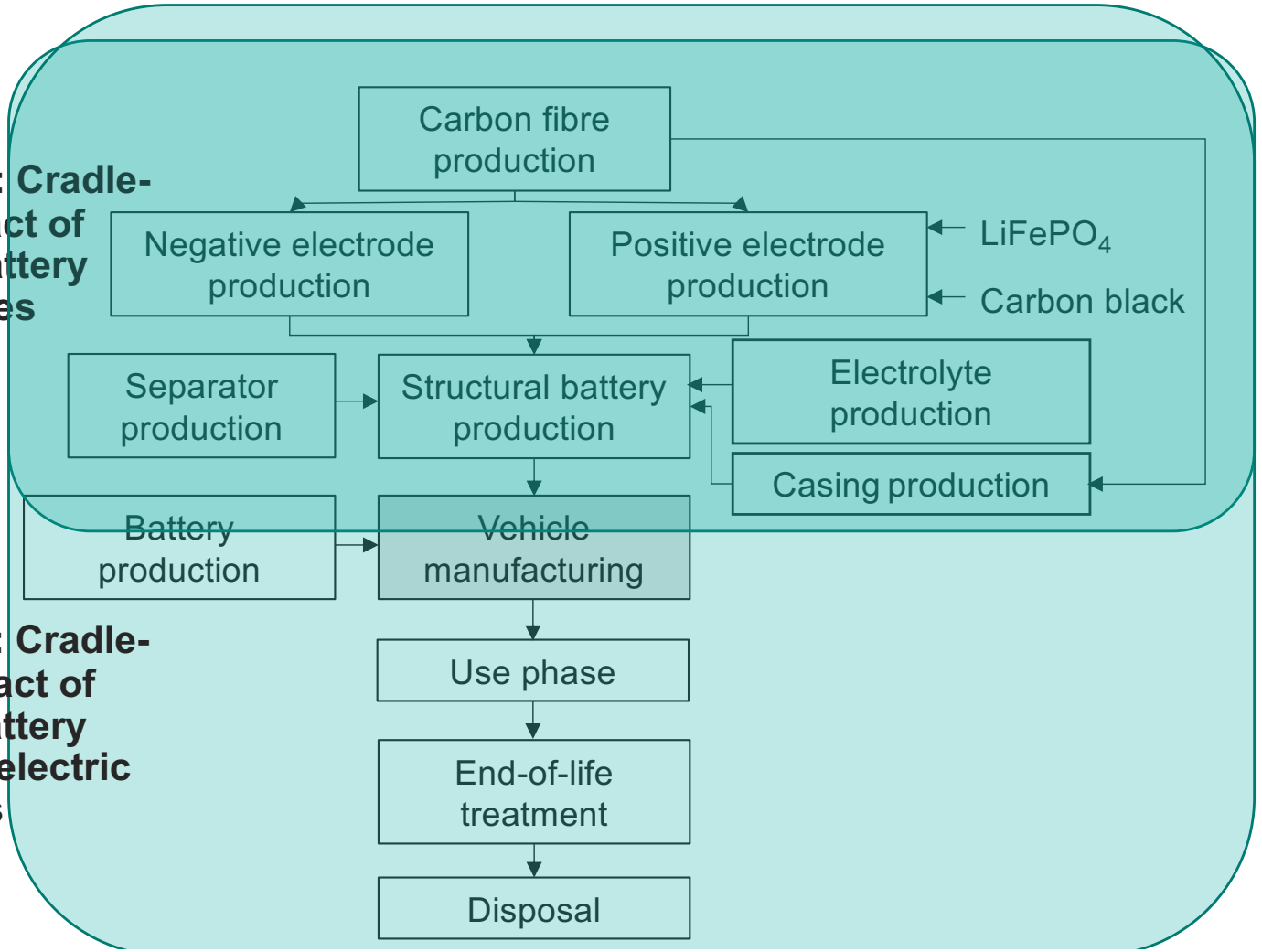
Structural battery composites basics

- A multifunctional material - Composites that also store energy
  - Carbon fibres carry the mechanical load **and** act as battery electrode
  - Polymer matrix transfers load **and** acts as electrolyte
- The use of structural battery composites (SBCs) can enable extended range of an electric vehicle through reduced weight or by allowing a larger battery
  - We focus on the lightweighting in electric road vehicles
- Some challenges compared to conventional carbon fibre composites
  - Carbon fibres need to be lithiated which affects their mechanical strength
  - Need for a polymer matrix that allows for lithium ion conduction as well as mechanical load transfer between the fibres.

Aim of study

- In this study, we use life cycle assessment (LCA) to assess:
  1. The cradle-to-gate environmental impact of structural battery composites
  2. The cradle-to-grave environmental impact of structural battery composites used in electric road vehicles following different technology development routes
- We want to answer the question: When is the use of structural battery composites in road vehicles a good idea (from an environmental point-of-view)?

Focus for aim 1: Cradle-to-gate impact of structural battery composites



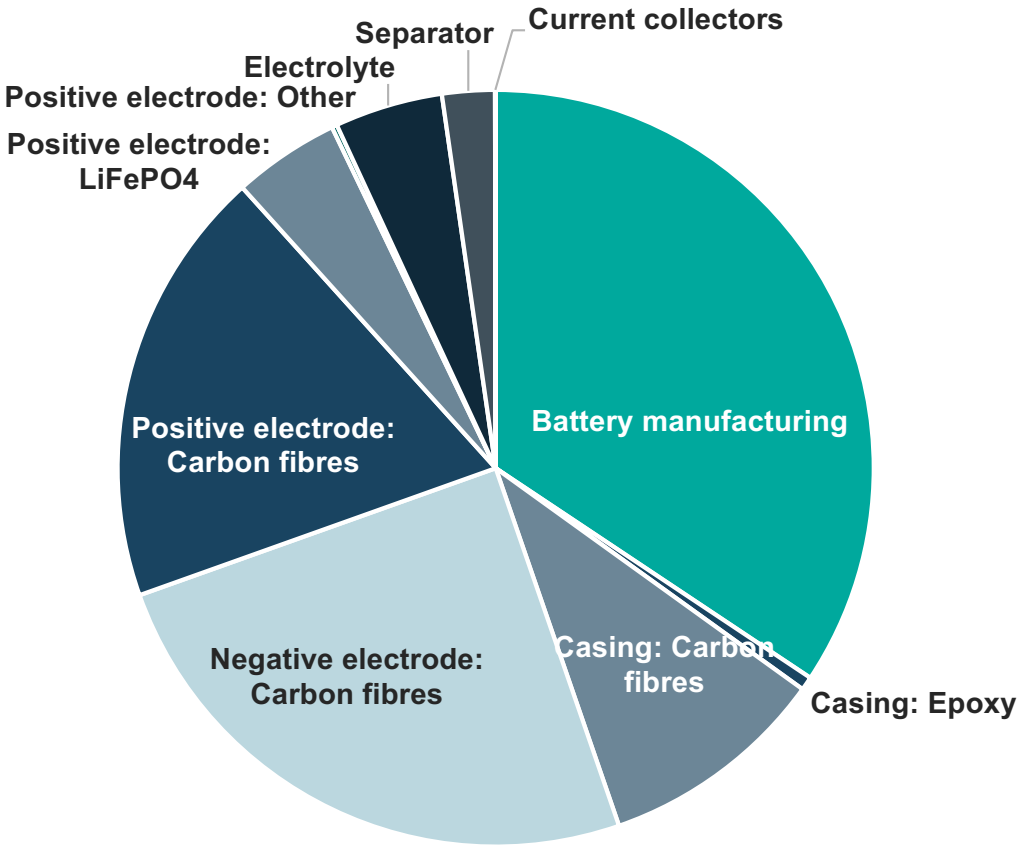
Focus for aim 2: Cradle-to-grave impact of structural battery composites in electric vehicles

LCA goal and scope: Cradle-to-gate

- Functional unit: The cradle-to-gate production of 1 kg of a structural battery composite
- Produced in Europe
- Produced from carbon fibres and electrolyte
  - Positive electrode fibres are lithiated using $LiFePO_4$
  - Electrolyte mainly consists of Bisphenol A dimethacrylate, ethylene carbonate, and propylene carbonate
  - Separator is made from cellulose
  - Battery cell is put in a carbon fibre composite casing
    - 65 vol% carbon fibres and 35 vol% epoxy
- Impact categories: Climate impact

Climate impact of 1 kg of SBC

More than half of the climate impact of the structural battery composite is related to the carbon fibres



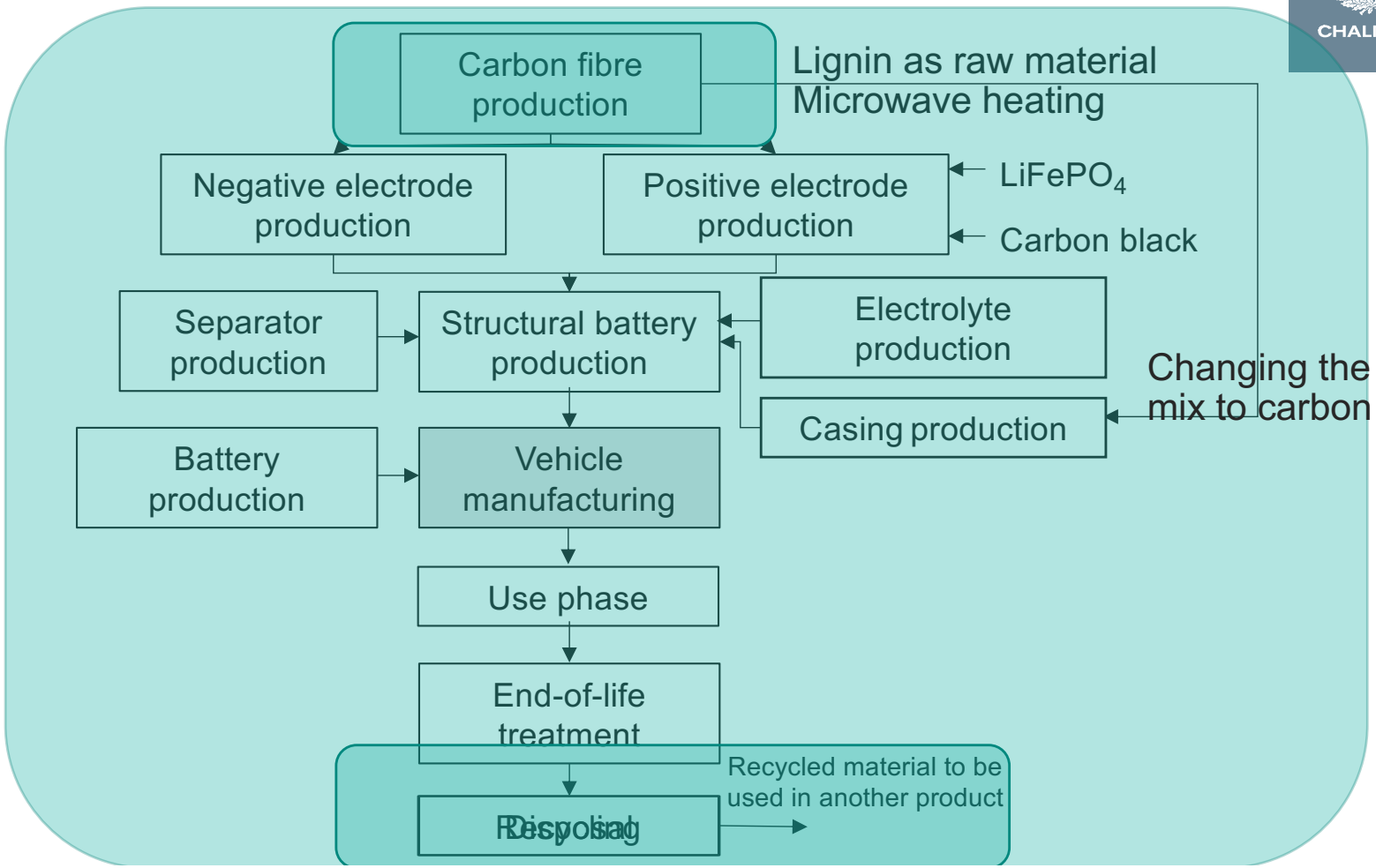
LCA goal and scope: Cradle-to-grave

- Functional unit: The roof, doors, hood, and the Li-ion battery for 200 000 km
- We design the car parts to maintain their flexural stiffness
- Car parts are assumed to be sent to landfill in base case
- Waste treatment of Li-ion battery is excluded
- Impact categories: Climate impact

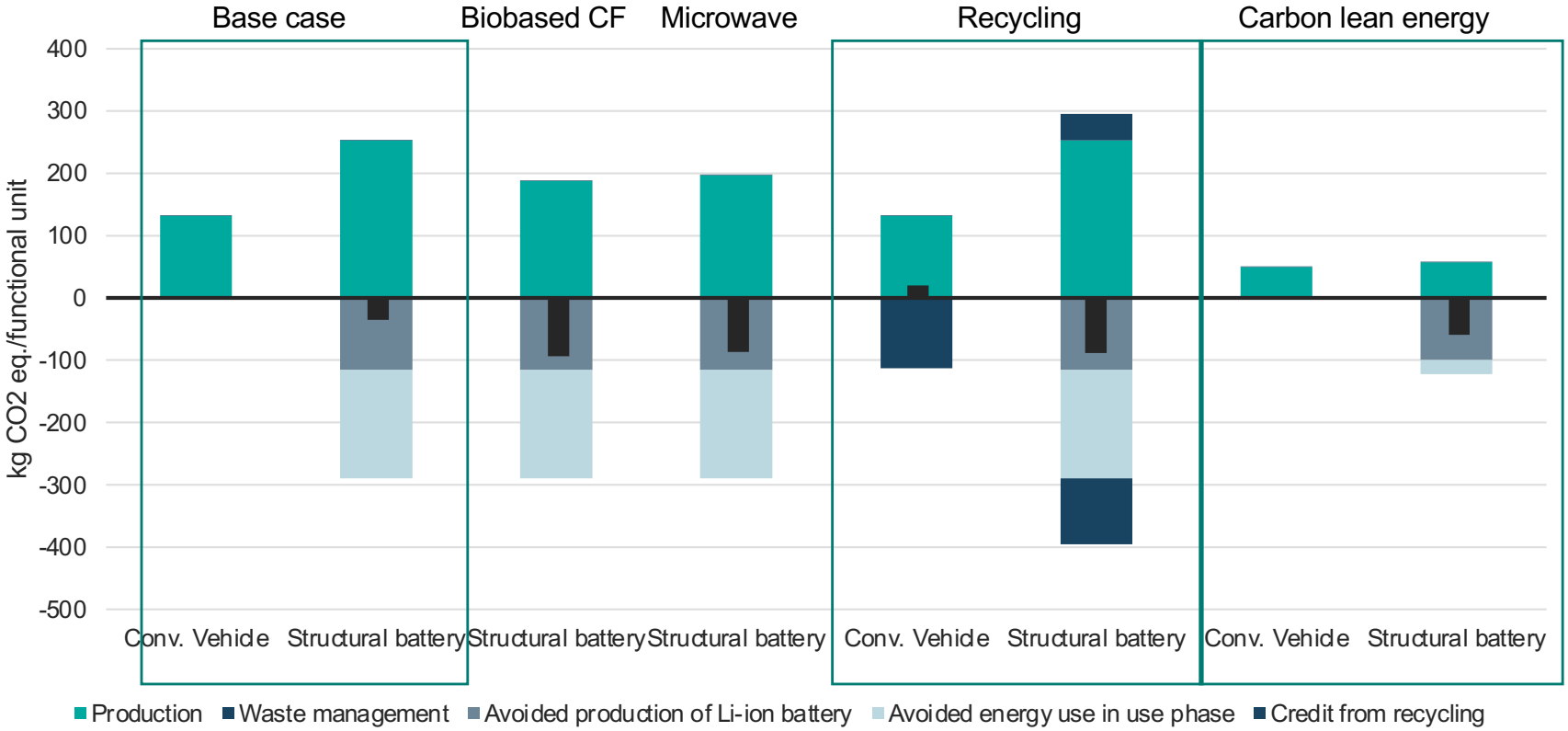
	Conventional vehicle	Structural battery composite vehicle
Materials considered	Aluminium and steel	Structural battery composites
Effective modulus (GPa)	210 (steel) 78.25 (aluminium)	70
Total mass of car parts (kg)	40	14
Energy density (Wh/kg)	0	70
Avoided battery (kg)	0	7
Avoided fuel use (kWh)	0	447

Technology development routes

- Carbon fibres are responsible for more than 50% of SBC's cradle-to-gate climate impact
  - Hermansson et al (2022) assessed different routes for decreasing the environmental impacts of carbon fibre reinforced polymers (CFRPs):
    - Using lignin as a raw material for carbon fibres
    - Using microwave heating for carbon fibre production
    - Recycling composites and recovering fibres
      - Recovery of oil-like substance and carbon fibres with tensile strength reduction
  - We also assess the influence of changes made to the background energy system
    - Switching to a carbon lean energy system
      - From European average to Swedish as far as possible


Carbon fibre production
Lignin as raw material
Microwave heating
Negative electrode production
Positive electrode production
$LiFePO_4$
Carbon black
Separator production
Structural battery production
Electrolyte production
Casing production
Changing the energy mix to carbon lean
Battery production
Vehicle manufacturing
Use phase
End-of-life treatment
Recycled material to be used in another product
Recycling
Disposal

Climate impact from using SBCs in the car



What if we change the properties of the material?

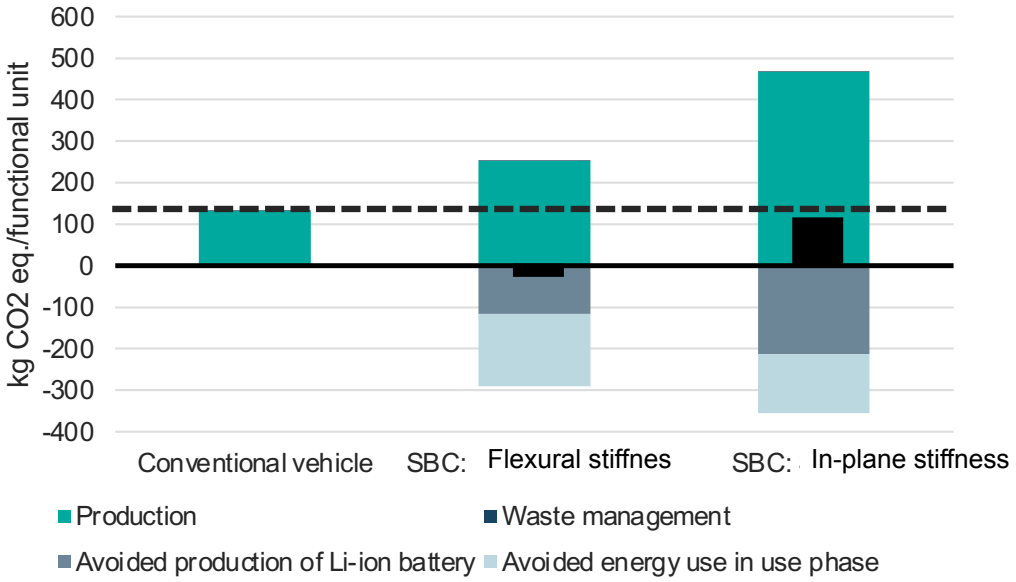
- We varied the effective modulus and the energy density of the structural battery composite with +/- 10%

	Base case	10% increase in effective modulus	10% decrease in effective modulus	10 % increase in energy density	10% decrease in energy density
Effective modulus (Gpa)	70	77	63	70	70
Energy density (Wh/kg)	70	70	70	77	63
Mass of SBC needed (kg)	14.0	13.5	14.5	14.0	14.0
Mass of avoided battery (kg)	6.8	6.6	7.1	7.5	6.2
Avoided fuel consumption (kWh)	447	450	443	456	437
Relative change compared to base case		-15%	17%	**-41%**	**41%**

What if we change the requirements for the car parts?

We replaced the metal car parts with an SBC that maintains the same in-plane stiffness

	SBC vehicle Same flexural stiffness	SBC vehicle Same in-plane stiffness
Effective modulus (GPa)	70	70
Total mass of car parts (kg)	14	26
Energy density (Wh/kg)	70	70
Avoided battery (kg)	7	13
Avoided fuel use (kWh)	447	363



Conclusions: When is the use of structural batteries a good idea?

- The use of structural battery composites decrease the environmental impact of electrical vehicles compared to steel and aluminium
  - Depends on the mechanical function by the car parts; in-plane stiffness or flexural stiffness?
    - We want to use SBCs in parts where there is less need for stiffness
- Efforts should be put into decreasing the environmental impact of the carbon fibres
  - All assessed routes proved fruitful for this!
- If there is a trade-off between increased energy density and increased effective modulus in further material development, the energy density of the material should be prioritized

Future work

- More carefully assess the manufacturing phase of the structural battery composites
  - Done in dry and clean rooms which is very energy intensive
  - We used literature data from Zackrisson et al. (2019) which is based on data for Li-ion manufacturing
- Assess the possibilities of combining SBCs with other materials in the vehicle
- Assess more applications than road vehicles
  - For example: Ferries and airplanes

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