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Potential metal requirement of active materials in lithium-ion battery cells of electric vehicles and its impact on reserves: Focus on Europe

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ABSTRACT

Shifting of motorized mobility toward electric propulsion has become an inevitable development direction in vehicle technology in the last few years. It raises some important questions from environmentally consciousness point of view. One of these aspects is the demand and availability of raw materials. Recent papers and studies on raw material availability are relating to a narrow topic, for example, focusing only on lithium in global consideration, or take into consideration an average metal content of batteries. Present paper makes a step toward expanding information on net metal demand of battery cell active materials and metal reserves focusing on Europe, as one of the world largest economy doing large effort to become world leader in electric mobility. Five potential cell chemistries were identified based on research trends and future expectations of researcher, car and battery manufacturers. Furthermore, a potential share of battery- and electric vehicle types in hypothetical car fleet was proposed, as well. Lithium, cobalt, manganese and nickel requirement and European reserves were examined. Present study pointed out that the potential share of electric mobility in road traffic of the European Union had a detectable, but insignificant impact on global metal production and reserves. In the case of a hypothetical European production of future traction battery cells, shortage in European lithium and nickel reserves might be expectable at around 2025. Demand on cobalt and manganese are found to be far below the available European reserves.

1. Introduction

The transport sector produces approximately 27% of the greenhouse gas emissions in the European Union (EU), while 14–42% of other major air pollutants, such as nitrogen oxides, non-methane volatile compounds, and particulates are caused also by this sector (Bach and Lienin, 2007). These emissions represent the most important airborne pollutants that constitute a risk to human health (HEI, 2010). Electric mobility is an option to mitigate air pollution in cities or overall greenhouse gas emissions of road transport (Hwang, 2010; Soret et al., 2014). At present, the trends in personal mobility indicate a rising interest in electric vehicles (EVs). The potential increase in market penetration of different EVs like plug-in hybrid (PHEVs) or battery electric vehicles (BEVs) could result in an enormous demand for electrochemical energy storage systems (EESs) (Berger, 2012a, 2012b).

Lithium-based traction batteries (LITBs) are promising systems that capable of providing high gravimetric energy and power density. LITBs show an excellent potential for a wide range of EES applications including EVs. The lithium-containing active materials in LITB cells play a key role in the electrochemical storage of energy. The anode is often made of carbonaceous material, while the cathode-active material comprises lithium and other metals like alkali-, alkali earth- or transition metals. Some of the used metals are defined as critical by recent studies (Morley and Eatherley, 2008; Moss et al., 2011; Reller, 2011). Therefore, the availability of these metals, especially of lithium, has been studied extensively. Results of distinct studies often suggest the opposite of future prospects of lithium (Tahil, 2006, 2008; Evans, 2008a, 2008b). Major conclusion of studies is that the result of an assessment of resource availability always depends on the criteria and system boundaries applied. Recent studies on metal availability in the context of electric mobility show different limitations. The focus placed often solely on lithium related issues or dealing with

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average lithium content or do not specify the composition of car fleet including the battery chemistry and the distinct storage capacities of traction batteries, or being out-of-date (Råde and Andersson, 2001; Gruber et al., 2011; Grosjean et al., 2012; Kushnir and Sandén, 2012; Speirs et al., 2014).

To update the state of the knowledge and approximate a realistic view, potential future scenarios were defined in terms of electric vehicle fleet and different cell chemistry of LITBs. Geographical boundary is the European Union (EU) as the second largest market of electric vehicles (IEA, 2013). The assumptions are based on the projections are reported in studies of OPTUM (Hacker et al., 2011), MERGE (Ball et al., 2011), and IEA (2011) (Tanaka, 2011) dealing with the expected EV usage as well as the opinions of material developers regarding potential future cell chemistry were also taken into consideration (Pellischek, 2011; Thielmann, 2013; Simon et al., 2014). The goal of present paper is to calculate and describe the potential effect of European electric vehicle market on the European metal reserves and production of metals used as active material in battery cells. The availability was examined on global and European level, as well. The analysis on European level aimed to imply the potential of European battery cell industry based on own resources.

Furthermore, error propagation was performed to analyze the uncertainty of prospective analysis and to support a proper evaluation of results. Both the defined battery mix and error propagation made a case to examine the availability issue from a realistic point of view.

2. Method

The comparison of the metal requirements and reserves for LITB cells comprised the consecutive combination of the following six steps:

1. Selection of battery chemistry (based on expert survey and technology roadmaps).
2. Amount of metal in LITB cells.
3. Electric car fleet and capacity demand scenarios.
4. Battery mix for future LITBs.
5. Forecasting of the potential changes in metal reserves.
6. Metal reserves in Europe

2.1. Selection of battery chemistry

Based on the expert survey, five different cell types were chosen for further analysis. The survey is subject of a previous publication of our research group. 40 professors, postdocs and PhD students from research area of lithium based battery (anode, cathode, electrolyte and whole systems) were asked for evaluation the importance of potential battery active materials and cell systems on a five-point scale regarding a mid-term time scale to 2030. The predicted trend in material development indicates the metals to be analyzed with respect to the potentially growing future demand. Further information is available in Simon et al. (2014).

The relevance of layered and spinel cathode materials with a single type of transition metal like $LiCoO_2$ or $LiMn_2O_4$ is expected to decrease, whereas high-voltage systems and conversion LIB systems, such as Li/S_8 and Li/O_2 systems, are deemed to be of growing importance (Simon et al., 2014).

Five systems were selected for a more detailed analysis:

1. Two mixed metal oxide cathodes, both with a graphite anode $Li(Ni_{0.4}Mn_{0.4}Co_{0.2})O_2$ (NMC/C) and $Li(Ni_{0.8}Co_{0.15}Al_{0.05})O_2$ (NCA/C);
2. One active material having an olivine structure, $LiFePO_4$, with graphite anode (LFP/C);
3. Li/S_8 and Li/O_2 systems as future conversion batteries.

NMC/C represents the state-of-the-art traction battery, LFP/C was chosen due to its high stability and safety, while NCA/C is likely to be of increasing relevance in the short term due to the expected high energy density. Furthermore, Li/O_2 and Li/S_8 systems are investigated, as they represent the most promising future batteries according to the expert survey.

2.2. Metal content of LIB cells

To calculate the net metal requirement for active materials of batteries, information on the composition of battery cells is needed. In present study, the capacity-related metal content is calculated (kg average metal content per kW h energy density), which shows some correlation with results reported by Råde and Andersson (2001). Primary data (average voltage, storage capacity, weight percent of cell parts, etc.) for calculation are taken from different international papers and studies. Absolute cell composition of NMC/C, LFP/C, and NCA/C was based on Gaines and Cuenca (2000), Gaines and Nelson (2009), Bauer (2010), Notter et al. (2010), Zackrisson et al. (2010), Duleep et al. (2011), Majeau-Bettez et al. (2011), Väyrynen and Salminen (2012) and Hagen et al. (2013). The metal content of Li/S_8 and Li/O_2 is limited to Li. Their capacity-related Li content is based on data from research papers and information sheets (Zhang et al., 2010; Hagen et al., 2013; Sion, 2014). The following materials are considered as active components:

1. Lithium salt in intercalation-type battery cathodes;
2. Metallic lithium in conversion-type batteries;
3. LiPF6 and LiTFSI (lithium bis(trifluoromethanesulfonyl)imide) components of the electrolyte.

Lithium (Li), cobalt (Co), manganese (Mn) and nickel (Ni) were selected for further detailed analysis as being important, substantial and probably critical metals, while aluminum and iron are excluded due to the unexpected supply shortage (Morley and Eatherley, 2008; NEDO, 2009; Moss et al., 2011; Reller, 2011).

Fig. 1 shows that the Li/S_8 system has the highest net lithium demand. Compared to the other battery types, the lithium demand is higher by more than a factor of 2. Another important system from the net metal demand perspective is the NCA/C cell-system, which requires a considerable amount of Ni and a slightly higher amount of Li and Co than the competing NMC/C system. The amount of Al needed for NCA/C is negligible compared to the other metals. NMC/C contains a moderate amount of Mn (about 0.4 kg/kW h). A noteworthy amount of iron is needed in the LFP/C battery.

2.3. Required storage capacity of future LITBs

To estimate the required storage capacity of EVs, first a potential vehicle fleet was defined. Forecasted number and types of electric cars were estimated on the basis of MERGE, OPTUM and IEA (2011) studies (see Table S1, Section 1) (Ball et al., 2011; Hacker et al., 2011; Pellischek, 2011; Tanaka, 2011). In the final step, the number of EVs was combined with the fleet composition and the average storage capacity required by the particular EV type. Average storage capacity of different EVs is reported by the MERGE study (see Table S2). Modeled EV fleet was divided into the following four types of electric cars: