POLICY PERSPECTIVES

The Lithium future—resources, recycling, and the environment

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Keywords
Biodiversity; Bolivia; environmental impact; human health; Lithium; recycling; resource use.

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Received
16 November 2010
Accepted
9 February 2011

Editor
Devid Pellow

doi: 10.1111/j.1755-263X.2011.00166.x

Abstract:

The demand for Lithium-ion batteries as a major power source in portable electronic devices and vehicles is rapidly increasing. I use cumulative data of vehicle, mobile phone, laptop, and digital camera production to show that demand will overshoot the available global Lithium resources before 2025. Even if 100% of all Lithium-ion batteries were recycled today, recycling could not prevent this resource depletion in time. As the increasing Lithium scarcity will increase the price, it will be feasible to mine diluted resources with a strong environmental impact. I highlight these impacts in Lithium-rich Bolivia, the potential new "Saudi Arabia of Lithium." Lithium extraction is likely to cause substantial water pollution, and—through impacts on native diversity—facilitate human health impacts from cyanobacteria that are normally kept at bay by native flamingos. The strongly intertwined Lithium extraction impacts on the environment, biodiversity, and human health from evaporative ponds and ore mining need to be taken into consideration when we discuss resource protection and opportunities from Lithium recycling. Overall, sensible Lithium recycling strategies can provide effective resource and environmental protection right now but urgently need to be supplemented by alternative technologies in the near-future.

Introduction

If you spend some time in public transport, cafés, or shopping centres, you will have noticed the omnipresent use of mobile phones and laptops. Until now, the increasing popularity of affordable electronics has led to an estimated total production of 12.7 billion mobile phones (Ramirez-Salgado & Dominguez-Aguilar 2009), 94.4 million laptop computers, and 768.9 million digital cameras (UNdata 2010). Once the status symbol of a small elite, many people are now striving for the latest technology of tomorrow. But while technology advances fast, all portable electronic devices still depend on energy—nowadays, Lithium-ion batteries. These batteries are the preferred energy source because of their high-energy density (compactness), low sensitivity to temperature variation (ruggedness), and higher resistance to "charging failure" (no memory-effect). While considered an environmentally viable alternative, the demand for Lithium-containing batteries already now requires 23% of the global Lithium production (USGS 2010).

The advent of electronic vehicles (i.e., powered from Lithium-ion batteries) in recent times, has driven global economic investment projected to reach US$ 30–40 billion by 2020 (Lache *et al.* 2008). Depending on the source considered, one of these vehicle batteries is using 3–20 kg of Lithium so that the annual Lithium demand for vehicles in the US alone was estimated to be 55,000 tons by 2050 (Gaines & Nelson 2009). In 2009, the US government made a multibillion dollar investment to open up a whole new industry to satisfy future demands in vehicle Lithium-ion batteries (USDE 2009). Thus, there is a rapidly growing demand and investment in Lithium for portable electronic device and vehicle batteries, which has ultimately to be satisfied with the global resources of 25.5 million tonnes. Accessing these resources will become more difficult with devastating impacts on the environment, but efforts may still not be enough to satisfy

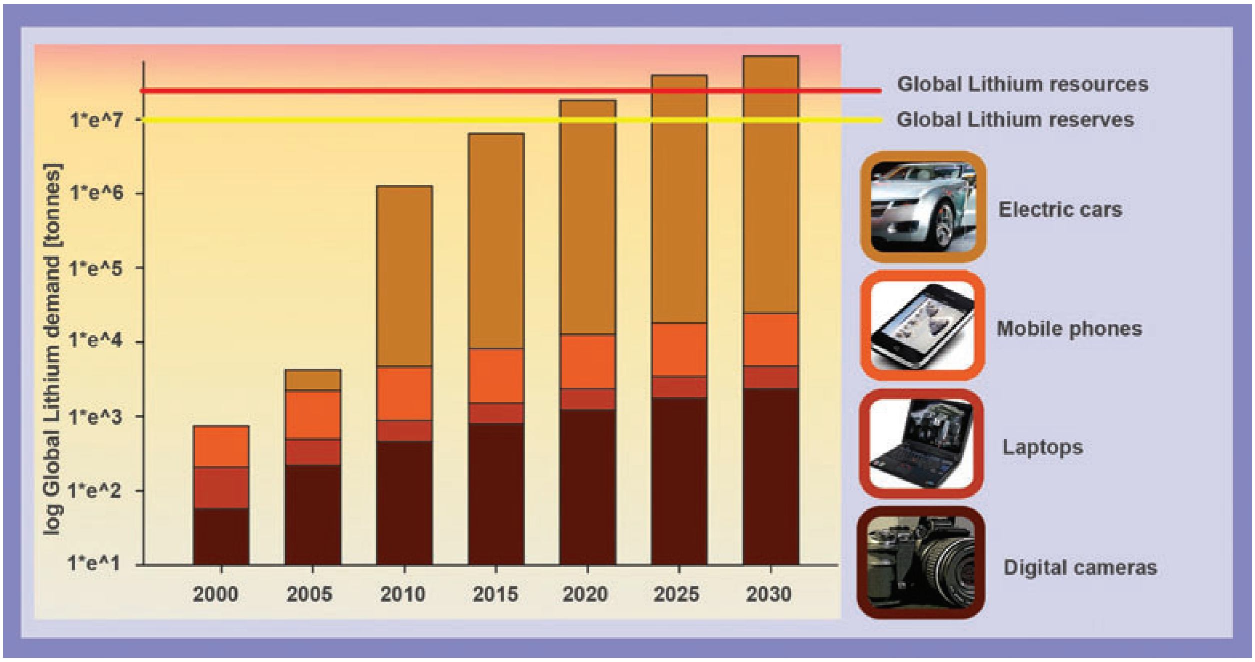

Figure 1 Global Lithium demand for Lithium-ion batteries and available global resources. The cumulative numbers of globally produced digital cameras, mobile phones, laptops, and electric cars were used to calculate the future demand of Lithium (Lithium content in the batteries of electronic devices was calculated based on the formula by the US Department of Transportation; USDT 2008) and battery specifications on all models from the eight leading manufacturers for digital cameras, mobile phones, and laptops. For the units of produced digital cameras, mobile phones, laptops, cars, and the percentage of electric vehicles see Hacker *et al.* (2009), Gaines and Nelson (2009), Ramirez-Salgado and Dominguez-Aguilar (2009), UNdata (2010), and White (2006). Note that the y-axis is on log scale to make the contributions of all electrical garment categories visible.

future Lithium demands. Although Lithium plays such an important role, it is surprising that the economic, environmental, and health impacts of future Lithium scarcity have not fully been looked at.

Unlimited Lithium resources?

While the advantages of Lithium-ion batteries and the future economic profits are undeniable, Lithium may become a limited resource. A conservative estimate of how long Lithium resources will last when we only consider electric vehicles (assume a maximum use of 20 kg of Lithium per vehicle battery, global Lithium resources of 25.5 million tonnes, a moderate vehicle production of 60 million per year leading to a total production capacity of 1.2 billion electric vehicles) suggest that vehicle production will succumb before 2031 (i.e., within 21 years)! However, considering the cumulative estimated car production until 2030 in addition to production estimates of laptops, digital cameras, and mobile phones, we are likely to exhaust Lithium reserves (i.e., minable resources; USGS 2010) even before 2020 (Fig. 1). The total global Lithium resources are likely to be depleted before 2025—in less than 15 years. This increasing scarcity in Lithium will be paralleled by a price increase. As a result, Lithium recycling as well as difficult to access resource mining strategies will become feasible.

Can Lithium recycling make a difference?

Current recycling efforts of Lithium-ion batteries focus mainly on the economically interesting cathode materials cobalt and nickel, but largely neglect Manganese and Lithium even where sophisticated recycling systems are in place (Dewulf *et al.* 2010). In Germany, for example, the consumer returns used batteries in provided boxes at public places. A recycling system, the GRS foundation supported by major global battery manufacturers, will then recycle the batteries as required by German law. However, Lithium is not considered for recycling (GRS 2010) because it is still cheap enough to dump old batteries and to mine the virgin material. Given the likely future increase in Lithium prices, it will pay to start using simple methods such as hydrometallurgical separation for Lithium recycling now (Ferreira *et al.* 2009). In addition, recycling of nickel and cobalt from these batteries can

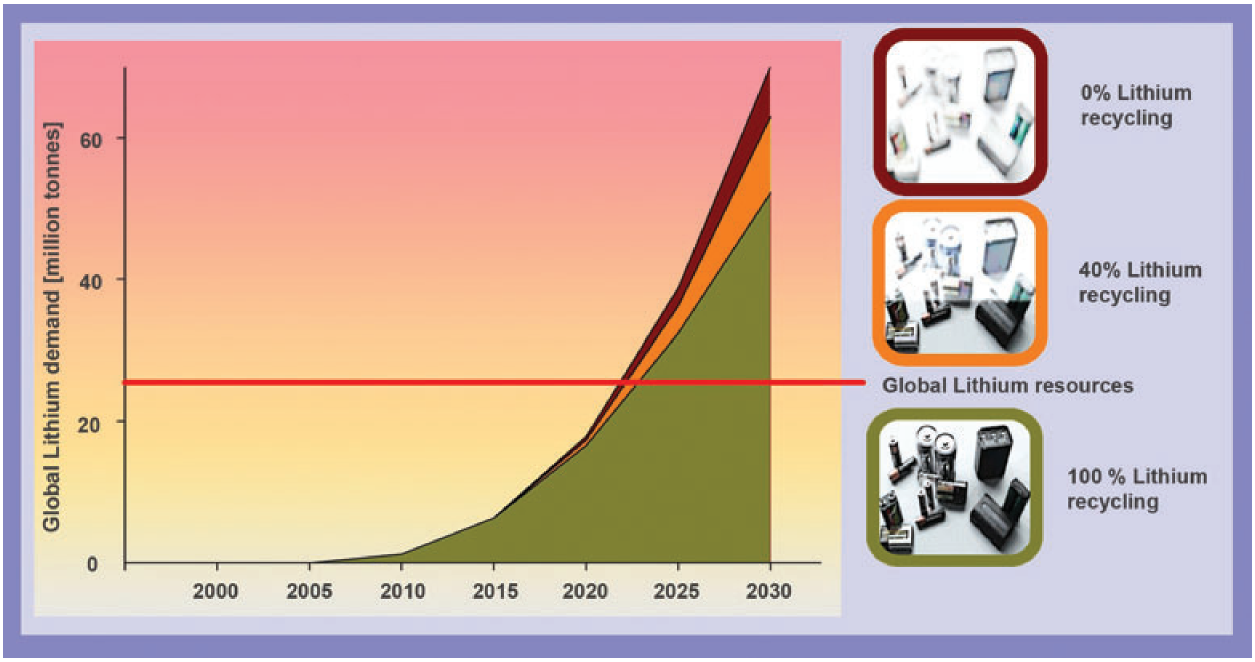

Figure 2 Effect of Lithium recycling on global Lithium demand. Shown are three scenarios assuming that 0, 40, and 100% of all Lithium required is recycled (40% was chosen because of current recycling efforts for other cathode materials like Nickel or Cobalt from Lithium-ion batteries; Dewulf *et al.* 2010). Due to a Lithium-ion battery lifetime, all scenarios assume a 10 years time lag (e.g., batteries produced in 2010 will be available for recycling only in 2020).

save 51% of the natural resources required (Dewulf *et al.* 2010). Thus, immediate recycling efforts would have economic and environmental benefits.

However, recycling alone—even if implemented on the spot—may not do the job. Assuming an average battery lifetime of 10 years and that 40 or 100% of all produced Lithium-ion batteries are recycled, future Lithium consumption may be reduced by 10.2 or 25.5%, respectively, by 2030 (Fig. 2). While not even the advent 100% recycling will prevent Lithium demand to overshoot the globally available resources before 2025, we are far from having a recycling system at this capacity. This suggests that recycling alone will not assure us Lithium battery powered mobile phones, laptops, cameras, and cars. Even with enormous recycling efforts, future Lithium scarcity will facilitate mining of lower grade deposits. The penalty of excessive exploitation in resource (Lithium-)-rich countries will be to the detriment of local people, biodiversity, and ecosystem services.

Lithium extraction and the environmental impact

Globally, the most important Lithium-production sites are in South America (Chile and Argentina). In large salt lakes, Lithium carbonate is produced through evaporation and washing with sodium carbonate in large scale polyvinyl chloride (PVC)—lined shallow ponds (Garrett 2004). To a lesser extend, spodumene ores as the main Lithium carrier are mined, for example, in Western Australia. In contrast to ore mining, environmental impacts of evaporative Lithium extraction are little understood but must be carefully evaluated.

A good example to illustrate side effects of Lithium extraction is the Bolivian salt pan Salar de Uyuni, harboring the world's second largest but untouched Lithium reserve (~5.4 million tonnes; USGS 2008). The salt pan is occasionally flooded by the Rio Grand river of Uyuni that provides freshwater for agriculture in the region (Messerli *et al.* 1997). In addition, the river and the Salar create an important but fragile habitat for the native biodiversity. Due to its natural beauty, the lake is the most visited tourist attraction in Bolivia and is considered to be one of the major income sources for the local people (Aguilar-Fernandez 2009).

Lithium processing in this region may cause changes in freshwater availability and water pollution with severe consequences for human health and native biodiversity. PVC barriers for the evaporation basins may leak chemical substances such as softeners into the environment. An evaluation of PVC drinking water pipes revealed that various compounds pose severe reproductive and functional health concerns to humans (Stern 2006). Chemical leakage may be worse for material involved in Lithium extraction and not related to human consumption. It has also been shown that aquatic diversity in the Neotropics is strongly affected by water pollution (Barletta *et al.* 2010), landscape modifications, and introduced sediments (Donohue & Molinos 2009). Negative effects on native biodiversity may have far-reaching consequences, also reflecting back onto local people. For example, the experimental reduction of flamingos feeding on cyanobacteria in Salar de Uyuni (Bauld 1981) changed ecosystem structure by increasing microbial biomass (Hurlbert & Chang 1983). While toxicity of cyanobacteria in hypersaline habitats is little understood, a survey across saltwater habitats in the US revealed that 85% of all species produced detectable levels of microcystins (Hudnell 2008). Microcystin, a toxin produced by various cyanobacteriae can have fatal consequences for humans and biodiversity (Chen *et al.* 2009; Hamilton 2009). As such, Lithium extraction will only benefit the poorest South American country (as suggested by Aguilar-Fernandez 2009), if impacts on the environment, biodiversity, and human health are taken into consideration. Moreover, it has to be assured that exploitative strategies, as seen during the past silver extraction in Bolivia, are not repeated.

Apart from evaporitic sequences, Lithium is also mined from pegmatite ores, for example, in Zimbabwe and Canada. Processing of spodumene, the main Lithium carrier in magmatic rocks is cost and energy consuming because the Lithium-incorporating silicates must be separated and then mostly transformed into carbonates for further processing. For ore mining and processing in general, environmental impacts such as physical land rearrangements (which can interfere with ground water carrying soil layers) and waste products (tail water from the mining sides often contain high concentrations of toxic compounds) are well documented and require proper management actions (Bridge 2004). Shocking examples come from eastern Africa, where mismanaged gold mining has lead to exorbitant mercury concentrations in rivers threatening aquatic diversity and downstream communities. There, mining workers are also suffering major health impacts from inhalation of siliceous dust and increasing malaria risk (Ogola *et al*. 2002). In collaboration with realistic conservation managers, it is the responsibility of mining companies to apply sustainable mining practice including suitable (i.e., low impact) extraction technology.

The environmental impact of evaporation ponds may be lower than that of Lithium or gold ore mining. Nevertheless, it is crucial to include environmental aspects in the discussion of how to sustainably manage Lithium resources with recycling and additional technologies.

The Lithium future

Overall, we will likely face a Lithium shortage with economic and environmental consequences. Like in the US, governments should make an effort to allocate funds for Lithium recycling projects (Hamilton 2009; USDE 2009). Immediate implementation of Lithium recycling will benefit investors, natural resources, and local people alike because resource exploitation costs and environmental impacts can be reduced. Given that recycling cannot prevent resource scarcity, Lithium technology must be supplemented by alternative energy concepts. In addition, effective recycling is only necessary, because consumption of Lithium demanding gadgets is ever growing and, hence, has to be sustainable itself.

There are already various alternative energy concepts. Metal-air batteries for instance seem promising but cannot yet serve a large energy market (insufficient power supply, short battery lifetime, inadequate recharging technology, and spacious design; MacKay 2008). Bioelectric battery concepts do not require natural resources as they generate power, for example, from glucose (Palmore 2004), but power supply is still very limited (GRS 2010). For electric vehicles, hydrogen fuel-cell powered cars with hydrogen produced from clean energy sources seems a promising solution. However, this technology has to become affordable for the public market, so that a new large-scale transportation industry can develop around this field (Zhang & Cooke 2009).

For economic growth, products (including electronic garments) are made for fast breakdown while advertisements suggest the consumer to always strive for the latest product; that is, products are designed for the dump (http://storyofstuff.org/electronics/). As such, Lithium recycling is urgently needed but the recycling process itself must be sustainable. In particular in poor parts of the world, where work labor is cheap and environmental standards are low, the recycling process must be strictly monitored. Ultimately, producers must find a better balance between economic growth and increased product longevity while the use of toxic material is minimized. Major policy actions should stringently regulate take-back actions and the subsequent recycling activities. In the meantime, everybody can contribute to resource protection beyond Lithium by wise consumer behavior: choose green products and think twice about how often you need to replace your car, mobile phone, laptop, and digital camera!

Acknowledgments

I thank B.W. Brook, N. Sodhi, T. Tscharntke, J. Schilling, I. Motzke, L. Traill, B. Scheffers, Q. Lan, and K. Darras for comments on the manuscript. Funding was provided through an Endeavour International Postgraduate Research Scholarship and a University of Adelaide scholarship, while preparing the manuscript.

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