Sustainable Materials and Technologies 1–2 (2014) 2–7

Contents lists available at ScienceDirect

Sustainable Materials and Technologies

The future of automotive lithium-ion battery recycling: Charting a sustainable course

Linda Gaines [1]

Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, United States

ARTICLE INFO

Article history:
Received 27 August 2014
Accepted 6 October 2014
Available online 15 November 2014

Keywords:
Lithium-ion
Battery
Recycling

ABSTRACT

This paper looks ahead, beyond the projected large-scale market penetration of vehicles containing advanced batteries, to the time when the spent batteries will be ready for final disposition. It describes a working system for recycling, using lead–acid battery recycling as a model. Recycling of automotive lithium-ion (Li-ion) batteries is more complicated and not yet established because few end-of-life batteries will need recycling for another decade. There is thus the opportunity now to obviate some of the technical, economic, and institutional roadblocks that might arise. The paper considers what actions can be started now to avoid the impediments to recycling and ensure that economical and sustainable options are available at the end of the batteries' useful life.

1. Introduction

Recycling, per se, is not inherently good or bad [1]. For some materials such as glass [2], the benefits are dubious and depend on factors like the shipping distance. There has been some debate about the benefits from recycling primary alkaline batteries over simple disposal [3] because the materials are abundant and non-toxic, now that the batteries no longer contain mercury. For automotive batteries, however, the environmental benefits are clear, although they vary with battery type and recycling method. There are potential economic benefits as well. If usable materials can be recovered from used batteries, less raw material needs to be extracted from the limited supplies in the ground. If the raw materials come from abroad, recycling domestically reduces the quantities that need to be imported, improving the balance of payments. In addition, significant negative environmental impacts can occur from mining and processing ores (e.g., SO_x emissions from smelting of sulfide ores, such as those that yield copper, nickel, and cobalt), and these are avoided if the materials can be recycled [4]. Recycling has its own environmental effects, but these are generally smaller than those from primary production. There are, of course, exceptions, such as recovering lithium from pyrometallurgical process slag. Recycling of materials avoids processing costs for waste treatment. In addition, some spent batteries are classified as hazardous wastes, increasing transportation, treatment, and disposal costs, as well as the effort needed to achieve regulatory compliance. Lithium-ion batteries are classified as Class 9 miscellaneous hazardous materials, and lead–acid batteries are listed as Class 8 corrosive hazardous materials under United States regulations (40 CFR 173.21(c)) [5].

Lithium-ion batteries are starting to be used in significant quantities for automotive propulsion. Because these batteries are expected to last the life of the vehicle, they will not be ending their useful lives in large numbers for about 10 years. They may subsequently be used for utility energy storage, but eventually their useful lives will end. The question is, what steps can be taken to ensure that these spent Li-ion batteries are recycled. In an ideal system, these batteries would be sent for responsible recycling and not be exported to developing countries with less stringent environmental, health, and safety regulations. Methods are needed for the safe and economical transport and processing of the spent batteries, as well as environmentally sound recycling. In addition, the recycled product needs to be of high enough quality to find a market for its original purpose, or it must find an alternative market. Fortunately, a battery recycling system is in place that already works well, and many lessons can be learned from it.

1.1. Lead–acid battery example

Lead–acid batteries are recycled more than any other major consumer product (see Fig. 1). Even with advertising programs, education, and convenient curb-side pickup, recycling of common consumer products in the United States has not been a resounding success. However, lead–acid batteries (and to a lesser extent discarded tires) have achieved exemplary recycling rates.

In the United States, about 99% of lead–acid batteries are recycled [6]. Lead–acid (Pb–acid) battery recycling is also working well in Europe and Japan. In disadvantaged areas, backyard operations have exploited children to disassemble batteries and electronics for treatment in smelters without emission controls, and dumped lead-contaminated acid into the water supply, but such practices are now being eliminated [7].

E-mail address: lgaines@anl.gov.
[1] Tel.: +1 630 252 4919; fax: +1 630 252 3443.

http://dx.doi.org/10.1016/j.susmat.2014.10.001

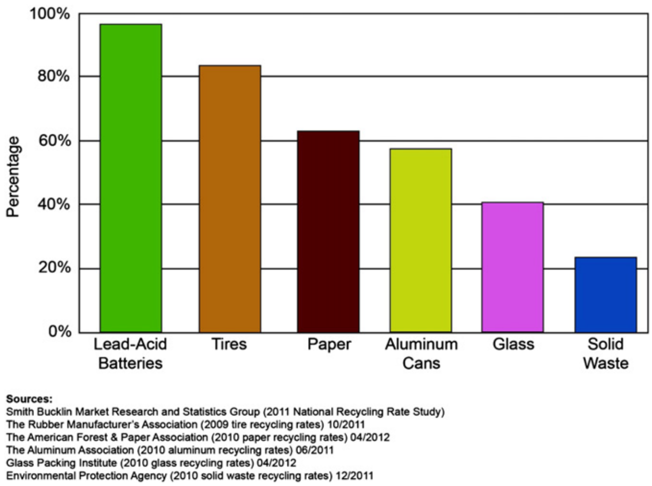

Fig. 1. Batteries are the most recycled consumer product.
(Courtesy of Battery Council International)

To date, the model shown in Fig. 2 has worked admirably for lead–acid battery recycling. We consider whether some variation of this model would work well for other battery types.

1.2. Comparison of automotive battery types

Before considering that topic, it is useful to first compare the physical and chemical structures of different types of automotive batteries: namely, the lead–acid batteries used for starting-lighting-ignition (SLI) and commonly found under the hood of most cars, nickel–metal-hydride (Ni–MH) batteries used in hybrid vehicles, and Li-ion batteries used in plug-in vehicles and some hybrids. The latter two battery types are used primarily for propulsion and heating, ventilation, and air conditioning (HVAC), although some designs are also available for use in conventional SLI applications. These will be discussed later.

The three battery types are all conceptually and structurally similar but chemically quite different. Each consists of electrode (cathode and anode) active materials on grids or foils that serve as the current collectors, with an electrolyte that carries charge between the electrodes.

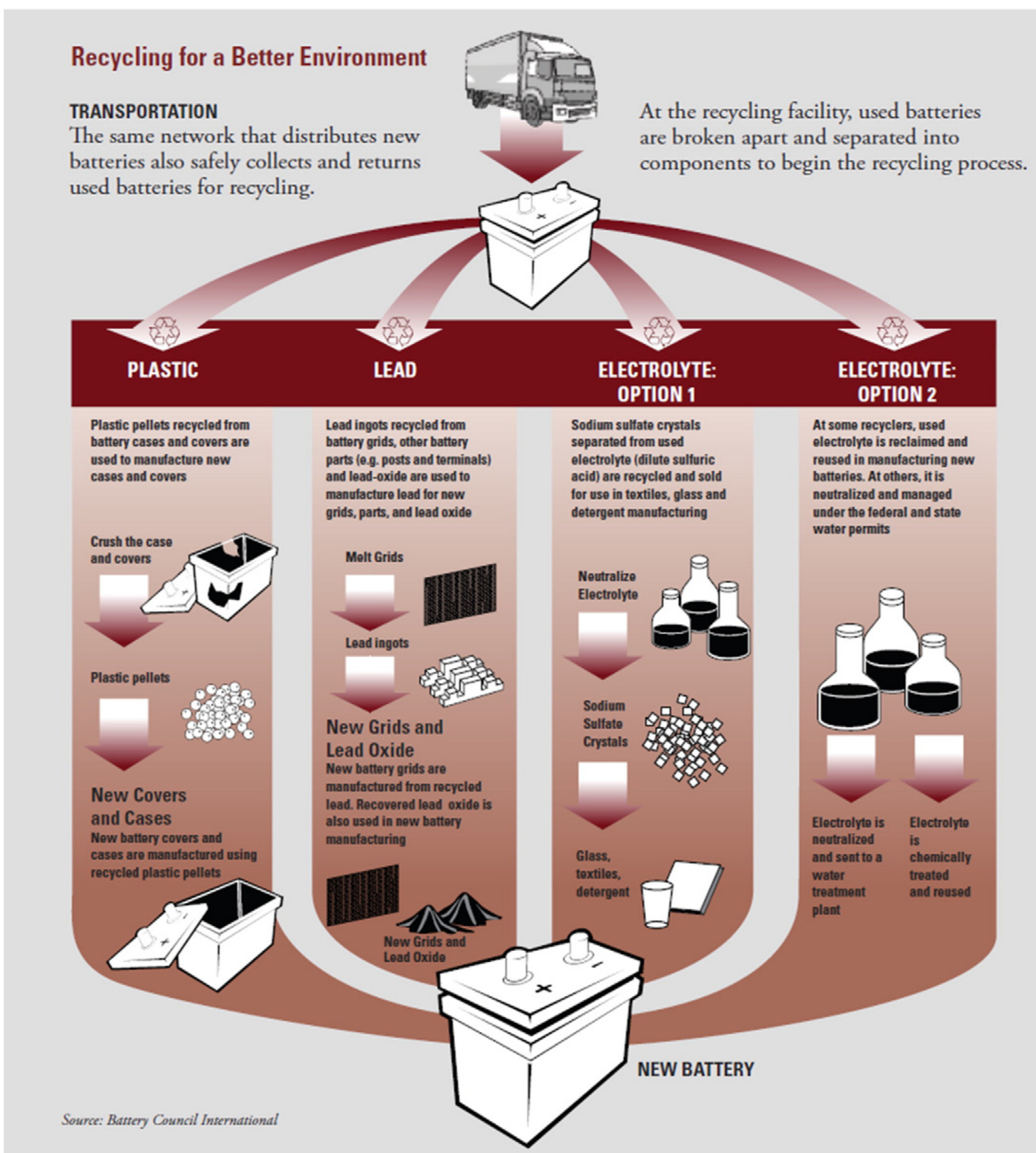

Fig. 2. Simple processes are used to recycle lead–acid batteries.
(Courtesy of Battery Council International)