Lessons learned when assessing emerging composite materials using life cycle assessment

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1. Introduction

The modern era of carbon fibres and carbon fibre reinforced polymers (CFRPs) started in the mid 1950s as the U.S. air force Materials Laboratory started producing carbon fibres to develop high strength composites. However, the historically high cost of carbon fibres has until recently kept the use to a small range of applications [1]. It is not until recently that the use of CFRP has become widespread, consequently, CFRP should be considered an emerging material [2]. This makes the environmental assessment difficult as there is a lack of available production data. On the other hand, the emerging nature still makes technology changes possible. This mitchmatch between available data for assessment and production improvements is sometimes referred to as the Collingridge Dilemma. Collingridge described a paradox between information and control: impacts are hard to predict when technology is not yet fully developed, while change becomes more difficult when the technology develops [3].

This paper aims to describe a multi-year effort to use life cycle assessment (LCA) for assessing the environmental impacts of emerging composite materials, focused on the specific example of CFRP. We will describe how we started with a meta-analysis to identify hotspots and key aspects for decreasing the environmental impacts of carbon fibres and CFRPs, to more recent efforts looking into possible future multifunctional use of CFRP for both light-weighting and energy storage in electric vehicles. Results focus on key insights and lessons learned in the process of assessing emerging composite materials using LCA as well as recommendations for decreasing the environmental impacts of carbon fibre composites.

2. Assessing the future environmental impacts of composite materials using LCA

To address the Collingridge Dilemma, Hermansson et al. [4] suggest doing a meta-analysis of available LCA studies. The paper suggests screening literature for similar technologies or partial systems with the aim of generating understanding in a field that has not yet, or has only sparsely, been assessed before. This was done by compiling earlier LCA results for CFRP, for lignin production and for CFRP recycling and by cutting out system pieces and redefining the functional unit to a common denominator. The study showed that the use of CFRP instead of conventional materials will not automatically decrease the environmental impacts of the product. It also showed that the carbon fibre production was the main contributor to the cradle-to-gate impacts of CFRP and that possible routes to decreasing the environmental impacts were recycling of the composites with recovery of the fibres or using lignin as a precursor for the carbon fibres. Other key findings include the significance of the choice of allocation method, both between the life cycles in recycling, but also between co-products in the lignin production.

Allocation in recycling and lignin production were addressed in Hermansson et al. [5] and Hermansson et al. [6]. Key findings include a recommendation of modelling the composite materials as separate materials (in the case of CFRP: carbon fibres and polymer matrix), in order to capture changes in quality, trade-offs and the environmental impact of the recycling system and to use both the cut-off and end-of-life recycling approaches in prospective life cycle assessments to illustrate the possible influence of changes in technology development and market saturation. Additionally, recommendations include handling the selection of allocation method for the multifunctional system of lignin production carefully, as the outcome of many allocation methods depend on demand and market saturation, something that is likely to change with time and are hard to foresee.

The findings in Hermansson et al. [4], Hermansson et al. [6], and Hermansson et al. [5] were applied in a case study assessing how different technology development routes, such as: (1) using lignin as a carbon fibre precursor, (2) using microwave heating in carbon fibre production, (3) the recycling of composites and recovery of fibres, and (4) a carbon lean energy system could influence CFRPs' environmental competitiveness to fibreglass when used in a road vehicle. Results showed that the most fruitful route for making CFRP environmentally competitive to fibreglass is the recycling and recovery of fibres. Some technology routes are likely to be implemented simultaneously depending on the focus of future policies. The different technology routes were therefore combined into three likely futures: a bioeconomy (focusing on reducing the use of fossils and emissions), a circular economy (focusing on decreasing waste) and a circular bioeconomy (decreasing the use of fossils, emissions, and waste). Results show that CFRPs have a high likelihood to achieve a lower environmental impact than fibreglass in all futures except for in a bioeconomy, where the high demand for lignin and changes made to the energy background system leads to a higher energy use [7].

A future possible development of CFRPs is as structural battery composites (SBCs), a material that provides mechanical integrity but also has the possibility to store electrical energy [8]. Compared to conventional CFRPs, in SBCs, the carbon fibres also act as a host for the lithium ions and conduct electrons, and the polymer matrix also provides ion conductivity [9]. The multifunctional properties of SBCs provides even more possibilities of lightweighting than conventional CFRPs, as both the size of the Li-ion battery and length of wires can be reduced in the vehicle [8]. Available studies show that the material has the potential to decrease the environmental impact of electrical vehicles, but depends on the mechanical properties required for the replaced car parts [10, 11] .

More research is needed to assess the potential environmental impacts of multifunctional composites. This includes the possible future influence of different technology development routes and addressing specific challenges in assessing an emerging multifunctional material using LCA. Methodologically, this can be about how allocation between several functions provided by a single material should be done. Another area that will have to be addressed is how accidents might influence the multifunctionality of the material, and how this should be incorporated into the LCA. Toxicity aspects related to production, accidents, and waste treatment might also have to be addressed.

3. References

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