Resources Policy 37 (2012) 93–103

Contents lists available at SciVerse ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

The time dimension and lithium resource constraints for electric vehicles

Duncan Kushnir*, Björn A. Sandén

Environmental Systems Analysis, Energy and Environment, Chalmers University of Technology, Göteborg 412 96, Sweden

ARTICLE INFO

Article history:
Received 1 July 2011
Received in revised form
29 November 2011
Accepted 29 November 2011
Available online 13 January 2012

JEL classification:
Q30

Keywords:
Transport
Battery
Electric
Vehicle
Transition
Lithium

ABSTRACT

The availability of lithium resources for a transition to electric vehicles is a vital topic for transport technology strategy. Recent debate seems to have concluded that there is 'sufficient' lithium available, but for the purposes of a technological transition, time matters. It is not simply the quantity of resource that is relevant—the flow rate into society may be a much more difficult constraint and transient events have disrupted heavily concentrated material supply chains in the past. Furthermore, critical assumptions such as the presence of recycling systems may not be justified without policy support. Complacency is therefore not an appropriate stance for a robust evaluation of material risks in the case of lithium.

Introduction

Issues of resource security and the end of cheap oil have sown the seeds for a discontinuous change in transportation vehicles and fuels. While there are many competing visions regarding what shape future transport systems can and should take, one prominent narrative is the adoption of plug-in hybrids as the first step toward a future of electric vehicles. The assumed technological core of these systems is the lithium ion battery, which possesses clear performance advantages versus other battery technologies at present for plug in hybrid (PHEV) and full battery electric (BEV) vehicles (Khaligh and Zhihao, 2010).

One of the strongest arguments for using electricity as a fuel is the promise of decoupling the production of transport energy from its end use; electric vehicles allow the maximum flexibility in choosing appropriate sources and mixes of energy for the transport sector. Whilst this is correct in principle, policies aimed at or hoping for a transformation of the transport sector towards electricity presuppose that batteries can be supplied in overall quantity sufficient for the scale of the project and at a rate that permits a sufficiently rapid change in the stock of vehicles. This has not gone unnoticed, yet there are divergent views on how best to assess resource adequacy in the long run; one begins from the truth that the planet and thus resources are finite and another holds that a better (only) way to measure scarcity is the opportunity cost of obtaining a resource and that the trend of this cost is unpredictable. An excellent description of this debate for resources in general is put forward by Tilton (2003).

Much research and data show that scepticism is appropriate towards claims of physical limits of resource availability; no case of general mineral depletion has existed as of yet (Simpson et al., 2005). Warnings of mineral scarcity have proven wrong time and time again because new discoveries and improving technology have outstripped the depletion of high grade resources. The empirical proof for this is that the real cost of most mineral commodities has thus far been falling over time, while the physical flow through society has increased (Govett and Govett, 1978; Slade, 1982; Tilton, 2003). The theoretical underpinnings of this trend are very relevant to policy makers and have been recently reviewed (Svedberg and Tilton, 2006) and defended (Tilton and Lagos, 2007). Despite this, given the importance of lithium to the vision of electric transport and of electric transport to some visions of sustainability, it is vital to not remain complacent and dismiss resource availability issues out of hand.

Discussions regarding the uncertain future of lithium availability have taken place for quite some time. With batteries now looming as another vast new demand for lithium, this debate has recently resurfaced. The scale of material use implied by some scenarios for mass production of vehicle batteries is sufficiently large that resource scarcity in the medium and long term cannot be ruled out outright for a number of potential battery metals (Andersson and Råde, 2001; Gaines and Nelson, 2009). With regards to lithium, generally accepted ideas of the magnitude of the resource seem to allow for a sizeable fleet of electric vehicles

* Corresponding author. Tel.: +46 31 772 1197.
E-mail address: kushnir@chalmers.se (D. Kushnir).

0301-4207/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.resourpol.2011.11.003

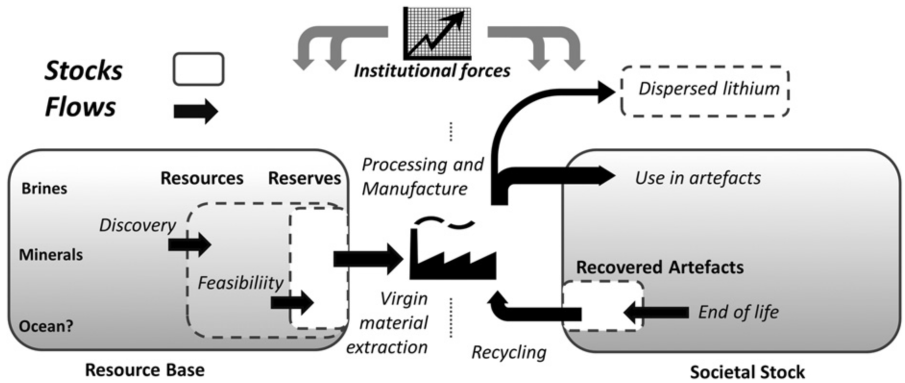

Fig. 1. A general material flow model for lithium.

(Evans, 1978, 2008a, 2008b; Will, 1996; Garrett, 2004; Gaines and Nelson, 2009; Yaksic and Tilton, 2009; Gruber et al., 2011). Many of the required resources are likely available without extreme cost or new technology, yet a closer look will show that visions of US or even Western European style mobility *or* vehicles with large batteries will test the boundaries of these assessments.

Furthermore, it is not sufficient to conclude that there is 'enough' lithium for a given scenario because there are other factors that complicate the issue with regard to lithium and which could ultimately be more relevant than the size of the resource or its projected cost of extraction. The rate of extraction needed to build up a large societal stock over a given time period (Andersson and Råde, 2001; Tahil, 2008) has implications, and historical cases featuring resources with similarly concentrated supplies, such as cobalt, give reason to believe that institutional inefficiency can be a major mechanism driving transitory scarcity (Alonso et al., 2007). While there is not necessarily reason for alarm over lithium supplies, there are risks and policy decisions that can affect the outcome. A strategic outlook on material availability demands explicit consideration of these risks and implications thereof, and thus it is our hope to continue the discussion on this important topic.

Analytic framework and paper layout

We use a somewhat stylized model to demonstrate key factors for the future of lithium. Fig. 1 illustrates the general stocks and flows of lithium as well as showing the layout of the argument presented here. The flows begin with the conceptual movement of a given bit of lithium from the resource base into the 'pseudo-stocks'[1] of resources and subsequently reserves from which they are extracted. As reserves are extracted into society they can be used in ways that result in the lithium being dispersed (e.g. grease), or they can be used in ways that form recoverable stocks that can later offset part of the supply flow into society if economics and technology allow. All such flows will be mediated and routed over time by a set of transient processes (institutional forces).

We begin in Section 2, by outlining possible global mobility scenarios and then work backwards from the implied vehicle battery stocks to determine the necessary flows into society and how they relate to the resources. The discussion on implications is structured by the time dimension; Sections 3–5 discuss possible constraints at the stock, flow and transient level. Our base assumption, discussed in Section 3, is that the work of Evans (2008b) and Yaksic and Tilton (2009) is approximately correct and that 25 million tons of lithium metal are viable (our word, discussed in Section 3) to recover from known resources plus another 5 million tons in marginal stocks, which we assume will be producible at prices that batteries will support. Beyond this, new discoveries or ocean extraction will be needed for further supply.

[1] So called because it is a conceptual subset of the total resource stock, not physically distinct.

Societal stocks and flows—estimating the demand for virgin lithium

We begin with the assumption that electric vehicles based on lithium batteries will become heavily adopted for transport in the future. The first level of comparison in our framework is thus to define what this means in terms of a societal stock. This will enable comparison with total and annual availability of virgin resources in following sections.

Stocks and flows related to current lithium applications

Availability of historically extracted lithium

Historical cumulative extraction (1940–2010) is estimated at about 0.5 Mt obtained by updating the 0.32 Mt that Andersson and Råde obtained for the cumulative extraction in 1999 with the annual mine production figures in the USGS lithium series for 1999–2011 (Andersson and Råde, 2001; Jaskula, 2006, 2011a, 2011b). This is a small amount compared to projected lithium demand and to resources still in the ground (indicating that lithium is a fairly new metal in industrial society). The amount contained in lithium batteries is also currently very small compared to any quantities projected for vehicles. Moreover, due to the many dissipative forms of lithium use and the limited utilization of recycling we assume that this potential resource can be neglected and that there is effectively zero recoverable lithium stock in society in 2011.

Expected use and dispersion of lithium in other applications

Current production of lithium is roughly 25 kt/yr as metal equivalent. As shown in Table 1, lithium has a variety of uses, but many are experiencing only modest growth compared to the total or to that of batteries. It is very uncertain how other lithium applications will react to a large new demand that possibly pushes prices up. To this end, no specific treatment of the elasticity of other lithium applications to price signals exists to the authors' knowledge. If the cumulative availability curve is sound and prices stay near where they are, then other applications could continue on their current trajectories, which are generally growing with the exception of lithium used in some