Resources, Conservation & Recycling 129 (2018) 263–277

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Review

A review on the growing concern and potential management strategies of waste lithium-ion batteries

Kevin M. Winslow, Steven J. Laux, Timothy G. Townsend*

Department of Environmental Engineering Sciences, University of Florida, P.O. Box 116450, Gainesville, FL 32611-6450, USA

ARTICLE INFO

Keywords:
Lithium-ion battery
End-of-life
Waste management
Regulations
Strategies
Recycling

ABSTRACT

This review paper discusses the available literature on end-of-life lithium-ion batteries (LIBs) from a waste management standpoint. The amount of LIBs entering the waste stream has increased in recent years because of their growing prevalence in electronic devices and vehicles. The electric vehicle (EV) industry, in particular, is expected to create a high demand for LIBs and this paper has identified them as a major contributor to the LIB waste stream in the near future. Waste LIBs exhibit many hazardous characteristics, such as the ability to spontaneously ignite and/or release hazardous chemicals under landfill conditions. The authors review the current findings with regards to their hazardous properties and present potential solutions to help mitigate these problems. One major solution is to manage LIBs as a hazardous or universal waste, which would entail special regulations for this waste stream. While lead-acid and nickel-cadmium batteries are often regulated as a hazardous or universal waste, most countries, such as the U.S., currently manage LIBs as a general solid waste. However, it may be plausible to consider these types of batteries as a hazardous or universal waste because they have frequently exceeded federal and state regulatory thresholds for certain metals, such as lead. This paper also identifies recycling as another major solution for end-of-life LIB management. Based on life cycle impact assessment studies, recycling certain types of LIBs results in a lower resource depletion potential and less air emissions than a cradle-to-grave management scenario.

1. Introduction

Since they were introduced commercially in the 1990s, lithium-ion batteries (LIBs) have been used extensively in cell phones, laptops, cameras, and other electronic devices. Their rechargeable nature and high energy density make them excellent candidates for portable applications where a frequent source of energy is needed. Recently, LIBs have found a niche as a power source for electric vehicles, gradually replacing nickel-metal hydride batteries (Wang et al., 2014). The growing share of LIBs in the global battery market has sparked an increased interest in understanding the environmental impacts associated the production, usage, and final stages of their life cycle.

This paper discusses the current body of literature on LIBs when they reach their end-of-life and become part of the waste stream. Many of the existing reviews on LIBs focus on recycling methods, the environmental impacts from their production and usage (cradle-to-gate), and technological innovations in battery design (Etacheri et al., 2011; Fergus, 2010; Peters et al., 2017; Vanitha and Balasubramanian, 2013; Xu et al., 2008; Zeng et al., 2014; Zhang, 2006). However, there is yet to be a review that discusses the disposal side of managing waste LIBs. This review brings together information on the characteristics, environmental impacts, and management strategies with regards to the end-of-life LIB waste stream. Specifically, the focus is on the composition of LIBs, future waste generation, potential destinations of the waste stream, impacts of disposal, current regulations, and recycling options. This review is needed because the world is experiencing an increasing reliance on this technology, so it is important to understand the environmental impacts when the product reaches its end-of-life and how the waste stream can be managed most sustainably.

2. Background

2.1. Lithium-ion battery design and function

An LIB is composed of four basic components: a cathode, an anode, an electrolyte separator, and an outer casing. The exact mass and chemical compositions of each component vary between different manufacturers (Zhang et al., 2013). The cathode comprises 25–30% of the battery's total weight and consists of a thin aluminum current collector sheet that is usually layered with a metal oxide, often referred to

* Corresponding author.
E-mail address: ttown@ufl.edu (T.G. Townsend).

https://doi.org/10.1016/j.resconrec.2017.11.001
Received 24 July 2017; Received in revised form 31 October 2017; Accepted 1 November 2017
0921-3449/ © 2017 Elsevier B.V. All rights reserved.

Table 1
Reported elemental and material concentrations in LIB samples.

Research group	Complete Battery, $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ cathode (Gaines et al., 2011)	Complete Battery, $LiMn_2O_4$ cathode (Gaines et al., 2011)	Complete Battery, $LiNiMnCoO_2$ cathode (Richa, 2016)	Complete Battery, $LiCoO_2$ cathode (Wang et al., 2016)	Complete Battery, $LiFePO_4$ cathode (Wang et al., 2016)
Metals	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)
Aluminum	21.9	21.7	22.72	5.2	6.5
Cobalt	2.3	0.0	8.45	17.3	0
Copper	13.3	13.5	16.6	7.3	8.2
Iron/Steel	0.1	0.1	8.79	16.5	43.2
Lithium	1.9	1.4	1.28	2.0	1.2
Manganese	0.0	10.7	5.86	0	0
Nickel	12.1	0.0	14.84	1.2	0
Other	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)	Conc. (mass%)
Binder	3.8	3.7	1.39	2.4	0.9
Carbon (non-graphite)	2.4	2.3	3.47	6.0	2.3
Electrolyte + Solvent	11.7	11.8	1.66	14.0	14.9
Fluoride	–	–	4.99	–	–
Graphite	16.5	16.3	–	23.1	13.0
Thermal Insulation	1.2	1.2	–	–	–
Oxygen	8.3	12.4	4.52	–	–
Phosphorus	–	–	2.04	0	5.4
Plastics	4.2	4.5	3.29	4.8	4.4

− means not reported or analyzed.

as the cathode material (Gaines et al., 2011; Zeng et al., 2014). Different cathode material chemistries result in different battery properties. Most of the valuable metals contained within an LIB can be found in the cathode (Zou et al., 2013). The anode represents 15–30% of the battery's total weight and is typically made up of a copper current collector sheet that is coated with a graphite layer (Gaines et al., 2011; Zeng and Li, 2014). The cathode material and anode material are fused with an inert binder, such as polyvinylidene fluoride (PVF), to help them adhere to their respective metal collector sheets (Zeng et al., 2014). A separator between the cathode and the anode contains an electrolyte dissolved in an organic solvent. The purpose of the electrolyte is to allow the controlled movement of lithium ions between the electrodes during the cycling process (Amarakoon et al., 2013). The cathode, anode, and electrolyte separator are all contained within the battery. An outer casing composed of steel, aluminum, or plastic isolates the inner components from the outside environment (Kushnir, 2015).

2.1.1. Cathode compositions

Common cathode materials incorporate oxides of transition metals that can undergo oxidation to a higher valence state when lithium ions are removed from the cathode during charging (Whittingham, 2004). Typical cathode material consists of 80–85% metal oxide powder, 10% polyvinylidene fluoride binder, and 5% acetylene black (Chagnes and Pospiech, 2013). Four of the more common lithium metal oxides used in the cathode include lithium cobalt oxide (LCO or $LiCoO_2$), lithium manganese oxide (LMO or $LiMn_2O_4$), lithium nickel manganese cobalt oxide (NMC or $LiNiMnCoO_2$), and lithium nickel cobalt aluminum oxide (NCA or $LiNiCoAlO_2$) (Ellis et al., 2010; Fergus, 2010). Lithium iron phosphate (LFP or $LiFePO_4$) is another common cathode material used that is not a metal oxide. LFP and LMO cathodes cost significantly less to produce than LCO cathodes because of the lower value metals used (Thackeray et al., 2005). However, the recycling value of LCO batteries is the highest among the different battery chemistries, mainly because of the valuable cobalt they contain (Amarakoon et al., 2013; Wang et al., 2014). Other valuable metals can be found within the cathodes in trace amounts. Niobium is found in some LFP cathodes in small quantities as an added ingredient to improve the electrical conductivity of the cathode (Wang et al., 2016). Many more cathode chemistries are in development with the goals of decreasing the costs of production and extending battery capacity and performance (Ellis et al., 2010).

2.1.2. Anode compositions

Graphite is commonly used as an anode material and consists of hexagonally bonded carbon atoms arranged in sheets. During charging, lithium ions become stored within the graphite, embedded between the sheets (De las Casas and Li, 2012). The capacity of the battery is determined by how many lithium ions can be stored in a given amount of anode material. The theoretical storage capacity of graphite is fairly low, at 372 mA h per g (De las Casas and Li, 2012; Moradi and Botte, 2016). A material commonly used as a replacement for graphite is the spinel form of $Li_4Ti_5O_{12}$, which offers a longer cycle life (Heelan et al., 2016; Yi et al., 2010). Carbon nanotubes, tin compounds, and metallic nanoparticles are among the latest technologies in development for improving anode performance (De las Casas and Li, 2012). These new chemistries could increase the recycling value of the anode, which is mostly recycled for the copper current collector (Moradi and Botte, 2016).

2.1.3. Separator and electrolyte compositions

The separator is usually made of micro-porous polypropylene or polyethylene that allows the passage of lithium ions during the cycling process (Chagnes and Pospiech, 2013; Zou et al., 2013). The separator contains a lithium salt electrolyte in a solvent typically consisting of a cyclic or linear carbonate, such as ethylene carbonate, propylene carbonate, or dimethyl carbonate (Aravindan et al., 2011; Dunn et al., 2012; Heelan et al., 2016). A wide variety of electrolytes exist with different properties that dictate their stability and how well they conduct lithium ions between the electrodes. Common electrolytes used in LIBs include $LiClO_4$, $LiBF_4$, $LiAsF_6$, $LiPF_6$, $Li(CF_3SO_3)$, $Li[N(CF_3SO_2)_2]$, and many others (Aravindan et al., 2011). The solvent containing the electrolyte typically has a high permittivity and low viscosity (Aravindan et al., 2011). Toxic gases can be released from the electrolyte and solvent if they are exposed to water in the atmosphere (Nan et al., 2005; Ribière et al., 2012; Sonoc et al., 2015). Previous studies have placed the electrolyte separator in an alkaline solution after dismantling to prevent the release of toxic pentafluoroarsenic, pentafluorophosphate, and hydrogen fluoride (Archuleta, 1995; Nan et al., 2005).

2.1.4. Typical mass compositions of LIBs

Table 1 presents the mass concentrations of materials in different types of LIBs as reported from multiple studies. Compositions will often

Download English Version:

https://daneshyari.com/en/article/7494556

Download Persian Version:

https://daneshyari.com/article/7494556

Daneshyari.com