Lowell Center for Sustainable Production

University of Massachusetts Lowell

An Investigation of Alternatives to Miniature Batteries Containing Mercury

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Prepared for
The Maine Department
of Environmental Protection

by
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Executive Summary

The Maine Department of Environmental Protection (DEP) will issue a report to the Maine legislature by January 14, 2005 that will review the use of mercury in miniature batteries. To assist in gathering information for this report, the Maine DEP commissioned the Lowell Center for Sustainable Production (LCSP) of the University of Massachusetts Lowell to conduct a study of alternatives to mercury containing miniature batteries. The objectives of this study were to accomplish the following:

- Investigate miniature battery product information available in the public domain
- Estimate the total amount of mercury used annually in the manufacture of button batteries
- Identify non-mercury alternatives for miniature batteries
- Conduct a qualitative evaluation of viable alternatives
- Investigate miniature battery recycling programs in the United States and Europe

Mercury from miniature batteries can be released to the environment during various stages of the product life cycle including manufacturing, use, and disposal. Once released, the mercury can transform to toxic organic forms, and can readily disperse in the environment through the air, soil, and water. Mercury is persistent in the environment, and also accumulates in concentration as it biomagnifies within the food chain. Mercury is highly toxic to humans; exposure can damage kidneys and the central nervous system. The fetus is particularly sensitive to mercury's toxic effects. Mercury also has adverse effects on wildlife including early death, weight loss, and reproductive issues.

Miniature batteries are used in numerous products that require compact sources of electrical power. Miniature batteries are mostly used for supplying electrical power for toys, hearing aids, watches, calculators, and other portable devices. The four major technologies used for miniature batteries are: lithium, zinc air, alkaline, and silver oxide. The lithium miniature batteries contain no intentionally added mercury. However, there is typically 0.1% to 2.0% mercury content in the formulations of most zinc air, alkaline, and silver oxide miniature batteries. Based upon available data, it appears that zinc air batteries contribute the most mercury to the environment because of their high sales volumes for use in hearing aids.

The function of the mercury is to inhibit gas formation inside the miniature battery cell. Gas buildup inside the cell could cause bulging and potentially result in leakage of battery cell materials. This leakage of battery cell materials affects the ability of the battery to continue functioning. In addition, this leakage can pose a health hazard as mercury and other toxic materials are no longer encapsulated and a potential human exposure pathway is created.

Marketing data are not available to determine the total number of miniature batteries sold in the U.S. or to estimate projected future sales. However, it is clear that the use of miniature

batteries is desirable for providing electrical power for a variety of portable products. To address the negative aspects of mercury in miniature batteries, there are opportunities for source reduction and recycling. Given the demand for electrical power for portable products and the current battery technology, using fewer batteries is not a likely opportunity for source reduction. However, using different materials and technologies can reduce and or eliminate the use of added mercury in miniature batteries.

Several alternatives to mercury containing miniature batteries were identified and evaluated. The review includes lithium miniature batteries, which do not contain mercury and are sometimes considered as a potential alternative to mercury containing miniature batteries. Original equipment manufacturers (OEMs) must evaluate numerous design considerations when selecting the best miniature battery for their end product. The most important considerations for OEMs appear to be cost, nominal voltage, capacity, physical size/shape, and discharge profile. Other considerations include: type of discharge, shelf life, energy density, operating temperature, replacement availability, leakage resistance, and mercury content. The level of importance for each of these considerations can vary greatly depending upon the requirements of each particular end product (calculator, toy, watch, etc.). The suitability for replacing one miniature battery technology for another miniature battery technology must be determined on a case-by-case basis by OEMs based upon the unique requirements of their particular product.

There are mercury-free models commercially available for silver oxide, alkaline manganese dioxide, and zinc air (Europe only) miniature batteries. The performance characteristics as presented by the manufacturers appear to be comparable for the mercury and mercury-free versions. Manufacturers have taken different approaches to eliminating the mercury for each miniature battery technology. A major concern for OEMs and end-users is the capability of these mercury-free miniature batteries to perform reliably in the field, especially as relates to the potential for buildup of internal gases, which is effectively prevented by the addition of mercury. Performance testing results for buildup of internal gases for mercury free miniature batteries are not available. Also, limited pricing information suggests that mercury-free miniature batteries command a 24% - 30% premium compared to their mercury containing counterparts. This cost differential is likely to decrease as the market matures.

There are well established and readily available miniature battery recycling services offered by hazardous waste handlers in the United States as another avenue for preventing the introduction of mercury from miniature batteries into the environment. From the perspective of recycling program administrators, miniature battery recycling programs run smoothly and safely but there is an ongoing challenge to increase the recycling rate. Battery manufacturers have raised concerns about the safety of collection and recycling of miniature batteries. Our review of the data found that the use of miniature batteries, not just recycling efforts, carries a small risk of potentially harmful adverse health outcomes from ingestion or insertion of a miniature battery in the ear or nose.

Because of its nature as a persistent, bioaccumulative toxin, there is growing local and global concern about the use of mercury in products. International pressures are being applied to manufacturers to significantly reduce or eliminate the use of mercury and for responsible

recycling of mercury-containing products at the end of their useful lives. This report provides an overview of mercury-containing miniature batteries and alternatives as well as opportunities for minimizing the environmental impact of mercury from miniature batteries.

1.0 Introduction

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- Conduct a qualitative evaluation of viable alternatives
- Investigate miniature battery recycling programs in the United States and Europe

Mercury from miniature batteries can be released to the environment during various stages of the product life cycle including manufacturing, use, and disposal. Once released, the mercury can transform to toxic organic forms, and can readily disperse in the environment through the air, soil, and water. Mercury is persistent in the environment, and also accumulates in concentration as it biomagnifies within the food chain. Mercury is highly toxic to humans; exposure can damage kidneys and the central nervous system. The fetus is particularly sensitive to mercury's toxic effects. Mercury also has adverse effects on wildlife including early death, weight loss, and reproductive issues.

Miniature batteries are used in numerous products that require compact sources of electrical power. Miniature batteries are mostly used for supplying electrical power for toys, hearing aids, watches, calculators, and other portable devices. The four major technologies used for miniature batteries are: lithium, zinc air, alkaline, and silver oxide. The lithium miniature batteries contain no intentionally added mercury. However, there is typically 0.1% to 2.0% mercury content in the formulations of most zinc air, alkaline, and silver oxide miniature batteries. Based upon available data, it appears that zinc air batteries contribute the most mercury to the environment because of their high sales volumes for use in hearing aids.

The function of the mercury is to inhibit gas formation inside the miniature battery cell. Gas buildup inside the cell could cause bulging and potentially result in leakage of battery cell materials. This leakage of battery cell materials affects the ability of the battery to continue functioning. In addition, this leakage can pose a health hazard as mercury and other toxic materials are no longer encapsulated and a potential human exposure pathway is created.

The scope of this review was limited to the use of mercury in miniature, primary (non-rechargeable) batteries. Miniature batteries include batteries that are button or coin shaped.

Miniature batteries may also be combined in stacks to form a small 6- or 12-volt cylindrical battery. However, mercury generally is not used in the manufacture of other cylindrical and rectangular batteries and those batteries are not examined in this report.

There are three miniature battery technologies on the market today in the United States that use mercury:

- Zinc air
- Silver oxide
- Alkaline manganese dioxide

For each of the three miniature battery technologies listed above, this report provides a listing of applications, pricing and availability information, performance attributes (such as voltage, capacity, discharge characteristics, energy density, and operating temperature), and a representative listing of various battery models. This report also provides a description of various non-mercury alternatives to these three mercury containing miniature battery technologies. The pricing information in this report is for initial battery purchase price only, and does not include lifecycle costs such as disposal and/or recycling.

The Lowell Center for Sustainable Production (LCSP) conducted a review of publicly available information for this study. This review included the following data sources:

- Product specifications
- Material safety data sheets
- Battery manufacturer manuals
- Marketing studies
- Health and safety data
- Miscellaneous battery reports
- Mercury product information compiled by the Interstate Mercury Education and Reduction Clearinghouse (IMERC)

The Interstate Mercury Education and Reduction Clearinghouse (IMERC) is an umbrella organization designed to assist states in their implementation of laws and programs aimed at getting mercury out of consumer products, the waste stream, and the environment. Launched under the auspices of the Northeast Waste Management Officials' Association (NEWMOA), IMERC has, among other things, helped implement product notification laws. These laws

prohibit the sale of mercury-added products in the states of Connecticut, Maine, New Hampshire and Rhode Island unless the manufacturer has disclosed the amount and purpose of the mercury.

The LCSP also conducted discussions and interviews with representatives from the following types of organizations:

- Miniature battery manufacturers and distributors
- Original equipment manufacturers (OEMs)
- Battery recyclers
- State and local government officials
- Battery testing organizations
- Non-government organizations

Several states have begun to focus on reducing the use or disposal of mercury-containing miniature batteries. These efforts include notification requirements for manufacturers and distributors, as well as public awareness programs. In addition, proposed European legislation provides several strong incentives for manufacturers to eliminate mercury from miniature batteries. Manufacturers of mercury-free miniature batteries will be “promoted by” the European States. Recycling costs will be borne by the manufacturer under the new legislation, providing further incentive to reduce mercury use.

2.0 Miniature Battery Overview

Miniature batteries are used in numerous products that require miniature sources of electrical power. Miniature batteries are mostly used for supplying electrical power for toys (often for lights or noise making), hearing aids, watches, calculators, and other portable devices. Miniature batteries are also used for providing memory backup for a variety of devices such as electronic organizers, fax machines, and mobile radios. For the purposes of this report, a miniature battery is defined as a small, round battery whose diameter is greater than its height. Miniature batteries can either be "button" shaped or "coin" shaped.

Miniature batteries power a wide range of products, from inexpensive toys with flashing lights or sounds to precision medical acoustic stethoscopes. The batteries may be used singly or in various combinations, depending on the needs of a particular product. Even within a general family of products, the power requirements can vary based on the design and features requiring power. For example, some miniature battery powered calculators use a single miniature battery, others use multiple batteries, and some use a combination of solar cells and battery power. Examples of battery configurations in products are shown in the following table, and a more detailed list of typical products is included in Appendix D.

Several battery companies make small cylindrical batteries that are a single unit comprised of a stack of individual miniature cells. From the outside of the battery, it is difficult to tell that there are multiple individual cells inside. Duracell, Energizer, Eveready, Eastman Kodak, Panasonic and Shanghai BiBa battery companies offer "button stack", "stacked cell" or "stackup" units of this type. Stacked cell batteries are offered in silver oxide and alkaline manganese. Stacked zinc air chemistries were found, but their use was very limited and solely for specialty industrial applications.

When the batteries are stacked in electrical series, the voltage of the individual cells is additive. For example, a stack of four 1.5 V cells produces a 6 V output. Stacked miniature batteries typically provide power for applications in which a higher voltage is needed, including remote controls (e.g. garage door opener remotes), dog control products (electronic training shock collar, electronic leash, bark collar) and camera applications.

In addition to the "button stack" single unit batteries, there are many products using multiple miniature batteries in series. In these products, individual batteries are dropped into the cylindrical battery compartment one on top of another. These products include flashlights, novelty strobe lights, toys that flash lights or make sounds and medical stethoscopes.

Table 2.1 Examples of Battery Configurations in Products

Single Miniature Battery	**Multiple Miniature Batteries** Inserted in a stack by consumer	**Stacked Miniature Battery** Single unit of multiple batteries over-wrapped by manufacturer
Watch Compact digital thermometers Digital tire pressure gauges Pedometers Small pocket lights (e.g. keychain light) Remote control for car door locks Hearing aids Example: Maxell CR2016: 	Garage door openers LED headlamps, flashlights Novelty strobe lights WiFi locators Child's toy that makes noise or flashes lights Endoscopy capsules (medical application) Example: Vinnic L736 (multiple): 	Invisible fence dog collar battery Garage door openers Vehicle locks Other remote control devices Example: Energizer TR175S:

The four major technologies used for miniature batteries are: lithium, zinc air, alkaline, and silver oxide. The lithium miniature batteries have no added mercury. However, there is typically 0.1% to 2.0% mercury content found in most zinc air, alkaline, and silver oxide miniature batteries. The function of the mercury is to inhibit gas formation inside the miniature battery cell.

Gas can form due to zinc corrosion. Zinc is used in silver oxide, zinc air, and alkaline manganese dioxide miniature batteries. As battery capacity is consumed, the zinc will corrode in

the alkaline electrolyte. This corrosion can cause electrolysis in the electrolyte and generate the production of hydrogen gas. This buildup of gas inside the cell could cause bulging and potentially result in leakage of battery cell materials. This leakage of battery cell materials affects the ability of the battery to continue functioning. In addition, this leakage can pose a health hazard as mercury and other toxic materials are no longer encapsulated and a pathway to human exposure exists. For these reasons, mercury is added to miniature batteries to prevent zinc corrosion and the resultant gas buildup. See Appendix B for a discussion of the components of miniature batteries.

2.1 Manufacturers

There are numerous manufacturers of miniature batteries. The following is a listing of known manufacturers, the principle location of their operations, and the status of their IMERC notification. Many of these manufacturers sell miniature batteries used for products sold in the U.S. including: Camelion, Chung Pak, Duracell, Eagle Picher, Eastman Kodak, Energizer, GP Batteries, Hitachi, New Leader, Panasonic, Rayovac, Renata, Schenzhen Konnoc, Schenzhen Jundong, Varta, and Wilson Greatbatch.

Table 2.2 Miniature Battery Manufacturers

Manufacturer	Location	IMERC Notification[1]
Camelion	China	-
Cegasa International	Spain	-
Chener Battery Works	Hong Kong	-
Chung Pak (Vinnic) (Evergreen)	Hong Kong	-
Daily Power Batteries Limited	China	-
Duracell	United States	Yes
Eagle Picher	United States	-
Eastman Kodak	United States	Yes
Energizer (Eveready)	United States	Yes – Eveready
Gloso (Novacell)	Hong Kong	-
Golden Power Industries	Hong Kong	-
GP Batteries International Limited (Gold Peak, Shanghai BiBa Batteries Co. Ltd)	Hong Kong	Yes – GPI Ltd Yes – Shanghai BiBa
Hitachi Maxell	Japan	-
IcellTech	Korea	-
Leclanche	Switzerland	-
New Leader	China	Yes
Panasonic	United States	Yes
Promax Battery Industries Limited	China	-
Rayovac	United States	Yes
Renata	Switzerland	-
Sanyo	Japan	-
Schenzhen King Kang	China	-

Manufacturer	Location	IMERC Notification[1]
Schenzhen Konnoc (Konnoc)	China	-
Schenzhen Jundong Industrial Co. (Votek)	China	-
Schenzhen Malintech Industrial Co. (Powtek)	China	-
Sony	Japan	-
Suzhou Industrial Park East Battery Co.	China	-
Tadiran	Israel	-
Toshiba	Japan	-
Tronic	Hong Kong	-
Varta	Germany	-
Wilson Greatbatch Technologies, Inc.	United States	-
Zhuhai Zhi Battery Co. Ltd. (Zenipower)	China	-

[1]IMERC database last checked on 10/14/04. A dash in the cell indicates the manufacturer was not listed in IMERC database by the name shown.

2.2 Pricing

The retail pricing information in this report is provided for the following miniature battery technologies: alkaline, silver dioxide, lithium, and zinc air. There are numerous factors that influence the retail price of miniature batteries including:

- *Battery technology* – The cathode, anode, electrolyte, and packaging materials are different for the various miniature battery technologies and some raw materials, e.g. silver, are more expensive than others.

- *Battery capacity* – The capacity of a battery varies greatly and can have an impact on pricing.

- *Battery manufacturer* – The price for batteries manufactured by different manufacturers may vary due to brand name recognition, scale of production, and other market factors.

- *Retail pricing versus OEM pricing* – The pricing available for retail customers purchasing replacement miniature batteries is often greater than the pricing provided to OEMs that incorporate miniature batteries into their end products.

- *Quantity of batteries purchased* – The price per battery often decreases as the quantity of batteries purchased increases.

- *Retailer* – The markup on battery prices may fluctuate depending on the retailer (e.g. Staples, CVS, www.batteries.com, etc.)

- *Marketing/promotional events* – Special promotional events may affect the price of miniature batteries on a short-term basis.

The miniature battery pricing information provided in this report is for retail purchases of replacement batteries. The pricing information for miniature batteries is provided in Appendix C: Cost and Availability. Pricing information is included for each miniature battery technology, including the range of retail pricing as well as a listing of the sources for pricing information. An exception to this is the pricing obtained for the New Leader mercury and non-mercury miniature batteries. New Leader non-mercury miniature batteries are only available for purchase by OEMs, and are not yet available for retail customers. Therefore, OEM pricing only was available for New Leader batteries.

2.3 Annual Sales

Miniature batteries are provided in the United States through two main markets:

1) *Original equipment market*: This includes items that are sold with miniature batteries embedded in the product. Examples include toys, watches, calculators, and hearing aids. Manufacturers of these products will be referred to as original equipment manufacturers (OEMs) in this report.

2) *After market*: This includes the purchase of miniature batteries by end-users to replace batteries in products from the original equipment market. These replacement batteries can be purchased from various retailers, mail order operators, and Internet based suppliers.

Manufacturers of mercury-added miniature batteries or products that contain mercury-added miniature batteries are required to disclose the amount of mercury in these batteries before selling their product in the following states that have mercury product notification laws: Connecticut, Maine, New Hampshire, Rhode Island and Washington. IMERC uses two forms to collect this data:

Mercury Added Product Notification Form: The term "mercury added" is used to indicate that the mercury was intentionally added to the product. This form requests manufacturer contact information, as well as information pertaining to the mercury in the product such as description of mercury added components, number of components, amount of mercury, and purpose of mercury in the product.

Total Mercury in all Mercury Added Products Form: This form requests manufacturer contact information, as well as total amount of mercury in all units sold in the United States for a particular product.

For this study, the mercury notification information in the IMERC electronic database was reviewed. This information was useful to help ascertain the total mercury sold in the United States for various products as reported by OEMs and miniature battery manufacturers. However, the reporting did not cover all the various products containing miniature batteries that are produced by domestic OEMs. In addition, most foreign battery manufacturers and foreign original equipment manufacturers have not reported this information to IMERC.

The LCSP tried to determine the total number of miniature batteries sold in the United States on an annual basis for both the original equipment and after market sales. However, the authors of this report were unable to locate any marketing information that provided comprehensive sales data for U.S. sales of all miniature batteries. In particular, we could not find meaningful data on the number of miniature batteries imported into the United States. Several marketing reports on batteries were investigated, from leading market research providers such as Mintel, Business Communications Company, and Freedonia. However, miniature batteries are often aggregated with other battery sizes and shapes for a particular battery technology (e.g. alkaline, lithium, zinc air, and silver oxide). For example, sales data is provided for total alkaline battery sales, with no breakdown for miniature batteries, cylindrical batteries, rectangular batteries, etc. Therefore, it is not possible to determine the sales quantities attributable to miniature batteries for the original equipment or after markets.

Despite the absence of definitive sales data, we were able to better understand the order of magnitude of miniature battery sales in the United States by using data from the National Electronics Manufacturer's Association (NEMA) and the 2003 European report "Impact Assessment on Selected Policy Options for Revision of the Battery Directive".

For the U.S. miniature battery market, NEMA data offered insight in miniature battery sales of its member companies, which include Duracell, Eveready Battery Company, Renata SA, Saft Inc., Eastman Kodak, Panasonic Industrial Company, Polaroid Corporation, Wilson Greatbatch Ltd., and Rayovac Corporation. Although these manufacturers represent only a subset of the manufacturers of miniature batteries sold in the U.S., the data is helpful to define a lower limit for estimated annual sales. In September 2003, NEMA conducted a survey of its members to ascertain the average mercury content and the U.S. sales quantity for silver oxide, zinc air, and alkaline miniature batteries. The results for 2002 sales are summarized in the table below:

Table 2.3 2002 Miniature Battery Sales in the U.S.

Battery Technology	Average Mercury Content (mg)	Total Amount of Mercury (Pounds)	Approximate Sales Quantity*
Zinc air	8.5	4,540.3	242 million
Silver oxide	2.5	473.6	86 million
Alkaline	10.8	269.6	11 million
Totals:		5,283.5	339 million

* The approximate sales quantity was calculated based upon data from the columns: "Average Mercury Content" and "Total Amount of Mercury".

The number of miniature batteries sold by non-NEMA companies in the United States is not known. Therefore, the 339 million miniature batteries reported by NEMA members represent only a portion of the total after market and original equipment market in the United States. In the after market, it is possible to purchase miniature batteries from numerous foreign sources of batteries through various retail and Internet-based channels. For example, we identified retail sources in the United States where one can purchase replacement batteries from companies such as Varta (Germany) and Konnoc (China).

In the original equipment market, there are several examples indicating that the quantities reported by NEMA members represents only a modest fraction of the total original equipment market. For example, the total quantity of alkaline miniature batteries reported by NEMA members was approximately 11 million units. However, millions of toys, novelties, and other products containing miniature batteries enter the United States from foreign sources. In one instance, Kellogg's provided Spidey 2 signal toys in various types of cereal boxes. The Spidey 2 toy is powered by a mercury-containing alkaline button cell. The quantity of button batteries for this one promotion alone was approximately 17 million toys. Further, China is considered the third largest battery supplier in the world after Japan and South Korea. It is estimated that China produced approximately 2.5 billion button cell batteries in 2003. (Global Sources, 2004) This output is anticipated to increase to 3 billion units in 2004, and increase to 5 billion units in 2005. It can be reasonably assumed that significant amounts of these batteries are included in original equipment manufactured in Asia and ultimately sold in the United States.

For the European miniature battery market, BIO Intelligence Service completed a report in July 2003 titled: "Impact Assessment on Selected Policy Options for Revision of the Battery Directive". In this report, the total sales of miniature batteries in Europe were estimated to weigh 373 metric tons in 2002. Miniature batteries were estimated to represent approximately 0.236% of the entire portable battery market of 158,270 metric tons in 2002. Further, it was estimated that 90% of these batteries were sold in the "after market" (replacement batteries), and 10% were sold in the original equipment market electric and electronic equipment.

Using an estimate of 640 miniature batteries per pound (this is described in more detail in Section 8 of this report), the sales in the European market for 2002 are estimated at approximately 526 million miniature batteries. This would result in approximately 473.4 million miniature batteries sold in the after market, and 52.6 million batteries sold in the original equipment market for electric and electronic equipment. This includes products such as toys, novelty items, watches, calculators, and hearing aids.

We made the assumption that most miniature batteries are used in consumer products (largely hearing aids) and that we could therefore use relative populations to estimate U.S. sales based on European sales. In 2002, the population of the European Union was approximately 380 million, while the population of the United States was 279 million. The population of the United States is 73.4% of the population of Europe, therefore we estimated that U.S. sales of miniature batteries at approximately 386.2 million. Of this, approximately 348 million are replacement batteries and approximately 39 million are sold in products. As previously stated, Kellogg's sold 17 million miniature batteries for one toy, which suggests this estimate of 39 million may significantly

underestimate the total amount of miniature batteries sold in products in the United States. While this approach does not fully take into account other important factors such as economic activity and other market factors, it provides an order of magnitude estimate.

Based on the NEMA data and the European Union study, it can be reasonably assumed that the total U.S. annual sales are a minimum of 340 million miniature batteries per year. Because of the lack of data for miniature batteries sold as a component in products, the total U.S. annual sales cannot be accurately estimated.

2.4 Battery Selection Considerations

Original equipment manufacturers (OEMs) must evaluate numerous design considerations when selecting the best miniature battery for their end product. Based on our discussion with OEMs and the review of available literature, we identified the most common factors/considerations for selection of miniature battery technologies.

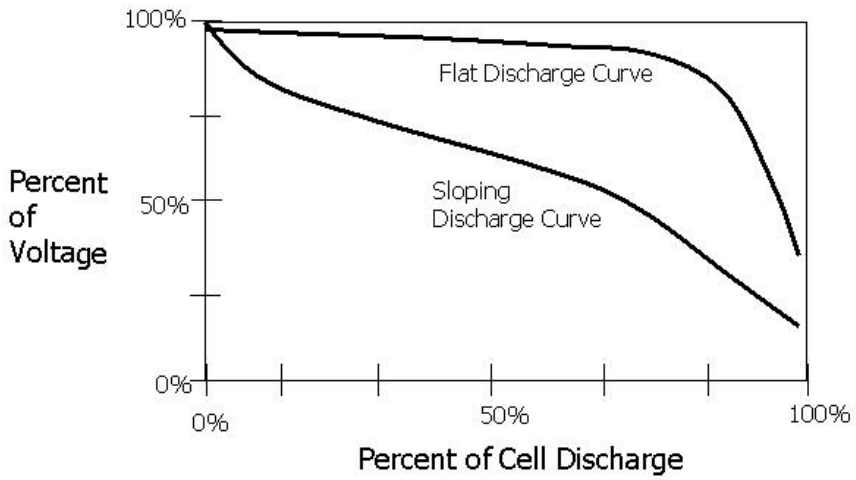
The most important considerations for OEMs appear to be cost, nominal voltage, capacity, physical size/shape, and discharge profile. Other considerations for OEMs include: type of discharge, shelf life, energy density, operating temperature, replacement availability, leakage resistance, and mercury content. For example, one original equipment manufacturer indicated that mercury content was an important consideration and therefore plans to use lithium miniature batteries for new products. The remainder of this section provides a brief description of each of the miniature battery selection considerations.

Cost – This includes the initial price to purchase the battery for the OEM product, as well as consideration for the cost of replacement batteries for the end-user.

Nominal voltage – The nominal voltage is generally accepted as typical of the operating voltage of the battery. For example, 1.4 Volts is the nominal voltage for a zinc-air battery.

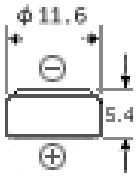
Battery capacity – This is the quantity of electricity measured in milli-Ampere-hours (mAh) that may be drawn from a fully charged miniature battery under specified conditions of discharge. In general, a 500-mAh battery will be able to provide 1 mA of current for 500 hours, provide 2 mA of current for 250 hours, etc. This information is used by some original equipment manufacturers to help calculate the Mean Time Between Failure (MTBF) for their products.

Battery discharge profile – The discharge profile for miniature batteries is typically either flat or sloping/tapered. A flat discharge profile indicates that the battery voltage remains approximately constant during the discharge of the battery energy. A sloping discharge profile indicates that the battery voltage decreases during the discharge of the battery energy.



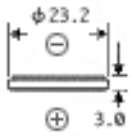
Physical size/shape – In general, a miniature battery can be defined as a small, round battery where the battery diameter is greater than the battery height. There are two shapes of miniature batteries: button and coin. For the purposes of this report, if the diameter is 1 to 6 times greater than the height then the miniature battery will be referred to as a "button" shaped batteries. In the button battery example below, the diameter is 11.6 millimeters and the height is 5.4 millimeters.

Button Shaped Battery: Side View



A variation of the miniature battery is the "coin" shaped battery. In the coin battery example below, the diameter is 23.2 millimeters and the height is 3.0 millimeters. For the purposes of this report, if the diameter is 7 or more times greater than the height the miniature battery will be referred to as a "coin" shaped battery.

Coin Shaped Battery: Side View



Type of discharge – The magnitude of the battery load/drain has a significant impact on battery performance. In addition, the energy of a miniature battery can be discharged in a continuous, intermittent, or a combination continuous/intermittent manner. For example, a digital watch may require a continuous low drain of a battery to display the time, however, there may be intermittent periods of high drain on the battery to provide alarm or backlighting functionality.

Shelf life – Miniature batteries are a perishable product and deteriorate as a result of chemical activity that occurs during storage. For certain end products, there may be a prolonged period before commencing use of the battery. Therefore, the rated shelf life can be an important consideration.

Replacement availability – The commercial availability of replacement batteries is a key consideration for OEM product designers. Ideally, the replacement battery will be available in a standard size, supplied by numerous manufacturers, and available in several on-line and physical retail outlets.

Energy density – The energy of a battery is often measured relative to its volume and/or weight. Volumetric energy density is typically measured in milli-Watt-hours per cubic centimeter. Gravimetric energy density is typically measured in milli-Watt-hours per gram.

Operating temperature – The operating temperature for the battery has a significant impact on battery performance. For example, lowering the operating temperature will reduce the level of chemical activity and increase the internal resistance of the battery. In general, lowering the operating temperature will result in a reduction of capacity and an increase in the slope of the discharge curve. At higher operating temperatures, the internal resistance decreases and the capacity may increase. However, at higher temperatures the chemical activity increases and could cause a phenomenon called self-discharge which may cause a net loss of capacity. Miniature batteries are often rated for use within a specified operating temperature range.

Mercury content – The amount of mercury contained within the miniature battery.

Leakage resistance – Miniature batteries often contain various hazardous substances. Leakage of these miniature battery materials is often undesirable from a safety standpoint, and can also adversely affect battery performance.

3.0 Zinc Air Miniature Batteries

3.1 Description

Zinc air miniature batteries are primarily used for hearing aids. Zinc air miniature batteries are the battery of choice for hearing aid applications because they have a high energy density and are excellent for continuous discharge use. Zinc air miniature batteries can also be used for wristwatch pagers, behind the ear speech processors, and cochlear (inner ear) implants. The PR2330 coin shaped zinc air battery is often used for credit card style pagers and for wireless telecom headsets. The PR2330 designation follows the battery nomenclature published by the International Electrotechnical Commission (IEC). The IEC nomenclature is described in Appendix B.

Zinc air miniature batteries use oxygen from ambient air to produce electrochemical energy. Ambient air enters through a hole on the positive terminal. This hole provides a path for oxygen to enter the cell and diffuse to the cathode catalyst site. Therefore, zinc air miniature batteries are good candidates for applications like hearing aids with access to ambient air.

The mercury content of the zinc air miniature battery is typically between 0.3% - 2.0% of total battery weight. However, Energizer offers mercury-free zinc air batteries in Europe for hearing aid users. The mercury-free Energizer battery is discussed further in the Non-Mercury Alternatives section of this report.

3.2 Performance

The zinc air miniature battery has a nominal voltage of 1.4 Volts. The zinc air battery has a flat discharge curve. Miniature zinc air batteries are mostly button shaped; however there are some commercially available coin shaped batteries (e.g. Panasonic PR2330 that has a diameter of 23.2 mm and a height of 3.0 mm). Zinc air miniature batteries are excellent for continuous, low discharge applications, and provide good leakage resistance.

For the battery models reviewed, the zinc air miniature battery offers the widest range and the highest level of capacity (33 to 1,100 mAh) compared to the other miniature battery technologies. However, the typical useful service life of a zinc air miniature battery is two to three months once the seal has been removed. Zinc air batteries also have the highest energy density compared with other battery systems. The gravimetric energy density is typically 210 to 370 mWh/g and the volumetric energy density is 770 to 1,300 mWh/cc. Therefore, the zinc air miniature batteries are excellent candidates for volume or weight critical applications.

During storage, the air access holes of the zinc air miniature battery are sealed to prevent gas transfer decay. Polyester tape is often used for sealing the battery during storage. Zinc air batteries have excellent long-term storage life if the seal remains intact. An 85% capacity retention has been measured in tests for 5-year storage periods, resulting in a self-discharge rate of approximately 3% per year.

The service life of the zinc air battery is significantly affected by pressure differences between the vapor pressure of the electrolyte and the ambient air. In low humidity environments, there can be excessive water loss that can increase the electrolyte concentration and eventually cause the cell to fail. In high humidity environments, excessive water gain dilutes the electrolyte and can reduce the electrochemical activity and eventually cause cell failure. Zinc air miniature batteries operate most effectively in the range of 0 degrees to 50 degrees C.

3.3 Manufacturers

There are numerous manufacturers of zinc air miniature batteries on a worldwide basis. The following table provides key information for some domestic and foreign manufacturers of zinc air miniature batteries:

Table 3.1 Manufacturers of Zinc Air Miniature Batteries

Manufacturer	Model	Applications	Hg Content	Capacity* (mAh)
Duracell	Models 10, 13, 312, 675	Not identified	<2%	70 - 600
Panasonic	630	Not identified	Not listed	1,100
Energizer	ACXX series	Hearing aids (eyeglass, behind the ear, in the ear), pagers	1.0 - 1.4%	33 - 635
Energizer	ACXX series	Hearing aids	None (zero mercury type)	33 - 635
GP Batteries International (Gold Peak)	ZAXX series	Hearing aids.	0.3 - 1.3%	70 - 600
Toshiba	ZAXX series and PR series	Hearing aids, BTE speech processors, cochlear implants, pagers	Not listed	75- 1,050
Varta	PXXX series	Hearing aids, implants	Not listed	35 - 650

* *Battery capacity* refers to the quantity of electricity measured in milli-Ampere-hours (mAh) that may be drawn from a fully charged miniature battery under specified conditions of discharge. See Section 2.4.

4.0 Silver Oxide Miniature Batteries

4.1 Description

Silver oxide miniature batteries can be used for numerous devices including: analog watches, digital watches, miniature clocks, calculators, electronic games, cameras, hearing aids, and electronic instruments. The cathode consists primarily of monovalent silver oxide (Ag2O), and the anode consists of powdered zinc.

The mercury content of the silver oxide miniature battery is typically between 0.2% to 1.0% of total battery weight. However, at least two manufacturers (New Leader and Sony) offer mercury-free silver oxide miniature batteries. These mercury-free batteries will be discussed further in the Non-Mercury Alternatives section of this report.

4.2 Performance

The nominal voltage of the silver oxide miniature battery is 1.55 Volts. In general, the silver oxide miniature battery has a flat discharge curve. However, there are at least two manufacturers (Chung Pak and New Leader) that provide silver oxide miniature batteries with a tapered discharge profile. In the case of New Leader, some of their silver oxide miniature batteries are manufactured with half the typical amount of silver for use in low cost applications. This reduction of silver content results in a tapered discharge profile.

For the battery models reviewed, the silver oxide miniature battery has the lowest range of capacity (5.5 to 200 mAh) compared to the other miniature battery technologies. The gravimetric energy density is typically 75 to 135 mWh/g and the volumetric energy density is 300 to 530 mWh/cc. The energy density of the silver oxide miniature battery is the third highest of the four miniature battery technologies.

The silver oxide miniature battery is capable of operation over a wide temperature range. For example, at an operating temperature of 0 degrees C the silver oxide miniature battery can deliver 70% of the capacity provided at 20 degrees C. Batteries using potassium hydroxide electrolyte are able to operate at lower temperatures than batteries with sodium hydroxide electrolyte.

Silver oxide miniature batteries are good for high or low drain applications. Potassium hydroxide is the preferred electrolyte for continuous low drain applications over long periods of time (e.g. five years). Sodium hydroxide is the preferred electrolyte for continuous low drain use with periodic high drain pulse demands. An example of this application would be an analog watch with alarm capability. Silver oxide miniature batteries exhibit long shelf and service life. Most batteries are designed to operate watches for five years without leakage. Test data indicates that storage up to ten years is possible at 21 degrees C.

Silver oxide batteries come in a variety of shapes and dimensions. For example, the SR41 is button shaped with a diameter of 7.8 mm and a height of 3.6 mm. The SR1116 is coin shaped with a diameter of 11.6 mm and a height of 1.65 mm.

4.3 Manufacturers

There are numerous manufacturers of silver oxide miniature batteries on a worldwide basis. The following table provides key information for some domestic and foreign manufacturers of silver oxide miniature batteries:

Table 4.1 Manufacturers of Silver Oxide Miniature Batteries

Manufacturer	Model	Applications	Hg Content	Capacity (mAh)
Duracell	D3X series	Not identified	< 1%	16 - 180
Eastman Kodak	KS76	Photo	< 0.6%	145
Energizer	3XX series	Watches, calculators, photoelectric exposure devices, hearing aids, and electronic instruments	0.3 - 1.0%	5 - 200
GP Batteries International (Gold Peak)	3XX series	Watch, calculator, electronic toy, hearing aid, lighter, photo	0.4 - 0.8%	7.5 - 165
Hitachi Maxell	SRXX series	Not identified	Not listed	5.5 - 165
New Leader	Hg Free SRXX series	Not identified	None	15 - 165
New Leader	SRXX series	Not identified	Not listed	15 - 165
Renata	3XX series	Watches (analog, digital), pocket calculators, electronic games, cameras, etc.	Not listed	5.5 - 190
Sony	Hg free SRXX series	Not identified	None	12.5 - 160
Sony	SRXX series	Wrist watches, small size thermometers, mobile game products	Not listed	4 - 180
Varta	V Series	Not identified	0.2 - 0.6%	6 - 180

5.0 Alkaline Manganese Dioxide Miniature Batteries

5.1 Description

Alkaline manganese dioxide miniature batteries can be used in numerous devices including: calculators, toys, key chains, tire gauges, remote controls, and photographic products. The cathode is primarily comprised of electrolytic manganese dioxide, and the anode is powdered zinc.

The mercury content of the alkaline manganese dioxide miniature battery is typically 0.1% to 0.9% of total battery weight. However, one manufacturer (New Leader) offers mercury-free alkaline manganese dioxide miniature batteries. These mercury-free batteries will be discussed further in the Non-Mercury Alternatives section of this report.

5.2 Performance

The alkaline manganese dioxide miniature battery has a nominal voltage of 1.5 Volts. The alkaline manganese dioxide miniature battery has a sloped discharge profile. The voltage starts around 1.5 Volts and gradually decreases during battery discharge. Most end products that use alkaline miniature batteries at low to moderate drains (i.e. toys, penlights, etc.) are generally able to tolerate this sloped discharge pattern.

Alkaline manganese dioxide miniature batteries are typically available in button shapes. These batteries are available in capacities ranging from 15 to 830 mAh. The alkaline manganese dioxide battery has the lowest energy density compared to other miniature battery technologies. The gravimetric energy density is typically 50 to 80 mWh/g and the volumetric energy density is 150 to 360 mWh/cc.

Alkaline manganese dioxide batteries discharge more efficiently as the operating temperature increases, up to a certain threshold. Alkaline manganese dioxide batteries can typically be operated in temperatures between –30 degrees C to 55 degrees C. In addition, these batteries also provide good leakage resistance.

Chemical reactions such as self-discharge, corrosion, and degradation of battery materials can occur during storage of an alkaline manganese dioxide battery. These chemical reactions will occur more rapidly if the battery is stored at higher temperatures and will occur more slowly at lower temperatures. Therefore, the storage temperature has a significant effect on charge retention. For example, a battery stored at 0 degrees C will have approximately 97% charge retention after four years, while a battery stored at 20 degrees C will have approximately 84% charge retention after four years.

5.3 Manufacturers

There are numerous manufacturers of alkaline miniature batteries on a worldwide basis. The following table provides key information for some domestic and foreign manufacturers of alkaline miniature batteries:

Manufacturer	Model	Applications	Hg Content	Capacity (mAh)
Eastman Kodak	K series	Photo, calculators	<0.5%	125 - 830
Energizer	1XX, AXX, E625G	Not identified	0.1 - 0.9%	31 - 200
GP Batteries International (Gold Peak)	164, A76, 18X, 19X, 625A	Watch, calculator, photo, toy, melody card, remote control	0.1 - 0.6%	8 - 190
Hitachi Maxell	LRXX series	Mini game machines, electronic calculators, electronic watches and clocks, measuring instruments, electronic lighters, electronic thermometers, cameras, compact radios, remote controllers	Not listed	26 - 60
New Leader	Hg Free LRXX series	Not identified	None	15 - 158
New Leader	LRXX series	Not identified	Not listed	15 - 160
Renata	LR4X	Calculators, electronic games, etc.	Not listed	73 - 105
Shenzhen Malintech	AG series	Not identified	Not listed	13 - 138
Varta	4XXX series	Not identified	0.2 - 0.5%	25 - 200

6.0 Non-Mercury Alternatives

6.1 Mercury-free Miniature Batteries

Silver Oxide:

In September 2004, Sony Corporation announced that it would provide mercury-free silver oxide miniature batteries. Ten models of mercury-free silver oxide batteries will be available on a worldwide basis starting in January 2005. These miniature batteries will be available in a variety of dimensions, with capacities ranging from 12.5 mAh to 160 mAh. This announcement from Sony Corporation also stated their goal to eliminate mercury from all of their silver oxide batteries. Sony's silver oxide miniature batteries are used mainly for watches, miniature thermometers, and mobile game products.

In a silver oxide miniature battery, the zinc anode will corrode in the presence of an alkaline electrolyte. The zinc corrosion causes electrolysis in the electrolyte that initiates the formation of hydrogen gas. The buildup of hydrogen gas in the miniature battery cell causes an increase in internal pressure that may lead to bulging and even rupture of the cell. Mercury is intentionally added to silver oxide miniature batteries to suppress the zinc corrosion and resultant formation of hydrogen gas.

To provide mercury-free silver oxide miniature batteries, Sony has utilized the following techniques:

- Use of a high quality zinc alloy powder that reduces the corrosion rate by a factor of ten compared to conventional powders.

- Use of an anti-corrosion additive material in the anode. The composition of this additive material has not been disclosed by Sony.

- Use of a unique surface process technology for the cathode material. This process technology is claimed to further suppress zinc corrosion.

- Use of a proprietary active cathode material. This material has high hydrogen absorption capacity.

New Leader, a battery manufacturer located in China, also provides mercury-free silver oxide miniature batteries. Currently, this mercury-free battery is available to original equipment manufacturers for use in their end products, but is not yet commercially available in the United States for purchase by end-consumers as replacement batteries. However, New Leader appears to be interested in selling the mercury-free silver oxide battery to the U.S. retail market in the near future.

The New Leader product specifications for mercury and mercury-free silver oxide miniature batteries were compared for the following three models: SG3/SR41, SG13/SR44, and

SG4/SR626. The specifications provide information for the following performance attributes: voltage, capacity, weight, diameter, height, and estimated average hours of service. The performance was found to be identical for each of these attributes for the mercury and mercury-free versions of the same model.

Currently, there is a price differential between the New Leader mercury and mercury-free models. The mercury-free models cost approximately 30% more than the similar models containing mercury. As the market for mercury-free miniature batteries expands, there will be increased competition as well as greater economies of scale for larger production runs. Therefore, it is reasonable to anticipate that the cost differential between mercury and mercury-free miniature batteries will decrease over time. The method that New Leader uses to achieve the mercury-free silver oxide battery is not publicly available.

No performance test results were found for the Sony and New Leader mercury-free batteries to demonstrate that formation of hydrogen gas and the resultant cell bulging and rupture is not an issue for these batteries. Presumably, these manufacturers are satisfied that they have overcome this problem as they are unlikely to market a product that could undermine their reputation for delivering quality products or expose them to product liability claims.

Alkaline Manganese Dioxide:

New Leader also offers mercury-free alkaline miniature batteries. Currently, this battery is available only to original equipment manufacturers for use in their end products such as toys. The mercury-free alkaline miniature battery from New Leader is not yet commercially available in the United States for purchase by end-consumers as replacement batteries. However, New Leader appears to be interested in selling it to the U.S. retail market in the near future. (Reference: Ivan Kong of New Leader) Specialized Technology Resources (STR) conducted mercury testing for the New Leader LR44 mercury-free alkaline button battery. The test results indicate that the mercury content is below detection levels of 0.0001 mg per battery.

New Leader has registered for a patent in China to use indium instead of mercury in alkaline manganese dioxide miniature batteries. Indium is a soft silver-white metal that is used in applications such as electronic components. The indium is pre-electroplated on the inside of the cathode cap by using a single face electro-plating technique. In addition, the zinc powder is pre-treated with an indium compound.

The New Leader performance specifications were compared for the mercury-containing and mercury-free versions for various alkaline manganese dioxide models. The performance attributes were similar between the mercury and mercury-free versions for AG1/LR621 and AG8/LR1120 as illustrated in the table below.

Table 6.1 New Leader Mercury and Mercury-free Miniature Batteries

Attribute	New Leader AG1/LR621 With Mercury	New Leader AG1/LR621 Without Mercury	New Leader AG8/LR1120 With Mercury	New Leader AG8/LR1120 Without Mercury
Voltage (V)	1.55	1.55	1.5	1.5
Capacity (mAh)	15	15	44	44
Weight (g)	0.3	0.3	0.86	0.86
Diameter (mm)	6.75	6.75	11.5	11.5
Height (mm)	2.15	2.15	2.1	2.1
Estimated Average Hours Service	Approx. 540	Approx. 540	Approx. 504	Approx. 504

Some differences in performance attributes can be identified for the New Leader mercury-containing and mercury-free models AG12/LR43 and AG13/LR44. The differences identified for capacity and estimated average hours service are highlighted in the tables below. The tables below also include data for comparable Energizer miniature batteries.

Table 6.2 Mercury and Mercury-free Miniature Batteries

Attribute	New Leader AG13/LR44 With Mercury	New Leader AG13/LR44 Without Mercury	Energizer A76 With Mercury
Voltage (V)	1.5	1.5	1.5
Capacity (mAh)	160	158	150
Weight (g)	2.0	2.0	2.3
Diameter (mm)	11.53	11.53	11.6
Height (mm)	5.43	5.43	5.4
Estimated Average Hours Service*	624	612	900

* A load of 5,000 ohms was used for the New Leader battery and a load of 7,500 ohms was used for the Energizer battery.

Table 6.3 Mercury and Mercury-free Miniature Batteries

Attribute	AG12/LR43 With Mercury	AG12/LR43 Without Mercury	Energizer 186 With Mercury
Voltage (V)	1.5	1.5	1.5
Capacity (mAh)	115	110	80
Weight (g)	1.6	1.6	1.4
Diameter (mm)	11.53	11.53	11.6
Height (mm)	4.2	4.2	4.2

Attribute	AG12/LR43 With Mercury	AG12/LR43 Without Mercury	Energizer 186 With Mercury
Estimated Average Hours Service	456	480	924

* A load of 5,000 ohms was used for the New Leader battery and a load of 15,000 ohms was used for the Energizer battery.

Currently, there is a price differential between the New Leader mercury and mercury-free models. The mercury-free models cost approximately 24% to 30% more than the similar models containing mercury.

New Leader has stated that these mercury-free batteries are being used for toys, electronic gifts, and products for the following customers: McDonalds, Hallmark Cards, Wal-mart, Chicco, Burger King, K-Mart, and Kellogg's. Several other companies are in the process of evaluating these batteries including Hasbro, Mattel, and Red Box. (Reference: Ivan Kong of New Leader)

There is no performance testing available for the New Leader mercury-free batteries to demonstrate that formation of hydrogen gas and the resultant cell bulging and rupture is not an issue for these batteries.

Zinc Air:

One battery manufacturer, Energizer, sells mercury-free zinc air miniature batteries in Europe for hearing aid applications. Energizer offers mercury containing and mercury-free miniature batteries for the following four models: AC10/230, AC13, AC312, and AC675. The Energizer engineering data sheets for the mercury containing zinc air miniature battery and the mercury-free zinc air miniature battery were compared for each of these four models. The performance data for the following parameters show no differences between the mercury containing and mercury-free models.

- Diameter
- Height
- Voltage
- Volume
- Average capacity
- Typical discharge characteristics
- Estimated average service
- Impedance
- Impedance vs. Frequency
- Impedance vs. Depth of Discharge

An exact timeline as to when these zinc air mercury-free miniature batteries will be commercially available in regions outside of Europe is not yet known. The price differential between the Energizer mercury and mercury-free zinc air models was not available. The method

that Energizer uses to achieve the mercury-free zinc air miniature battery is not publicly available.

Other Mercury-free Batteries

The following companies indicate either on their website or elsewhere on the Internet that they have mercury-free miniature batteries:

- Schenzhen Konnoc (China)
- Chung Pak (Hong Kong)
- Gloso (Hong Kong)
- Promax Battery (China)

However, the LCSP was not able to obtain product specifications or datasheets for these batteries.

Stacked Batteries

There were no mercury-free alternatives identified for stacked silver oxide or stacked alkaline manganese batteries. (Recall that these stacked batteries are a single unit comprised of multiple individual miniature cells in electrical series, to provide a higher voltage).

A possible alternative for mercury containing stacked miniature batteries is to stack mercury free versions of the alkaline and silver oxide miniature batteries. It appears that this would provide similar performance characteristics. However, we did not find a non-mercury stacked miniature battery product that was commercially available at this time.

6.2 Lithium Miniature Batteries

Lithium miniature batteries do not contain mercury, and are sometimes considered a potential alternative to mercury containing miniature batteries. As stated previously, there are numerous design considerations for OEMs in selecting a miniature battery technology for their end products. The requirements for each end product vary greatly, and consequently the level of importance for each of the design considerations will vary as well. Therefore, depending on the end product, the lithium miniature battery may or may not be a suitable alternative for mercury containing miniature batteries. For example, nominal voltage and physical size/shape may be important design considerations for a particular end product. Since lithium miniature batteries have a much higher nominal voltage and a different physical shape (typically flatter and wider - coin shaped) than the other three miniature battery technologies, they cannot easily be substituted in existing products. In one situation, a toy manufacturer investigated the replacement of a mercury-containing button battery with a lithium miniature battery. However, the requirement to retool the plastic mold for this toy product to accommodate the lithium battery was determined to be cost prohibitive.

Description:

Lithium miniature batteries are used as the main power source for devices such as electronic games, watches, calculators, car lock systems, and garage door openers. They are also used in

memory backup for telecommunications devices such as cordless telephones and mobile radios, as well as for office automation equipment such as printers, fax machines, and electronic typewriters. In addition, lithium miniature batteries can be used as the main power and the memory back up for the same device, such as an electronic organizer.

Lithium is an excellent candidate for use as a battery anode material because of its desirable properties such as: low density, high voltage, and good conductivity. Therefore, lithium is used as anode material for numerous battery chemistries in a variety of configurations (i.e. miniature, cylindrical, prismatic, etc.). Lithium metal reacts vigorously with water, and consequently must be used with non-aqueous electrolytes. There is a concern about the potential for fire when lithium batteries are collected. This issue is further discussed in Section 8 of this report.

The two primary lithium miniature battery chemistries are: 1) lithium/manganese dioxide, and 2) lithium/carbon monofluoride.

Performance:

The lithium/carbon monofluoride and lithium/manganese dioxide miniature batteries do not contain mercury. They each have a nominal voltage of 3.0 Volts, and have a flat discharge curve. The lithium batteries are commercially available in a wide range of capacities, from 25 to 1,000 mAh, and are mostly available in coin shaped batteries. However, there are also some models available in button shapes (e.g. Eastman Kodak model K58L, Sony model CR2477, and Varta model 6131 which has a 11.6 mm diameter and a 10.8 mm height).

Lithium miniature batteries have the second highest energy density compared to other miniature battery technologies. The gravimetric energy density is typically 200 to 230 mWh/g and the volumetric energy density is 400 to 545 mWh/cc. These batteries have excellent storage characteristics. The self-discharge rate for both lithium batteries is approximately 1% per year for up to ten years. This is the lowest self-discharge rate of the four miniature battery technologies. They also provide excellent leakage resistance.

Both lithium miniature batteries are ideal for applications requiring low current drain over an extended period of time. The maximum continuous drain recommended for these batteries is usually between 2 to 5 mA. They can accommodate current pulses up to 5 to 20 mA depending upon battery size.

Both lithium battery types can be used for a wide range of operating temperatures, from about –20 degrees C to 55 degrees C. Furthermore, lithium carbon monofluoride miniature batteries are also available in high operating temperature models. These batteries can be operated in a temperature range from –40 degrees C to 150 degrees C. They can be mounted on printed circuit boards and used for long term, low drain applications. The high operating temperature models offer the greatest range of operating temperatures compared to the other miniature battery technologies.

Manufacturers:

There are numerous manufacturers of lithium miniature batteries. The following table provides key information for some domestic and foreign manufacturers of lithium miniature batteries:

Table 6.4 Manufacturers of Lithium Miniature Batteries

Manufacturer	Model	Applications	Hg Content	Capacity (mAh)
Duracell	DL2X series	Not listed	None	(DL 2025) 150
Eastman Kodak	KCR series	Date book	None	80 - 230
Eastman Kodak	K58L	Photo	None	160
Energizer	CRX series	Audio equipment, calculators, cameras & light meters, data acquisition systems, electronic communication devices, electronic games, electronic wristwatches and clocks, hearing aids, industrial monitors/controls, medical equipment, memory retention, micro cassette recorders, military electronics, switchboards, transceivers & radios, security devices, small electronic instruments, remote keyless entry	None	29 - 575
GP Batteries International (Gold Peak)	CR1XXX, CR2XXX Series	Watch, computer memory backup, remote control, photo	None	36 - 270
Hitachi Maxell	CR2XXX series	Timepieces, calculators, cameras, medical instruments, office equipment, backup power for integrated circuits (ICs) and real time clocks (RTCs), home electronic instruments, automobile keyless entry, PC boards	None	50 - 610
Panasonic	BR series - High Operating Temperature	Automotive electric systems, toll way transponders, radio frequency identification products	None	48 - 1,000
Panasonic	CR series	Calculators, cameras, cordless applications, electronic translators, watches, memory backup in all types of devices (with tab terminals)	None	30 - 1,000
Panasonic	VL series	Memory back-up in facsimiles, memory cards, personal computers, sequencers, telephones, tuners, video cameras	None	1.5 - 100
Sanyo	CRXXXX series	Not listed	None	38 - 1,000

Manufacturer	Model	Applications	Hg Content	Capacity (mAh)
Shenzhen Malintech	CRXXXX series	Not listed	None	30 - 1,000
Varta	CRX series	Car keys/remote controls, alarm systems, watches (digital & analog), electronic databases/calculators, memory back-up, real-time clock, medical equipment, mini-flashlights	None	27 - 560
Varta	MC6XX Series	Cellular phones, personal digital assistants (PDAs), pagers, consumer devices	None	1.5 - 3

6.3 Cylindrical Alkaline Batteries

There are non-miniature cylindrical alkaline batteries ("cylindrical alkaline") that could be considered as alternatives to silver oxide, zinc air, and alkaline miniature technologies. The cylindrical alkaline batteries do not have added mercury. The smaller batteries of this type include:

Common Designation	IEC Designation	Voltage	Diameter (mm)	Height (mm)	Weight Note 1	Capacity
N	R1	1.5 V	12.0	30.2	9 g	1000 mAh [Note 2]
AAAA	N/A	1.5 V	8.3	42.5	6.5 g	625 mAh [Note 3]
AAA	R03	1.5 V	10.5	44.5	11.5 g	1250-1375 mAh [Note 4]
AA	R6	1.5 V	14.5	50.5	23 g	2850-3135 mAh [Note 5]

Notes:
[1] As a reference, miniature batteries typically fall in the 0.3-3.0 gram range
[2] Energizer e90 alkaline battery
[3] Energizer e96 E2 alkaline battery
[4] Energizer e92 alkaline battery & Energizer X92 alkaline battery
[5] Energizer e91 alkaline battery & Energizer X91 alkaline battery

The cylindrical alkaline batteries require considerably more battery compartment space and weigh much more than miniature batteries. Therefore cylindrical batteries would not be ideal candidates for applications that are either volume or weight sensitive, such as hearing aids. On the plus side, a typical cylindrical alkaline battery offers far greater capacity and significantly lower cost than most miniature batteries so their use would be favorable for consumers.

6.4 Secondary (Rechargeable) Batteries

There are several miniature battery technologies available for secondary batteries. These include the following technologies:

- Nickel Metal Hydride
- Lithium Ion
- Titanium Carbon Lithium Ion

- Lithium Manganese Dioxide

Nickel metal hydride miniature batteries typically contain less than 0.0005% mercury. The other technologies listed above for rechargeable batteries do not have any mercury content.

6.5 Other alternatives

Capacitors: Some OEMs have used capacitors instead of miniature batteries to provide memory backup power for certain electronic devices. Capacitors are non-mercury electronic components that store and release electrical charge. In some instances, the use of capacitors instead of miniature batteries can increase product reliability and reduce product costs. However, the technical and economic feasibility of using capacitors instead of miniature batteries should be evaluated by the OEM based upon the memory backup requirements for each particular application.

Solar Powered: Photovoltaic powered consumer products use amorphous silicon to capture sunlight and artificial light. Existing consumer products that use photovoltaic cells include watches, calculators, radios, cameras, cellular phones, headphones, flashlights, garden lamps, and dust busters. The disadvantages of this alternative include: need sunlight to power, output is directly related to light intensity, not appropriate for shaded areas, cost, and difficult to store electricity for later use.

Mechanically Powered: Mechanical energy can sometimes be used as an energy source for portable devices. Examples of sources of mechanical power include:

- Hand cranks/manual wind-up
- Self-winding
- Finger power from keyboard usage
- Trackball movement
- Watches powered by wrist motion

7.0 Alternatives - Summary and Conclusions

The following table summarizes key battery performance data from the preceding sections:

Consideration	Alkaline (Hg Containing)	Silver Oxide (Hg Containing)	Zinc Air (Hg Containing)	Lithium (No Hg)
Typical Mercury Content	0.1 – 0.9 %	0.2 – 1.0 %	0.3 – 2.0 %	None
Cost	$0.33/battery (min) $6.99/battery (max) $2.29/battery (median)	$1.20/battery (min) $18.99/battery (max) $3.19/battery (median)	$0.62/battery (min) $1.35/battery (max) $1.08/battery (median)	$0.33/battery (min) $5.09/battery (max) $2.99/battery (median)
Nominal Voltage (V)	1.5	1.55	1.4	3.0
Capacity (mAh)	15 - 830	5.5 - 200	33 – 1,100	25 – 1,000
Discharge profile	Tapered	Mostly flat, Tapered for reduced silver	Flat	Flat
Physical shape	Button	Mostly button, Some coin	Mostly button, Some coin	Mostly coin, Some button
Energy density: Gravimetric (mWh/g)	50 - 80	75 – 135	210 – 370	200 – 230
Energy density: Volumetric (mWh/cc)	150 - 360	300 - 530	770 – 1,300	400 - 545
Operating temperature (degrees C)	-20 to 55	0 to 55	0 to 50	Typical: -20 to 55, High temp. version: –40 to 150
Shelf life (self discharge rate at 20 degrees C, loss per year	Approximately 4%	Approximately 6%	Approximately 3%	Approximately 1%
Replacement Availability	Numerous retail and on-line options available	Numerous retail and on-line options available	Numerous retail and on-line options available	Numerous retail and on-line options available
Leakage resistance	Good	Good	Good	Excellent
Type of discharge	Good for high or low drainage applications.	Good for low drainage applications. KOH electrolyte preferred for high drainage.	Most effective for medium to high drain applications that use up capacity in a short period.	Excellent for low drainage, or high drainage, intermittent pulse applications.
Other key factors	Good resistance to shock and vibration.	High recycling rate due to silver content.	Requires access to ambient air. Short service life.	Excellent for memory backup applications.

Several alternatives to mercury containing miniature batteries were identified and evaluated. Lithium miniature batteries do not contain mercury, and are sometimes considered as

a potential alternative to mercury containing miniature batteries. Original equipment manufacturers (OEMs) must evaluate numerous design considerations when selecting the best miniature battery for their end product. The most important considerations for OEMs appear to be cost, nominal voltage, capacity, physical size/shape, and discharge profile. Other considerations include: type of discharge, shelf life, energy density, operating temperature, replacement availability, leakage resistance, and mercury content. The level of importance for each of these considerations can vary greatly depending upon the requirements of each particular end product (calculator, toy, watch, etc.). The suitability for replacing one miniature battery technology for another miniature battery technology must be determined on a case-by-case basis by OEMs based upon the unique requirements of their particular product. Therefore, depending on the end product, the lithium miniature battery may or may not be a suitable alternative for mercury containing miniature batteries.

Manufacturers are beginning to market mercury-free versions of silver oxide, alkaline manganese dioxide, and zinc air miniature batteries. Some of these batteries are targeted for the European market, but most are intended for worldwide use. The performance characteristics as published by the manufacturers appear to be comparable for the mercury and mercury-free versions. The costs of the mercury and mercury-free versions of these batteries were not available from some manufacturers. Based on pricing provided by one manufacturer, there is a 24% - 30% premium for their mercury-free miniature batteries compared to their mercury containing batteries. It is likely that this cost differential will close as sales volumes increase for mercury-free miniature batteries.

Manufacturers have taken different approaches to eliminating the mercury for the three mercury-containing miniature battery technologies. Since mercury is added to prevent the buildup of internal gases that can lead to battery cell bulging and rupture, it is important to assure that mercury-free miniature batteries will be reliable and comparable in performance to mercury-added miniature batteries with respect to leakage and rupture. Although the manufacturers of mercury-free batteries appear confidant that their batteries will not rupture and leak, there are no data currently available on the long-term performance of the mercury-free miniature batteries in this area.

8.0 Recycling

The most effective strategy for reducing the environmental emissions and potential health hazards of mercury from miniature batteries involves substituting mercury-containing batteries with mercury-free batteries. As noted in the previous sections, there are numerous mercury-free miniature batteries available today, although the feasibility of each substitution will depend on the specific application and the particular design considerations of each OEM. While new directives in Europe may be encouraging OEMs to convert to mercury-free miniature batteries, there will continue to be mercury-containing batteries on the market for the immediate future. To address the mercury-containing batteries currently on the market and the legacy of mercury-containing batteries still in use, it is useful to consider the use of battery recycling programs to manage potential environmental and health hazards of mercury in miniature batteries.

A recent European proposal notes that recycling miniature batteries provides the opportunity to avoid external costs that are usually paid for by society in the form of cleanup costs, environmental deterioration, or adverse health effects. Metals in the spent batteries that might normally be lost to disposal can be recycled and put back into products. Other substances such as acids, salts, and plastics will be diverted from the waste stream and managed appropriately. Potential air and water pollution and other environmental impacts from incinerating or landfilling the spent batteries can be avoided, ultimately translating to reduced human exposures and abatement costs. (Reference: Commission of the European Communities, 2003, p.22 and discussion in Appendix E)

Recycling programs for miniature batteries are currently available and carried out throughout the United States. There are multiple vendors and options for recycling miniature batteries. Although some in the business community have raised concerns about the safety and cost effectiveness of miniature battery recycling, the existing evidence suggests that most of these concerns can be effectively addressed.

8.1 Battery Recycling Programs in The United States

Four recycling programs in the United States were interviewed by phone and their costs and recovery rates are shown in the following Table 8.1. The programs represented two counties in the United States, a town in Massachusetts and a municipal waste provider serving 69 communities in the Northeast, all of which offer recycling programs that include miniature batteries. The four programs were selected for interviews because of the ability to provide data, longevity or breadth of the program, and/or the ability to provide a cogent overview of their experience. (More details from these interviews are included in Appendix F).

The town and counties represented in our interviews have collection sites or containers set up in multiple areas in the town or regions. A major city in one of the counties also provides curbside pickup of miniature and other dry cell batteries. Miniature battery collection containers (typically cardboard boxes) fall under the universal waste rule and are collected within 1 year. Batteries from the boxes are often consolidated into a pail or larger container and then shipped for sorting and recycling.

Batteries fall under the Universal Waste Rules of the Environmental Protection Agency. These rules reduce the administrative and regulatory burdens associated with hazardous waste. As a result, battery collection containers may be left in place for 1 year and then shipped by a common transport system such as United Parcel Service. (That is, it is not considered hazardous waste and does not require special documentation or handling).

These local battery-recycling programs are voluntary. While each of these programs has had some success with local merchants or with aggressive promotional campaigns, those interviewed suggested that the actual recycling rate for miniature battery recycling appeared lower than they could be.

Different cost structures make it difficult to compare recycling costs from program to program, although the recycling costs from these communities appear to fall in the $2.50-$5.00 per pound range. However, in most recycling programs, miniature batteries are not the sole waste being collected or the only container being transported. Miniature battery recycling typically takes place in the context of larger recycling programs that aggregate the costs.

Table 8.1

Location	Population Served	Miniature Battery Recycling Cost/Pound	Average Cost/Year (N/A – not available)	Pounds (Lbs) Batteries Recycled	Population - based Recycling Level
County in Midwest	1,112,259	$5.05/pound	$4424/year	876 lbs/year	7.8×10^{-4} lb/person
County in Northeast	150,000	$2.50/pound	$150/year	60 lbs/year	2.2×10^{-4} lb/person
Massachusetts Town	17,000	State contracted price for recycling applies: $0.65/lb for alkaline batteries, $3.50/lb for Hg batteries, $2.50/lb for silver oxide, $3.50/lb for lithium batteries, $.20/lb for sorting	N/A; combined with other recycling costs in Waste Contract	N/A	
Wheelabrator; Operator of 3 Municipal Waste Combustors in Northeast	1,428,856	N/A; mercury reduction programs are funded by $0.50/ton set aside from tipping fees charged to communities	N/A	67.5 lbs/year (2003) or approximately 43,200 batteries/yr[1]	0.5×10^{-4} lb/person

[1] Wheelabrator Program Coordinator estimates 640 miniature batteries/pound

In the interviews with representatives of four U.S. recycling programs, it was found that some recycling programs rely on contracts established directly with recycling firms, other programs are tied into municipal waste contracts, and some other programs are pay as you go, using pre-paid boxes or paying a sum based on the weight of small individual recycling containers.

Representatives of two battery-recycling companies were interviewed about their options for small-scale miniature battery recycling in communities. Each offers a user-friendly system for

collecting and recycling button batteries, briefly outlined in the following Table. According to the representatives, their containers are commonly found in public locations (e.g. town hall, library, senior center).

Table 8.2 Recycling Services

Company	Program Offered	Costs
Battery Solutions Http://www.batteryrecycling.com/pailmail.html	Pail Mail® program: Customer purchases a plastic bucket that serves as a collection and shipping container. When a customer calls in with a full container, Battery Solutions will send a shipping label and arrange for a FedEx Ground battery pickup on the following business day.	Reusable Bucket - $8 Recycling charge - $2.50/lb Shipping charge – approximately $13 (estimate for ground shipping 30 lb)
Toxco Http://www.biggreenbox.com/	Big Green Box program: Customer purchases box that is self-contained collection & shipping unit. Purchase price of $58 includes collection box, return shipping cost and battery recycling cost. Box includes plastic baggies for batteries and return shipping label. (Note: Box capacity 43 pounds)	Big Green Box - $58 total

8.2 Battery Recycling in Europe

Recycling data were also available for miniature battery recycling in European Union-15 (EU-15) states (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom) and Norway and the Swiss Confederation and are included in Table 8.3. (Reference: BIO Intelligence Service). Unlike the United States where miniature battery recycling is voluntary, recycling of mercury-containing miniature batteries in the European Union is influenced by existing battery legislation under "Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances, as amended by Commission Directive 98/101/EC". The key points of this legislation are summarized in Appendix G.

The Member States of the European Union have taken divergent approaches to battery recycling. Therefore, results vary widely from state to state and the overall collection efficiency of spent batteries in the Member States is low. Many batteries are still landfilled or incinerated instead of being collected and recycled. In a report commissioned by the European Commission Directorate General Environment, BIO Intelligence Service estimated the current recycling level of button batteries in Europe in 2002 at 15%. That is, 15% of the spent batteries available for collection enter a recycling plant.

Table 8.3 Recycling in Europe (2002)

Location	Population Served	Miniature Battery Recycling Cost/Pound	Average Cost/Year (N/A – not available)	Pounds (Lbs) Batteries Recycled	Population -based Recycling Level
EU-15, Norway and Swiss Confederation	Approximately 380,000,000	France – approximately $1.49/pound[1] Belgium – approximately $2.29/pound[1]	N/A	83,752 pounds/year[2] This is equivalent to 15% of batteries available for collection, or 10% of annual sales	4×10^{-4} lb/person

[1]Based on 10/22/04 conversion rate of $1.2639/Euro (Reference: Federal Reserve)
[2] (38 tonnes/year x 2204 lbs/tonne) = 83,752 lbs/year

8.3 Fire Hazards

There is some concern that the collection of miniature batteries for recycling could raise the risk of fire. There is a widely held perception that discarded lithium miniature batteries (an alternative to mercury-containing miniature batteries) have the potential for smoldering or causing fires in collection containers. One can understand the concern about battery fires when reading information available online. These statements and others raise the specter of fires occurring at local collection sites. In our phone interview with David Miller of Toxco, many concerns about collecting lithium miniature batteries for recycling were allayed. According to Miller:

- His company has never had a fire in a community collection box or during transit of miniature batteries.
- Lithium metal is the dangerous form associated with fires. As a miniature battery is consumed, the lithium is converted to lithium manganese dioxide, which is a stable form.
- Any recycler who handles lithium is going to have a fire sooner or later. However those fires are from much more potent forms of lithium: scrap lithium anode, government and industrial batteries, lithium boilers that contain ~15 pounds of elemental lithium, for example.

The National Fire Protection Association (NFPA) was contacted and they stated that there are no NFPA codes or standards that apply to miniature batteries. The NFPA representative noted that NFPA writes codes, including fire codes and electrical codes. While a code might specify requirements such as use of smoke detectors, for example, it is up to others to determine the necessary standards and/or functionality of a device or its components. NFPA does not conduct research, nor does it have lab or testing facilities.

Underwriters Laboratories (UL) is an independent, not-for-profit product-safety testing and certification organization was also contacted. UL has no voluntary safety standards for zinc air, silver oxide, alkaline, or lithium miniature batteries.

There is no evidence that mercury-containing miniature batteries pose a significant fire hazard. For a fire to occur, four elements are needed to initiate and sustain a fire: fuel, oxygen, heat, and a chemical chain reaction. In general, there would be only as small amount of electrical energy left in spent miniature batteries (making the potential for heat generation minimal), the

closed box will limit oxygen availability, and there would be little or no fuel to sustain a fire. Therefore it is unlikely that conditions supporting a fire would occur in a miniature battery collection box.

While there is always some risk of fire in most municipal waste recycling programs, we could not find evidence of any elevated risk associated with mercury-containing battery collection and recycling programs.

8.4 Human Ingestion Hazards

Additional concern has focused on the risks of human ingestion of miniature batteries or insertion of a miniature battery in the ear or nose when they are removed from products or stored prior to collection. Our review of the data found that the use of miniature batteries carries a small risk of ingestion, especially by children and the elderly.

Data show that miniature battery ingestions represent 0.1% of exposures reported to poison control centers in the United States. (Reference: Annual Reports of the AAPCC, 1998-2002 and Appendix H). Although most miniature battery ingestions result in no long-term adverse medical outcomes, a very small percentage will have more serious outcomes. In 2002, about 10 people reported a major medical outcome (life-threatening or significant residual disability or disfigurement) from ingesting miniature batteries. (Annual Report of the AAPCC, 2002)

Risk of ingestion is associated with the use of miniature batteries, not just conditions that might occur with battery recycling. Approximately 60% of battery ingestions occur immediately after removal from a product or with batteries taken directly from the package, while the remaining battery ingestions (40%) involve batteries lying loose, sitting out or discarded. (Reference: Litovitz and Schmitz, 1992). More complete data on battery ingestions are included in Appendix H.

Our research did not reveal any specific miniature battery standards promulgated by consumer product safety agencies, packaging organizations or advocacy groups. The Consumer Product Safety Commission (CPSC), for example, does not have specific input or regulations for miniature batteries. Some of the CPSC regulations, however, such as regulations pertaining to small parts on children's toys, might indirectly pertain to miniature batteries.

The mishandling of miniature batteries that leads to ingestion or insertion of the battery into the human body does occur. Removing a miniature battery from a product such as a hearing aid to replace it presents an opportunity for such ingestion. However, once the battery is removed, the difference in risk of ingestion between setting it aside for disposal or for recycling is determined by where and how the battery is stored prior to collection. Further research is needed to determine the degree to which this is significant.

8.5 Recycling - Results and Conclusions

Recycling programs for miniature batteries are available throughout the United States and there are private vendors who have demonstrated capacities in battery recycling. Different cost

structures make it difficult to compare recycling costs from program to program, however the recycling costs appear to fall in the $2.50-$5.00 per pound range. This is higher than recycling costs of approximately $1.50 - $2.30 per pound reported in two European Union countries, but still amounts to less than 1¢ per battery assuming 640 batteries per pound.

Although there is not enough information to establish recycling rates, by comparing the U.S. recycling levels with the European levels (estimated at 15% of batteries available for collection) the evidence from the local programs reviewed suggests that the U.S. rates are low and could be significantly improved. A comparison with Europe also suggests that if miniature battery recycling becomes more widespread and recycling volumes increase, economies of scale will be reflected in more efficient, cost effective options for collection, transportation and recovery processes.

Mercury-containing miniature batteries (as individual units) do not have any applicable codes, standards or certifications to measure or control their inherent safety or safe use and there are no standards or regulations specific to recycling miniature batteries. While there is no evidence that the batteries pose an elevated fire hazard during recycling, data that shows a risk of human ingestion associated with the use of miniature batteries should be considered in promoting domestic battery recycling programs. However, this factor should be considered at any time for the safe use of replacement miniature batteries and any products that contain miniature batteries.

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Appendices

Appendix A: Miniature Battery Components

The following figure illustrates the basic components of a miniature battery.

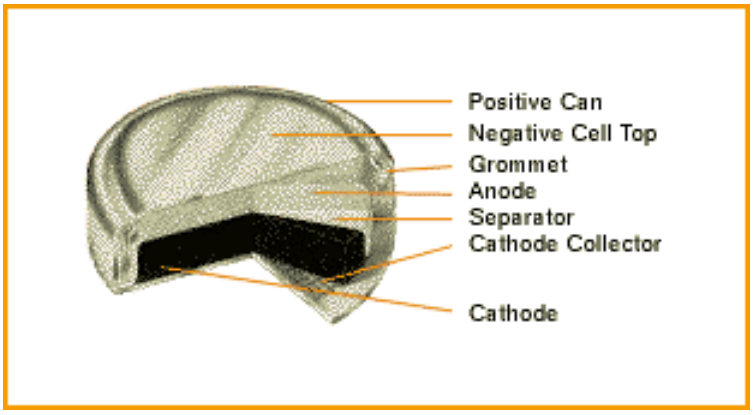

Figure 1: Miniature Battery Components

In general, the primary components of the primary miniature battery technologies are as follows:

Cathode: The electrode in an electrochemical cell where reduction occurs. During discharge, the positive electrode of the electrochemical cell is the cathode.

Anode: The electrode in an electrochemical cell where oxidation occurs. During discharge, the negative electrode of the electrochemical cell is the anode.

Electrolyte: The medium that provides the ion transport mechanism between the positive and negative electrodes of a cell.

Packaging: The cathode, anode, and electrolyte are typically housed in two metal cans that are crimped together to form the miniature battery. The metal cans are often plated with a protective layer of nickel. There is often a gasket used to seal the cell and prevent leakage of battery cell materials.

Zinc Air
The major components of the zinc air miniature battery are as follows:

Cathode: Oxygen from ambient air

Electrolyte: The aqueous electrolyte typically consists of 20 to 40% potassium hydroxide (KOH) or sodium hydroxide (NaOH).

Anode: Granulated zinc powder mixed with the electrolyte.

Packaging: The metal can houses the cathode and anode active materials and acts as the positive and negative terminals. A plastic gasket provides insulation between the two cans.

Silver Oxide

The major components of the silver oxide miniature battery are as follows:

Cathode: The cathode consists primarily of monovalent silver oxide (Ag2O) blended with 1% to 5% powered graphite. The cathode may also contain manganese dioxide (MnO2) or silver nickel oxyhydroxide (AgNiO2)

Electrolyte: The aqueous electrolyte typically consists of 20% to 45% potassium hydroxide (KOH) or sodium hydroxide (NaOH). Potassium hydroxide has higher electrical conductivity and allows cells to discharge over a wide range of current levels. Sodium hydroxide is used mostly for long life cells not requiring a high discharge rate.

Anode: A powdered zinc metal.

Packaging: The outer surface is steel with a protective layer of nickel, and the inner surface is high purity copper or tin. The gasket used to seal the cell is made from an electrolyte resistant plastic such as nylon.

Alkaline Manganese Dioxide

The major components of the alkaline-manganese dioxide miniature cell are as follows:

Cathode: The cathode is primarily comprised of electrolytic manganese dioxide. Carbon, usually in the form of graphite, is used as an electronic conductor.

Electrolyte: The aqueous electrolyte typically contains 35 – 52% potassium hydroxide (KOH).

Anode: Powered zinc metal. The anode may also contain mercury used as a gassing suppressor, electronic conductor, or discharge accelerator.

Packaging: The can is made of steel plated on both sides with nickel. The seal is a thin plastic gasket.

Lithium Manganese Dioxide

The major components of the lithium manganese dioxide miniature batteries are as follows:

Cathode: Heat-treated form of manganese dioxide (MnO_2)

Electrolyte: Lithium salts in a mixed organic solvent such as propylene carbonate and 1,2-dimethoxyethane.

Anode: Lithium

Packaging: A non-woven polypropylene separator is used to separate the manganese dioxide pellet and the lithium anode disk. The battery cell is crimp sealed, with the can providing the positive terminal and the cap providing the negative terminal.

Lithium Carbon Monofluoride

The major components of the lithium carbon monofluoride miniature cell are as follows:

Cathode: Polycarbon monofluoride $(CF)_n$, where n is typically between 0.9 to 1.2. The carbon monofluoride is formed by the reaction between carbon powder and fluorine gas.

Electrolyte: Common electrolytes used are 1) lithium hexafluoroarsenate ($LiAsF_6$) in gamma-butyrolactone, or 2) lithium tetrafluoroborate ($LiBF_4$) in propylene carbonate and dimethoxyethane.

Anode: Lithium

Packaging: Nickel plated steel or stainless steel is often used for the case material. The battery cells are crimp sealed using a polypropylene gasket.

Appendix B: Miniature Battery Nomenclature

The International Electrotechnical Commission (IEC) has published standards for primary batteries. The IEC nomenclature scheme for primary batteries is based on the electrochemical system as well as the size and shape of the battery. The following table indicates the IEC nomenclature for electrochemical systems relevant to this study.

IEC Letter Code	Negative Electrode	Positive Electrode	Nominal Voltage
B	Lithium	Carbon monofluoride	3
C	Lithium	Manganese dioxide	3
L	Zinc	Manganese dioxide	1.5
P	Zinc	Oxygen (air)	1.4
S	Zinc	Silver oxide	1.55

The IEC uses the letter "R" to designate round batteries. The IEC uses many numerical designations to indicate the acceptable range for battery diameter and height. The following table provides some examples:

IEC Designation	Maximum Diameter (mm)	Minimum Diameter (mm)	Maximum Height (mm)	Minimum Height (mm)
R44	11.6	11.25	5.4	5.0
R64	5.8	5.55	2.7	2.4
R1620	16	15.7	2.0	1.8
R2032	20	19.7	3.2	2.9

Many manufacturers base the model numbers for their miniature batteries on the IEC nomenclature. The following two examples are provided to illustrate the IEC nomenclature for miniature batteries:

- The IEC nomenclature for a lithium manganese dioxide miniature battery with a diameter of 20 mm and a height of 3.2 mm would be: CR2032.

- The IEC nomenclature for a silver oxide miniature battery with a diameter of 11.6 mm and a height of 5.4 mm would be: SR44.

Appendix C: Miniature Battery Cost and Availability

Hearing Aid Batteries
Chemistry: Zinc Air

Battery Size	Date	Vendor	Description	price	qty/pkg	$/unit
10	7/22/04	Walgreens.com	Walgreens Size 10	14.99	24	$0.62
10	10/23/04	www.radioshack.com	Part number 23-776	10.99	16	$0.69
10	10/23/04	www.radioshack.com	Part number 23-076	5.99	8	$0.75
10	7/22/04	Walgreens.com	Walgreens Size 10	8.99	12	$0.75
10	7/22/04	Walgreens.com	Walgreens Size 10	4.99	6	$0.83
10	7/26/04	Walgreens Pharmacy	Duracell	12.99	12	$1.08
10	7/22/04	Walgreens.com	Duracell Size 10	12.99	12	$1.08
10	7/22/04	CVS.com	Duracell Easy-Tab DA 10B8	8.99	8	$1.12
10	7/26/04	Walgreens Pharmacy	Duracell	8.99	8	$1.12
10	7/26/04	Walgreens Pharmacy	Rayovac	8.99	8	$1.12
10	7/26/04	Walgreens Pharmacy	Energizer EZ Change	8.99	8	$1.12
10	7/22/04	Walgreens.com	Duracell Size 10	8.99	8	$1.12
RS 10	10/23/04	www.radioshack.com	Part number 23-056	5.99	8	$0.75
13	7/22/04	Walgreens.com	Walgreens Size 13	14.99	24	$0.62
13	10/23/04	www.radioshack.com	Part number 23-778	10.99	16	$0.69
13	10/23/04	www.radioshack.com	Part number 23-078	5.99	8	$0.75
13	7/22/04	Walgreens.com	Walgreens Size 13	8.99	12	$0.75
13	7/22/04	Walgreens.com	Walgreens Size 13	4.99	6	$0.83
13	7/26/04	Walgreens Pharmacy	Rayovac	14.99	16	$0.94
13	7/26/04	Walgreens Pharmacy	Duracell	12.99	12	$1.08
13	7/22/04	Walgreens.com	Duracell Size 13	12.99	12	$1.08
13	7/22/04	CVS.com	Duracell Easy-Tab DA 13B8	8.99	8	$1.12
13	7/26/04	Walgreens Pharmacy	Duracell	8.99	8	$1.12
13	7/26/04	Walgreens Pharmacy	Rayovac	8.99	8	$1.12
13	7/26/04	Walgreens Pharmacy	Energizer EZ Change	8.99	8	$1.12
13	7/22/04	Walgreens.com	Duracell Size 13	8.99	8	$1.12
RS 13	10/23/04	www.radioshack.com	Part number 23-058	5.99	8	$0.75
312	7/22/04	Walgreens.com	Walgreens Size 312	14.99	24	$0.62
312	10/23/04	www.radioshack.com	Part number 23-779	10.99	16	$0.69
312	10/23/04	www.radioshack.com	Part number 23-079	5.99	8	$0.75
312	7/22/04	Walgreens.com	Walgreens Size 312	8.99	12	$0.75
312	7/22/04	Walgreens.com	Walgreens Size 312	4.99	6	$0.83
312	7/26/04	Walgreens Pharmacy	Rayovac	14.99	16	$0.94
312	7/22/04	Walgreens.com	Duracell Size 312	12.99	12	$1.08
312	7/22/04	CVS.com	Duracell Easy-Tab 312B8	8.99	8	$1.12
312	7/26/04	Walgreens Pharmacy	Rayovac	8.99	8	$1.12
312	7/26/04	Walgreens Pharmacy	Energizer EZ Change	8.99	8	$1.12
312	7/22/04	Walgreens.com	Duracell Size 312	8.99	8	$1.12
675	7/22/04	Walgreens.com	Walgreens Size 675	14.99	24	$0.62
675	10/23/04	www.radioshack.com	Part number 23-077	5.99	8	$0.75

675	7/22/04	Walgreens.com	Walgreens Size 675	8.99	12	$0.75
675	7/22/04	Walgreens.com	Walgreens Size 675	4.99	6	$0.83
675	7/26/04	Walgreens Pharmacy	Duracell	12.99	12	$1.08
675	7/26/04	Walgreens Pharmacy	Rayovac	8.99	8	$1.12
675	7/22/04	CVS.com	Duracell Easy-Tab DA 675B6	6.99	6	$1.17
675	7/26/04	Walgreens Pharmacy	Duracell	6.99	6	$1.17
675	7/26/04	Walgreens Pharmacy	Energizer EZ Change	6.99	6	$1.17
675P	10/24/04	RadioShack stores & online	Model 675HP Zinc-Air Pager/Hearing Aid Battery 2-Pack. Cat. No. 23-150	2.69	2	$1.35
675	7/22/04	Walgreens.com	Duracell Size 675	6.99	6	$1.17

Minimum	$0.62
Maximum	$1.35
Median	$1.08

Silver Oxide Batteries

Battery Size	Date	Vendor	Description	price	qty/pkg	$/unit
76	10/24/04	Radio Shack stores & online	Model 76 1.55V/165mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
301	7/25/04	www.batteries.com	Renata	$3.47	1	$3.47
301	7/25/04	www.batteries.com	Energizer	$4.39	1	$4.39
303	10/24/04	Radio Shack stores & online	Model 303 1.55V/170mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
303	7/25/04	www.batteries.com	Renata 303R	$4.39	1	$4.39
303	7/25/04	www.batteries.com	Energizer 303	$5.09	1	$5.09
309	7/25/04	www.batteries.com	Energizer	$4.84	1	$4.84
315	7/25/04	www.batteries.com	Renata 5-Pack 315 Coincell Batteries	$5.99	5	$1.20
317	10/24/04	Radio Shack stores & online	Model 317 1.55V/8mAh S-O Button-Watch/Calculator Battery	$3.19	1	$3.19
317	7/25/04	www.batteries.com	Energizer Button Cell	$4.29	1	$4.29
319	7/25/04	www.batteries.com	Renata 5-pack 319 Coincell Batteries	$5.99	5	$1.20
319	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
319	10/24/04	Radio Shack stores & online	Model 319 1.5V/16mAh Silver-Oxide Battery 1 Pack	$3.19	1	$3.19
319	7/25/04	www.batteries.com	Energizer Button Cell	$4.59	1	$4.59
321	7/25/04	www.batteries.com	Renata 5-pack 321 Coincell Batteries	$5.99	5	$1.20
321	10/14/04	www.radioshack.com	1.55V/13mAh S-O Button Battery, Catalog # 23-515	$3.19	1	$3.19
321	7/25/04	www.batteries.com	Energizer Button Cell	$3.29	1	$3.29
329	7/25/04	www.batteries.com	Renata 329R Button Cell Battery	$3.09	1	$3.09
335	10/24/04	www.radioshack.com	Model 335 1.55V/5mAh Renata Silver-Oxide Battery 1-Pack	$2.99	1	$2.99
335	7/25/04	www.batteries.com	Renata 335R Button Cell Battery	$3.72	1	$3.72
335	7/25/04	www.batteries.com	Energizer Button Cell	$4.29	1	$4.29
337	7/25/04	www.batteries.com	Renata 337R Button Cell	$4.20	1	$4.20
339	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
341	10/24/04	www.radioshack.com	Model 341 1.55V/13.5mAh Silver-Oxide Battery 1-Pack	$2.99	1	$2.99
341	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
344	10/24/04	www.radioshack.com	Model 344 1.55V/105mAh Renata Silver Oxide Battery 1-pack	$2.99	1	$2.99
344	7/25/04	www.batteries.com	Renata 344R Button Cell Battery	$3.09	1	$3.09
344	7/25/04	www.batteries.com	Energizer Button Cell	$3.99	1	$3.99
346	10/24/04	www.radioshack.com	Model 346 1.55V 10mAh Renata Silver Oxide Battery	$2.99	1	$2.99
346	7/25/04	www.batteries.com	Renata 346R Button Cell Battery	$3.82	1	$3.82
346	7/25/04	www.batteries.com	Energizer Button Cell	$4.29	1	$4.29
350	10/24/04	www.radioshack.com	Model 350 1.55V 105mAh Renata Silver Oxide Battery - 1 Pack	$2.99	1	$2.99
350	7/25/04	www.batteries.com	Renata 350R Button Cell Battery	$3.73	1	$3.73
350	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
357	7/26/04	Walgreen's Pharmacy	Energizer 357	$6.99	3	$2.33
357	7/25/04	www.batteries.com	Renata 357R	$3.09	1	$3.09
357	10/24/04	Radio Shack stores & online	Model 357 1.55V/165mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19

357	7/25/04	www.batteries.com	Energizer Button Cell	$3.89	1	$3.89
361	7/25/04	www.batteries.com	Renata 361R Button Cell Battery	$3.09	1	$3.09
361	7/25/04	www.batteries.com	Energizer Button Cell	$3.69	1	$3.69
362	7/25/04	www.batteries.com	Renata 5-pack 362 Coincell Batteries	$5.99	5	$1.20
362	7/25/04	www.batteries.com	Renata 362R Button Cell Battery	$3.09	1	$3.09
362	10/24/04	Radio Shack stores & online	Model 362 1.55V/21mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
362	7/25/04	www.batteries.com	Energizer Button Cell	$3.79	1	$3.79
364	7/25/04	www.batteries.com	Renata 5-pack 364 Coincell Batteries	$5.99	5	$1.20
364	7/26/04	Walgreen's Pharmacy	Energizer 364	$2.99	1	$2.99
364	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
364	10/24/04	Radio Shack stores & online	Model 364 1.55V/20mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
364	7/25/04	www.batteries.com	Energizer Button Cell	$3.29	1	$3.29
365	10/24/04	www.radioshack.com	365 1.55V 40mAh Renata Silver Oxide Battery 1 Pack	$2.99	1	$2.99
365	7/25/04	www.batteries.com	Energizer Button Cell	$3.79	1	$3.79
366	10/24/04	www.radioshack.com	Model 366 - 1-pack 1.55V/33mAh Renata Silver Oxide Battery	$2.99	1	$2.99
366	7/25/04	www.batteries.com	Renata 366R Button Cell Battery	$3.62	1	$3.62
366	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
370	7/25/04	www.batteries.com	Renata 5-pack 370 Coincell Batteries	$5.99	5	$1.20
370	7/25/04	www.batteries.com	Renata 370R Button Cell Battery	$3.34	1	$3.34
370	7/25/04	www.batteries.com	Energizer Button Cell	$3.99	1	$3.99
371	7/25/04	www.batteries.com	Renata 5-Pack 371 Coincell Batteries	$5.99	5	$1.20
371	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
373	7/25/04	www.batteries.com	Renata 5-Pack 373 Coincell Batteries	$5.99	5	$1.20
373	10/24/04	Radio Shack stores & online	Model 373 1.55V/23mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
373	7/25/04	www.batteries.com	Energizer Button Cell	$4.29	1	$4.29
376	10/24/04	Radio Shack stores & online	Model 376 1.55V/26mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
376	7/25/04	www.batteries.com	Energizer Button Cell	$3.39	1	$3.39
376	7/25/04	www.batteries.com	Renata 376R Button Cell Battery	$3.46	1	$3.46
377	7/25/04	www.batteries.com	Renata 5-Pack 377 Coincell Batteries	$5.99	5	$1.20
377	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
377	7/25/04	www.batteries.com	Energizer Button Cell	$3.09	1	$3.09
377	10/24/04	Radio Shack stores & online	Model 377 1.55V/26mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
379	7/25/04	www.batteries.com	Renata 5-pack 379 Coincell Batteries	$5.99	5	$1.20
379	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
379	7/25/04	www.batteries.com	Energizer Button Cell	$3.09	1	$3.09
379	10/24/04	Radio Shack stores & online	Model 379 1.55V/14mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
380	7/25/04	www.batteries.com	Renata 380R Button Cell Battery	$3.99	1	$3.99
381	7/25/04	www.batteries.com	Renata 381R Button Cell Battery	$3.43	1	$3.43
381	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
384	10/24/04	Radio Shack stores & online	Model 384 1.55V/42mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
384	7/25/04	www.batteries.com	Renate 384R Button Cell Battery	$3.32	1	$3.32
384	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09

386	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
386	7/25/04	www.batteries.com	Renata 386R Button Cell Battery	$3.09	1	$3.09
386	10/24/04	Radio Shack stores & online	Model 386 1.55V/120mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
386	7/25/04	www.batteries.com	Energizer Button Cell	$3.79	1	$3.79
387	10/24/04	www.radioshack.com	Model 387S Energizer 1.5V/80mAh Silver-Oxide Button Battery	$2.99	1	$2.99
387	7/25/04	www.batteries.com	Renata 387R Button Cell Battery	$4.39	1	$4.39
389	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
389	7/25/04	www.batteries.com	Renata 389R Button Cell Battery	$3.09	1	$3.09
389	10/24/04	Radio Shack stores & online	Model 389 1.5V/85mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
389	7/25/04	www.batteries.com	Energizer Button Cell	$4.39	1	$4.39
390	10/24/04	Radio Shack stores & online	Model 390 1.55V/85mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
390	7/25/04	www.batteries.com	Energizer Button Cell	$3.99	1	$3.99
391	10/24/04	Radio Shack stores & online	Model 391 1.5V/24mAH Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
391	7/25/04	www.batteries.com	Renata 391R Button Cell Battery	$3.35	1	$3.35
391	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
392	7/25/04	www.batteries.com	Renata 5-Pack 392 Coincell Batteries	$5.99	5	$1.20
392	7/25/04	www.batteries.com	Energizer Button Cell	$3.09	1	$3.09
392	10/24/04	Radio Shack stores & online	Model 392 1.55V/42mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
393	10/24/04	Radio Shack stores & online	Model 393 1.55V/70mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
393	7/25/04	www.batteries.com	Energizer Button Cell	$3.29	1	$3.29
394	7/25/04	www.batteries.com	Renata 5-Pack 394 Coincell Batteries	$5.99	5	$1.20
394	10/24/04	Radio Shack stores & online	Model 394 1.5V/67mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
394	7/25/04	www.batteries.com	Energizer Button Cell	$3.99	1	$3.99
395	7/25/04	www.batteries.com	Renata 395R 5-pack Button Cell Batteries	$5.99	5	$1.20
395	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
395	10/24/04	Radio Shack stores & online	Model 395 1.55V/42mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
395	7/25/04	www.batteries.com	Energizer Button Cell	$3.29	1	$3.29
396	10/24/04	Radio Shack stores & online	Model 396 1.55V/25mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
396	7/25/04	www.batteries.com	Energizer Button Cell	$3.19	1	$3.19
397	7/25/04	www.batteries.com	Renata 5-Pack 397 Coincell Batteries	$5.99	5	$1.20
397	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
397	10/24/04	Radio Shack stores & online	Model 397 1.55V/30mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
397	7/25/04	www.batteries.com	Energizer Button Cell	$4.09	1	$4.09
399	7/25/04	www.batteries.com	Renata 5-Pack 399 Coincell Batteries	$5.99	5	$1.20
399	10/24/04	Radio Shack stores & online	Model 399 1.55V/55mAh Silver-Oxide Battery 1-Pack	$3.19	1	$3.19
399	7/25/04	www.batteries.com	Energizer Button Cell	$3.99	1	$3.99
23-221	10/24/04	Radio Shack stores & online	Pet Collar Replacement Battery; 7.5 V, Silver Oxide. Catalog #: 23-221. Appears to be stacked.	$18.99	1	$18.99
357/303	7/26/04	Walgreen's Pharmacy	Energizer 357/303	$2.99	1	$2.99

387S	7/25/04	www.batteries.com	Energizer Button Cell	$4.49	1	$4.49
PX28S	7/29/04	www.zbattery.com	(Stack) PX28S Silver Oxide 6V Battery (Note 2)	$4.27	1	$4.27
RFA-16-11	10/19/04	www.petsafestore.com	6 Volt Silver oxide battery for Pet pager Receiver, Electronic Leash or Receiver. (Appears to be stacked miniature cells)	$6.95	1	$6.95
S76	7/29/04	www.zbattery.com	Duracell MS76B Photo Battery	$2.69	1	$2.69
TR175S	7/29/04	www.zbattery.com	(Stack) Energizer TR175S (Silver Oxide) Dog Collar Battery (Note 1)	$5.93	1	$5.93
	10/24/04	www.radioshack.com	1.55V/45mAh Vinnic S-O Button-Watch/Calculator	$2.99	1	$2.99
	10/24/04	www.radioshack.com	1.5V Button Vinnic (S-O) Battery	$2.99	1	$2.99
	10/24/04	www.radioshack.com	1.5V Button Vinnic (S-O) Battery	$2.99	1	$2.99
	10/24/04	www.radioshack.com	1.5V Button Varta (S-O) Battery	$2.99	1	$2.99
	10/24/04	www.radioshack.com	1.5V Renata Button (S-O) Battery	$2.99	1	$2.99
	10/24/04	www.radioshack.com	1.55V/7.5mAh Maxell Button S-O Battery 1-Pack	$2.99	1	$2.99

minimum	$1.20
maximum	$18.99
median	$3.19

Alkaline Manganese Dioxide Batteries

Battery Size	Date	Vendor	Description	price	qty/pkg	$/unit
See descrip.	6/16/04	Ocean State Job Lot	Konnoc Alkaline MicroCell AG1/LR621/364	$0.99	3	$0.33
See descrip.	6/16/04	Ocean State Job Lot	Konnoc Alkaline MicroCell AG3/LR41/392	$0.99	3	$0.33
See descrip.	6/16/04	Ocean State Job Lot	Konnoc Alkaline MicroCell LR44/357	$0.99	3	$0.33
See descrip.	6/16/04	Ocean State Job Lot	Konnoc Alkaline MicroCell LR521/379	$0.99	3	$0.33
See descrip.	6/16/04	Ocean State Job Lot	Konnoc Alkaline MicroCell LR626/AG4/377	$0.99	3	$0.33
LR44	7/29/04	www.zbattery.com	Renata	$195.00	500	$0.39
LR44	7/29/04	www.zbattery.com	Renata	$50.00	100	$0.50
76A	7/29/04	www.zbattery.com	Duracell 76A Medical Battery	$9.50	12	$0.79
76A	7/29/04	www.zbattery.com	Duracell PX76A/675AB	$0.89	1	$0.89
6V Stack	10/24/04	www.radioshack.com	6V Vinnic Alkaline Remote Control Battery. Appears to be stacked. Catalog #: 960-0363	$1.79	1	$1.79
9V Stack	10/24/04	www.radioshack.com	9V/33mAh Vinnic Alkaline Battery. Catalog #: 960-0362. Appears to be stacked	$1.79	1	$1.79
76A	7/26/04	Walgreen's Pharmacy	Duracell	$2.79	1	$2.79
TR175A	7/29/04	www.zbattery.com	(Stack) Exell A175 Alkaline Dog Collar Battery (Note 1)	$2.98	1	$2.98
12V Stack	10/24/04	Radio Shack stores & online	New 12V GP27A Alkaline Battery; Cat. No. 23-279. Appears to be stacked	$3.19	1	$3.19
12V Stack	10/24/04	Radio Shack stores & online	2-pack 12V Radio Shack Alkaline Battery; for remote controls. Appears to be stacked. Cat. No. 23-154	$6.59	2	$3.30
23-1504		Radio Shack stores & online	1.5V Alkaline Photo/Miscellaneous. Catalog #: 23-1504	$3.39	1	$3.39
12V Stack	10/24/04	Radio Shack stores & online	12V Alkaline Pager/Remote Battery (Pkg. 1); Cat. No. 23-144. Appears to be stacked	$3.59	1	$3.59
RFA-35	10/19/04	www.petsafestore.com	6 Volt Alkaline battery. Used for Pet pager receiver, electronic leash, bark collar, receiver. Appears to be stacked miniature cells	$4.95	1	$4.95
960-0357	10/24/04	www.radioshack.com	1.5V Exell Photo (Alkaline) Battery. Catalog #: 960-0374	$4.99	1	$4.99
E625G	7/25/04	www.batteries.com	Energizer E625G Button Cell Battery	$6.39	1	$6.39
4.5V Stack	10/24/04	www.radioshack.com	4.5V Photo (Alkaline) Battery; Catalog #: 960-0357. Appears to be stacked	$6.99	1	$6.99
175	10/24/04	www.radioshack.com	7.5V 120mAh Excel Alkaline #175 Camera Battery.	$6.99	1	$6.99
					Minimum	$0.33
					Maximum	$6.99
					Median	$2.29

Lithium Batteries

Battery Size	Date	Vendor	Description	price	qty/pk	$/unit
CR1/3N	7/29/04	www.zbattery.com	Sanyo CR113N (Note 1)	$2.54	1	$2.54
CR1025	7/29/04	www.zbattery.com	Duracell DL1025B	$1.05	1	$1.05
CR1025	7/25/04	www.batteries.com	Energizer ECR1025 Lithium Coin Cell Battery	$2.85	1	$2.85
CR1025	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
CR1025	7/25/04	www.batteries.com	Renata CR1025 Coin Cell Battery	$3.09	1	$3.09
CR1216	7/29/04	www.zbattery.com	Duracell DL1216B	$1.05	1	$1.05
CR1216	7/25/04	www.batteries.com	Energizer ECR1216 Lithium Coin Cell Battery	$4.09	1	$4.09
CR1220	7/25/04	www.batteries.com	Energizer ECR1220 Button Cell Battery	$5.09	1	$5.09
CR1225	7/25/04	www.batteries.com	Energizer ECR1225 Coin Cell Battery	$4.29	1	$4.29
CR1616	7/29/04	www.zbattery.com	Duracell DL 1616B	$1.42	1	$1.42
CR1616	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
CR1616	7/25/04	www.batteries.com	Energizer ECR1616 Coin Cell Battery	$4.29	1	$4.29
CR1620	7/29/04	www.zbattery.com	Duracell DL1620B	$1.19	1	$1.19
CR1620	7/25/04	www.batteries.com	Energizer ECR 1620 Button Cell Battery	$4.39	1	$4.39
CR1632	7/25/04	www.batteries.com	Energizer ECR1632 Lithium Coin Cell	$3.39	1	$3.39
CR2012	7/25/04	www.batteries.com	Energizer ECR2012 Coin Cell Battery	$5.09	1	$5.09
CR2016	6/16/04	Ocean State Job Lot	Konnoc MicroCell Lithium	$0.99	3	$0.33
CR2016	7/29/04	www.zbattery.com	Duracell DL2016B	$1.19	1	$1.19
CR2016	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
CR2016	7/25/04	www.batteries.com	Renata CR2016R Coin Cell Battery	$4.09	1	$4.09
CR2016	7/25/04	www.batteries.com	Energizer ECR2016 Coin Cell Battery	$5.09	1	$5.09
CR2025	6/16/04	Ocean State Job Lot	Konnoc MicroCell Lithium	$0.99	3	$0.33
CR2025	7/29/04	www.zbattery.com	Duracell DL2025B	$1.19	1	$1.19
CR2025	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
CR2025	7/25/04	www.batteries.com	Energizer ECR2025 Coin Cell Battery	$3.39	1	$3.39
CR2025	7/25/04	www.batteries.com	Renata CR2025R Coin Cell Battery	$4.09	1	$4.09
CR2032	7/29/04	www.zbattery.com	Renata CR2032-25	$22.25	25	$0.89
CR2032	7/29/04	www.zbattery.com	Renata CR2032	$0.99	1	$0.99
CR2032	7/29/04	www.zbattery.com	Duracell DL2032B	$1.19	1	$1.19
CR2032	7/26/04	Walgreen's Pharmacy	Duracell "Medical"	$4.99	2	$2.50
CR2032	7/25/04	www.batteries.com	Energizer ECR2032 Coin Cell Battery	$5.09	1	$5.09
CR2320	7/25/04	www.batteries.com	Renata CR2320R Coin Cell Battery	$3.61	1	$3.61
CR2320	7/25/04	www.batteries.com	Energizer ECR2320 Coin Cell Battery	$5.09	1	$5.09
CR2325	7/25/04	www.batteries.com	Renata CR2325 Coin Cell Battery	$2.89	1	$2.89
CR2430	7/29/04	Www.zbattery.com	Duracell DL2430B	$1.29	1	$1.29
CR2430	7/25/04	Www.batteries.com	Energizer ECR2430 Coin Cell Battery	$3.89	1	$3.89
CR2450	7/29/04	Www.zbattery.com	Duracell DL2450B	$2.42	1	$2.42
CR2450	7/26/04	Walgreen's Pharmacy	Energizer	$2.99	1	$2.99
CR2450N	7/29/04	Www.zbattery.com	Renata	$1.50	1	$1.50
DL1/3N	7/29/04	Www.zbattery.com	Duracell (Note 1)	$3.73	1	$3.73
					Minimum	$0.33
					Maximum	$5.09
					Median	$2.99

1. DL1/3N 3V Li Button Battery used in Invisible Fence® brand Powercap® dog collars

Appendix D – Miniature (Non-Lithium) Batteries in Products

Note: The following list of products is a complement to the products reported to the Interstate Mercury Education and Reduction Clearinghouse (IMERC) Mercury-Added Products Database. [IMERC is a resource of the Northeast Waste Management Officials' Association (NEWMOA)]. Because the Maine DEP maintains a complete and updated summary of the IMERC data, the intent here is to use other sources to identify products using mercury-containing miniature batteries and perhaps identify products not captured in the IMERC database.

Tables:
Compact Fever Thermometers
Flashlights
Toys, Party Favors
Medical Products

Compact Fever Thermometers

Product	**Mfr (or Source)**	**Product Description**	**Cost**	***Batteries***
Omron 20 Second Flexible Digital Thermometer	Omron http://www.freemedicineprogram.com/category/Home+Diagnostics+%3E+Thermometers	Fast measurement in just 20 seconds. Flexible tip for added comfort and safety. Jumbo display for easy reading. Memory recalls last temperature. Measures Fahrenheit and Celsius. Automatic shut-off after 10 minutes. Battery included	$10.16	One 1.5V Button-type battery
TIMEX Accu-Curve Digital Thermometer Item/Pkg:MPT80002-EA	Mfr: Medport www.carepathways.com	Includes 1.5V button-type battery. TIMEX™ Accu-Curve Thermometer. Results in 30 seconds. Extra large digital display with INDIGLO® nightlight. Compact and lightweight. Mercury-free. Displays last temperature taken when Thermometer is turned on. Fahrenheit or Celsius. Unit comes with long-life battery, travel case, 5 disposable probe covers and instructions. Lifetime warranty.	$11.99	One 1.5V button-type battery

Flashlights

Product	**Mfr (or Source)**	**Product Description**	**Cost**	***Batteries***
Flashlight	Pelican www.pelican.com Pricing from http://hardinoptical.com	LED Flashlight #1930 L1 L1 LED Light provides a concentrated close quarter beam. Available in white, red or blue/green. Provides up to 50,000 hours of usage. Four replaceable LR 44 alkaline coin	14.95	4 LR44 batteries

		cells (included) offer up to 130 hours of battery life. Equipped with a neck lanyard and a handy push button on/off switch that can be used with only one hand. Water resistant (not for diving applications). You break it, we Replace it... forever.		
Mini-flasher	Pelican www.pelican.com Pricing from www.rei.com	Mini Flasher with red LED #2130 MINI FLASHER keeps track of joggers, hikers, children, pets and can identify equipment and campsites at night. Flashing LED lamp produces a light so powerful that is visible up to a .50 mile (800 m) for 130 hours. Submersible to 300 feet, the Mini Flasher is ideal for warning or emergency light. Small .56 oz (16 gr). Includes 2 coin cell batteries. You break it, we replace it... forever.	$10.95	2 alkaline coin

Toys, Party Favors

Note: Miniature batteries were typically found in novelty items that made noise or flashed lights.

Product	**Mfr (or Source)**	**Product Description**	**Cost**	***Batteries***
Dream Capsule Key Chain	Team Products, Inc. Phone: 877-227-5832 Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Key chain that lights up, bright changing colors. Includes 3 spare AG3 batteries.	$1.99	Uses 3 AG3 batteries (1.5V Energizer 392 or Duracell 392)
Sqooshy keychain Flashlight	Team Products, Inc. 877-227-5832 Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Flexible, gel-like translucent flower with what appeared to be a single LED Light, e.g. to illuminate keyhole at night. Battery must have been button.	$1.99	Did not specify battery. (Because of size & shape, had to be button or coin)
Glo-Wand ($1.99) Flashing Strobe Light	Team Products, Inc. 877-227-5832 Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Glo-Wand) Flashing Strobe Light keychain uses 3 batteries and includes 3 extra batteries	$1.99	3 LR 44 batteries
NeoGlo Light Show Strobe	Team Products, Inc. 877-227-5832 Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Strobe light on keychain uses 3 batteries and includes 3 extra batteries.	$1.99	3 LR 44 batteries
Pocket Strobe	Team Products, Inc. 877-227-5832 Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Keychain strobe light	$1.99	3 LR44 batteries
Milton Bradley "Perfection" electronic race car game	Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Compact electronic game uses 1 button cell battery	$12.99	1 button cell battery (type not specified)
Little Muscle	Seen at: Ocean State Job Lot,	Toy car uses 3 button cell	$3.99	3 button cell

Chevrolet	Marlboro, MA, 07/09/04	batteries to move eyes, mouth and make sounds, by Racing Champions Ertl (Plastic car ~8” long x 4”wx 6” h)		batteries (type not specified)
Light up gyroscope	Seen at: Ocean State Job Lot, Marlboro, MA, 07/09/04	Uses 2 button cell batteries for lights	$1.29	2 button cell batteries (type not specified)

Medical Products

Product	**Mfr (or Source)**	**Product Description**	*Batteries*
Electronic Stethoscope	ST3 (Starkey Laboratories, Minneapolis, Minnesota).	The ST3 (Starkey) is a Classic II (Littmann) stethoscope modified for people with hearing problems. The amplification system, powered by a 1.5-V button cell, is integrated into the tubing of the Littmann stethoscope. (Grenier et al)	1
Electronic Stethoscope	Labtron (Graham Field, Hauppage, New York	The amplification system of the Labtron is integrated into a large chest piece and the amplified sounds are transmitted into the acoustic tubing. It is powered by 4 1.5-V button cells (Grenier et al)	4
M2A Endoscopy capsule produced by Given Imaging Ltd.		http://batteriesdigest.com/id243.htm: One of these new devices is a battery powered diagnostic capsule which, after being swallowed, maps the human small intestine with a video camera. The views are transmitted to a belt mounted receiver carried by the patient. A second battery pack powers the data recorder worn by the patient as a belt pack. While ultra miniature semiconductors are heralded as the backbone of this unique investigational device, batteries in both the capsule and belt data recorder provide the power which makes the product possible. The capsule is shown being held in the fingers to illustrate its small size. It is swallowed to obtain detailed photos and streaming video of the small intestine. Equipped with illuminating light source, camera, processing electronics and data radio transmitter, the capsule is powered by two silver oxide primary batteries during its eight hour journey through the digestive system to provide pictures for medical diagnostics.	2 Silver oxide for capsule

Reference:
Grenier, Marie-Claude MSc; Gagnon, Katerie ID; Genest, Jacques Jr. MD; Durand, Jocelyn BEng; Durand, Louis-Gilles PhD, Clinical Comparison of Acoustic and Electronic Stethoscopes and Design of a New Electronic Stethoscope, The American Journal of Cardiology, Volume 81(5) 1 March 1998 pp 653-656

Appendix E: Description of Proposed European Battery Legislation

Reference: Proposal for a Directive of the European Parliament and of the Council on Batteries and Accumulators and Spent Batteries and Accumulators, Commission of the European Communities [SEC(2003)1343]
http://europa.eu.int/eur-lex/en/com/pdf/2003/com2003_0723en01.pdf

In its "Proposal for a Directive of the European Parliament and of the Council on Batteries and Accumulators and Spent Batteries and Accumulators" (Proposal), the Commission of the European Communities outlines a plan for a major revision of its current battery recycling legislation. The Proposal is now making its way through the legislative approval process.

The European Communities' existing battery legislation, often referred to as the Battery Directives (Directive 91/157/EEC, amended by Commission Directives 98/101/EC and 93/86/EEC), includes batteries containing mercury, cadmium and lead. The Commission reports that the goal of the Directive, to reduce the use and environmental impact of these dangerous metals, has not been met.

The impetus for changing the legislation addressing the way batteries are handled came from the EU Sixth Community Environment Action Program (6EAP), which outlined environmental objectives and priorities for the decade starting in July 2002. The 6EAP identified the four specific objectives shown below and stipulated that the battery legislation would be one avenue used for supporting those objectives. The objectives include:

1. Reduce the overall quantity of waste generated, including both hazardous and non-hazardous categories (source reduction),
2. Encourage re-use of wastes,
3. Give preference to options for recovery and recycling over disposal, and
4. Minimize the quantity of waste for disposal and safely dispose of it.

(Reference: Proposal, p. 6)

The four objectives are consistent with the solid waste reduction hierarchy model, which prioritizes the environmentally sound strategies for municipal solid waste as:
Source Reduction – Reuse - Recycle & Compost – Dispose
(Reference: EPA Region 7, http://www.epa.gov/Region7/waste/solidwaste/index.htm).

In developing the Proposal, the Commission considered the following points:

- All batteries contain substances which are more or less harmful to the environment
- "All battery" collection schemes are more efficient than schemes that collect only specific battery types. In the European States a low collection rate is attributed to consumers having difficulty distinguishing between batteries covered by the current Directive (batteries with mercury, lead, and cadmium) and other general purpose batteries. (Proposal, page 17)
- All batteries contain metals that are recyclable, so recycling helps save resources.
- For consumer batteries, producers should finance the costs of the collection and treatment obligations at least from the collection point onwards.

To support the desired objectives, the Commission's Proposal lays out policy measures to divert all spent batteries from landfill and incineration and to ensure that member states adopt environmentally sound waste management practices that foster efficient collection and recycling of spent batteries and a proper function of the internal market. Member states are required to set up schemes to ensure that all batteries are collected for recycling and thus ensure a closed loop system for all batteries. The articles specify that within 4 years, member states shall achieve a minimum average collection rate equivalent to 160 grams per inhabitant per year for all spent portable batteries and accumulators (rechargeable batteries), including portable nickel-cadmium batteries.

Some key points of the Proposal:

- The Directive will apply to all batteries, excluding military batteries or batteries for equipment protecting essential interests of security of Member states, regardless of their shape, volume, weight, material composition or use.
- It is prohibited to market batteries which contain >0.0005% mercury by weight, except for button cells and batteries made up of button cells with a mercury content of no more than 2% by weight.
- Member States will promote research and development into increasing overall environmental performance of batteries throughout their entire lifecycle and will promote the marketing of batteries that contain smaller amounts of dangerous substance or contain less polluting substances, in particular as substitutes for mercury, cadmium and lead.
- The Commission shall establish detailed rules for monitoring the municipal solid waste stream and Member States shall report annually on waste statistics.
- Member States shall take the necessary measures to prevent the final disposal of spent batteries and to aim at achieving a closed loop system for all batteries.
- Member States shall ensure that schemes are set up under which spent batteries can be returned free of charge and collection facilities are available and accessible. When setting up collection schemes, the negative external impacts of transport will be taken into account.
- Within four years of implementing the legislation, Member States shall achieve a minimum average collection rate equivalent to 160 grams per inhabitant per year for all spent portable batteries and accumulators (rechargeable batteries), including portable nickel-cadmium batteries. (Portable means a battery used in household applications, cordless power tools, emergency lighting and electrical and electronic equipment or other applications by either consumers or professional users).
- Member States shall ensure producers or third parties acting on their behalf achieve recycling efficiencies of 55% by average weight of the materials contained in batteries, other than lead-acid batteries (65% efficiency) and nickel-cadmium batteries (75% efficiency).
- Member States shall ensure that producers or third parties acting on their behalf arrange the financing for at least the treatment, recycling, and sound disposal of all spent portable batteries deposited at collection facilities.

Appendix F – Interviews With Representatives of United States Recycling Programs

A sampling of four recycling programs in the United States was identified for phone interviews. The interviews were held with representatives of two counties in the United States, a town in Massachusetts and a municipal waste provider serving 69 communities in the Northeast, all of which oversee recycling programs that include miniature batteries. The four programs were selected because of some combination of their ability to provide data, longevity and/or breadth of the program, and ability to provide a cogent overview of their experience.

Each representative was asked about how his or her program operates, the amount of miniature batteries collected, recycling costs, and safety concerns. The following paragraphs discuss the findings and a summary is shown in Tables F.1 and F.2.

2 Counties and 1 Town - The town and counties represented in our interviews have collection sites or containers set up in multiple areas in the town or regions. A major city in one of the counties also provides curbside pickup of miniature and other dry cell batteries. Miniature battery collection containers (typically cardboard boxes) fall under the universal waste rule and are collected within 1 year. Batteries from the boxes are often consolidated into a pail or larger container and then shipped for sorting and recycling.

Safety concerns - While each of the representatives had heard of fire hazards associated with lithium battery collection, no one systematically addresses this concern at the community collection points. One of the counties has an intermediary sort and consolidate miniature batteries, and the poles of the lithium batteries are taped (electrically insulated) at that stage prior to shipment to the recycler. None had experienced a problem with heat, smoldering or fire in the community collection containers. No one was aware of any safety problems that had arisen in his or her miniature battery collection programs, either related to electrical safety or the potential for batteries being mishandled, such as children removing batteries from collection containers.

Recycling effectiveness – Miniature cell battery recycling is voluntary. Each of the representatives cited the difficulty in getting the target population engaged in recycling miniature batteries. One county representative has perceived a leveling or even a slight decrease in recycling volumes, which is counterintuitive to her perception that more products contain miniature batteries and hence volumes should be increasing. She noted that this may reflect a need for renewed outreach to the public. The Recycling Coordinator in the town interviewed has had very favorable results working with merchants on recycling programs, so that when a product (such as a miniature battery or fluorescent bulb) is brought in for replacement, the merchant takes the spent product for recycling. The Recycling Coordinator has engaged the local camera shop on recycling batteries and she estimated that the camera shop was the source of approximately 80% of the miniature batteries collected. The coordinator calls the camera shop about a month before a battery pickup and the camera shop turns the batteries in to the town.

Table F.1. Summary of Interviews

Location	Comments	Cost for Recycling Miniature Batteries
County in Midwest Population of 1,112,259 in county	Mixed button batteries are collected in small cardboard boxes provided by the County at 176 locations throughout the county and there are an additional 166 locations with larger 30-gallon containers that collect mixed button batteries and larger dry cell batteries. There is curbside battery recycling in one city, and batteries are also removed from electronics collected via the consumer electronics program. Battery collection sites include public and private sites, such as city halls, county buildings, drug stores, health care facilities, hardware stores, jewelers, libraries, photo stores, retail stores, senior apartment complexes and senior organizations. A courier collects and replaces the recycling boxes and delivers full box to a business that sorts and consolidates batteries. Sorted batteries are shipped to a recycling contractor. The program is funded by the county.	$5.05/pound ~876 pounds/year recycled = $4424/year This is estimated to be ~560,640 miniature batteries. [Note]
County in Northeast ~150,000 people covered by County Solid Waste District	Batteries are collected by the District at a permanent hazardous waste facility, 8 drop off centers, and a mobile facility called the Rover that visits rural towns and cities from March-October. A truck collects batteries from each site and brings it to the main hazardous waste facility where the collected batteries are aggregated for shipment to the recycler. Recycling is paid for by a tax on the trash.	$2.50/pound ~60 pounds/year recycled = $150/year This is estimated to be approximately 38,400 miniature batteries, of which ~22% are lithium.[Note]
Massachusetts Town Town population of 17,000	Containers are scattered around the town, e.g. library, town house, Council on Aging. The Town Recycling Coordinator collects the batteries and they are taken with the fluorescent bulbs pickup by Onyx (formerly Superior Special Services). Onyx subsequently sorts the batteries and tapes the Lithium miniature batteries. Note: Onyx/Superior Special Services is the state-contracted mercury material recycling firm and they will accept mixed batteries from Massachusetts municipalities and businesses for recycling and/or safe management at the state negotiated price. (per State contract number ST7J211). State contract cost for recycling: $0.65/pound for alkaline batteries, $3.50/pound for mercury batteries, $2.50/pound for silver oxide, $3.50/pound for lithium batteries, and $0.20/pound for sorting.	Town contract with solid waste hauler includes $2000/year in their contract allocated for all recycling. (Contract applies to households only; businesses arrange their own waste removal).

[Note] This is based on the estimate of 640 miniature batteries/pound, described in the next section.

Municipal Waste Combustor (MWC) – Wheelabrator runs three municipal waste combustion facilities in the state of Massachusetts that currently serve 69 communities under long term waste contracts. The Massachusetts Department of Environmental Protection (DEP) requires that owners and operators of MWCs submit a material separation plan (MSP) and run a program for the diversion of mercury-bearing products from municipal solid waste. Wheelabrator's mercury effort is subcontracted to and run by Pat Scanlon of Scanlon Associates, who was interviewed for this report.

The goal of the Wheelabrator MSP is to attempt to divert mercury-containing products from the municipal solid waste stream and to provide its communities with resources for proper disposal and recycling of mercury-containing products. To fund the mercury effort, $0.50/ton is

set aside from the contracted tipping fees charged to the communities. One of the programs offered to the Wheelabrator communities is miniature battery recycling; participation is voluntary. The operation is similar to the town and counties described above, with battery collection boxes provided and placed around the communities that have chosen to participate in the program. Wheelabrator provides collection boxes to participating communities and it is a community's responsibility to distribute and monitor the boxes, then place batteries with other mercury devices for collection. A Wheelabrator service provider picks up and sorts a full bucket of mercury products. Batteries are weighed and consolidated in a 55 gallon drum that is sent for recycling. Scanlon noted that he has collected hundreds of thousands of miniature batteries over the past decade and that he uses an estimate of 640 miniature batteries per pound to convert from pounds collected to number of batteries.

Safety concerns - Scanlon has never observed or received feedback about safety concerns related to miniature battery collection in communities.

Recycling effectiveness – Although all of the towns contracting with Wheelabrator pay for the mercury programs, very few take advantage of miniature battery recycling. Successful recycling requires a strong volunteer base to manage and champion the program locally. It was noted that one city stands out for its high participation relative to other Wheelabrator communities, and Scanlon attributes this to the high visibility the miniature battery recycling program receives. For example, the city has a guess-the-number contest at the library, in which visitors can guess the number of miniature batteries collected and displayed in a fish bowl. Prizes are given out at the mayor's office and the contest receives good press. Without high visibility and a strong local effort, however, miniature battery recycling lacks vitality.

Table F.2. Summary of Interview with Mercury Program Coordinator

Wheelabrator, Owns and operates 3 municipal waste combustors in Massachusetts	Wheelabrator contracts with Pat Scanlon of Scanlon Associates to manage their mercury control efforts. Scanlon develops and administers the Material Separation Plan for mercury, which includes voluntary programs for miniature battery recycling. Scanlon estimates there are approximately 640 miniature batteries per pound.	**Wheelabrator North Andover Inc.** Note 1 FY 2002 –2003 budget of $6000 for Miniature Battery Collection. 2003: collected 31,360 miniature batteries from 4 participating communities (of 23 communities in consortium, representing a total population of 454,222) **Wheelabrator Millbury** Note 2 FY 2002-2004 budget of $6000 for Miniature Battery Collection 2003: Collected 1920 batteries Note 3 from 1 participating community (of 36 communities in consortium, representing a total population of 663,598) **Wheelabrator Saugus J.V.** Note 4 FY 2004-2006 budget of $1000 for a Miniature Battery Collection 2003: Collected 9920 batteries from 3 participating communities (8 communities in consortium, representing a total population of 311,036)

Notes:

[1]*Reference: Material Separation Plan for the Diversion of Mercury (MSP2) July 1, 2002-June 30, 2004, Wheelabrator North Andover Inc., North Andover, MA (March 2002)*

[2]*Reference: Material Separation Plan for the Diversion of Mercury (MSP2) July 1, 2002 – June 30, 2004, Wheelabrator Millbury Inc., Millbury, MA. (March 2002)*

[3]*Scanlon noted the need to average battery collection over several years. For example, this town presently has ~20,000 miniature batteries queued up for collection.*

[4]*Reference: Material Separation Plan for the Diversion of Mercury (MSP3) July 1, 2004 – June 30, 2006, Wheelabrator, Saugus J.V., Saugus, MA (March 2004)*

Appendix G - Recycling in Europe

A web search was conducted and information was sought from the Commission of European Communities and ChinaBattery Online (Chinese battery industry web site) about miniature battery recycling programs in their regions, environmental legislation related to miniature batteries and disposal, and any associated health and safety concerns. The Commission responded to the request for information by directing us to existing and pending environmental legislation and informative support documentation. They did not offer any insight on health and safety concerns. No response was received from ChinaBattery Online and other searches did not yield additional substantive information about recycling outside the U.S. Our discussion therefore is limited to the European Union (EU) and its member states.

The Commission of European Communities uses terminology slightly different from the terminology of this report. In the following paragraphs, the Commission's term "button cell" is equivalent to the term miniature battery used in the rest of this report: "'button cell'... means a small round battery… whose diameter is greater than its height and which is used to special purposes such as hearing aids, watches and small portable equipment." (Reference: Commission of the European Communities, 2003, page 38). Button cells, per the Commission's description, are mainly zinc air, silver oxide, manganese oxide and lithium batteries.

The Commission of European Communities is cognizant of the adverse environmental impact of button cell batteries: "The biggest part of current mercury emissions from batteries in the EU originates from special purpose mercury button cells". (Reference: Commission of the European Communities, 2003, page 10). The EU's existing battery legislation is "Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances, as amended by Commission Directive 98/101/EC". (Reference: The Council of European Communities, Council Directive 91/157/EEC, as amended by commission Directive 98/101/EC).

Key points of this legislation include:

- There is a prohibition on marketing batteries containing more than 0.0005% mercury from January 2000 onwards. Button cells with a mercury content of no more than 2% by weight and batteries composed of multiple button cells are exempted from this marketing restriction but all other requirements of the Directive still pertain to the button cells.
- Member States must ensure the collection separate from household waste of the batteries covered by the Directive, with a view to their recovery or disposal;
- Batteries covered by the Directive must be marked to indicate the heavy metal content, requirement for separate collection, and recycling, where appropriate
- Member States must establish four-yearly programs (programs over four years) designed to 1) reduce the heavy metal content of batteries, 2) promote the marketing of batteries containing smaller amounts of dangerous substances and/or less polluting substances, 3) foster a gradual reduction of spent batteries in household waste, 4) promote research into more benign batteries and better recycling methods, and 5) achieve separate disposal of spent batteries.
- Member States shall ensure efficient and separate collection systems for batteries.

The Commission reports that in practice the Directive has had limited success because it does not delineate clear, measurable guidelines for preventing uncontrolled disposal into the

environment. As a result States have taken divergent approaches, results vary widely from state to state and the overall collection efficiency of spent batteries in the Member States is low. Many batteries are still landfilled or incinerated, instead of being collected and recycled. In a report commissioned by the European Commission Directorate General Environment, BIO Intelligence Service estimated the current situation for sales and recycling of button batteries in Europe in 2002 at 15%, as shown in the following Table G.1. (Reference: BIO Intelligence Service, 2003).

Table G.1: European Sales and Recycling of Button Batteries
Europe, including EU-15, CH, N (Note 1)

Year	***2002***
Button Battery Sales	373 tonnes (Note 2)
% of portable battery market(Note 3)	0.2%
Average annual growth rate	1%
Spent batteries available for collection(Note 4) **Entering a recycling plant** Disposed with municipal solid waste Total	 **38 tonnes (15%)** 215 tonnes (85%) 253 tonnes (100%)

Notes
[1] European Union-15 (EU-15): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom
Norway (N) and Swiss Confederation (abbreviated CH, for Confederatio Helvetica, the Latin version of the official name)
[2] 10% of this total is estimated to be sold in Electrical and Electronic Equipment (EEE)
(Ref: BIO Intelligence Service, "Impact Assessment on Selected Policy Options for Revision of the Battery Directive, Final Report, July 2003, page 50)
[3] "Portable battery…" means a battery… used in household applications, cordless power tools, emergency lighting and electrical and electronic equipment or other applications by either consumers or professional users. (Proposal, page 38)
[4] Reference: BIO Intelligence Service, 2003, page 54

Estimates of recycling costs for button cell battery recycling in 2002 are available for France and Belgium:

Table G.2: Recycling Costs

Country	Recycling Cost	Equivalent cost in U.S. units
France	2600 Euros/tonne	~$1.45/lb
Belgium	4000 Euros/tonne	~$2.25/lb

Note: 2204 lbs/metric tonne
Reference: (BIO Intelligence Service, 2003, p. 65, 201, 200)

The Commission currently has a proposal for a major restructuring of its battery legislation that is making its way through the legislative approval process. If approved, this will have a significant impact on many miniature battery aspects including manufacturer responsibility, battery design/composition, pricing and recycling. A description and discussion of the proposed legislation is included in Appendix E.

Appendix H – Data on Battery Ingestions

Data show that miniature battery ingestions represent 0.1% of exposures reported to poison control centers. In 2002 about 10 people had a major medical outcome (life-threatening or significant residual disability or disfigurement) from ingesting miniature batteries. It is estimated that approximately 60% of battery ingestions occur immediately after removal from a product or with batteries taken directly from the package. The remaining battery ingestions involve batteries lying loose, sitting out or discarded.

Data related to battery mishandling are shown below. One valuable source of information is the Toxic Exposure Surveillance System (TESS) data, compiled annually by the American Association of Poison Control Centers (AAPCC), in cooperation with the majority of US poison centers. Another source of information is from Georgetown University Hospital's National Capital Poison Center and its National Button Battery Ingestion Hotline and Registry.

TESS data represents human exposure cases reported to a central registry by participating poison control centers. AAPCC uses the term "disc batteries" for miniature batteries. The following table shows the contribution of disc battery ingestions to the total for the past 5 years.

Table H.1. Exposures Reported to Poison Control Centers

Year	All Exposures	All ingestions	Disc Battery Ingestions	Disc batteries as % of all exposures	Disc batteries as % of all ingestions
2002	2,380,028	1,900,816	2611	0.11%	0.14%
2001	2,267,979	1,807,448	2005	0.09%	0.11%
2000	2,168,248	1,729,950	1804	0.08%	0.10%
1999	2,201,156	1,731,553	1939	0.09%	0.11%
1998	2,241,082	1,749,792	2063	0.09%	0.12%

Reference: Annual Report of the American Association of Poison Control Centers Toxic Exposure Surveillance System for 1998, 1999, 2000, 2001 and 2002

The 1998 TESS data was also analyzed and presented as Pediatric Exposures to Non-pharmaceuticals and Pharmaceuticals. The following table shows the relative contribution of disc batteries to the pediatric exposures; also at 0.1% of all exposures.

Table H.2. 1998 Pediatric Exposures (< 6 yrs) Reported to Poison Control Center

Year	Pediatric Exposures (<6 yrs) category	Exposures	Disc Battery Exposures	Disc batteries as % of exposures
1998	Non-pharmaceuticals	731,407	1252	0.2% of non-pharmaceuticals
	Pharmaceuticals	477,452		
	Total pediatric exposures	1,208,859		0.1% of all pediatric exposures

1998 Pediatric Exposures, http://www.aapcc.org/poison1.htm

The TESS reports also show that for most cases of disc battery ingestions the medical outcomes were reported as "none", but each year there are a small number of ingestions with serious outcomes

Table H.3. Medical Outcomes of Disc Battery Ingestions[(Note)]

Year	Outcome reported as "none"	Outcome reported as "minor"	Outcome reported as "moderate"	Outcome reported as "major"	Outcome reported as "death"
2002	86.8%	10.1%	2.7%	0.4%	0%
2001	88.3%	8.6%	2.9%	0.2%	0%
2000	88.8%	8.1%	2.6%	0.6%	0%
1999	90.1%	7.7%	1.9%	0.3%	0%
1998	90.2%	7.1%	2.1%	0.5%	0.1%
1998 Pediatric Expos.	92.7%	5.3%	1.3%	0.7%	0%

Medical Outcome Categories

No effect: The patient developed no signs or symptoms as a result of the exposure.

Minor effect: The patient developed some signs or symptoms as a result of the exposure, but they were minimally bothersome and generally resolved rapidly with no residual disability or disfigurement. A minor effect is often limited to the skin or mucous membranes.

Moderate effect: The patient exhibited signs or symptoms as a result of the exposure that were more pronounced, more prolonged, or more systemic in nature than minor symptoms. Usually some form of treatment is indicated. Symptoms were not life-threatening and the patient had no residual disability or disfigurement.

Major effect: The patient exhibited signs or symptoms as a result of the exposure that were life-threatening or resulted in significant residual disability or disfigurement.

Death: The patient dies as a result of the exposure or as a direct complication of the exposure.

Note: This represents the percentage of known outcomes

References:

Annual Report of the American Association of Poison Control Centers Toxic Exposure Surveillance System for 1998, 1999, 2000, 2001 and 2002

1998 Pediatric Exposures, http://www.aapcc.org/poison1.htm

In another perspective on battery ingestions, Dr. Toby Litovitz and Barbara Schmitz analyzed 2382 cases of battery ingestions reported to the National Button Battery Ingestion Hotline during the 7 year period of July 1983 through June 1990. (Litovitz and Schmitz) (Note: The National Button Battery Ingestion Hotline and Registry was established in 1982 at Georgetown University Hospital's National Capital Poison Center. This is one of the Poison Centers that participates in the AAPCC TESS program described above. It services areas of Washington, DC, Virginia, and Maryland). Of the 2383 cases, 62 were standard cylindrical cells (e.g. AAA, AA, A, etc.) and the remaining 2320 were miniature cells. For 2034 cases where the battery ingestion scenario and source were determined, Litovitz and Schmitz found the following trends:

Table H.4. Ingestion Timing & Battery Discharge State

%	**When Ingestion Occurred** (n=2034)
52.5%	Immediately following removal
41.4%	Involved batteries which were loose, sitting out, or discarded

5.4%	Batteries obtained directly from packaging
	Battery Discharge State (n = 1800)
66.4%	Partially Spent
17.8%	Spent
15.8%	New cells

Table H.5. Common Uses of Batteries that were Ingested

%	Use
44.6%	Hearing Aids
16.1%	Watches
13.6%	Games and Toys
9.3%	Calculators
3.7%	Camera Equipment
3.2%	Beeping or lighted key chains
2.5%	Clocks
1.4%	Remote Control Devices

They also found that in 312 (32.8%) of the 952 cases where the battery was intended for use in a hearing aid, the battery was actually removed by the child from the child's own hearing aid. (These 312 cases represent 15% of overall ingestions). In 8.5% of the battery ingestions, more than one battery was ingested (table below). Suicidal intent was implicated in 1.3% of battery ingestions (31 cases) and nine individuals ingested batteries while in prison or to avoid incarceration.

Table H.6. Number of Batteries Ingested

# Batteries Ingested	# Patients
2 batteries	153 patients
3 batteries	20 patients
4-6 batteries	19 patients
7-9 batteries	5 patients
11-36 batteries	5 patients

The National Capital Poison Center (where this study was done) has an online fact sheet "Swallowed a Button Battery?" (http://www.poison.org/prevent/battery.asp) that describes what to do and presents facts about miniature battery ingestions.

In addition to ingestion of miniature batteries, the literature also describes cases in which miniature batteries have been placed in the ear or nose. All of these data points attest to the fact that the choice to use miniature battery powered devices comes with the need to manage the associated risk of battery mishandling. (Lin et al, Strachan et al, Alvi et al, Ansley et al, Brown and Dannenberg)

Appendix I - Adverse Environmental Impact of Collecting and Transporting Batteries for Recycling

The business community has raised concerns that collecting and transporting batteries may have greater detrimental environmental impacts than benefits gained from recycling batteries. It is beyond the scope of this report to assess the net effect (positive or negative) of all upstream and downstream environmental costs associated with miniature battery recycling, however it is worth noting the following points.

- In most recycling programs, miniature batteries are not the sole waste being collected or the only container being transported. Miniature battery recycling typically takes place in the context of larger recycling programs, to the advantage of the overall effort. For example, Wheelabrator collects and transports miniature batteries with other mercury containing devices (e.g. thermostats, thermometers, barometers) from its participating towns. For the miniature battery collection in dedicated boxes or buckets, shipping is by United Parcel Service or common package carriers to the recycling center thus utilizing existing efficient methods of transportation.
- As recycling becomes more widespread and recycling volumes increase, economies of scale will be reflected in more efficient, cost effective options for collection, transportation and recovery processes.
- Recycling provides the opportunity to avoid external costs that are usually paid for by society in the form of cleanup costs, environmental deterioration, or adverse health effects. Metals in the spent batteries that might normally be lost to disposal can be recycled and put back into products. Other substances such as acids, salts, and plastics will be diverted from the waste stream and managed appropriately. Potential air and water pollution and other environmental impacts from incinerating or landfilling the spent batteries can be avoided, ultimately translating to reduced human exposures and abatement costs. (Reference: Commission of the European Communities, 2003, page 22)
- A major component of miniature batteries is metal, including steel, nickel, tin and zinc. Recycling of miniature batteries can put metals back into the supply chain and potentially offset the mining of virgin metals. According to the Environmental Protection Agency (EPA), extraction and refining of metals produces significant amounts of waste and byproducts. Environmental impacts are extensive, including: erosion, vehicle exhaust, dust, acid rock drainage, loss of habitat, loss of fish, plant, and water fowl population, and structural damage from blasting. (Reference: EPA Sector Notebook; Profile of the Metal Mining Industry). The North American Steel Recycling Institute estimates that "every ton of steel recycled saves 2,500 pounds of iron ore, 1,400 pounds of coal, and 120 pounds of limestone." (Reference: The Steel Recycling Institute, Fact sheet)

Our study also included the review of two European documents that consider adverse environmental impacts of battery recycling: the Commission of the European Communities "Proposal for a Directive of the European Parliament and of the Council on Batteries and Accumulators and Spent Batteries and Accumulators" [SEC(2003) 1343)] and the United Kingdom (UK) Department of Trade and Industry (DTI)-commissioned report "Analysis of the Environmental Impact and Financial Costs of a Possible New European Directive on Batteries"

(Reference: Environmental Resources Management, 2000). The first document, which is discussed in Appendix E, outlines proposed legislation for member states of the European Economic Community and the latter document was prepared in anticipation of the proposed legislation to help the UK prepare its response to the legislation when it was unveiled. (Note: The DTI is a government group that works to create an environment for business success and to champion UK business at home and abroad.)

The Commission Proposal outlines a rationale for amending legislation and heightening control of waste batteries. The Commission's assessment is that recycling all batteries will have an overall favorable effect on the environment. The Proposal specifically aims to: 1) manage the risks of the hazardous materials used in batteries and their contribution to air emissions, polluting incinerator residues, and landfills and 2) contribute to resource savings by re-introducing battery metals into the economic cycle. These are strategic points because environmental concerns of batteries are mainly due to the materials they contain, and the main environmental impacts occur during the production and waste management phases. Batteries are viewed as an ore of secondary raw materials, and the Proposal notes that the metallic content of a zinc ore (15%) is comparable to the zinc content of some batteries (20%). (Reference: Commission of the European Communities, 2003, page 15) The positive environmental impacts of recycled metals versus virgin metals can be seen in reduced energy use and reduced pollution related to the avoidance of mining of the virgin metal. An example is cited for zinc, showing that the relation of energy needed for recycling and energy needed for extraction from primary sources is 2.2 to 8. Use of recycled metals is particularly significant because primary production of metals is the source of approximately 10% of the global CO_2 emissions. (Reference: Commission of the European Communities, 2003, page 15)

The November 2000 report "Analysis of the Environmental Impact and Financial Costs of a Possible New European Directive on Batteries" was commissioned by the Department of Trade and Industry to assist the Department in preparing a Regulatory Impact Assessment and to support the UK's negotiating stance during the passage of the proposed Directive. (Reference: Environmental Resources Management, 2000) At the time the report was done, the Directive had not been made public and the researchers speculated on its likely content in order to conduct their study. This study concluded that the environmental impact of battery recycling outweighed the benefits of material recovery, but it did not substantiate its conclusion. Instead there was merely a very general statement that adverse environmental impacts (due to collection, transportation and recycling processes) associated with increased recycling "are offset only to a limited extent by the avoided impacts associated with the recovery of materials through recycling". (Reference: Environmental Resources Management, 2000, page 14)