Eco Design Notes

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Battery Toxicity and Eco Product Design

This is the first in a series of Eco Design Notes. It provides a comparison of the hazards associated with the types of batteries that are commonly used in off-grid lighting products, as well as a summary of the potential to address these hazards through product design, proper disposal, and recycling. More information can be found at:

www.lightingafrica.org/resources/briefing-notes.html

Introduction

Modern off-grid lighting devices are a promising, low cost alternative to fuel-based lighting. Such lights have the potential to deliver socio-economic, environmental, and public health benefits to the users and communities they serve. These off-grid lighting products use batteries, and some battery chemistries contain toxic metals and caustic electrolytes that pose a danger to people and the environment if batteries are handled or disposed of improperly.

Batteries come in a variety of types and chemistries, and each type is composed of a different mix of chemicals and heavy metals. Mercury, lead, cadmium, and nickel are common heavy metals that pose health and environmental risks with improper disposal. If incinerated, these heavy metals may be released into the air or concentrate in the ash produced by combustion. In landfills, heavy metals sometimes leach into the soil, surface water, or ground water. The health effects vary by heavy metal type and exposure level, but common symptoms from ingestion or inhalation of heavy metals may include headaches, abdominal discomfort, seizures, and comas.

Manufacturers are encouraged to design products with less hazardous battery chemistries. By making this environmentally sound design choice, manufacturers can prevent toxic battery components from entering the consumer waste stream, protecting both consumers and the environment. In general, Nickel Metal Hydride and Lithium Ion based batteries have lower toxic content than other battery types and are considered the most environmentally benign (even these, however, have safety and environmental hazards that should be considered)

Battery Quality often determines the number of cycles a rechargeable battery will deliver and thus the lifetime of that battery. Higher quality batteries will increase a product's usefull life (a benefit to the consumer) and also reduce the number of batteries for disposal (a benefit to the environment).

A Summary of Battery Types

While a wide range of types and chemistries are available, batteries are divided into two broad classes: primary (single-use) and secondary (rechargeable) batteries.

<u>Primary Batteries (single-use, disposable)</u>

Zinc Carbon batteries are the cheapest primary battery. Widely used in Sub Saharan Africa, zinc carbon batteries perform poorly in high-drain applications such as digital cameras, but are moderately effective in low to medium-drain applications such as flashlights and radios.

Alkaline batteries provide better performance than zinc carbon, at an increased price. Alkaline batteries can contain mercury, although the use of mercury has been restricted or banned in some countries.

Button Cell batteries are found in hearing aids, calculators, and watches. A variety of chemistries exist such as zinc air, and lithium, silver and mercuric oxide. They have a high energy density and are inexpensive but have limited applications. Some button cells contain mercury and are restricted or banned in some countries.

Rechargeable Batteries (multi-use, "secondary")[1]

Lead-Acid batteries are inexpensive and rugged when handled properly. "Wet-cell", lead acid batteries are the main source of power for cars, trucks, boats and other vehicles. Sealed lead-acid (SLA) batteries are commonly used to power industrial equipment, emergency lighting, and are often used in off-grid LED lighting applications. They are the most economical battery for high-power applications where weight is of little concern. Lead acid batteries contain large amounts of lead (relative to heavy metal content in other batteries), a very toxic heavy metal.

Nickel-Cadmium (Ni-Cd) batteries are a mature secondary battery technology. They are relatively inexpensive and have a moderate energy density. Ni-Cd batteries are used where long life, high discharge rate and extended temperature range are important. Their potential for voltage depression ("memory effect") and toxic cadmium content are important disadvantages.

Nickel Metal Hydride (NiMH) batteries were developed as a cadmium-free replacement for Ni-Cd. NiMH batteries have a higher energy density and are less prone to "memory effect" than Ni-Cd, but have a shorter cycle life. They are more expensive than Ni-Cd, but less expensive than Li-Ion. NiMH battery technology is also viewed as the predecessor to lithium-based systems.

Lithium-Ion (Li-ion) batteries are most commonly found in laptops and cell phones. Li-Ion batteries have a high energy density, are lightweight, and provide excellent performance. They are historically the most expensive rechargeable battery, but in recent years prices have dropped due to mass adoption by the cell phone market. Li-ion batteries must contain protection circuits to limit voltage and current for safety reasons.

Lithium-Iron Phosphate (LFP) batteries are the newest rechargeable battery technology. LFP batteries are a type of Li-ion battery where the cathode is composed of $LiFePO_4$. The iron composition increases the stability of the cathode and decreases cost.

Health and Safety Risks of Battery Components

Strong electrolytes and heavy metals are essential components in battery chemistry, but they are also toxic and hazardous materials. If batteries are not recycled or disposed of properly, their components will eventually enter the soil, air, and water supply, posing serious health risks to humans and the environment.

Electrolytes[2]

A variety of electrolytes are utilized for different battery types, and they are generally caustic, corrosive, or flammable.

Potassium Hydroxide is caustic, and may cause burns or damage to skin, eyes, or the respiratory system.
Found in: Alkaline, Button Cell, Nickel-Cadmium, Nickel Metal Hydride, and Lithium Ion batteries.

Sulfuric Acid is corrosive and may cause burns or damage to skin eyes or respiratory system.
Found in: Lead-Acid and Sealed Lead Acid batteries.

Ethyl Methyl Carbonate(EMC), Ethylene carbonate(EC), Propylene Carbonate(PC), Dimethyl carbonate(DMC) and lithium hexaflurosphate (LiPF6) are the main ingredients of the electrolyte in a lithium-ion battery. The chemistry is flammable and may decompose to hydrofluoric acid if exposed to moisture.
Found in: Lithium-ion batteries.

Heavy Metals[3,4]

Heavy metals cannot be degraded or destroyed. As trace elements, some heavy metals are essential to maintain metabolism and enter our bodies via food, water, and air. However, at higher concentrations they can cause poisoning. Heavy metal poisoning could result from drinking water contamination, high ambient air concentrations near emission sources, or intake via the food chain.

Mercury is a recognized developmental toxicant. The nervous system is very sensitive to mercury; brain and kidney damage can result from mercury exposure. *Found in:* Alkaline batteries in countries that have not banned or restricted the use of mercury, and Mercuric oxide type button cells.

Cadmium is carcinogenic and a recognized developmental and reproductive toxicant. Long term exposure is associated with renal disfunction and bone defects.
Found in: Nickel-Cadmium batteries.

Nickel is considered semi-toxic. While the most common effect of nickel exposure is skin irritation and allergic reactions, nickel and nickel compounds are also considered potentially carcinogenic for those with chronic exposure to airborne nickel dust.
Found in: Nickel-Cadmium, Nickel Metal Hydride, and some Lithium based batteries.

Lead is a carcinogen and a recognized developmental and reproductive toxicant. Exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. High levels of exposure may affect the kidneys, gastrointestinal tract, reproductive system, and the nervous system.
Found in: Lead-Acid and Sealed Lead Acid batteries.

Cobalt and Cobalt Compounds are considered potentially carcinogenic.
Found in: Lithium-ion and Nickel Metal Hydride batteries.

Battery Safety

It is important to note that if most battery types are stored, charged, or used improperly there is a danger of short-circuiting, ignition, or explosion. For example, If the protection circuits of Lithium-Ion batteries are damaged by incorrect charging or use a serious hazard of ignition or explosion exists. Batteries should also not be incinerated as this too can cause explosion and/or produce toxic heavy metal vapors.

Design Choices and Battery Selection

The first and best opportunity to prevent toxic battery components from entering the waste stream comes during the design process when a manufacturer chooses the battery type. Nickel Metal Hydride and Lithium based cells are good environmental choices for off grid lighting products. They exhibit high performance and have a low toxic content, and are the most benign battery types in terms of disposal. Well designed products that use NiMH or Li based batteries are currently in the marketplace that have good lifetimes and high performance at reasonable consumer prices.

Battery Disposal and Recycling

Proper battery disposal and recycling practices depend on the chemistry of each battery. Regulations enforcing proper battery disposal vary widely between countries and municipalities. The economic feasibility of recycling, availability of hazardous waste facilities, as well as consumer awareness of proper disposal practices greatly influence how batteries are treated at the end of their useful life.

Disposal

It is essential that batteries are disposed of properly, according to chemistry type, because the toxic materials they contain can endanger human health and the environment. These proper disposal methods and their corresponding battery types are described below and summarized in Table 1.

Sanitary ("lined") landfill

Landfill disposal is considered acceptable for Zinc Carbon, Alkaline (mercury-free), Button Cell (mercury-free), NiMH, and Li-Ion batteries, but only in very small quantities. "If ten or more batteries are accumulated, the user should consider disposing the batteries in a secure waste landfill" (Buchmann 2006). There is still a risk of contamination with this method of disposal because the liners of landfills can eventually fail. It is also preferable to recycle certain types such as Li-Ion and NiMH because of the scrap value of their components.

Hazardous waste disposal site

Batteries containing toxic mercury, cadmium, and lead must either be disposed of in a designated hazardous waste facility or recycled because of the potential health threats they pose. Disposal of batteries in hazardous waste facilities is expensive, the availability of such facilities is limited, and there is still a risk of air, water, and soil contamination. In addition, some types of batteries are considered economically desirable for recycling. Hazardous waste disposal for batteries is not considered ideal, but a good option if recycling is not available or not economically feasible.

Recycling

Recycling is an ideal way to dispose of most if not all types of batteries. In practice, however, recycling is often quite limited by economic and logistical barriers. Battery recycling consumes a lot of energy, facilities can be limited depending on location, and the cost of shipping to recycling facilities can be expensive because of the weight of batteries. For some battery types recycling is preferred because of the resale value of scrap metal (e.g. NiMH), while for others it is preferable to recycle in order to divert heavy metals and other toxicants from the waste stream (e.g. Mercuric oxide). Some batteries fall into both categories (e.g. Lead Acid). Table 1 categorizes the reasons for recycling by battery type.

Battery Disposal in Africa

Zinc Carbon and Lead Acid are the most common battery types in use in Sub Saharan African (SSA) countries. However, the quantities of NiMH, Ni-Cd, and Li-Ion types entering the waste stream continue to grow with the increased prevalence of mobile phones and off-grid lighting products.

Battery disposal practices and the effectiveness of municipal solid waste collection vary widely by location. In general, few proper sanitary landfills exist and the trash is agglomerated in unlined garbage pits (often defunct quarry sites). Non-lead batteries are typically mixed in with household waste either in the garbage pits, by the roadside and abandoned lots as litter, or in the latrine. Many batteries are also burned in trash fires, which can mobilize heavy metals into dangerous air-born forms.

The availability of Hazardous Waste facilities in SSA is extremely limited. At the time of writing this report, South Africa is found to be the only SSA country with an effective Hazardous Waste Management system.

There is a robust market in SSA for lead scrap metal, so lead-containing batteries are collected by the informal sector and sold to scrap metal dealers. Some countries have made significant advances in the collection of battery and electronic waste, particularly South Africa and Kenya.

Battery Recycling[5,6]

Battery recycling provides invaluable environmental and public health benefits -- this should be the primary goal of battery recycling. It can also potentially yield some limited economic benefits. While scrap metal provides a promising economic incentive to protecting humans and the environment, "significant subsidies are still required from manufacturers, agencies and governments to support the battery recycling programs"[1]. Sorting the batteries by type is expensive and greatly adds to the cost of recycling. In addition, the weight of batteries results in prohibitive shipping costs if recycling facilities are not nearby. The price garnered for scrap metals after the battery recycling process is tied to market values and fluctuates daily. It is calculated as a percent of the price of pure metals on the London Metal Exchange (LME). Metal purity and global demand also highly influence the value of battery scrap metal.

While there are many nuances to recycling based on battery chemistry, the recycling process generally starts by removing the battery casing material with shredders, hammer mills, or heat. The electrolytes are then neutralized with a chemical bath, and the cells are chopped into small pieces. The heavy metals are recovered by pyrometallurgical processes, and are sold back into the manufacturing chain.

Alkaline and Zinc Carbon batteries contain zinc, manganese and some iron which can be recovered by recycling. The end metal product can be used to make low-grade steel (i.e. rebar), or slag usable in road construction. The scrap value of Alkaline and Zinc Carbon is relatively low compared to other chemistries.

Button Cell batteries that are mercury-free are considered desirable for recycling because of the value of recoverable materials (silver, zinc, and steel), their small size, and their easy handling relative to other battery types. Market value for reclaimed metal varies by chemistry.

Nickel-Cadmium batteries can be recycled to recover Cadmium and ferronickel metals that yield a moderate market price.

Nickel Metal Hydride batteries yield the best return on recycling. The recycling process is less expensive than that of Li-Ion, and the recoverable Nickel metal has a high scrap value.

Lithium-Ion batteries are the most expensive to recycle because they require complex recycling processes. However, because the recoverable cobalt and other metals also have relatively high scrap value, Li-Ion is considered an economically desirable battery to recycle (where facilities exist).

Lead Acid batteries are the most frequently recycled batteries worldwide. The plastic casings, lead, and sulfuric acid contained in lead-acid batteries can all be recovered and reused in other industries. There is a mature, global resale market for scrap lead that yields a moderate market value.

Batteries containing mercury undergo a controlled-temperature process to recover the mercury. While the resale value of recovered mercury may only yield a moderate to low market price, it is important that batteries containing mercury are recycled because of toxicity.

Battery Recycling in Africa

Lead Acid batteries are widely recycled throughout SSA because there is a robust market for lead scrap metal. While there are some formal battery recycling programs, lead-containing batteries are often collected by the informal sector and sold to scrap metal dealers. Lead recycling has its own environmental health hazards, and if unregulated, can cause serious air, water, or soil pollution.

Wastewater from cleaning lead batteries, emissions from melting them down, and the leftover metal "slag" are all toxic by-products of lead recycling. Many countries in SSA "Lack adequate institutional capacity in hazardous waste management and monitoring…" (Brice, 2004), and do not regulate lead recycling operations. "The wastewater from cleaning the batteries is contaminated with lead and is often discharged directly into sewer systems" (Brice, 2004). While there are many environmental and health benefits, recycling lead doesn't necessarily represent a complete solution to the toxicity issue of lead battery disposal, given current practices in SSA.

At the time of writing, it is believed that only lead-acid batteries are collected and recycled on a large scale in SSA. Information about SSA recycling and battery disposal practices in literature and on the internet is limited. However, it was found that a battery smelter in South Africa is currently trying to obtain certification of a facility to recycle "Ni-Cd and other chemistries".

Design Choices and Manufacturer Responsibility

Limited disposal and recycling options for batteries places more responsibility on off grid lighting product manufacturers to use less toxic battery types in their products. Sealed lead acid batteries, found in some low cost, low quality products, are of particular concern. Some of these have short lifetimes (very high lumen depreciation) and are gaining a reputation as disposable products despite being marketed as rechargeable. SLA batteries contain large amounts of lead, and evidence suggests that the vast majority of these products are not disposed of properly.

There are two primary concerns with these types of low quality, high toxicity products. The heavy metals and toxins, when disposed of improperly, can contaminate the environment and pose a health risk to people and children who live and work in the area. Further, low quality products can contribute to market spoilage, whereby off grid lighting products in general gain a poor reputation due to poor consumer experiences.

Manufacturers may be influenced to use lead and cadmium type batteries because of cost concerns, as Ni-Cd and SLA batteries tend to be less expensive than the more environmentally benign NiMH and Li-ion batteries. The design of an efficient product, however, can minimize system component sizes and help mitigate or eliminate the added cost of NiMH and Li-ion batteries. As an example, doubling the efficiency of the light source (LED, driver electronics, optics) could allow a battery pack (and battery capacity) reduction of 50% as well as a smaller solar panel without sacrificing any performance as seen by the consumer. Add to this the benefits of NiMH and Li-ion batteries (high energy density, long lifetimes, small size), and the off grid lighting product can provide good performance for the customer, long service life, and be an environmentally responsible alternative to fuel based lighting.

References

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Table 1: Proper Battery Disposal by Type*

Battery Type	Sanitary Landfill	Hazardous Waste Facility	Recycling
Primary			
Zinc Carbon	X		OK
Alkaline (mercury free)	X		OK
Alkaline (contains mercury)		X	T
Button Cell (mercury free)	X		V
Button Cell (contains mercury)		X	T
Secondary			
Lead Acid and SLA		X	T, V
Ni-Cd		X	T, V
NiMH	X		V
Li-Ion	X		V

* Chart Codes: **(X)** Acceptable disposal method, **(OK)** Can be recycled- no toxicity or particular market value. **(T)** Recycle for toxic components, **(V)** Recycle for value of recoverable materials

Table 2: Summary of Recoverable Materials via Battery Recycling

Battery Type	Recycling Process
Alkaline and zinc carbon	Both hydro and pyrometallurgical processes are available to recover zinc, steel and ferromanganese or slag.
Nickel cadmium	Pyrometallurgical processes are used to recover 99.9% purity cadmium that is reused in new NiCd batteries, as well as ferronickel.
Nickel Metal Hydride	Processed to recover nickel, iron and other metals.
Lithium Based	Processed to recover cobalt, iron and other metals.
Lead Acid	Lead is recovered for reuse in new batteries.
Button Cells	Silver oxide types used in watches are collected by jewelers and recycled to recover silver metal. Other types can be recycled to recover mercury, zinc and steel.

Source: European Portable Battery Assn- http://www.epbaeurope.net/recycling.html#battery

Battery Comparison Table (I)			
Primary (single use) Batteries			
			
Battery Type	**Alkaline**	**Zinc Carbon**	**Button Cell**
Common Name(s)	"Copper top", Alkaline	"Classic", Super, Heavy Duty, General Purpose	Button Cell
Common Applications	radios, toys, clocks, household*	flashlights, toys, radios, remote controls, household*	watches, toys, calculators, hearing aids
Advantages	better performance than zinc carbon	low cost, good storage life, no mercury	high energy density, relatively inexpensive
Disadvantages	More expensive than zinc carbon, can contain mercury	very low energy density (i.e. short life span)	limited applications, can contain mercury
Toxicity[1]	Low to high (if contains mercury)	Low	Varies by chemistry. Low to High (if contains mercury)
Disposal	Lined landfill at minimum. Recycle or Hazardous Waste Disposal recommended. No landfill disposal if contains mercury.	Lined landfill at minimum. Recycle or Hazardous Waste Disposal recommended.	Varies by chemistry. Lined landfill at minimum. Recycle or Hazardous Waste Disposal recommended. No landfill disposal if contains mercury.
Recycling [2]	Zinc, steel and ferromanganese can be recovered. Low market value for reclaimed metal.	Zinc, steel and ferromanganese can be recovered. Low market value for reclaimed metal.	Recycle to recover valuable silver. Zinc, mercury and steel can also be recovered. Market value for reclaimed metal varies by chemistry.

[1]batteryuniversity.com

[2]Relative market prices for battery scrap metal were obtained from Todd Coy, Toxco battery recyclers, phone interview, 24 June 2008.

*Commonly found in AA, AAA, 9V, etc sizes for regular household use.

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Battery Comparison Table (II)

Rechargeable (secondary) Batteries

					
Battery Type	**Nickel Cadmium**	**Nickel Metal Hydride**	**Lithium-Ion**	**Lead Acid**	**Sealed Lead Acid**
Common Name(s)	Ni-Cd, Ni-Cad	NiMH, Ni-Li, Ni-Hydride	Li-Ion, Lithium Iron Phosphate	car battery, starting battery, wet cell, deep cycle	SLA, SSLA, valve-regulated, VRLA, Gel
Common Applications	modern off-grid lighting, powertools, cordless phones, professional radios, medical, household*	modern off-grid lighting, laptops, cell phones, household*	laptops, cell phones, handheld electronics	Cars, trucks, and other vehicles, standby/backup systems	off-grid lighting, wheelchairs, backup power systems
Estimated Cycle Life[1]	300-1000	500-1000	500-2000	200-700	300-1000
Advantages	Low cost, rugged, higher energy density than SLA	Higher energy density than Ni-Cd, no cadmium	light weight, high energy density	inexpensive, rugged	inexpensive, rugged
Disadvantages	contains cadmium memory effect	High self discharge higher cost compared to Ni-Cd	highest cost rechargeable, requires protection circuit	Heavy, low energy density, low cycle life, contains lead	Heavy, low energy density, contains lead
Toxicity[1]	Highly toxic- contains cadmium	Low to Moderate	Low	Highly toxic- contains large amounts of lead	Highly toxic- contains large amounts of lead
Disposal	Recycle or Hazardous Waste Disposal	Landfill in small quantities (<10 cells). Recycling recommended.	Landfill in small quantities (<10 cells). Recycling recommended.	Recycle or Hazardous Waste Disposal	Recycle or Hazardous Waste Disposal
Recycling[2]	Cadmium and ferronickel can be recovered which yield a moderate market price.	Recycle to recover nickel. NiMH is the most cost-effective battery to recycle because of the high market value for scrap nickel.	Cobalt and other metals can be recovered which have a high resale value, but the recycling process is more complex (ie more expensive).	The most commonly recycled battery worldwide. Lead and plastic casings can be recovered. Moderate market value for scrap lead and a mature resale market.	The most commonly recycled battery worldwide. Lead and plastic casings can be recovered. Moderate market value for scrap lead and a mature resale market.

[1]Battery University:http://www.batteryuniversity.com/partone-3.htm
Product

[2]Relative market prices for battery scrap metal were obtained from Todd Coy, Toxco battery recyclers, phone conversation, 24 June 2008.

*Commonly found in AA, AAA, 9V, etc sizes for regular household use.