Primary and secondary supply options for lithium and their contribution to the environmental impact of a lithium-ion battery

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Abstract

Rechargeable lithium batteries are considered to be a very promising option to meet the future requirements of electric vehicles (EV), which in turn are expected to play a major role in the transition towards a more sustainable mobility. The high energy density and long life span of these batteries is essentially due to the geochemically scarce metal lithium, which is the lightest metal with the highest electrochemical potential.

In this contribution we appraise the contribution of the environmental impacts related to different lithium extraction options to the overall cradle to gate environmental impacts of a lithium-ion (Li-ion) battery using an LCA approach. The study is supplemented by an overview of possible recycling options for Li-ion batteries and of driving forces necessary for their implementation. The analysis is based on a case study of an exemplary primary production system (lithium extraction from brines) and a survey of possible recycling options for Li-ion batteries. The results are the basis for an estimation of the environmental impacts of other lithium production systems.

The LCA results show that the primary production of lithium carbonate from brines is a low input process, since the main energy input is “free of charge” (evaporation in solar ponds). Therefore, at present lithium supply is not critical regarding the environmental impacts of a Li-ion battery for EV (it accounts for about 1.2 % of the total environmental impact of the cradle-to-gate LCIA of the battery production (eco-indicator 99)). However, the results only have limited validity, because the large land consumption and the related ecosystem change can currently not be adequately included into LCIA.

Regulatory focus and economic aspects are the most influential variables for recycling activities. Since the economic incentive for lithium recovery still appears rather weak, motivating regulatory measures will be necessary to ensure high collection and recycling rates.

Keywords: Lithium, Batteries, LCA.

1 Introduction

1.1 Background

Many emerging technologies have functionalities, which necessarily require geochemically scarce metals. Should these technologies become widely implemented, as it is expected for some emerging energy technologies in particular, the demand for these metals will rise significantly.

Rechargeable lithium-ion (Li-ion) batteries are considered to be a very promising option to meet the future requirements of electric vehicles (EV), which in turn are expected to play a major role in the transition towards a more sustainable mobility. Their high energy density and long life span is essentially due to the geochemically scarce metal lithium, which is the lightest metal with the highest electrochemical potential. The potential for rapid demand growth and recycling restrictions are the reasons why e.g. UNEP (Buchert et al., 2009) considers lithium as a critical metal and encourages further research.

1.2 Goal and Scope

Environmental impacts of lithium production are only insufficiently known. However, this information is needed in order to assess the life cycle environmental impacts of Li-ion batteries and of EV containing these batteries, respectively.

In this contribution we appraise the contribution of the environmental impacts related to different extraction forms of Lithium to the overall cradle to gate environmental impacts of a Li-ion battery using an LCA approach. The study is supplemented by an overview of possible recycling options of Li-ion batteries, respectively of driving forces necessary for their implementation.

The analysis is based on a case study of an exemplary primary production system and a literature review and small case study regarding Li-ion battery recycling and secondary supply of lithium. The results are the basis for an estimation of the environmental impacts of other lithium production systems.

2 Lithium production systems

2.1 Primary production systems

There are different primary supply options for lithium, such as extraction from brines and mineral ores and in principle also seawater, where lithium occurs in trace amounts together with other salts. Today, mainly the brine extraction option is used, however, other sources could gain in importance, if the easier accessible deposits are depleted by a strong surge in demand.

Concerning primary supply, environmental impacts from production processes vary e.g. due to difference in accessibility, speciation and grade of the deposit. It is therefore conceivable that if more favourable deposits are depleted, the environmental impact of the extraction will probably increase.

In the case study, we assessed the life cycle environmental impacts of the production of lithium carbonate (Li_2CO_3) from the world leading producer SQM (market share 30%: SQM, 2009), which is located at the Salar de Atacama in Chile. Li_2CO_3 is the main feed material for lithium based products, e.g. batteries.

2.2 Secondary production system

The actual potential for lithium recovery through recycling is highly uncertain (Buchert et al., 2009). Since battery production represents 25% of the global demand for lithium, recycling of Li-ion batteries is one of the main potential sources for lithium recovery (USGS, 2008).

Up until present time, recycling of Li-ion batteries has predominantly been aimed at recovering cobalt and copper, due to the high market prices of these materials. However, in order to reduce the costs of the batteries and to increase their performance characteristics, alternative battery chemistries are developed or considered (Armand & Tarascon, 2008). This development has the potential to shift the requirements and the economical feasibility on the recycling operations set up to treat Li-ion batteries.

Techniques for the treatment of spent Li-ion batteries can be separated into hydrometallurgical and pyrometallurgical processes. General advantages of hydrometallurgical recycling processes are products of better quality and better control over process-related environmental impacts, but with the disadvantages of being more sensitive to variations in process input and more expensive than pyrometallurgical processes. Pyrometallurgical treatment methods for recycling of batteries are normally more cost-efficient and are less sensitive to the composition of the waste-input, but commonly suffer from high energy consumption and difficulties in recovery of materials oxidized in the process, e.g. aluminum, lithium, and organic electrolytes (e.g. Cheret, 2007)).

We assessed driving forces influencing future decisions affecting Li-ion battery recycling and the potential for the recovery of lithium. A case study in collaboration with the material recycler Umicore was concerned with the potential for the recovery of lithium from the slag of a pyrometallurgical process.

3 Method

3.1 Primary supply

The Life Cycle Inventory (LCI) for the case study on a primary production system was based on environmental reports and personal communications. The study includes processes from cradle to gate; the background data was taken from the ecoinvent database version 2.1 (Ecoinvent, 2009)

The results of the Life Cycle Impact Assessment (LCIA) are presented using aggregated parameters (eco-indicator 99).

Based on the case study we derived the main factors to estimate ranges for other brine operations. The standard ecoinvent process for Li_2CO_3 production was adapted to cover production processes from ores.

3.2 Secondary supply

An extensive literature review and consultation of experts in the battery recycling industry or from industry-related associations formed the basis for the overview of possible recycling options for Li-ion batteries and lithium recovery (shown in section 2.2), as well as for the related driving forces. In the small case study in collaboration with Umicore, different options to use the slag of the pyrometallurgical processing of spent Li-ion batteries were assessed. System expansion was used in order to compare these strategies. Background data was taken from the ecoinvent database version 2.1 (Ecoinvent, 2009). Due to proprietary reasons we cannot present the complete results in this paper, however, we hope to present some of the insights at the conference.

3.3 Comparison with environmental impacts of the whole Li-ion battery

The calculated environmental impacts of the production of Li_2CO_3 were compared with the cradle to gate LCIA results of an ongoing study of a whole Li-ion battery for electric vehicles at Empa. This study will soon be published and refers to a battery with a lithium manganese oxide cathode ($LiMn_2O_4$).

4 Results

4.1 Primary supply

Figure 1 shows the flowchart of the production of Li_2CO_3 from brines at SQM (Salar de Atacama). Primary production of Li_2CO_3 is a low input process, since the main energy input is “free of charge” (evaporation in solar ponds). The high land consumption and related land use change are not accounted for, since a standard is missing which defines how to integrate the conversion (salt flat → solar ponds) into LCIA.

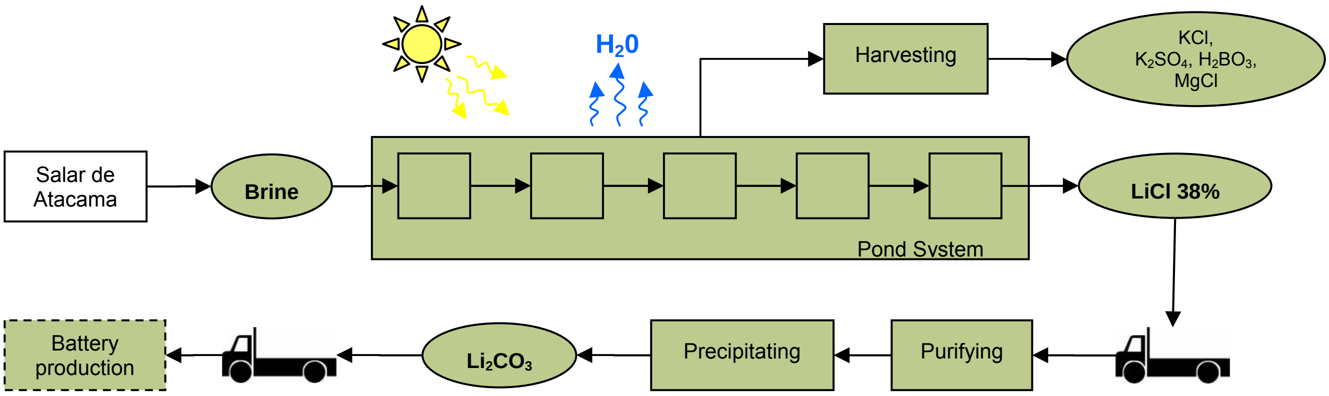

Figure 1: *Flowchart of the processes considered in the LCI of lithium extraction (Salar de Atacama, Chile) and further processing to* Li_2CO_3

Li_2CO_3 accounts for 4 % of the total weight of the Li-ion battery and its primary production (regarding the case study) only for about 1.2 % of the total environmental impact of the cradle-to-gate LCIA of the battery production (eco-indicator 99. paper Empa in preparation).

The Salar de Atacama, the case study region, benefits from favourable conditions (e.g. high lithium concentration and evaporation rate, low Mg:Li ratio), which simplifies the process requirements (see table 1). This is far less the case for other brine operations, which therefore are assumed to have higher environmental impacts; especially if land consumption is accounted for (suboptimal preconditions can lead to higher land consumption). Li_2CO_3 production from ores is more energy intensive, since the process starts with a thermal conversion step (high temperatures, no “free” solar energy as in brine operations).

Brine	Salar de Atacama	Salar de Hombre Muerto	Lake Zabuye	Salar de Uyuni	Seawater
Country	Chile	Argentina	China	Bolivia	-
Lithium content	0.15wt%	0.062wt%	0.097wt%	0.096wt%	$1.7 \cdot 10^{-8}$ wt%
Mg:Li	6.4	1.4	0.01	20.8	?
Evaporation rate	3200mm/a	2300 mm/a	"lower"	1500 mm/a	-
Estimated Li reserves	3'000'000t	800'000t	1'000'000t	5'000'000t	$2.5 \cdot 10^{11}$t
Exploiting?	yes	Yes	starting	no	no

Table 1: *Selected characteristics of some lithium brine deposits (Garrett, 2004; Kamienski et al., 2004; Steinberg & Dang, 1975)*

4.2 Secondary supply

Regulatory focus and economic aspects are the most influential variables for recycling activities. The value of recovered materials traditionally has been a key driver for voluntary recycling. However, several novel chemistries are currently being considered, which will decrease or even eliminate the economical incentive for Li-ion battery recycling (e.g. substitution of expensive material such as cobalt with materials of lower value such as iron phosphate). Thus, motivating regulatory measures will be necessary to ensure high collection and recycling rates.

The results of the case study with Umicore cannot be presented here due to proprietary reasons.

5 Concluding Remarks

At present, Li_2CO_3 production is not critical regarding the environmental impacts of a Li-ion battery for EV (eco-indicator 99). However, the results only have limited validity, because the large land consumption and the related ecosystem change, can currently not be adequately included into LCIA.

Alternative brine operations will most probably have similar or slightly higher environmental impacts, depending on the inclusion of land consumption and related effects, amongst others. The production processes of Li_2CO_3 from ores or seawater not only have higher environmental impacts, but are presently also economically not competitive

Concerning recycling activities, the introduction of lithium-ion battery systems in e-mobility and stationary applications is anticipated to facilitate considerably higher collection rates than what is currently experienced for these battery types in portable consumer applications. Increased efficiency in the collection system might, at least partly, counteract decreasing use of valuable and recoverable materials in the batteries. Even though the price of lithium has increased in recent years (USGS, 2009), the economic incentive for lithium recovery still appears rather weak.

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