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Life cycle assessment of lithium-air battery cells

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ABSTRACT

Lithium-air batteries are investigated for propulsion aggregates in vehicles as they theoretically offer at least 10 times better energy density than the best battery technology (lithium-ion) of today. A possible input to guide development is expected from Life Cycle Assessment (LCA) of the manufacture, use and recycling of the lithium-air battery.

For this purpose, lithium-air cells are analyzed from cradle to grave, i.e., from raw material production, cathode manufacturing, electrolyte preparation, cell assembly, use in a typical vehicle to end-of-life treatment and recycling. The aim of this investigation is highlighting environmental hotspots of lithium-air batteries to facilitate their improvement, in addition to scrutinizing anticipated environmental benefits compared to other battery technologies. Life cycle impacts are quantified in terms of climate impact, abiotic resource depletion and toxicity. Data is partly based on assumptions and estimates guided from similar materials and processes common to lithium-ion technologies. Laboratory scale results for lithium-air systems are considered, which include expectations in their future development for efficiency gains.

At the present level of lithium-air cell performance, production-related impacts dominate all environmental impact categories. However, as the performance of the lithium-air cell develops (and less cells are needed), battery-related losses during operation become the major source of environmental impacts. The battery internal electricity losses become heat that may need considerable amounts of additional energy for its transportation out of the battery.

It is recommended that future battery cell development projects already at the design stage consider suitable methods and processes for efficient and environmentally benign cell-level recycling. LCA could provide additional arguments and a quantitative basis for lithium battery recycling. This emphasizes the need to develop LCA toxicity impact methods in order to properly assess lithium.

1. Introduction

Lithium-air battery cells are currently being investigated for propulsion aggregates in vehicles as they theoretically can provide a 10-fold increase in energy density compared to the best battery technology (lithium-ion) of today (Badwal et al., 2014). The current state of research is however far from large scale implementation, and the technology must overcome many hurdles involving voltage stability, charge over potential, electrolyte stability, and many other physical-chemical factors that should ideally include full cell development that operates in ambient air (Bhatt et al., 2014). The purpose of this work is to highlight environmental hotspots linked with lithium-air batteries in order to guide improvement at full cell level, and to illustrate some potential benefits to the adaption of lithium-air batteries in vehicles.

Electric vehicles are seen as the main answer to the transport sector's problems of climate impact and diminishing oil supplies. Provided that the electricity can be generated from renewable energy sources, considerable reductions of CO_2 emissions from the transport sector are possible (Notter et al., 2010). However,

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List of acronyms and abbreviations

CO_2-eq	Carbon dioxide equivalents
CNT	Carbon Nanotubes
CTU	Comparative Toxic Unit
CVD	Chemical Vapour Deposition
EV	Electric Vehicle
GDL	Gas Diffusion Layer
GLO	Global
ICEV	Internal Combustion Engine Vehicle
LCA	Life Cycle Assessment
LFP	Lithium iron phosphate, $LiFePO_4$, battery
LMO	Lithium manganese oxide, $LiMn_2O_4$, battery
MWCNT	Multi Walled Carbon Nanotubes
NA	Not Applicable
NMC	Lithium nickel Manganese Cobalt oxide battery
NMP	N-Methyl-2-Pyrrolidone
PHEV	Plug-in Hybrid Electric Vehicle
PVDF	Polyvinylidenfluoride
PP	Polypropylene
RER S,U	RER = Region Europe, S = system process, U = unit process
Sb	Antimony
STABLE	STable high-capacity lithium-Air Batteries with Long cycle life for Electric Cars
TEGDME	Tetra Ethylene Glycol Dimethyl Ether
UCTE	Union for the Co-ordination of Transmission of Electricity (association of transmission system operators in continental Europe)

development of battery performance is crucial in the transition from combustion engines to electric motors in automobiles.

The LCA presented here was performed in the context of the European STABLE project aiming at STable high-capacity lithium-Air Batteries with Long cycle life for Electric cars carried out 2012–2015. LCA is generally considered very useful in the product development stage in order to identify environmental hot-spots and aid in directing development efforts in relevant areas (Rebitzer et al., 2004) (Zackrisson, 2009).

This article documents the characteristics and performance of a lithium-air battery cell and conducts an LCA of a working prototype developed in the project, where reversible and efficient cycling was a primary technological goal. The LCA was conducted on several scenarios, including a battery designed to be close to the theoretical maximum energy density of lithium-air technology.

2. Method

Members of the STABLE consortium have delivered detailed data about raw materials, manufacturing, use and recycling related to lithium-air batteries. Material needs were determined based on one of the prototypes achieved in the project, using materials, methods and advancements guided by the current state of the art (Luntz and McCloskey, 2014). Associated resources and emissions were found in existing databases for LCA and represent in general European or global averages. Data have mainly been drawn from the database Ecoinvent 3.1 (Ruiz et al., 2014).

With the aim of influencing the design and development of the lithium-air technology, a screening LCA was carried out early on in the project.

2.1. Functional units

In order to put the battery in the application context of a vehicle (Del Duce et al., 2013), this study presents the results as environmental impact per vehicle kilometre. The vehicle context is realized via assumptions about car weight, electricity consumption and total mileage. Thereby, the results can easily be compared and classified in relation to vehicle emissions targets, e.g. the European passenger car standards of 95 g CO_2-eq/km fleet average to be reached by 2021 by all manufacturers (EC, 2009). The principal functional unit of the study is one vehicle kilometre and the corresponding reference flow is battery capacity and battery power losses for one vehicle kilometre. LCA-databases typically contain vehicle emissions data per person kilometre, which can be converted to vehicle kilometre. The LCA database Ecoinvent, for example, uses 1.59 passengers per vehicle to convert from vehicle kilometre to person kilometre. It could be argued that larger vehicles carry more passengers, but occupancy rates of passenger cars in Europe fell from 2.0 in the early 1970s to 1.5 in the early 1990s, due to increasing car ownership, extended use of cars for commuting and a continued decline in household size (EEA, 2016). It indicates that the actual number of passengers per car is largely decoupled from the size of the car.

It should be noted that the emissions target in a legal sense only applies to tail-pipe emissions and does not include a life cycle perspective. However, it is still a useful benchmark.

The use of vehicle kilometre as the functional unit facilitates comparisons with combustion vehicles and of different battery technologies in the same vehicle. However, it does not facilitate comparisons between different size batteries; smaller batteries, e.g. batteries for hybrid vehicles would normally have less environmental impact per vehicle kilometre. For such comparisons, the functional unit per delivered kWh over the lifetime is more appropriate.

2.2. System boundary and data

The system boundary for the study is shown in Fig. 1. The vehicle itself is not present in the system, only the use of the battery cell in the vehicle. In essence, the study will include the production phase of the battery cell, those use phase losses that can be related to the cell itself and the recycling of the cell materials. In this study, we address only the battery cell including its packaging. Electronics, wiring, packaging of modules and battery casing are not included, nor are the other parts of the drive train that deliver power from plug to wheel: charger, inverter(s) and motor(s).

STABLE project partners in Spain and Italy provided data (material, energy, emissions) from their laboratories specific to the manufacturing of the working prototype cell, which was complemented with fitting background data, e.g. for electricity.

It should be emphasized that the use phase does not include propulsion related environmental burdens, but was limited to losses that can be attributed to the battery cell. Recycling data is estimated since reliable data on recycling of lithium battery cells are exceedingly limited in scope and detail.