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Dissipative application of lithium – lost for the future?

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Abstract – In recent years, lithium received increasing attention as lithium-ion rechargeable batteries appear to be the most promising candidates for future electric vehicles. Several studies forecast a strong increase in demand most likely brought about with the implementation of lithium-ion batteries in the automotive sector. Thus, the availability of lithium could be an important constraint for this emerging technology. Concerning lithium availability the future developments of supply and demand as well as the recycling potential play major roles. In respect of recycling it has to be distinguished in general between dissipative and non-dissipative applications. As several studies (e.g. [1] G. Angerer, F. Marscheider-Weidemann, M. Wendl, M. Wietschel, Raw materials for emerging technologies: the case of lithium, Karlsuhe 2009) predict lithium recycling to play an important role for future lithium availability the recyclability of lithium in different applications has to be analysed for estimating the contribution of lithium recycling to future supply.

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In the recent past a rising interest in lithium both from industry and scientific researchers could be observed. This is not only a result of the growing market for lithium-ion rechargeable batteries in mobile information and communication technologies but rather due to the fact that lithium based electrochemical storage systems are the most promising candidates so far for future plug-in hybrid electric vehicles (PHEVs), hybrid vehicles (HVs), and fully electric vehicles (EVs). The mentioned trends in the electronic and automotive sector are responsible for an increasing demand for lithium causing the fear that potentially limited lithium availability may be an important constraint for these emerging technologies. Particularly with regard to the fact that the advantages of rechargeable lithium-ion batteries like low weight and high energy density are associated with the unique characteristics of lithium which disables an effective substitution [2].

It follows from these facts that recycling will play an important role for future lithium supply. The contribution of recycling to future lithium supply is dependent on the recyclability as well as the recycling potential of the several lithium applications. Lithium has a wide range of applications with glass & ceramics and batteries being the major ones (Fig. 1). But lithium is also used in lubricants, aluminum production, air conditioning, chemicals, pharmaceuticals, alloys and several smaller end uses, including dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganics [4].

One factor of the recycling potential is the individual lithium amount consumed by the several lithium products. For a comprehensive understanding of the respective lithium flows a detailed material flow model was developed to trace the fate of lithium [5]. The model enables to differentiate between lithium applications that are predominantly dissipative and those that could be recycled. As different levels of dissipation can be distinguished, sectors can be identified in which recycling activities should be enhanced.

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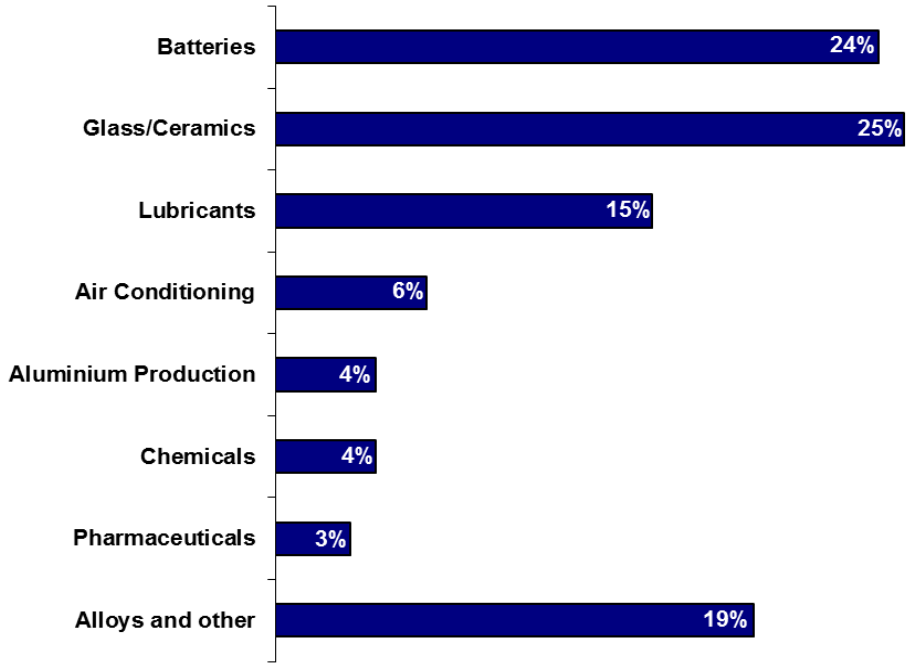


Fig. 1. End usage of lithium (2007) (data source [3]).

1 Lithium material flow model

Material flow analysis (MFA) is a scientific method for the systematic assessment of material flows and stocks within a system defined in space and time [6]. A detailed material flow model accounts for the whole life cycle including production, manufacture, use as well as recycling and landfilling, and allows the identification of possible stockpiling, recycling potentials and dissipative losses. Complemented by information about reserves and resources and trend of demand this model serves as the basis for detailed analysis of future resource availability.

The designed material flow model of lithium is the outcome of an extensive literature research of the different material flows. As data on lithium flows is rare and some data sources show differing information the amounts of lithium flows had to be aggregated from various literature and statistical sources and had to be evaluated critically. Based on this an initial MFA for the key processes and flows on a global perspective was developed. This MFA of lithium was conducted along the four basic life cycle stages production, manufacture, use, and recycling and waste management. This lithium material flow model also contains detailed information about the different resources as well as the individual applications of lithium within the basic life cycle stages which allows a more comprehensive understanding of the global lithium cycle.

1.1 Overview about processes

(*See Table 1 next page*)

1.2 Modelling and Results

The material flow model (Fig. 2) was assembled from the individual lithium flows through the four processes (Tab. 1) from ores as a special environmental component to the environment in the end. This model simply represents the flows and does not indicate any changes in stocks. Data on these flows was inserted as far as it was available. Where such data was lacking assumptions had to be made to complete the model.

The designing of the model revealed that there presently is a disparity between lithium production of 25,750 t/a and its consumption of 21,620 t/a. In the balance of materials the use sector "Unknown" was inserted for this difference of 4,130 t/a lithium.

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Table 1. Input and output flows of lithium.

Processes	Input		Output	
	Flow	Source	Flow	Source
Production	Li from Brines Li from Spodumene Li from Lepidolithe/ Petalite	[7,8]	Lithium derivatives	assumption
Manufacture	Lithium derivatives	assumption	Li for Batteries Li for Glass & Ceramics Li for Lubricants Li for Air Conditioning Li for Aluminium Production Li for Chemicals Li for Pharmaceuticals Li for Alloys & Other Uses	[3]
Use	Li for Batteries Li for Glass & Ceramics Li for Air Conditioning Li for Aluminium Production Li for Chemicals Li for Alloys & Other Uses Li for Lubricants Li for Pharmaceuticals	[3]	Li-Batteries to Li-recycling Li-Glass & Ceramics to WM Li-Air Conditioning to WM Li-Aluminium production to WM Li-Chemicals to WM Li-Alloys & Other Uses to WM Li-Lubricants to environment Li-Pharmaceuticals to environment	assumption
Recycling and Waste Management	Li-Batteries to Li-recycling Li-Glass & Ceramics to WM Li-Air Conditioning to WM Li-Aluminium production to WM Li-Chemicals to WM Li-Alloys & Other Uses to WM	assumption	Secondary Li to production Li-slag to other uses Li-containing recycled products to manufacture Li-containing secondary products to other uses Li-containing wastes to environment	[4] [9] assumption

As changes in stocks are excluded, this variation could be due to statistical imprecision or another possibility is that certain use sectors have not been considered. However, none of the assumptions could be verified under these conditions.

2 The case of dissipation and recycling

Figure 2 shows two different lithium flows from the use phase. It has to be distinguished between dissipative applications and non- or little dissipative applications. Thus, the lithium flows from the use phase are either directed to the process recycling and waste management or reach straightly the environment and therefore are lost for reuse. Hence, the amount of lithium used in recyclable or dissipative products determines the contribution of lithium recycling to lithium supply.

2.1 Dissipative applications of lithium

A use or application of a metal is called dissipative when during the use phase the metal is dispersed or scattered making it exceptionally difficult and costly to recycle [10].

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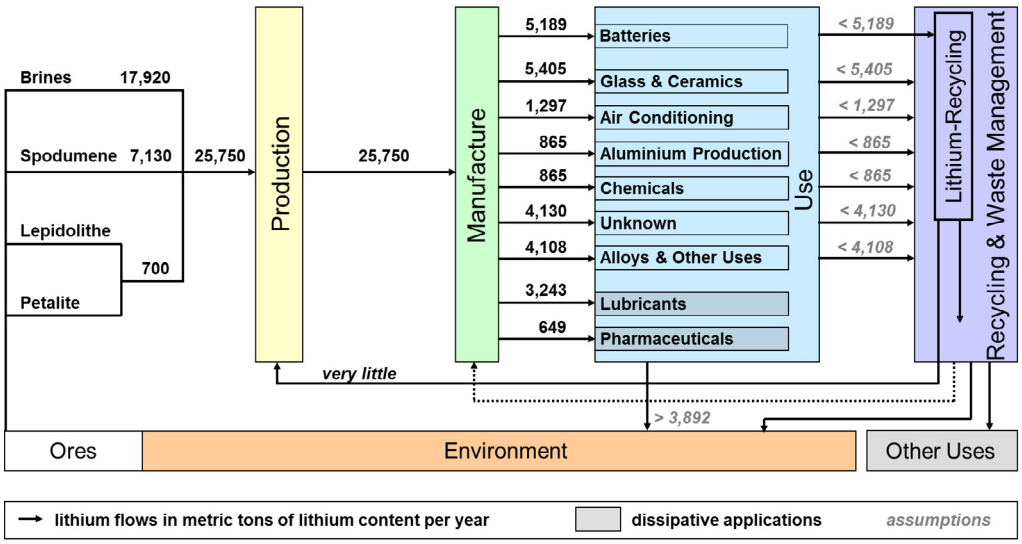


Fig. 2. Material flow model of lithium for the year 2007 (data sources [3, 4, 7, 8]).

Dissipative uses of lithium are pharmaceuticals and lubricants. Pharmaceuticals are consumed in the way that after their intake the contained lithium ends up dispersed in the waste water and after passing a wastewater treatment plant finally in the environment. There is not any possibility to recover the dissipated lithium.

Lubricants are predominantly used up during their use phase and reach the environment on differing paths. These lithium-based soaps used in multipurpose lubricating greases for automotive and industrial applications (e.g. heavy machinery) are worn off over distinct periods of time and the majority of the contained lithium is dispersed through different pathways into the environment.

2.2 Potentially recyclable applications of lithium

A recyclable material is generally defined as a raw or processed material that can be recovered from a waste stream for reuse [11]. In case of lithium products there has to be distinguished between two groups of lithium uses with differing recycling abilities:

1. applications where lithium recovery is practicable and,
2. applications where only a recycling of lithium containing products without lithium recovery seems possible.

Primary and secondary lithium based batteries belong to the first group due to the fact that recycling processes for a possible recovery of lithium exist [12]. From primary batteries a small quantity of lithium in form of lithium carbonate is recovered during the recycling process [4]. From secondary lithium batteries especially lithium-ion rechargeable batteries in the currently executed recycling processes lithium is in practice not recovered at all, but just the particular materials like nickel and cobalt. Lithium ends up in the slag and could at most only be reused as an additive to concrete for e.g. road construction [9]. The development of recycling processes for lithium automotive batteries is the subject of ongoing research activities. At the moment the lithium price is too low and the proportion of lithium in batteries is too small to allow economic lithium recycling in form of distinct lithium recovery from rechargeable batteries. Thus, it is not foreseeable when the lithium price will be high enough in the future to enable profitable lithium recycling. Furthermore, it has to be considered that other lithium based battery systems could aggravate lithium recycling additionally. As they often contain more organic compounds or have a more complex system composition it will be more difficult

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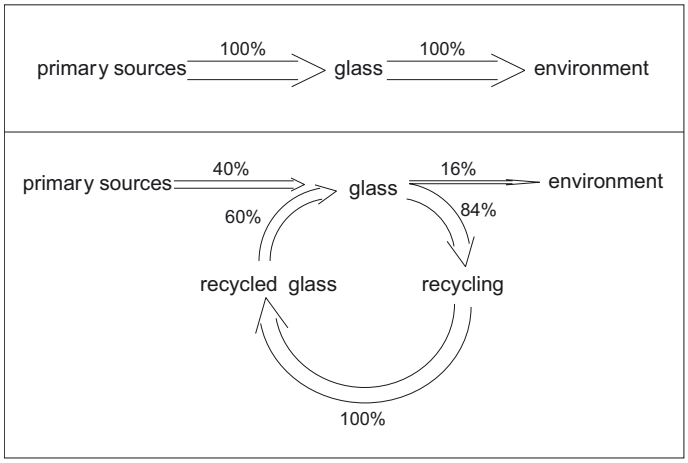


Fig. 3. Glass production with and without recycling.

to extract the lithium from such compounds and systems.

With regard to the material flow model (Fig. 2) it could thus be assumed that the mass flow of 5,189 t/a from batteries reaches lithium recycling as a special component of the process recycling and waste management. The recovered (secondary) lithium from primary batteries could attain to production, but this seems to be only very little. Additionally it is neither known if the recovered lithium reaches production nor in which form and in which applications it could be used again. Due to economic reasons in the current recycling processes for rechargeable lithium batteries lithium ends up in the slag, which could be required for other uses or reaches the environment in form of lithium containing wastes. However, only from primary and secondary battery recycling a replacement of primary lithium in the future seems plausible.

The second group consists of the lithium use sectors glass & ceramics, chemicals, aluminium production, air conditioning, alloys & other uses and has currently the highest market share (58% cf. Fig. 1). It could be assumed therefore that the lithium flow from use to recycling and waste management corresponds to the individual lithium content of the potentially recyclable products summing up to 12,540 t/a at the maximum (cf. Fig. 2). Within these applications a recycling of the lithium products should be possible (e.g. air conditioning) or is to some extent already executed at the moment (e.g. glass, alloys). Usually lithium remains embodied in the recycled products and is most likely not recovered. In this case there would not be any secondary lithium or appropriate lithium compounds that could attain to production and thus reduce the required amount of lithium from primary sources. Depending on whether and how recycling of lithium products is executed there are flows of lithium contained in secondary products from recycling and waste management. These lithium flows might on the one hand either reach other uses, e.g. the cement or concrete industry or end up as wastes and emissions in the environment. On the other hand if there were recycled lithium products transferred to production and/or manufacture instead of reaching other uses or ending up in the environment there might be a possibility to reduce the required amount of primary lithium from ores and brines. To explain that further the example of lithium used in glass bottles is described in more detail.

The use of lithium in manufacturing glass bottles enables lighter weight and thinner walled products. As far as no recycling exists the production of glass bottles needs 100% of primary raw materials (with a certain amount of lithium). As far as a glass recycling is established the recycled glass replaces at least 60% of the primary raw materials [13]. The required primary lithium is in this way also reduced (cf. Fig. 3).

In Germany a glass recycling is established. At present 84% of the produced glass bottles and containers are recycled [13] and can substitute primary raw materials

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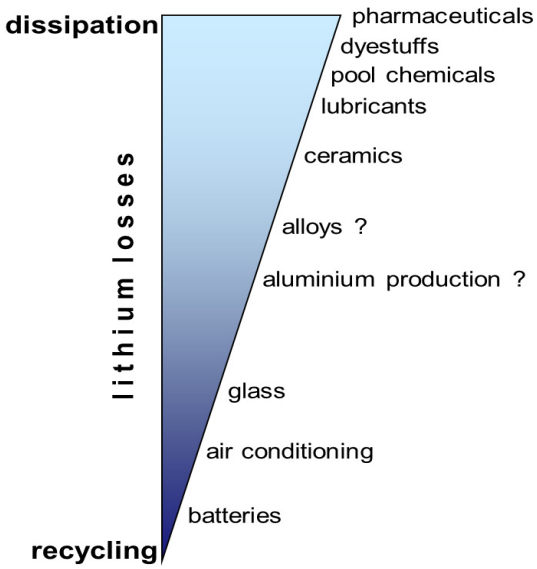


Fig. 4. Level of dissipation of lithium applications.

in different glass application fields. One of them is glass bottle production, which is shown in Figure 3.

However, it should be taken into account that lithium is also used in a variety of other glass applications [14] such as borosilicate glass, fiberglass, flaconnage, internally nucleated glass ceramics, pharmaceutical glass, photochromic glass, soda lime glass, television tubes, thermal shock resistant cookware (for freezer-to-oven use), optical glass, mirrors and glass-ceramics, and refractories (e.g. specialty brick for furnace linings). Thus, it could be a problem to separate the different glass types in order to reach high-purity-quality recycled products instead of low-quality products with a mixed degree of purity.

3 Conclusions

The future availability of lithium results from the development of supply and demand [15]. Concerning future supply the recycling of lithium in its different applications plays a major role. With regard to lithium recycling both the design of products and the execution of recycling processes is decisive. Due to the explanation of lithium flows and recyclability of several lithium products it can be differentiated between dissipative applications and non- or little dissipative applications. In Figure 4, it is attempted to distinguish different lithium applications regarding the level of dissipation. Pharmaceuticals are dissipative products whereas primary and secondary lithium batteries allow for lithium recycling. The other lithium uses show different amounts of lithium losses that are not quantifiable yet, which is a task for further research. In any case all mass applications of lithium in products should be recyclable to minimize the dependency on primary lithium in the future.

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