Managing Canada's Waste Batteries

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May 2012

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Changes, Challenges, and Opportunities

By the end of this summer, more than two thirds of Canadians (those in BC, MB, ON, QB) will have mandatory collection and recycling programs for primary portable batteries. Three of these provinces (BC, MB, QB) also mandate the recycling of rechargeable batteries.

Data availability on batteries is limited. Mandated programs, which are required to provide annual reports, do quantify estimates for sales and collection. But these reports are inconsistent with each other; they derive sales using different methodologies, and may lack third-party oversight and detail.

Further challenges with data come from a rapidly changing marketplace for single and especially rechargeables batteries. Our best available estimates for national sales data in 2011 are derived from Kelleher (2009), which used trending information available at the time to attempt to predict the unpredictable. When that report was written, no one could have foreseen the significant growth of hand-held devices.

Canada is fortunate that it has recycling capacity for all battery types available in both Canada and the United States. These recycling industries are making investments to continue to improve and expand their capacity to recycle batteries.

Increased battery use by Canadians, combined with investments in new collection channels and recycling infrastructure, offers tremendous opportunity for battery diversion and recovery.

These new programs offer fresh education efforts that will encourage more people to recycle their batteries instead of disposing them in garbage. Some of these programs also offer financial collection incentives to help evolve a more convenient and effective collection network.

I trust you will find this report to be informative in your efforts. Please do not hesitate to contact me if you require other data or further analysis.

Respectfully yours,

Clarissa Morawski
Principal

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Part I: Introduction

A Primer

Battery recycling in Canada is happening today. In fact, mandated programs are running in British Columbia and Manitoba for all portable battery types and in Ontario for primary batteries. Quebec is also commencing a new program for all portable batteries on July 14, 2012. In addition to these new programs, long-running voluntary rechargeable collection initiatives offered by the Rechargeable Battery Recycling Corporation continue to operate throughout Canada.

Compared to other waste products collected through stewardship programs in Canada, batteries have yielded little data. The *Battery Recycling in Canada 2009 Update*, produced by Kelleher Environmental (http://www.kelleherenvironmental.com/) for Environment Canada and Natural Resources Canada, contains the most comprehensive data set, systems summaries, and trending analysis available on the subject. Kelleher's work has established a baseline data set that enables a more informed review of the new program data. It also offers the tools to facilitate quantification of upstream energy and avoided greenhouse gas emissions from metal and element recovery in the battery recycling process. Finally, Kelleher's report is still the best available data on programs in which public reporting is not currently required for portable primary and/or secondary batteries.

In this first edition of ***Managing Canada's Waste Batteries***, we aim to report on, clarify, and offer insight into the new battery collection and recycling programs in Canada. Program data from British Columbia and Ontario (2010 & 2011) and Manitoba (2011) are presented together, and clarification is offered on definitions of recovery and recycling rates being reported, what they include and exclude, and how they relate to program performance.

The subject of waste batteries is extremely complex given the varieties and chemistries, types of use, and end-of-life impact that batteries have. With the introduction of the new battery recycling programs in Canada, this report is timely. Managing Canada's Waste Batteries is our response to the need for transparency, data scrutiny, and clarity on this important subject, so it is designed for use by businesses, governments, members of the public, and the media. Our research and reporting is ongoing.

Methods Used in This Report

This study is based on secondary research. This means evaluating existing authoritative literature, government-sponsored studies, and industry reports. Evaluating the sources within the scope of this study also includes assessing the transparency and certainty of data in order to present the study as objectively as possible on the basis of compatible results. In addition, experts and system operators were interviewed, and discussions were held with stakeholders with a view to validating work results.

In particular, this study relies heavily on the information contained in the following sources:

Resources researched for this report

Unit weight measurements

1) Kelleher Environmental, *Battery Recycling Update in Canada 2009 Update*.

Sales data

2) Kelleher Environmental, *Battery Recycling Update in Canada 2009 Update*. Estimated sales and available for collection figures for 2011.
3) Call2Recycle®, *2010 Annual Report to the Ministry of the Environment for the Province of British Columbia.*
4) Stewardship Ontario, *2010 Stewardship Ontario Annual Report* and 2011 data from SO.

Specific battery chemistry: History, advantages, properties, toxicological concerns, and common applications

5) Estimated sales from Kelleher Environmental, *Battery Recycling Update in Canada 2009 Update*.
6) http://www.batteryfacts.co.uk/BatteryTypes/index.html
7) http://www.fusionteq.com/html/battery_101_-_the_basics.html
8) http://www.powerstream.com/BatteryFAQ.html
9) http://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery.htm
10) http://www.tumblr.com/tagged/how+do+zinc+carbon+batteries+work

11) http://www.wisegeek.com/what-is-a-zinc-carbon-battery.htm
12) http://www.doitpoms.ac.uk/tlplib/batteries/batteries_zn_c.php
13) http://www.baj.or.jp/e/knowledge/structure.html
14) http://electrochem.cwru.edu/encycl/art-b02-batt-nonr.htm
15) http://www.gravitaexim.com/Battery-Recycling/Battery-History.html
16) http://science.howstuffworks.com/electric-battery-info1.htm
17) http://www.duracell.com/media/enUS/pdf/gtcl/Technical_Bulletins/Zinc%20Air%20Tech%20Bulletin.pdf
18) http://batteryuniversity.com/

Recycling performance metrics

19) Product Stewardship Institute – *Battery Performance Metrics: Recommendations for Best Practices.*
20) Kelleher Environmental, *Battery Recycling Update in Canada 2009 Update.*
21) Consortium ESWI, *Study on the Calculation of Recycling Efficiencies and Implementation of Export Article (Art. 15) of the Batteries Directive 2006/66/EC.*

Life cycle assessment

22) *Life Cycle Impacts of Alkaline Batteries with a Focus on End-of-Life*, For NEMA, by MIT: E. Olivetti, J. Gregory, et al. February, 2011.
23) *A Review of Battery Life-Cycle Analysis State of Knowledge and Critical Needs*, Argonne National Laboratory, J.L. Sullivan, L. Gaines. October 2010.
24) A review of technologies for the recovery of metals from spent alkaline and zinc-carbon batteries. E. Sayilgan et al. / *Hydrometallurgy* 97. 158–166. 2009.
25) Battery Waste Management Life Cycle Assessment, *Final Report for Publication*, DEFRA, October 2006.

Processing

26) Kelleher Environmental, *Battery Recycling Update in Canada 2009 Update*.
27) Call2Recycle®, *2010 Annual Report to the Ministry of the Environment for the Province of British Columbia.*
28) Stewardship Ontario list of approved Battery Incentive Program processors. http://www.stewardshipontario.ca/sites/default/files/BIP-Processor%20April%202%202012.pdf

Battery composition materials: Toxicology

29) Agency for Toxic Substances and Disease Registry
30) Environment Canada list of toxic substances managed under CEPA *(Canadian Environmental Protection Act, 1999)*

Abbreviations

Ag	Silver
AgO	Silver oxide
Al	Aluminum
AlMn	Alkaline manganese
BIP	Battery Incentive Program
BPI	Battery Processing Incentive
BRI	Battery Recovery Incentive
C2R	Call2Recycle®
Cd	Cadmium
CEPA	Canadian Environmental Protection Act
Co	Cobalt
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DHHS	Department of Health and Human Services
EC	Environment Canada
EFW	Energy from waste
EPA	U. S. Environmental Protection Agency
EU	European Union
Fe	Iron
H2S04	Sulfur
Hg	Mercury
HgO	Mercury oxide
IARC	International Agency for Research on Cancer
IFO	Industry-funded organization
KWh	Kilowatt hour
LCA	Life cycle assessment
Li	Lithium
Li-ion	Lithium ion
LiMn	Lithium manganese
MHSW	Municipal household special waste
MIT	Michigan Institute of Technology
Mn	Manganese
MnO	Alkaline manganese
NEMA	National Electrical Manufacturers Association
Ni	Nickel
NiCd	Nickel cadmium
NiMH	Nickel metal hydride
Pb	Lead
PbA	Lead acid
PSI	Product Stewardship Institute
RBRCC	Rechargeable Battery Recycling Corporation of Canada
RER	Recycling efficiency rate
RMC	Raw Materials Company
SO	Stewardship Ontario
SSLA	Small sealed lead acid
Zn	Zinc
ZnC	Zinc carbon

Unit-to-weight standard measurements: Tonnage to unit conversions

To determine the number of units sold and units available for collection, it is necessary to estimate a unit weight of each battery type in grams. The Kelleher report calculates unit weights utilizing European data to create a range of weights by battery chemistry.

Table 1: Estimated unit weights of battery types

PRIMARY	UNIT WEIGHT (grams)	UNIT WEIGHT RANGE (grams)
Zinc carbon (ZnC)	27	27–28
Alkaline ($ZnMnO_2$)	28	26–32
Zinc air (ZnO_2)	33	33
Lithium (primary)	16	
Zinc air button cell (ZnO_2)	0.9	
Silver oxide button ($ZnAgO_2$)	1.2	.12–2.5

SECONDARY	UNIT WEIGHT (grams)	UNIT WEIGHT RANGE (grams)
Nickel Cadmium (NiCd)	203	11– 450
Nickel metal hydride (NiMH)	93	9 –178
Lithium ion (Li-ion)	40	11–75
Lithium Polymer (Li-poly	40	11–75
Small sealed lead acid (SSLA)	1045	1015–1075

Part II: Battery Sales

Canadian Market Share of Primary and Secondary Portable Batteries

Statistics for Canadian battery sales are estimated Canadian sales for 2011 from *Battery Recycling in Canada 2009 Update*, submitted to Environment Canada and Natural Resources Canada by Kelleher Environmental. According to the report, primary batteries make up 78% of total sales, by weight, in the country.

The most common battery chemistry in Canada (on a weight basis) is the alkaline cell, which makes up 58% of the total market. After alkaline, the zinc carbon battery (also primary) is the most common at 18%, followed by the nickel cadmium (rechargeable) at 14%, and the nickel metal hydride (rechargeable) at 4%. Lithium primary batteries and small sealed lead acid batteries (rechargeable) each represent 2% and lithium ion 1% of the total market. Silver oxide button cell, zinc air button cell, other primary batteries, and other secondary batteries combined make up less than 1% of the total market.

Figure: 1: Market share for primary and secondary batteries based on estimated Canadian sales, 2011

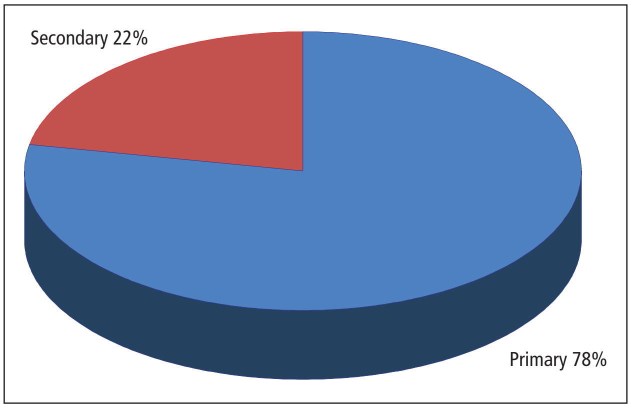
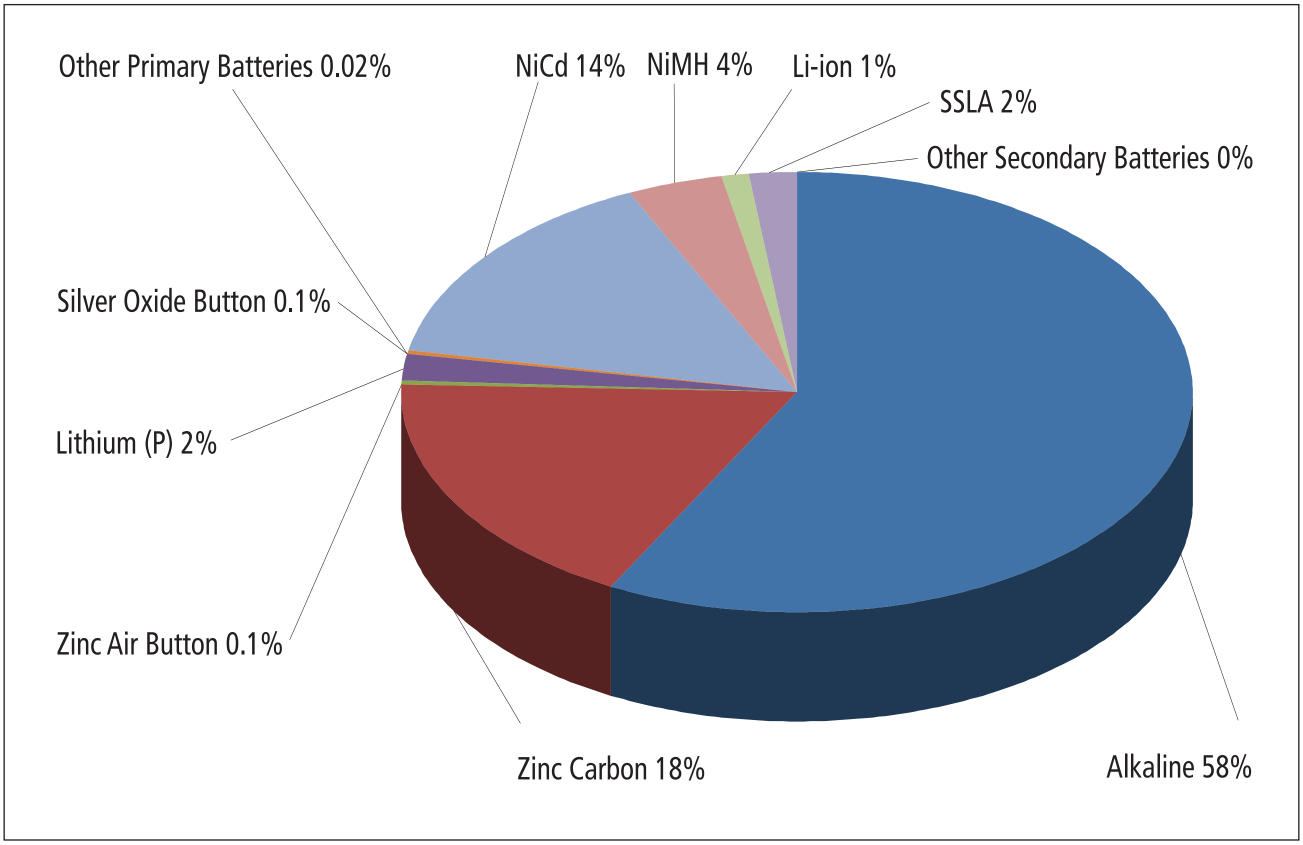


Figure 2: Market share for batteries, by battery type, based on tonnes sold, 2011



Canadian Sales and Available for Collection of Primary Batteries

A battery sold in 2011 is not likely to reach end of life in 2011. All batteries have a lifespan, and many are hoarded for a period of time after their useful life. The Kelleher report developed a model to ascertain the number of batteries "available for collection" or disposal at end of life.

In 2011, the available for collection figure for alkaline batteries is roughly 15% lower than sales for the same year. Zinc carbon batteries, on the other hand, are seeing sales diminish so rapidly that the available for collection number is 18% higher than sales for 2011.

Secondary or rechargeable batteries have a longer lifespan and probably a greater hoarding rate. On average, the 2011 available for collection number is 32% lower than the number sold in 2011, assuming a 5-year hoarding rate.

Figure 3: Estimated tonnes of primary batteries sold and available for collection in Canada, 2011

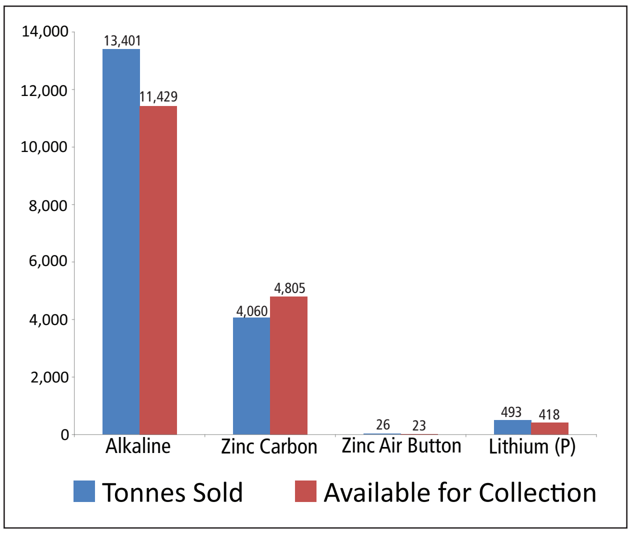
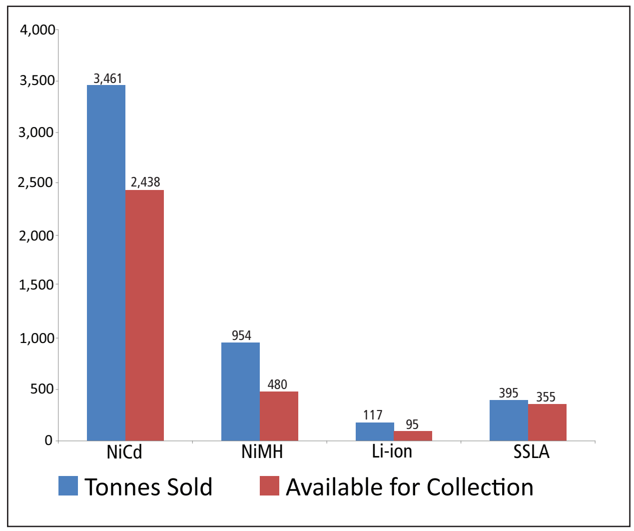


Figure 4: Estimated tonnes of secondary batteries sold and available for collection in Canada, 2011



Part III: Battery Recycling

Recycling Performance Metrics

Measuring battery recycling programs has traditionally been limited to calculating the rate of collection, in other words, to measuring what is collected against what is "available" to be collected. Measuring the availability of waste batteries can be done through two distinct methods.

Collections-to-waste method: This method of defining "availability" is based on the quantity of portable batteries disposed of in the MHSW system. The data come from actual waste audits.

Collections-to-sales method: This method of defining "availability" is based on annual sales within a jurisdiction (excluding exports). In some cases, this sales figure is further refined to take into consideration a battery's average lifespan and consumers' hoarding behaviour. Relative decreases in "availability" will change as the lifespan and hoarding variables change, and they are also impacted by the relative year-over-year sales of particular battery types.

The collections-to-waste method may appear to be the most accurate because it considers actual disposal. However, it is the collections-to-sales approach that is used for reporting recycling performance in most cases. Municipal waste audit methodologies used mostly by municipalities to produce waste composition estimates differ greatly, which creates challenges when measuring performance. A more harmonized approach in terms of reporting metrics will also allow for program comparisons with other jurisdictions and help identify best practices more easily.

In an attempt to equalize the information available, the authors compared sales to "available for collection" of primary battery figures on a per capita basis. The data show that the number of batteries reported as sold into BC (per capita) is 15% lower than the adjusted (i.e., lowered) available for collection data in Ontario.

Collection per capita is significantly higher in Ontario as well. In 2011, British Columbia (Call2Recycle) collected 0.063 kgs of primary batteries per capita, and 0.011 kgs in MB. Ontario (Stewardship Ontario) collected 0.079 kgs of primary batteries per capita, which is approximately 25% more than in BC.

Table 2: Comparison of available for collection and collected – Primary Batteries 2011

SOURCE/ PROGRAM	PROVINCE	SALES OR AVAILABLE FOR COLLECTION IN TONNES	SALES OR AVAILABLE FOR COLLECTION PER CAPITA IN KGS	TONNES COLLECTED	KGS COLLECTED PER CAPITA
Orange Drop	ON	7,115	0.55	1,012	0.079
Call2Recycle	BC	2,052	0.47	285	0.065
Call2Recycle	MB	416	0.34	13	0.011
Kelleher forecast (2009)	ON	6,410	0.50		
	BC	2,195	0.50		

Definitions

In this first edition of *Managing Canada's Waste Batteries*, 2012, we have attempted to provide transparent performance measurements. This means identifying not only how many batteries are collected but also what happens to them when they are collected, how they are recycled, and what they are recycled into. Several Canada-specific parameters exist that help define the methods needed to review performance; these include or exclude energy from waste (EFW) and/or slag as recycling. Given these parameters, we have defined 5 separate performance rates (see table 3).

The following will further clarify these definitions:

Collection: Battery collection is always measured on a weight basis and usually divided into primary and secondary battery categories.

Diversion: Diversion is simply the quantity of collected batteries not sent to landfill. It includes batteries being converted into raw materials, fuel for energy, and process slag used for road fill.

Table 3: Performance measurement definitions

	DEFINITIONS
COLLECTION RATE	The amount collected compared to the weight of batteries placed on the market in that jurisdiction, excluding exports.
DIVERSION RATE	The amount of collected material that is not sent to landfill after processing (includes material used as slag and EFW) compared to the weight of batteries placed on the market in that jurisdiction.
RECOVERY RATE	The amount of material that is recovered for recycling and energy recovery (EFW) compared to the weight of batteries placed on the market in that jurisdiction, excluding exports.
RECYCLING RATE	The amount of material after processing that is recycled into a raw material for future application by product manufacturers compared to the weight of batteries placed on the market in that jurisdiction, excluding exports.
RECYCLING EFFICIENCY RATE (RER)	The amount of material that is recycled into a raw material for future application by manufacturers (excluding EFW and slag) compared to the amount of material that was processed (a measure of input-output efficiency).

Recovery: The recovery rate recognizes the amount of material collected that was converted into raw materials, including fuel for energy but excluding slag used for road construction.

Recycling Rate: The recycling rate recognizes the amount of raw material available for future application by product manufacturers (excluding EFW and slag utilization).

Recycling Efficiency Rate (RER): In line with the *European Batteries Directive* (2006/66/EC), the RER defined in this report recognizes recycling as the **whole process of recycling starting from waste batteries as received after collection, sorting, and processing until obtaining final fractions to be used for their original purpose (for battery manufacturing) or for other purposes, which do not undergo further treatment.** The EU provides this definition in its directive: "recycling is the reprocessing in a production process of waste materials for their original purpose or for other purposes, but excluding energy and water."

The EU also includes the weight of the elements and compounds contained in the slag used for road construction material (as long as they meet heavy metal limits). The EU's decision to include slag as "recycled" in the RER was based on a reasoning methodology that considered the existing recycling capacity and technology in Western Europe.

For the most part, battery recycling technology is based on the pyrometallurgical process, which results in a considerable amount of slag as an end product. Slags are an output fraction of many thermal processes. They can partly be recovered in construction work (e.g., road construction, landfill construction, and backfilling) or are used as feedstock material for further production processes.

In deciding whether to include the content of battery materials transferred to slag in its measurement of recycling efficiency, the EU conducted an overview of the advantages and disadvantages from an environmental, economic, and social perspective. The conclusion was that, in the case of the European Union, "The accountability of slag for the recycling efficiency is decisive in several cases for the achievability of the required recycling efficiency,"… "economic losses can be avoided," and "job losses can be avoided." [1]

For the purposes of this Canadian report, the RER will not include the weight of elements and compounds used as co-product for slag as aggregate. We believe that a line should be drawn that reflects best practices in Canada.

This determination utilizes the same decision methodology as did the EU (see above), but it appropriately applies the advantages and disadvantages to the Canadian context. In this case, existing recycling capacity enables Canada to exceed the mandated recycling efficiency rates in Europe, as well as the targets in Canadian provinces, without the inclusion of the weight of the slag in the recycling rate.

Inclusion of slag as recycling may lead to discrimination of existing battery recyclers in collection programs where presently slag is not authorized to be used for road construction, instead of better recovery methods. This may lead to economic and job losses in Canada.

Another related issue is controlling undesired contamination when slag is used in particular applications (i.e., meeting the limit values for heavy metals when slag is used as road construction material). This is also an important factor affecting both whether to include the slag in the RER, and, if it is included, how to monitor which slag meets the minimum levels of toxicity.

Although the European Union includes slag weight in the recycling rate, Ontario's primary battery recycling program (operated by Stewardship Ontario and funded by battery brand owners) does not.

It is also worth mentioning that existing life cycle assessment (LCA), which has been applied to alkaline batteries, demonstrates that there is no environmental benefit to landfill diversion when the recycling end products are combined primarily of energy from waste: slag and disposal. These factors alone suggest that a meaningful recycling efficiency standard should not include the weight of material sent for slag or to be used in energy-from-waste processes. Recycling efficiency should be based on high rates of recovery of the metals and elements to be used as substitutes for virgin materials that would otherwise have to be extracted, thereby achieving the maximum environmental benefit. For this reason, although we use several performance rates that include slag (e.g., the diversion rate), we do not include slag in the recycling rate, the recovery rate, or the RER. We leave it to readers to decide which rate is relevant to their needs.

Targets

Table 4 provides a summary of legislated targets as well as voluntarily reported performance rates in other jurisdictions based on the definitions provided above.

Table 4: Performance targets

DEFINITIONS	EUROPEAN UNION (legislated)	ONTARIO (in approved stewardship plan	BRITISH COLUMBIA (in approved stewardship plan)	MANITOBA (in approved stewardship plan)
COLLECTION RATE	25% by Sept. 2012; 45% by Sept. 2016 for all battery types	Approved stewardship plan – primary batteries: 20% (Y1); 25% (Y2); 30% (Y3); 35% (Y4); 40% (Y5); 45% (Y6)	Approved stewardship plan – primary batteries: 12% (2010); 18% (2011); 25% (2012); 32% (2013); 40% (2014)	Approved steward-ship plan – all battery types: 15% (2012); 18% (2013); 21% (2014); 25% (2015)
RECYCLING RATE		10.3% (Y1); 12.6% (Y2); 15.2% (Y3); 17.7% (Y4); 20.2% (Y5)		
RECYCLING EFFICIENCY RATE (RER)	INCLUDES SLAG/ EXCLUDES EFW 25%; NiCd; 65%: Lead acid; 50% for all other primary and secondary batteries	EXCLUDES SLAG & EFW 80% primary	INCLUDES SLAG & EFW 50%: Alkaline, Lithium ion, Nickel metal hydride; 75% Nickel cadmium; 65% SSLA	

Performance Rates

Figures 5 and 6 provide performance rates for two years of Ontario and British Columbia's primary battery program, and the first year of Manitoba's program.

Figure 7 provides collection rates for two years of British Columbia's secondary battery program and the first year of Manitoba's program. Detailed summaries on the amounts of different types of rechargeable batteries is not available for this publication. As such, a detailed analysis of diversion, recovery and recycling rates cannot be estimated.

Figure 5:
Performance rates and collection rates

Performance rates: (BC, MB, ON) PRIMARY BATTERIES

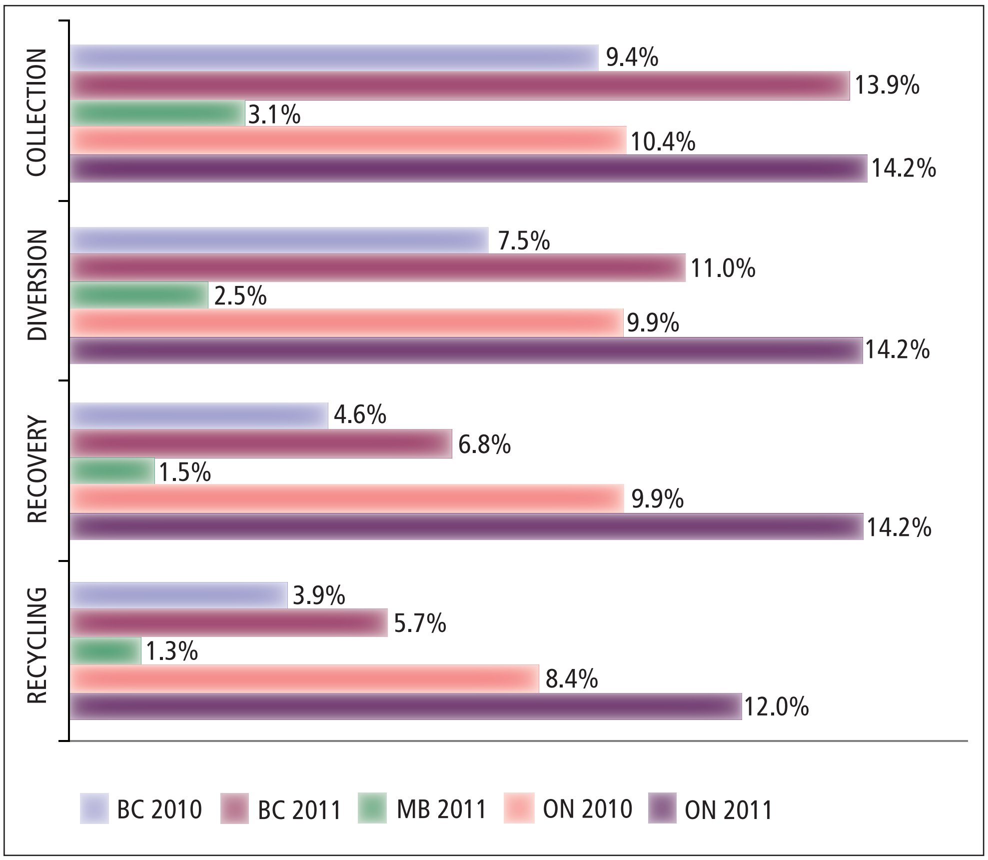


Figure 6: Performance rates: by Province/Year PRIMARY BATTERIES

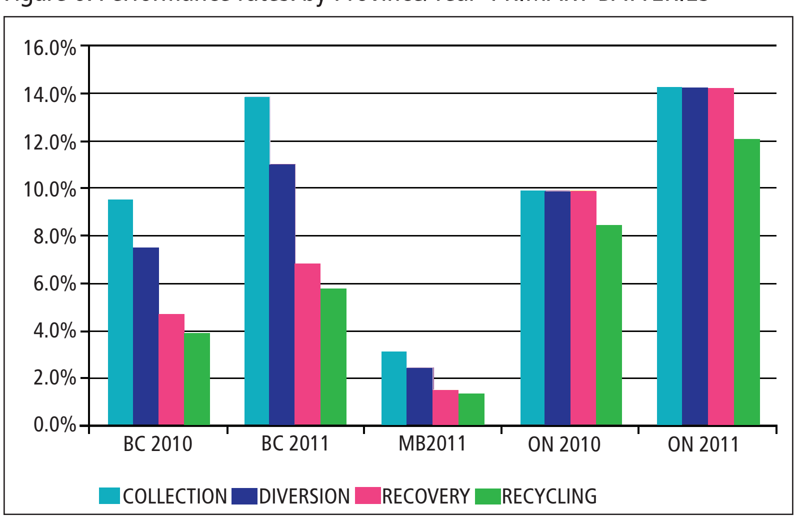
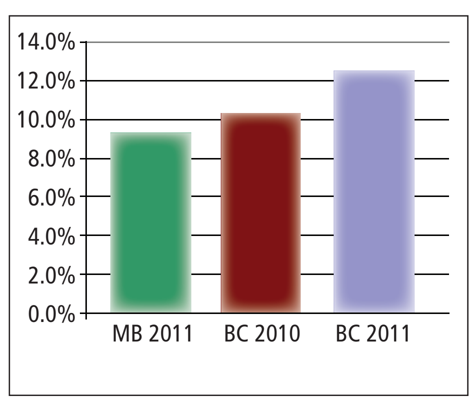


Figure 7: Collection rates: (BC & MB) SECONDARY BATTERIES (NiCd, NiMH, Li-ion, SSSLA)



Total diversion rates for batteries at approved processors for specific battery chemistries:

Table 5 shows the percentage, by weight, of each battery that is recovered for raw materials (metal and elements), slag, energy, or disposed of. The collector and processor for Stewardship Ontario's primary batteries is Raw Materials Company (RMC), in Port Colborne, Ontario. RMC sends the Ni-Cd batteries it collects voluntarily to Toxco in Ohio. Batteries collected from the Call2Recycle® program in BC are shipped for sorting at Toxco in Trail, BC. Toxco keeps the Lithium based batteries and ships all other batteries to Inmetco in Pennsylvania. For greater detail of where batteries collected in various Canadian programs go for processing, refer to *Battery Recyclers for Canadian Collection Programs in Part V.*

These are the rates reported by Raw Materials Company (RMC), and Call2Recycle®. Information from Toxco (Ni-Cd and Lithium Batteries) is unavailable currently.

Table 5: Diversion rates for batteries at approved processors, by battery chemistry

Battery Type	Alkaline/ Zinc Carbon	Alkaline	Li-ion	Li-ion	Li-ion	NiMH	NiMH	Ni-Cd	Ni-Cd
Process/Company	Inmetco	RMC	Xstrata	RMC	Toxco	Inmetco	RMC	Inmetco	Toxco
% IN METALS AND ELEMENTS					N/A				N/A
Fe, Ni, Mn, Cu, Co				29%		57%	60%	50%	
Zinc Oxide, MnOxide, Potassium		59%							
Co, Al,Cu				27%			11%		
Co, Ni, Cu			27%						
Fe, Ni, Mn, Cu	35%								
Fe, Cu		25%							
Hg, Zn, Mn									
Zn*	6%					1%		1%	
Cd								12%	
METAL and ELEMENT RECOVERY	41%	84.5%	27%	56%		58%	71%	63%	
SLAG*	38%					17%		4%	
ENERGY RECOVERY	8%	15%	44%	25%		10%	25%	12%	
TOTAL DIVERSION	79%	99.5%	71%	81%		85%	96%	79%	
DISPOSAL	21%	0.5%	29%	19%		15%	4%	21%	

*Zinc bearing dust is sent with other electric arc furnace (EAF) dust for further processing. It is blended with other material in a rotary kiln. Industry reports that approximately 60% of the dust is separated into an iron-rich slag and sent for use in cement and asphalt. The remaining 40% by weight—known as "crude zinc oxide"—is used as feedstock in a zinc smelter. Approximately 60% is recovered as zinc for zinc bearing products, and the remaining approximately 40% non-zinc residual material is sent for disposal. The values reflected in the table account for this downstream processing.

Figure 8: Diversion rates by battery chemistry and processor

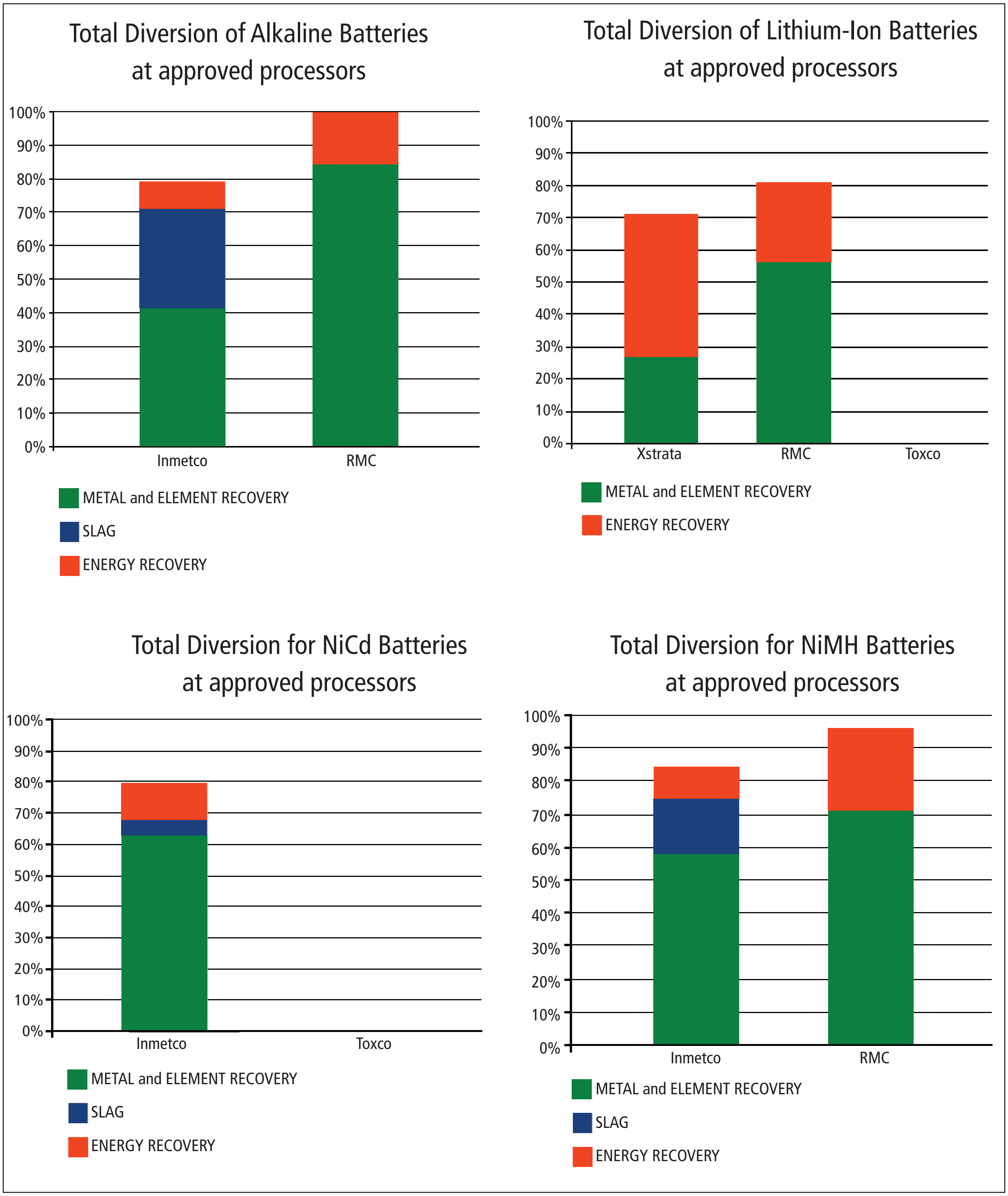


Table 6:
Percentages of batteries diverted, recovered, recycled, and disposed by battery type and processor

Battery Type	Alkaline	Alkaline	Li-ion	Li-ion	Li-ion	NiMH	NiMH	NiCd	NiCd
Process/Company	Inmetco	RMC	Xstrata	RMC	Toxco	Inmetco	RMC	Inmetco	Toxco
Diversion from landfill disposal	79%	100%	71%	81%	N/A	85%	96%	79%	N/A
Diversion from landfill and road base aggregate or fill	49%	100%	71%	81%	N/A	68%	96%	75%	N/A
Recycling Efficiency Rate (metals & element recovery)	41%	84%	27%	56%	N/A	58%	71%	63%	N/A
Disposal	21%	1%	29%	19%	N/A	15%	4%	21%	N/A

Recommended Best Practices for Reporting

A more harmonized approach in terms of reporting metrics will also allow for program comparisons with other jurisdictions, and help identify best practices more easily.

We propose the following considerations with regards to best practices for reporting.

First, these data are needed for full transparency:
1) Sales (excluding exports) by unit, weight, and weight per capita
2) Available for recycling by weight and per capita (with lifespan and hoarding assumptions outlined)
3) Weight of batteries collected and per capita weight
4) Weight of batteries sent for use as slag
5) Weight of batteries used to generate energy through thermal treatment or as a reductant agent
6) Weight of metals and elements recovered for use by product manufacturers

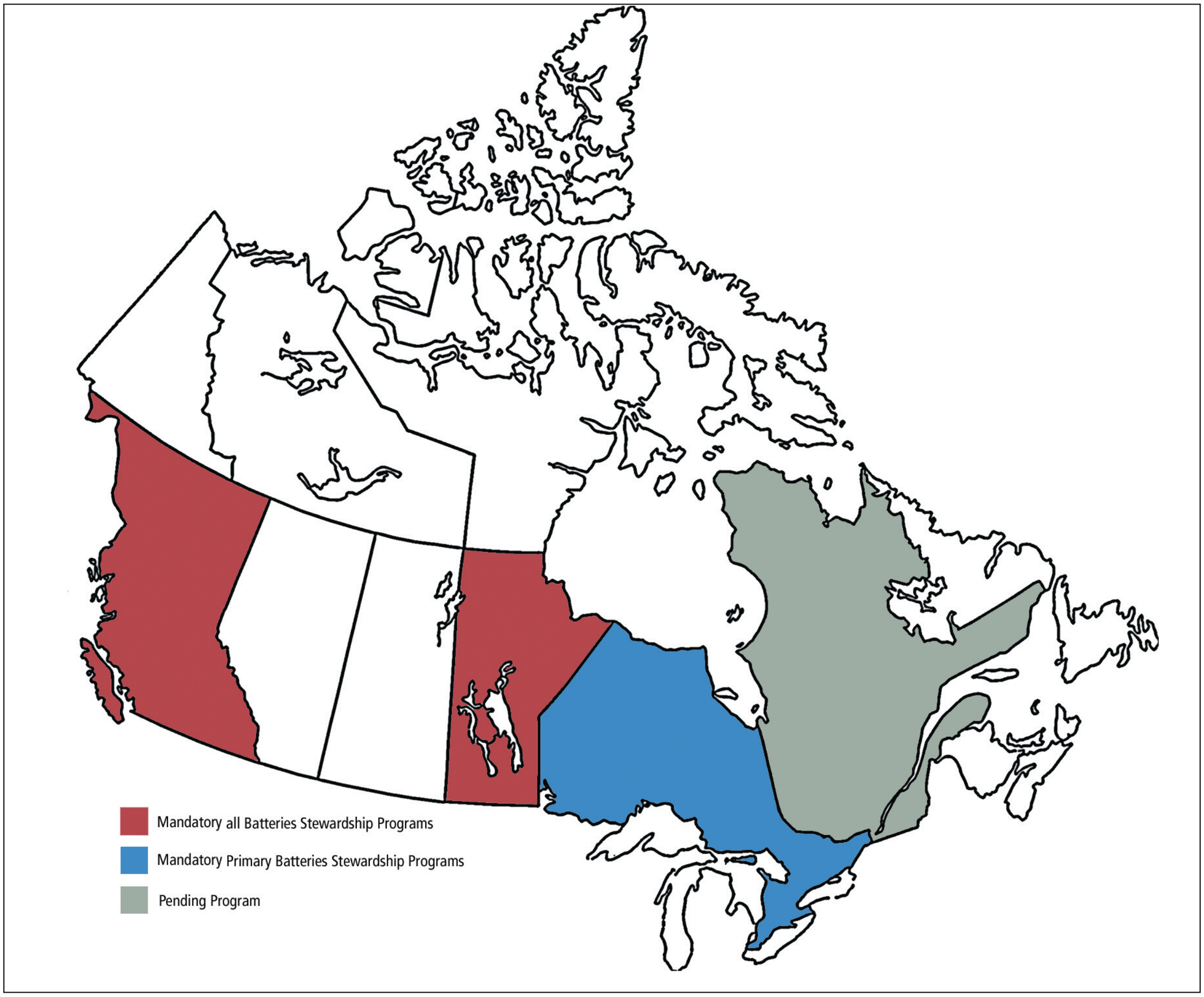
All data should be clearly referenced and methodologies for data refinement need to be transparent. All data should be verified through independent audits.

Reporting should show performance for these measures, along with a clear definition of each.

1. Collection rate (waste to sales, both for straight sales and adjusted with a model)
2. Diversion rate (including slag and waste to energy)
3. Recycling rate (**not** including waste to energy or slag)
4. Recycling efficiency rate (RER)

Part IV: Canadian Program Summaries

Figure 9: Map of Canadian battery stewardship programs and pending programs



British Columbia

Electronic and Electrical Product Stewardship Program

Program scope and targets

Schedule 3 of the *Recycling Regulation* covers batteries in the electronic and electrical product category. It sets out 5 phases of products to be added to the program. As new products are phased in, for example electric or electronic tools such as drills (due to be phased in on July 1, 2012), so too are the batteries used for those products.

Included in the program as of February 2012 are televisions, computers, computer equipment, printers, audio-visual and consumer equipment, thermostats, cell phones, residential fluorescent lamps, smoke detectors, and small appliances and the batteries used in those products.

As of July 1, 2012, the fifth phase of the program will begin, and these products and the batteries used to power them will be included: electrical and electronic tools, medical devices, automatic dispensers, lighting equipment, toys, leisure and sports equipment, monitoring and control instruments, telecommunications equipment, and large appliances.

The Rechargeable Battery Recycling Corporation of Canada (RBRCC), through Call2Recycle®, is the industry steward for the program. The organization has set target "recycling rates" and "collection rates." The recycling rate is also called a "recovery rate" and refers to the percentage of a battery's weight reclaimed for use in a secondary product. The "recovery rate" is 50% for primary alkaline batteries, 75% for nickel cadmium batteries, 65% for SSLA batteries, and 50% for all other rechargeables.

The *Recycling Regulation* calls for a 75% recovery rate or another recovery rate established by the director. The collection rate targets established by Call2Recycle® are 12% of batteries sold into BC for 2010, 18% for 2011, 25% for 2012, 32% for 2013, and 40% for 2014. The Call2Recycle® plan notes that the "collection rate" is the batteries collected for recycling in the market divided by the number available for collection (expressed as a percentage).

The denominator, batteries sold into BC, is defined in RBRCC's 2010 plan as "estimates developed by industry stewards based on total Canadian battery sales allocated by provincial population. Years 2010–2012 assume an annual increase in sales of 2%. Upon launch, more accurate baseline information will be used based upon collection of sales data from battery stewards." The 2011 estimate of batteries sold into BC is 2,564,000 kilograms.

Supporting regulatory framework

In October of 2004, British Columbia consolidated all product stewardship regulations into the *Recycling Regulation* under the *Environmental Management Act*.

Summary of initiative

The program targets brand owners or first importers (stewards) of electronic or electric products and their batteries. Stewards are required to submit stewardship plans describing the development and operation of the collection program. An approved plan must also provide for producer operated and financed end-of-life management for products; reasonable and free consumer access to collection facilities; consumers awareness, performance assessment, and dispute resolution procedures; environmental impact mitigation; and adherence to the order of preference in the pollution prevention hierarchy. This hierarchy is defined in the *Recycling Regulation* as the following, in order of preference:

(a) reduce the environmental impact of producing the product by eliminating toxic components and increasing energy and resource efficiency;
(b) redesign the product to improve reusability or recyclability;
(c) eliminate or reduce the generation of unused portions of a product that is consumable;
(d) reuse the product;
(e) recycle the product;
(f) recover material or energy from the product; or
(g) otherwise dispose of the waste from the product in compliance with the *Environmental Management Act.* (Section 5[3])

Collection

RBRCC had 1,569 collection sites at the end of 2010. Of these sites, 1,372 or about 87% were defined as active (returned batteries and/or cell phones within the 2010 period), and the remaining 197 or close to 13% were inactive (returned no batteries and/or cell phones within the 2010 period). Many inactive sites are expected to become active once the container weight threshold is met (filled). The target site count for 2015, the fifth year of the program is 2,000 sites.

The breakdown of the 1,569 collection sites for 2010 is as follows: 891 "retail" sites collecting 44% of batteries collected by weight, 199 "business" sites collecting 38%, 354 "public agency" sites collecting 10%, and 125 "municipality" sites collecting 8%. How the 197 "inactive" sites are distributed over the four types of sites is unknown.

Given the 2010 population figure (4,400,057), 1,569 collection sites translates to a per capita rate of 1 collection site per 2,804 British Columbians.

Promotion and education

For the six months that ended December 31, 2010, RBRCC's direct expenditures on education and promotion were approximately $69,000. In addition, RBRCC had two individuals substantially dedicated to education and promotion in the province. Program support outreach programs included consumer advertising, public event sponsorship, an exhibit at the Pacific National Exhibition, and other initiatives.

Program financing

The Call2Recycle® program is financed by over 175 manufacturers. Some are direct producers of rechargeable batteries, and others produce products powered by rechargeable batteries. This last category includes cellular phone manufacturers. A licensee fee is assessed for units and weights sold into North America. Funding for costs of the RBRCC program attributable to the management of primary batteries will be paid by the stewards of those products who support the Call2Recycle® stewardship plan.

There is mention in the Call2Recycle® plan dated February 2010 that the program will consider transitioning to a charge per unit sold in the province. This change would not take place during the first two years of operation in the province.

Sales

Sales of batteries into BC for 2011 are estimated to be a total 2052 and 512 tonnes of primary and secondary batteries respectively. The sales are not broken down further by chemistry, but, if we use sales proportions from the Kelleher report, pro-rated sales by chemistry are as follows.

Alkaline: 1,523 tonnes
Zinc carbon: 461 tonnes
Zinc air button cell: 3 tonnes
Lithium (P): 56 tonnes
Silver oxide button cell: 1 tonne
Other primary batteries: 1 tonne
Nickel cadmium: 354 tonnes
Nickel metal hydride: 98 tonnes
SSLA: 40 tonnes
Lithium ion: 18 tonnes
Other secondary batteries: 2 tonnes

Collection rates and tonnage

The collection rates reported for 2011 are 13.9% or 285,118 kgs for primary batteries and 12.5% or 63,918 kgs for secondary batteries.or 51,706 kilos for secondary batteries.

Toxics disposed of at end of battery life in 2011

According to 2011 British Columbia sales and collection, approximately 1,767 tonnes of primary batteries and 448 tonnes of secondary batteries were not collected. This represents approximately 362 tonnes of manganese, 274 tonnes of zinc, 105 tonnes of nickel, 46 tonnes of cadmium, 6 tonnes of cobalt, 394 kgs of silver, 397 kgs of lead, and 30 kgs of mercury.

Manitoba

Household Hazardous Material and Prescribed Material Stewardship Regulation

Program scope and targets (mandated for primary and rechargeable)

The Manitoba *Waste Reduction and Prevention (WRAP) Act* was proclaimed in force in 1990. The *Household Hazardous Material and Prescribed Material Stewardship Regulation* has only just come into force as of April 2011. It adds 10 categories of materials to the *WRAP Act*, including rechargeable batteries (Section 2[i]) and other batteries (Section 2[j]).

The *Household Hazardous Material and Prescribed Material Stewardship Regulation* does not call for a specific recovery rate or target. The Rechargeable Battery Recycling Corporation of Canada (RBRCC), through Call2Recycle®, is the industry steward for the program. The collection rate targets established by Call2Recycle® are 11% of batteries sold into Manitoba for 2011, 15% for 2012, 18% for 2013, 21% for 2014, and 25% for 2015. The Call2Recycle® plan notes that the "collection rate" equals the batteries collected for recycling in the market divided by the number available for collection (expressed as a percentage).

The denominator, batteries sold into Manitoba, is defined in the plan as "estimates developed by battery industry representatives … based on total Canadian battery sales allocated by provincial population. Years 2011–2015 assume an annual increase in sales of 2%. Upon launch, more accurate baseline information will be used based upon collection of sales data from battery stewards." The 2011 estimate for batteries sold into Manitoba is 553,000 kilograms. The target is 11% or 60,100 kilos. The breakdown of this target is 51,100 kilos of primary batteries (80% of the total) and 9,000 kilos of secondary batteries (20% of the total).

Call2Recycle® has also set target "recycling rates." The recycling rate is also referred to as a "recovery rate" and represents the percent of a battery's weight reclaimed for use in a secondary product. The "recovery rate" is 50% for primary alkaline batteries, 75% for nickel cadmium batteries, 65% for SSLA batteries, and 50% for all other rechargeables.

Supporting regulatory framework

The Manitoba Waste Reduction and Prevention Act, which was proclaimed in force in 1990, is the main regulatory framework. Added to this recently is the *Household Hazardous Material and Prescribed Material Stewardship Regulation*, which has only just come into force as of April 2011.

Summary of initiative

This initiative targets stewards; in the regulation, a steward is defined as

"(a) the first person who, in the course of business in Manitoba, supplies a designated material to another person; or

(b) a person who, in the course of business in Manitoba, uses a designated material obtained in a supply transaction outside of Manitoba" (p.2).

Collection

As of April, 2011 the existing collection network includes 338 active sites, including retail, business, and municipal depots in Manitoba. A detailed breakdown is not available, but the collection site locator on the website lists 80 locations in or within 50 km of Winnipeg, 58 of which are "active."

Promotion and education budget

According to the C2R plan for Manitoba, in 2011, Call2Recycle® will spend roughly $100,000 for Manitoba outreach and promotion activities.

Program financing

The Call2Recycle® program is financed by over 175 manufacturers of rechargeable batteries or of products powered by rechargeable batteries. This last category of producer includes cellular phone manufacturers. A licensee fee is assessed for units and weights sold into North America. Funding for costs of the RBRCC program attributable to the management of primary batteries will be paid by the stewards of those products who support the Call2Recycle® stewardship plan.

Sales

Call2Recycle® estimates the total primary and rechargeable batteries sold into Manitoba in 2011 at 553,000 kilograms. Sales are not broken down by chemistry, but, if we use sales proportions from the Kelleher report for 2010, sales by chemistry are as follows.

Alkaline: 310.4 tonnes
Zinc carbon: 93.6 tonnes
Zinc air button cell: 0.6 tonnes
Lithium (P): 11.4 tonnes
Silver oxide button cell: 0.3 tonnes
Other primary batteries: 0.1 tonnes
Nickel cadmium: 79.8 tonnes
Nickel metal hydride: 22.0 tonnes
SSLA: 9.1 tonnes
Lithium ion: 4.1 tonnes
Other secondary batteries: 0.3 tonnes

Collection rates

The collection rates reported for 2011 are 3.1% or 13,229 kgs for primary batteries and 9.3% or 10,699 kgs for secondary batteries.

Ontario

Municipal Hazardous or Special Waste Program

Program scope and targets (mandated for primary)
The Municipal Hazardous or Special Waste Program was established by Stewardship Ontario, an industry-funded organization (IFO), in response to a program request letter from the Minister of the Environment under the *Waste Diversion Act*.

The *Municipal Hazardous or Special Waste Program Plan (Volume II: Material-Specific Plans*), dated July 30, 2009, provides key information on the 20 groupings of products and materials covered by the plan. So, for batteries, the document provides a definition, market and product information, and details about the institutional and commercial generators of batteries, the quantity supplied for use (and how that quantity is calculated), the quantity available for collection, the current management infrastructure and its performance, the barriers and opportunities to increased diversion, research and development for batteries, collection accessibility strategies, promotion and educational initiatives, the targets related to collection and to collection accessibility, recycling targets, and the costs and fee rates attributable to battery stewardship.

Supporting regulatory framework

The *Waste Diversion Act* became law in June 2002. Sections 3 and 4 create Waste Diversion Ontario (WDO) and determine the composition of its board. In Section 5 of the act, WDO is charged with developing, implementing, and operating diversion programs for designated wastes and with monitoring the effectiveness and efficiency of those programs. WDO also determines the amount of money required by the IFOs, promotes public awareness and participation, establishes dispute resolution processes, ensures that programs affect the marketplace in a "fair manner," and advises or reports to the Minister of Environment and Energy.

Section 23 of the act gives the minister the power to develop a waste diversion program for a designated waste, in cooperation with an industry-funded organization. Section 24 describes the establishment of an IFO.

Summary of initiative

The initiative targets stewards, defined in the May 23, 2007 *Municipal Hazardous or Special Waste Program P*lan as "brand owners and/or first importers into Ontario of products that result in the generation of municipal hazardous or special waste" (p. 2).

Collection

The program has a total of 1,351 permanent battery collection points. Of these, 1,152 are "Battery Incentive Program" drop-off locations. The majority of these sites are schools, hospitals, retirement homes, pharmacies, and retailers. Approximately 480 are retailers (not including pharmacies), the majority of which are Hasty Market (196), Staples (131), Home Hardware (52), Costco (26), and Min-A-Mart (20) stores.

The drop-off network also includes 111 Home Depot and Lowes stores that are not part of the Battery Incentive Program (BIP). This brings the total retail locations to approximately 591 (excluding pharmacies).

The 88 municipal depots that are part of the drop-off network are also not part of the BIP.

In 2011, Stewardship Ontario held 297 one-day municipal events, often at public works yards, landfills, or transfer stations. Many of these events were held in towns not served by a permanent drop-off location.

Incentives

The Battery Incentive Program (BIP), which began in February of 2011, is designed to effectively and efficiently increase the diversion of obligated batteries, to achieve a target of 20% of the primary batteries generated annually. There are two different incentives being paid to two different participant groups.

The Battery Recovery Incentive (BRI) pays approved transporters for the collection, recovery, and delivery of batteries to an approved battery processor. An approved transporter will be paid $1.54/kg collected and transported in southern Ontario and $3.86/kg collected and transported in northern Ontario.

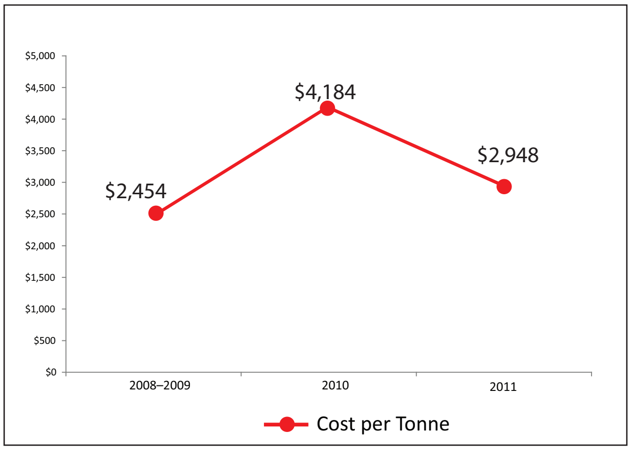
The Battery Processing Incentive (BPI) pays approved processors for the sorting, processing, and disposition reporting of batteries in accordance with the MHSW Program Processor Standards. Approved processors are paid $1.24/kg processed.

Program financing

Stewardship Ontario charges industry a lump sum based on market share. It is left up to the Individual stewards and retailers to determine if they wish to recoup or absorb those costs as they do with other supply chain costs. Some retailers may elect to recoup those costs by charging a fee to customers at the point of sale.

For 2011, the total cost to Stewardship Ontario for the battery program was $2,980,267. This figure is down 7% from 2010. The program collected 1,011 tonnes of primary batteries for a cost per tonne of $2,948. This cost per tonne figure is down 30% from 2010, as volume collected has increased dramatically despite the decrease in program costs.

Figure 10:
Cost per tonne for primary battery recycling in Ontario, 2011



Sales/available for collection

Stewardship Ontario estimates that 7,115 tonnes of primary batteries were available for collection in Ontario in 2011. This estimate is based on a 30% five-year hoarding model. Sales are not broken down by chemistry, but, if we use sales proportions from the Kelleher report for 2010, sales by chemistry are as follows.

Alkaline: 5280 tonnes

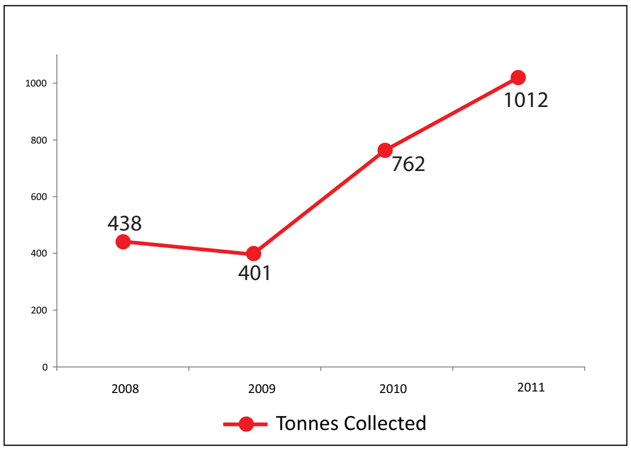
Zinc carbon: 1,600 tonnes
Zinc air button cell: 10 tonnes
Lithium (P): 194 tonnes
Silver oxide button cell: 5 tonnes
Other primary batteries: 2 tonnes

Collection rates and tonnage

Stewardship Ontario (SO) set targets of 1,595 tonnes for 2011 (735 tonnes for the first and second quarters and 860 tonnes for the third and fourth.) Actual collection was 1,012 tonnes or 14%. The Battery Incentive program began in February, so the data does not reflect a full year of the program. As such, the collection rate of 14% is likely understated.

SO continues to raise targets ambitiously each year. Although these targets are not being met, the collection rate has continued to rise and will likely improve again as the BIP sites improve their visibility.

Figure 11:
Tonnes collected by Stewardship Ontario, 2008–2011



Toxics disposed of at end of life in 2011

In Ontario in 2011, approximately 6,103 tonnes of available primary batteries were not recovered. This represents 1,247 tonnes of manganese, 944 tonnes of zinc, 24 tonnes of nickel, 1 tonne of silver, 1 tonne of lead, and 105 kgs of mercury.

Part V: Collection and Recycling

Collection Networks

Comparing 2011 Ontario, British Columbia, and Manitoba data shows that the Ontario program collects far more batteries per site with fewer return locations per capita. This comparison is made difficult by several factors.

Since launching the Battery Incentive Program in February 2011, Stewardship Ontario nearly doubled the number of collection sites (from 634 non-municipal sites to 1,263 today). In addition, not all of the recovered batteries in Ontario are collected through Stewardship Ontario's Orange Drop network.

In British Columbia, there was already a collection network for batteries in place before the legislated program began. Many of these collection sites were inherited by the Call2Recycle® program once in place.

Figure 12: Comparing the number of collection sites to tonnes of primary batteries collected per site

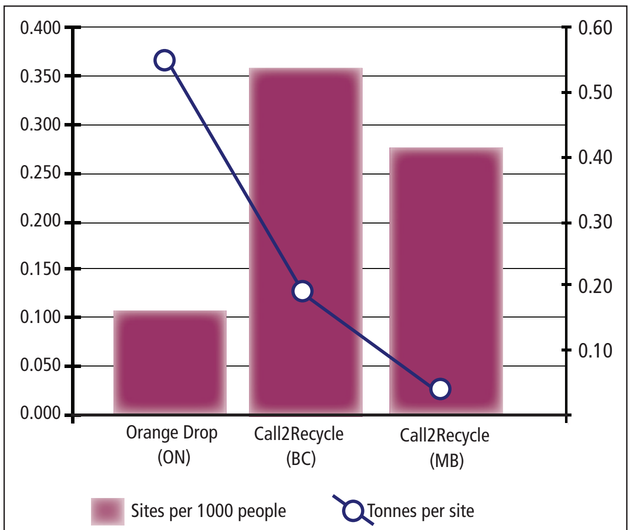
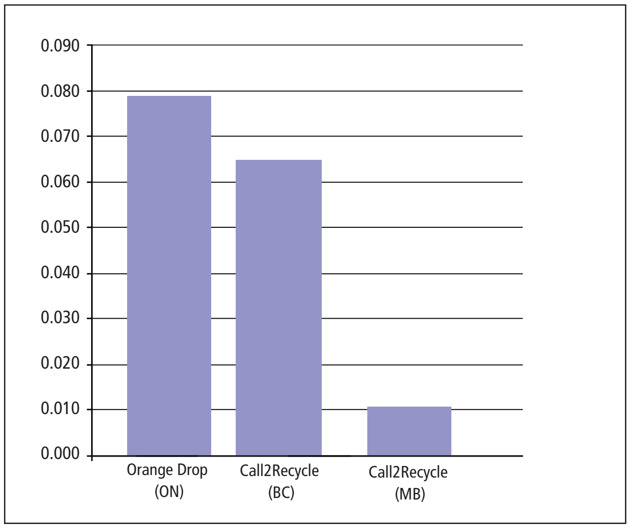


Figure 13 shows the recovery of primary batteries per capita. The sales figures provided by SO and RBRCC show that Ontario has higher sales of primary batteries per capita (17% higher) than BC and MB. In Ontario, the sales (available for collection) figure is .55 kg/person. In BC and MB, the sales figure is .47 kg/person, so it is not surprising that in Ontario, Stewardship Ontario recovers more batteries per capita.

Nevertheless, collection per capita is significantly higher in Ontario. In 2011, British Columbia (Call2Recycle) collected 0.063 kgs of primary batteries per capita, and 0.011 Kgs in MB. Ontario (Stewardship Ontario) collected 0.079 kgs of primary batteries per capita, which is 25% more than in BC.

Figure 13:
Collection per capita for primary batteries, in kilograms, 2011



Battery Recyclers for Canadian Collection Programs

Currently, batteries collected by SO and RBRCC are processed by several different agents in North America.

All batteries collected through Stewardship Ontario's collection channels are sent to Raw Materials Company (RMC) in Port Colborne, Ontario. RMC uses a hydrometallurgical (using water) process to recycle all primary batteries except lithium primary batteries which are sent to Toxco in Trail, BC, where they are recycled using a cryogenic (freezing) process. This program also voluntarily collects Ni-Cd, Li-Ion, NiMH and SSLA batteries. NiMH and Li-Ion batteries are processed by RMC. Ni-Cd batteries are sent by RMC to Toxco in Ohio and SSLAs are sent to Newalta in Quebec.

Batteries collected by RBRCC from British Columbia go to Toxco in Trail, BC where they are sorted and sent to different processors depending on battery chemistry. Lithium primary and secondary batteries stay with Toxco for processing. The largest portion of BC's batteries, (Alkaline, Zinc Carbon, NiCd, and NiMH) are sent to INMETCO, where they are put through a pyrometallurgical process. SSLA batteries are sent to Newalta in Ville Sainte-Catherine, QC.

Table 7: Canadian collection program use of battery recyclers, by battery chemistry

Program	Company Name	Location	Alkaline	Zinc Carbon	Lithium Primary	Li-ion	NiCd	NiMH	SSLA
BC & MB Call2Recycle	Inmetco	Ellwood City, Pennsylvania, USA	■	■			■	■	
BC & MB Call2Recycle	Newalta	Ville Sainte-Catherine, Quebec							■
BC & MB Call2Recycle	Toxco	Trail, BC			■	■			
ON Stewardship ON	RMC	Port Colborne, Ontario	■	■					
ON Stewardship ON	Toxco	Trail, BC			■				
ON RMC (voluntary)	RMC	Port Colborne, Ontario				■		■	
ON RMC (voluntary)	Newalta	Ville Sainte-Catherine, Quebec							■
ON RMC (voluntary)	Toxco	Lancaster, Ohio					■		
E. Can. Call2Recycle (voluntary)	Inmetco	Ellwood City, Pennsylvania, USA	■	■	■		■	■	
E. Can. Call2Recycle (voluntary)	Xstrata	Sudbury, Ontario				■			
W. Can. Call2Recycle (voluntary)	Toxco	Trail, BC			■	■			
W. Can. Call2Recycle (voluntary	Inmetco	Ellwood City, Pennsylvania, USA	■	■			■	■	
Canada Call2Recycle (voluntary)	Newalta	Ville Sainte-Catherine, Quebec							■

Life Cycle Assessment (LCA) and Battery Recycling

Life cycle assessment (LCA), which is also known as life cycle analysis, evaluates the mass balance of inputs and outputs of systems and organizes the findings into environmental themes or categories relative to resource use, pollution, human health, and ecological impact. To provide an overview of the impacts of battery recycling technologies, we examined the most recent LCAs available on the subject. A summary is provided in the table below.

Table 8: Life cycle assessments (LCAs) on battery recycling

Title	Authors	Date
Life Cycle Impacts of Alkaline Batteries with a Focus on End-of-Life	For NEMA, by MIT: E. Olivetti, J. Gregory, and R. Kirchain	February 2011
A Review of Battery Life-Cycle Analysis: State of Knowledge and Critical Needs	Argonne National Laboratory: J.L. Sullivan and L. Gaines	October 2010
A review of technologies for the recovery of metals from spent alkaline and zinc-carbon batteries.	E. Sayilgan et al. in *Hydrometallurgy*, 97(3–4), pp.158–166	July 2009
Battery Waste Management Life Cycle Assessment, Final Report for Publication	For Environmental Resource Management, by DEFRA: K. Fisher et al.	October 2006

The LCAs examined illustrated that, in order to truly understand the impacts of recycling batteries, the actual recycling facilities themselves need to be examined because of the many facility-specific operating variables that can affect the results. There are no peer-reviewed LCAs for the group of battery recycling facilities that recycle Canadian-generated batteries, and most of the LCA data that do exist come from facilities operating in Western Europe (France, Belgium, Switzerland, United Kingdom).

These data can, however, provide some helpful information on both traditional **hydrometallurgical** recycling processes, which use water and chemicals to recover elements and metals, versus the more commonplace **pyrometallurgical** recycling processes, which break down the batteries through thermal treatment.

Hydrometallurgical and Pyrometallurgical Recycling Processes: Understanding the Difference

Both technologies and individual operating facilities have a different set of process inputs and outputs. A study summarized in *Hydrometallurgy* concludes that, overall, hydrometallurgical is preferable to pyrometallurgical recycling due to the first's "low cost requirements, possible recovery of leachants and a decrease of air pollution as there are no particles produced. However, some pre-treatment steps are required in order to improve metal dissolution rates in the aqueous phase, like battery classification, dismantling, magnetic separation, and leaching but per tonne of alkaline batteries processed" (Sayilgan et al., 2009, p. 161).

A comparative analysis commissioned by the UK Department for Environment, Food and Rural Affairs (DEFRA) and published in 2006 found that a pyrometallurgical facility owned by Batrec, a Swiss company, discards more water for processing and cooling than the hydrometallurgical facility operated by Recupyl in France.

Approximately fourteen times more water (1,400 litres) is discharged to the sewer using pyrometallurgy per tonne of batteries processes, compared to an estimated 100 litres from a hydrometallurgical process. The hydro process does require approximately 569 litres of water per tonne of batteries as input, but most of it gets re-circulated (recycled) back into the process (DEFRA, 2006), p. 59).

The pyrometallurgical process requires significantly more energy input as well. Per tonne of alkaline batteries, the pyrometallurgical process reviewed requires 1,690 kWh of electricity versus 959 kWh for the hydrometallurgical process. The pyrometallurgical process also requires an additional 58 kg of light fuel oil and 6 kg of propane per tonne processed.

Raw Materials Company, based in Port Colborne, reports that it requires 103 kWh, almost entirely from hydro electricity, to recycle a ton (short) of batteries. Per ton of batteries recycled 98 kWh of energy is generated off site from the paper and plastic recovered. Each ton of that plastic/paper mix generates approximately 498 kWh (net) of energy from thermal treatment.

Despite the additional energy required for the pyrometallurgical facility in Switzerland, the study illustrates that this facility has a more favourable global warming potential because it draws energy from a renewable source (hydroelectric power). In relation to energy consumption, location plays a key factor for both technologies because it helps determine the type of energy the facility uses.

Comparing the technologies for lithium-ion batteries consistently shows that the pyrometallurgical process requires approximately 6 times more electricity (800 kWh) than the hydrometallurgical process, which uses only 140 kWh for the same batteries. The hydrometallurgical process discharges one third the water (330 litres versus 1000 litres).

Finally, the greatest benefit from recycling batteries is what is actually recovered; these recovered resources preserve raw materials by becoming their substitute. The benefit from avoiding the production of virgin metals is the most significant factor in the LCA, which means that, if the process has a high recycling efficiency rate (RER), it is more likely to also have a more favourable environmental profile. This relationship is especially true for the recycling of zinc carbon and alkaline manganese chemistries because avoiding the environmental impacts of raw material extraction, energy and fuel consumption, and the transportation and production of virgin zinc and manganese or ferromanganese contribute the greatest benefit overall, far outweighing the impacts associated with battery collection, sorting, transport, disposal, and energy consumption during processing.

As Sayilgan and colleagues (2009) conclude,

> "Compared to pyrometallurgical methods, hydrometallurgical methods are becoming a well-established and efficient method for recovering metals from raw materials. Hydrometallurgical methods are chosen as an extraction process and environmental control as well, since the metal extracted will avoid waste production. For the long-term, effective, economical and practical recovery technologies are required not only for metal recoveries but also for other components of batteries such as plastic, paper, steel, etc. "(p. 164)

Part VI: Battery Types

Profiles: Primary or Single Use Portable Batteries

Alkaline

Alkaline batteries are by far the dominant battery on the market. By weight, alkaline batteries comprise 58% of all batteries sold. With sales of zinc carbon batteries dropping, alkaline batteries will continue to constitute the largest portion of the batteries recovered by collectors and processors.

Estimated Canadian sales in units 2011:
480,746,000 units
Estimated Canadian sales in tonnes 2011:
13,461 tonnes
Estimated Canadian tonnes available for collection 2011:
11,429 tonnes

History: Alkaline battery chemistry was first introduced in the early 1960s, and this battery has become the most popular type for consumer use. The alkaline cell gets its name because it uses alkaline aqueous solutions as electrolytes.

Advantages: Alkaline batteries are 8 to 10 times more powerful than zinc carbon batteries and have a longer shelf life (alkaline batteries can deliver up to 80% of their original capacity after being stored for 4 years). They also have greater leakage resistance. Alkaline cells operate over a wider temperature range at high discharge rates.

Properties: Alkaline cells have an anode of zinc powder, a cathode of manganese dioxide (MnO_2) powder, and use potassium hydroxide for an electrolyte. Component materials of alkaline batteries are steel, zinc, manganese, nickel, other metals, alkali, water, and other non-metals.

Table 9: Component materials of alkaline batteries

Fe/steel	Zn	Mn	Ni	other metals	alkali	water	other non-metals	plastic/paper/ carbon
24.8%	14.9%	22.3%	0.5%	1.3%	5.4%	10.1%	14%	6.9%

Toxicological concerns: In 2011, alkaline batteries sold into Canada contained 1,997 tonnes of zinc, 2,988 tonnes of manganese, 67 tonnes of nickel, 724 tonnes of alkali, and some amount of copper.

Common applications: These batteries are used in portable televisions and radios, toys, flashlights, and for photoflash and other high-drain applications.

Zinc Carbon

Sales of zinc carbon batteries are decreasing as alkaline batteries become an even more dominant player in the primary battery market.

Estimated Canadian sales in units 2011:
150,375,000 units
Estimated Canadian sales in tonnes 2011:
4,060 tonnes
Estimated Canadian tonnes available for collection 2011:
4,805 tonnes

History: The zinc carbon cell is based on the very first batteries created in the late 1800s. In 1886, a "dry" version of the wet Leclanche cell was patented by Dr. Carl Gassner. This cell used a zinc cup as the anode and a plaster of Paris mixture as the electrolyte. These dry cells really gained popularity after being introduced at the 1900 World's Fair in Paris by Gassner. Improvements throughout the century, such as using purer zinc or better sealing, gave the cell a fourfold increase in capacity by 2000.

Advantages: The zinc carbon cell is very inexpensive compared to other types of cells.

Properties: Zinc carbon cells have an anode of zinc chloride and a cathode that is a paste of manganese dioxide and carbon powder (usually graphite powder). Component materials of zinc carbon batteries are steel, lead, zinc, manganese, other metals, alkali, water, and other non-metals.

Table 10: Component materials of zinc carbon batteries

Fe/steel	Mn	Ni	Li	other non-metals	plastic/paper/ carbon
50.0%	19%	1.0%	2%	19%	9%

Toxicological concerns: In 2011, zinc carbon batteries sold into Canada contained 4 tonnes of lead, 788 tonnes of zinc, 609 tonnes of manganese, and 244 tonnes of alkali.

Common applications: These batteries are used in small portable electronic devices that require a low to moderate level of power, such as flashlights.

Lithium

Lithium primary batteries make up only 2% of the total battery market, but sales are growing.

Estimated Canadian sales in units 2011:
30,829,000 units
Estimated Canadian sales in tonnes 2011:
493 tonnes
Estimated Canadian tonnes available for collection 2011:
418 tonnes

History: Early forms of the lithium battery were being used in the United States as early as the late 1950s, but it was not until the 1970s that the Matsushita Battery Industrial Co., Ltd. (currently Panasonic Energy) began to mass produce this chemistry for commercial purposes.

Advantages: The lithium cell uses inexpensive materials and has a high energy density for low volume by weight and mass. The battery also has very low self-discharge characteristics, allowing it to have an excellent lifespan compared to other primary battery chemistries.

Properties: A typical consumer lithium cell uses metallic lithium as an anode and manganese dioxide for the cathode. The electrolyte is lithium dissolved in an organic solvent. Component materials of lithium primary batteries are steel, nickel, manganese, lithium, and non-metals.

Table 11: Component materials of lithium batteries

Fe/steel	Mn	Ni	Li	other non-metals	plastic/paper/ carbon
50.0%	19%	1.0%	2%	19%	9%

Toxicological concerns: In 2011, lithium primary batteries sold into Canada contained 10 tonnes of lithium, 94 tonnes of manganese, and 5 tonnes of nickel.

Common applications: These include digital wristwatches, headlamps, LED lights, smoke detectors, and wireless alarm systems.

Silver Oxide Button Cells

Estimated Canadian sales in units 2011:
11,334,000 units
Estimated Canadian sales in tonnes 2011:
14 tonnes
Estimated Canadian tonnes available for collection 2011:
13 Tonnes

History: Silver oxide button cells were first available on the commercial market in 1960. The battery became the battery of choice for quartz watches, and the market grew during the 1970s as these watches dominated the market. The pocket calculator also made use of the silver oxide button cell. When the value of silver rose sharply in the late 1970s, use of this type of battery dropped and use of the coin-type lithium battery grew.

Advantages: These batteries have a very high energy/weight ratio. However, they are costly due to the high price of silver.

Properties: The cathode (positive electrode) is composed of silver dioxide. The negative electrode (the anode) is powdered zinc. The zinc makes up the top layer of the battery itself. The electrode materials and the separator are infused with an alkaline electrolyte. The component materials of the silver oxide button cell battery are steel, zinc, manganese, nickel, silver, mercury, other metals, alkali, water, and other non-metals.

Table 12:
Component materials of silver oxide button cell batteries

Fe/steel	Zn	Mn	Ni	Ag	Hg	other metals	alkali	water	other non-metals	plastic/paper/ carbon
42%	9%	2%	2%	31%	0.4%	4%	1%	2%	4%	2.5%

Toxicological concerns: In 2011, silver oxide button cell batteries sold into Canada contained .05 tonnes of mercury, 1.1 tonnes of zinc, 4 tonnes of silver, and less than 1 tonne of manganese, nickel, and other metals.

Common applications: Two types of silver oxide batteries are available, one type with a sodium hydroxide (NaOH) electrolyte and the other with a potassium hydroxide (KOH) electrolyte. Sodium hydroxide types last 2 to 3 years, making them highly suitable for quartz analogue digital watches or digital watches without backlights. Potassium hydroxide types are better for the short bursts of higher current drains that are required from LCD watches with backlights. Hearing aids and electronic measuring instruments also use batteries with a potassium hydroxide electrolyte in combination with a special separator to match the application.

Zinc Air Button Cells

Estimated Canadian sales in units 2011:
29,088,000 units
Estimated Canadian sales in tonnes 2011:
26 tonnes
Estimated Canadian tonnes available for collection 2011:
23 tonnes

History: Mass production of button-type zinc air batteries began in the 1980s.

Advantages: Small and lightweight, zinc air button cells have a higher capacity-to-volume (and weight) ratio than other types of battery because air from the atmosphere is one of the battery reactants.

Properties: The anode in a zinc air cell is a powdered zinc amalgam. The zinc powder contains a very low level of mercury (max. 25 mg per cell). The air cathode in a zinc air cell is a mixture of carbon, Teflon, and a small amount of manganese dioxide impressed onto a nickel-plated screen. The electrolyte is an aqueous solution of potassium hydroxide with a small amount of zinc oxide to prevent self-discharge of the anode. (Note: electrolyte form is specific to a Duracell® zinc air button.) The component materials are steel, zinc, mercury, other metals (at least for the Duracell® model described above), alkali, water, and other non-metals.

Table 13:
Component materials of zinc air button cell batteries

Fe/steel	Zn	Hg	alkali	water	other non-metals	plastic/paper/ carbon
42%	35%	1%	4%	10%	3%	5%

Toxicological concerns: In 2011, zinc air button cell batteries sold into Canada contained .03 tonnes of mercury, 9 tonnes of zinc, and 1 tonne of alkali.

Common applications: These batteries are commonly used in hearing aids.

Profiles:

Secondary or Rechargeable Portable Batteries

Nickel Cadmium (NiCd)

Sales of NiCd batteries are slowing down. According to the Kelleher report, 2010 sales of over 22 million units are the high point, and sales will fall to less than 7.5 million units in 2015.

Estimated Canadian sales in units 2011:
17,051,000 units
Estimated Canadian sales in tonnes 2011:
3,461 tonnes
Estimated Canadian tonnes available for collection 2011:
2,438 tonnes

History: In 1899, Swedish inventor Waldemar Jungner developed the first nickel cadmium battery. It wasn't until the 1960s that the battery was commercialized.

Advantages: NICd batteries have a long shelf and use life and can be charged up to 300 times. They feature a flat discharge curve, meaning they will deliver full voltage evenly over a long period and then quickly discharge rather than slowly delivering less and less voltage until empty. One prominent disadvantage of NiCd batteries is that they can suffer from the memory effect, sometimes called the "lazy battery effect." The problem is that, if the NiCd battery is frequently recharged after being only partially discharged, it will no longer deliver its full capacity.

Properties: NiCd batteries have an anode of cadmium and a cathode of nickel oxyhydroxide $Ni(OH)_2$. The electrolyte is aqueous potassium hydroxide (KOH). The component materials of NiCd batteries are steel, nickel, cadmium, alkali, water, and other non-metals.

Table 14:
Component materials of nickel cadmium batteries

Fe/steel	Ni	Cd	alkali	water	other non-metals	plastic/paper/ carbon
35%	22%	15%	2%	5%	11%	10%

Toxicological concerns: In 2011, nickel cadmium batteries sold into Canada contained 52 tonnes of cadmium, 76 tonnes of nickel, and 7 tonnes of alkali.

Common applications: These include calculators, digital cameras, flashlights, medical devices (e.g., defibrillators), electric vehicles, and space applications.

Nickel Metal Hydride (NiMH)

As in the case of NiCd batteries, sales for NiMH batteries are slowing, but not nearly as quickly. Sales are expected to drop by roughly 1 million from 2010–2015.

Estimated Canadian sales in units 2011:
10,263,000 units
Estimated Canadian sales in tonnes 2011:
954 tonnes
Estimated Canadian tonnes available for collection 2011:
480 tonnes

History: NiMH batteries were introduced in the late 1980s and early 1990s, and they rapidly took market share away from NiCd batteries in the portable computing industry.

Advantages: NiMH batteries have a higher energy density than NiCd batteries. They also last longer and can be charged more, up to 500 times before permanently losing charge. Cost is higher than for NiCd batteries, however.

Properties: The anode of NiMH batteries is made of rare earth or nickel alloys with many metals (one example given is V, Ti, Zr, Ni, Cr, Co, and Fe). The cathode is made of nickel oxyhydroxide. The electrolyte is potassium hydroxide. The component materials are steel, zinc, manganese, nickel, cobalt, other metals, alkali, water, and other non-metals.

Table 15:
Component materials of nickel metal hydride batteries

Fe/steel	Zn	Mn	Ni	Co	other metals	alkali	water	other non-metals	plastic/paper/ carbon
20%	1%	1%	35%	4%	10%	4%	8%	8%	9%

Toxicological concerns: In 2011, nickel metal hydride batteries sold into Canada contained 38 tonnes of cobalt, 334 tonnes of nickel, 10 tonnes of zinc, and 10 tonnes of manganese.

Common applications: NiMH batteries are used in laptops, cell phones, camcorders, power tools, and electric vehicles.

Lithium Ion (Li-ion)

Sales of lithium ion batteries are growing and were forecasted in 2009 to reach nearly 5 million units by 2015. Given the recent growth of handheld divices this forecast is likely low.

Estimated Canadian sales in units 2011:
4,434,000 units
Estimated Canadian sales in tonnes 2011:
177 tonnes
Estimated Canadian tonnes available for collection 2011:
95 tonnes

History: The first mass-produced lithium ion batteries were commercialized by Sony in 1991. This battery type is now the chemistry of choice for most portable electronic devices.

Advantages: This battery is generally much lighter than other types of rechargeable batteries of the same size. A lithium ion battery pack loses only about 5% of its charge per month, compared to a 20% loss per month for NiMH batteries. Li-ion batteries experience no memory effect, which means that the user need not discharge them completely before recharging. And they can handle hundreds of charge-discharge cycles. Li-ion cells are considered environmentally preferable to NiCd or NiMH cells because they do not contain cadmium or mercury.

Properties: The anode in lithium ion cells is a combination of carbon compound and graphite. The cathode is lithium oxide. The electrolyte in the batteries currently produced is liquid ($LiPF_6$ or $LiBF_4$ are given as examples), and it uses an organic solvent. Component materials include steel, cobalt, lithium, aluminum, and other metals. Also, compared to other batteries, these have

Table 16:
Component materials of lithium ion batteries

Fe/steel	Co	Li	Al	other metals	other non-metals	plastic/paper/ carbon
22%	18%	3%	5%	11%	28%	13%

Toxicological concerns: In 2011, lithium ion batteries sold into Canada contained 32 tonnes of cobalt, 5 tonnes of lithium, and 9 tonnes of aluminum.

Common applications: These include laptops, PDAs, power-assisted bicycles, cell phones, smart phones, and iPods.

Small Sealed Lead Acid (SSLA)

Estimated Canadian sales in units 2011:
378,000 units
Estimated Canadian sales in tonnes 2011:
395 tonnes
Estimated Canadian tonnes available for collection 2011:
355 tonnes

History: The first sealed, or maintenance-free, lead acid batteries emerged in the mid-1970s.

Advantages: The SSLA battery can combine oxygen and hydrogen to create water and prevent water loss.

Properties: Rather than submerging the plates in a liquid, the electrolyte is impregnated into a moistened separator, a design that resembles nickel- and lithium-based systems. This design enables the operation of the battery in any physical orientation without leakage. Component materials include steel, sulfuric acid, other metals, and other non-metals.

Table 17:
Component materials of small sealed lead acid batteries

Fe/steel	H_2SO_4	other metals	other non-metals	plastic/paper/ carbon
65%	16%	4%	5%	10%

Toxicological concerns: In 2011, SSLA batteries sold into Canada contained 1.64 tonnes of sulfuric acid (H_2SO_4).

Common applications: SSLA batteries are commonly used in biomedical and healthcare devices in hospitals and retirement homes.

Part VII: Toxicology of Battery Materials

Battery Composition Materials

The following defines the metals, elements, and other component materials of batteries and outlines how these can affect humans and the environment. Also detailed are the ways in which humans might be exposed to these materials and any extant federal regulations or recommendations related to them. The materials are presented in order of most tonnes sold into Canada as battery components, except that alkali, being neither a metal nor an element, is positioned near the end.

Manganese (Mn)

Manganese is the third largest portion, by weight, of zinc carbon batteries and the second largest portion, by weight, of alkaline batteries. Manganese is also present in lithium primary, nickel metal hydride, and silver oxide button cell batteries. In 2011, 3,701 tonnes of manganese were sold in Canada within batteries.

What is manganese?

Manganese is a naturally occurring metal that is found in many types of rocks. Pure manganese, however, does not occur naturally because, in nature, the metal combines easily with elements such as oxygen, sulfur, or chlorine. Manganese compounds occur naturally in many foods, and pure manganese is sometimes added to foods. Manganese is used principally in steel production to improve hardness, stiffness, and strength.[2]

Exposure to manganese

The primary way one can be exposed to manganese is by eating manganese-containing nutritional supplements or food. Occupations such as working in a factory where steel is made may lead to increased chances of being exposed to high levels of manganese. Manganese is regularly found at low levels in groundwater, drinking water, and soil.

How manganese affects humans

Manganese is an essential nutrient, and most people eat a small amount of it each day. Workers exposed to high levels of manganese, however, can suffer health problems, the most common of which involve the nervous system. These negative health outcomes include behavioural changes and other nervous system effects, for example, movements that become slow and clumsy. This combination of symptoms, when sufficiently severe, is referred to as "manganism."

The EPA concluded that existing scientific information could not determine whether excessive manganese exposure can cause cancer.

Manganese in the environment

Manufacture, use, and disposal of manganese-based products can lead to the release of manganese to the air, soil, or water. Manganese will not break down in the environment. In water, manganese tends to attach to particles or settle into the sediment. The chemical state of manganese and the type of soil determine how fast it moves through the soil and how much is retained in the soil.

Federal regulations or recommendations regarding manganese

Manganese is listed as a "special case" in the *Guidelines for Canadian Drinking Water Quality.* [3]

Zinc (Zn)

Zinc is the largest portion, by weight, of zinc carbon batteries and the third largest portion, by weight, of alkaline batteries. Zinc is also present in NiMH, zinc air button cell, and silver oxide button cell chemistries. In 2011, 2,804 tonnes of zinc was sold within batteries, primarily in alkaline and zinc carbon batteries

What is zinc?

Zinc is a very common element in the earth's crust. It is present in air, soil, and water, and is in all foods. Zinc has many commercial uses, for example, within coatings to prevent rust, in dry cell batteries, and as a substance to mix with other metals to make alloys like brass and bronze. Zinc combines with other elements to form zinc compounds. Common zinc compounds include zinc chloride, zinc oxide, zinc sulfate, and zinc sulfide.

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[2] Manganese, *Agency for Toxic Substances and Disease Registry*, www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=23.

[3] Health Canada, *Guidelines for Canadian Drinking Water Quality*, http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php.

Exposure to zinc

One can be exposed to zinc by drinking contaminated water or a beverage that has been stored in or flows through metal containers or pipes that have been coated with zinc to resist rust. Eating too many dietary supplements that contain zinc or working at any job that involves the use of zinc or zinc compounds can also expose individuals.

How zinc affects humans

Zinc is an essential element in our diet. Too much zinc is harmful, but not enough zinc can cause problems. Negative effects generally begin at levels 10–15 times above the amount needed for good health. Large doses taken by mouth can cause stomach cramps, nausea, and vomiting. Confirmed studies on rats have shown that feeding them large amounts of zinc can cause infertility.

Inhaling large amounts of zinc (as dusts or fumes) can cause a specific short-term disease called metal fume fever. The long-term affects of breathing high levels of zinc are unknown.

Zinc in the environment

Some zinc is already present in the environment, having been released by natural processes, but most comes from human activities like mining, steel production, coal burning, and the burning of waste. Zinc will attach to soil, sediments, and dust particles in the air. Rain and snow will cause zinc dust particles to settle to earth. Depending on the type of soil to which they become attached, zinc compounds may move into the groundwater and into rivers, streams, and lakes. Much of the zinc in soil, however, remains attached to soil particles and will not dissolve in water. It will build up in fish and other organisms, but will not build up in plants.

Federal regulations or recommendations regarding zinc

Zinc smelters and refineries are considered to be "toxic" as defined in Section 64 of the *1999 Canadian Environmental Protection Act* (CEPA). Consequently, the by-products of zinc smelters and refineries were added to the "List of Toxic Substances" in CEPA as "particulate matter containing metals that is released in emissions from zinc plants" (see #68 in Schedule 1).

Nickel (Ni)

Significant amounts of nickel are found in nickel cadmium and nickel metal hydride batteries. Small amounts are also present in alkaline, lithium primary, and silver oxide button cell batteries. In total, 1,168 tonnes of nickel were sold in Canada within batteries in 2011.

What is nickel?

Nickel is a common and plentiful natural element. Nickel can be combined with other metals, such as iron, copper, chromium, and zinc, to form alloys. Coins, jewellery, and other items are made from these alloys. Most nickel is used to make stainless steel. Nickel can also combine with elements such as chlorine, sulfur, and oxygen to form nickel compounds. Many nickel compounds dissolve fairly easily in water. Nickel compounds are used for nickel plating, to colour ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions.

Exposure to nickel

Eating food containing nickel is the primary source of exposure for most people. Another common form of exposure is skin contact. Higher exposure may occur if you work in industries that process or use nickel.

How nickel affects humans

From 10 to 20% of the population is sensitive to nickel and can have an allergic reaction to it. The most common reaction is a skin rash at the site of contact. Some people who are sensitive to nickel have asthma attacks following exposure.

Chronic bronchitis and reduced lung function have been experienced by workers in nickel refineries or nickel-processing plants. Some who drank water containing high amounts of nickel experienced stomach ache and suffered adverse affects in their blood and kidneys.

Cancers of the lung and nasal sinus have occurred in workers who breathed dust containing high levels of nickel compounds while working in nickel refineries or nickel-processing plants. The U.S. Environmental Protection Agency (EPA) determined that nickel refinery dust and nickel sulfide are human carcinogens.

Tests on animals have shown damage to their lungs and nasal cavities due to breathing nickel compounds, lung disease due to eating or drinking large amounts of nickel, and affects on their stomach, blood, liver, and reproductive and immune systems.

Nickel in the environment
Nickel can be released into the atmosphere by oil-burning power plants, coal-burning power plants, trash incinerators, or industries that make or use nickel, nickel alloys, or nickel compounds. In the air, it attaches to small particles of dust, which can settle to the ground due to rain or snow. Nickel released in industrial wastewater ends up in soil or sediment, where it attaches to particles containing iron or manganese. Nickel seems not to accumulate in the food chain.

Federal regulations or recommendations regarding nickel
Nickel is on the "List of Toxic Substances" managed under CEPA (Schedule 1).

Cadmium (Cd)

Cadmium makes up 15%, by weight, of nickel cadmium batteries. In 2011, NiCd batteries containing 519 tonnes of cadmium were sold in Canada.

What is cadmium?
Cadmium is a natural element in the earth's crust. All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Cadmium is often extracted during the production of other metals like zinc, lead, and copper. Cadmium has many uses, including in batteries, metal coatings, and plastics.

Exposure to cadmium
Breathing contaminated workplace air, drinking contaminated water, or living near industrial facilities that release cadmium into the air can result in exposure to this element. Humans are also exposed by smoking cigarettes, breathing cigarette smoke, or eating foods containing cadmium.

How cadmium affects humans
High levels of cadmium ingested into the lungs can cause severe damage. High levels of exposure from eating food or drinking water containing cadmium can irritate the stomach, leading to vomiting and diarrhoea. Long-term exposure may lead to a build-up of cadmium in the kidneys, possibly resulting in kidney disease. Other long-term effects are lung damage and fragile bones.

The U.S. Department of Health and Human Services (DHHS) has determined that cadmium and cadmium compounds are known human carcinogens.

Cadmium in the environment
Cadmium enters the environment from mining, industry, and burning coal and household wastes. It will not break down in the environment, but may change forms. Airborne cadmium particles may travel long distances before falling to the ground or water. Animals and plants take up cadmium from the environment.

Federal regulations or recommendations regarding cadmium
Inorganic cadmium compounds are on the "List of Toxic Substances" managed under CEPA (Schedule 1). Cadmium is included in the *Hazardous Products (Glazed Ceramics and Glassware) Regulations.*

Cobalt

Cobalt is an element in nickel metal hydride and lithium ion batteries. In total, 70 tonnes of cobalt was sold into Canada within batteries in 2011.

What is cobalt?
In nature, cobalt is found in rocks, soil, water, plants, and animals. Cobalt can be used to produce alloys that are used to manufacture aircraft engines, magnets, grinding and cutting tools, and artificial hip and knee joints. Cobalt compounds are also used to colour glass, ceramics, and paints.

Exposure to cobalt
Exposure to low levels of cobalt can occur through breathing air, eating food, or drinking water. Food and drinking water are the primary sources of exposure to cobalt for the general population. Some level of exposure may also occur in those working in mining, smelting, or refining industries or in industries that process cobalt metal or ores or that produce cobalt alloys.

How cobalt affects humans
Cobalt can be beneficial or harmful to human health. High levels of cobalt exposure may result in lung and heart effects and dermatitis. Liver and kidney effects have also been observed in animals exposed to high levels of cobalt.

Non-radioactive cobalt has not been found to cause cancer in humans or animals following exposure through food or water.

Cobalt in the environment
Cobalt cannot break down, but it can change form or attach to or separate from particles. Cobalt might enter the environment from the burning of coal or oil or the production of cobalt alloys. Cobalt released into the air will associate with particles that may settle to the ground within a few days. Cobalt released into water or soil will stick to particles.

Federal regulations or recommendations regarding cobalt
There are no Canadian regulations or recommendations, but the International Agency for Research on Cancer (IARC) has determined that cobalt and cobalt compounds are possibly carcinogenic to humans.

Lithium (Li)

Lithium is present in lithium ion and lithium primary batteries. Batteries containing a total of 15 tonnes of lithium reached end of life in 2011.

What is lithium?
Since lithium is a natural earth metal, it is found in soils, rocks, dusts, surface water, ground water, and seawater. Because of its natural presence, it is found in plants, animals, food products, and beverages. Human-made products that contain lithium and industrial processes that involve lithium can produce higher concentrations in some areas than would be found under natural conditions.

Exposure to lithium
Everyone is exposed to lithium in food, beverages, air, and soil. Ingestion of lithium is normal, and it is probably beneficial to health at low doses. Most people get an average of 2 milligrams (mg) of lithium per day, mainly from their food. Lithium is excreted rapidly from the body through urine. Doctors may prescribe lithium chloride as a medication for patients with bipolar disorder. Typical doses prescribed by doctors range from 140–1200 mg/day (50–600 times more than the average daily intake from food).[4]

How lithium affects humans
Ingested in excessive amounts, lithium primarily affects the gastrointestinal (GI) tract, the central nervous system, and the kidneys. Acute GI effects include abdominal pain, nausea, vomiting, and diarrhoea. Nervous system effects include tremors, loss of muscle coordination, muscle rigidity, and exaggerated reflexes. Sedation, mental confusion, agitation, seizures, and coma may occur at high doses. Symptoms associated with kidney toxicity include an initial increase in urine output (polyuria), subsequent elevation in blood non-protein nitrogen, and, finally, diminished urine output (oliguria). Inhalation of finely divided lithium particles may result in serious injury to the nasal passages, upper airways, and lungs due to the formation of lithium hydroxide (LiOH), a strong base that is highly corrosive.[5]

Inhaled lithium salts cause nasal and respiratory irritation. Lithium salt contact with skin or eyes can cause burns and irritation.

Oral exposure to excessive amounts of lithium, which occurs mainly when people are taking lithium as a medication, can cause tremors, weakness, convulsions, nausea, vomiting, diarrhoea, kidney failure, diabetes insipidus, or excessive thirst. Chronic oral exposure to high doses of lithium over time (e.g., at doses greater than 140 mg/day for medical treatment) can also disrupt the normal functioning of the thyroid gland, eventually leading to goitre (swelling of the thyroid gland) and hypothyroidism. Hypothyroidism is a disease in which the thyroid does not produce enough thyroid hormone. Symptoms of hypothyroidism include weight gain, muscle weakness, joint and muscle pain, depression, fatigue, brittle hair and fingernails, decreased senses of taste and smell, puffy face and hands and feet, slow speech, thickening of the skin, and thinning of the eyebrows. Lithium has also been shown to cause reproductive and developmental toxicity in animals at doses within the range that people receive who are being medicated with lithium.[6]

Lithium in the environment
Both lithium chloride and lithium sulphate have high water solubility, and the compounds will dissociate in aqueous environments. No lithium compounds are classified for adverse environmental effects. No data regarding the bioaccumulation of lithium was found, but, based on its low affinity to particles, it is not expected to bioaccumulate.

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[4] Oregon Health Authority, *Technical Bulletin—Health Effects Information: Lithium* (Portland, OR: Office of Environmental Public Health, 2011), 3.

[5] H. Aral, A. Vecchio-Sadus, "Toxicity of lithium to humans and the environment—A literature review," *Ecotoxicology and Environmental Safety* 70(2008): 349–356. http://www.hkmacme.org/course/2009BW11-01-00/SP%20CS_Nov.pdf.

[6] Oregon Health Authority, *Technical Bulletin—Health Effects Information: Lithium* (Portland, OR: Office of Environmental Public Health, 2011), http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Monitoring/Documents/health/lithium.pdf.

Lithium found naturally or from manufactured sources does not disappear or break down in the environment. It may combine with other materials, but it does not diminish or disappear unless it is physically removed by treatment processes.

Federal regulations or recommendations regarding lithium
There are none, but there are some regulations about the transportation of lithium-containing batteries.

Aluminum (Al)

Small amounts of aluminum are present in lithium ion batteries. In 2011, 9 tonnes of aluminum was contained in Li-ion batteries that reached end of life.

What is aluminum?
Aluminum can be found in soil, rocks (particularly igneous rocks), and sometimes as aluminosilicate minerals. Aluminum does not exist in its pure form in the environment; it only exists in a combined state with other elements.

Aluminum compounds are used for water treatment, abrasives, and furnace linings. Powdered aluminum metal may be used in explosives and fireworks. Aluminum compounds are also used in consumer products such as foil and antiperspirants, over-the-counter and prescription drugs such as antacids, and food additives.

Exposure to aluminum
Exposure to aluminum can occur from eating food, drinking water, and consuming medicinal products such as antacids. Since aluminum is found in some topically applied consumer products such as antiperspirants, first aid antibiotics, and sunscreen and suntan products, exposure via skin contact also occurs.

Workers can inhale aluminum or otherwise be exposed to it during the refining of the primary metal or while employed in secondary industries that fabricate aluminum products or engage in aluminum welding.

How aluminum affects humans
The nervous system is the likeliest target for aluminum toxicity. Neurobehavioral tests of the motor function, sensory function, and cognitive function of animals exposed to aluminum have shown impaired performance. Animals exposed during gestation or lactation have also exhibited neurobehavioral alterations. In some cases, aluminum workers have shown impaired lung function and fibrosis.

Aluminum in the environment
Aluminum cannot be destroyed in the environment. It can only change its form or become attached to or separated from particles. Aluminum is not bioaccumulated to a significant extent.

Federal regulations or recommendations regarding aluminum
Aluminum is listed as a "special case" in the *Guidelines for Canadian Drinking Water Quality*.[7] The Department of Health and Human Services has not classified aluminum for carcinogenicity. The International Agency for Research on Cancer (IARC) and the Environmental Protection Agency (EPA) have not classified aluminum for carcinogenicity. Available information has not shown that aluminum is a potential carcinogen.

Lead (Pb)

Trace amounts of lead are present in zinc carbon batteries. Lead makes up only 0.1% of the total weight of this battery chemistry. In 2011, the total tonnage of lead sold into the Canadian market in batteries was 4 tonnes.

What is lead?

Lead is a naturally occurring metal found in the earth's crust. Lead can be found in all parts of our environment.[8]

Exposure to lead

Humans can be exposed to lead by eating food or drinking water that contains lead, spending time in areas where lead-based paints have been used and are deteriorating, or working in a job where lead is used. There is no conclusive proof that lead causes cancer in humans.

How lead affects humans

Lead can affect nearly any organ and system in the body. The effects are identical whether it enters the body through breathing or swallowing. In both adults and children, the nervous system is the primary target for lead toxicity. The long-term exposure of adults to lead can

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[7] Health Canada, *Guidelines for Canadian Drinking Water Quality*, http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php.
[8] Lead, *Agency for Toxic Substances and Disease Registry*, http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=22

result in the decreased performance of some functions of the nervous system. Lead exposure can also cause small increases in blood pressure, particularly in middle-aged and older people, and anaemia. High levels of exposure to lead can severely damage the brain and kidneys in adults or children and will ultimately cause death. In pregnant women, high levels of exposure can cause miscarriage. High-level exposure in men may cause damage to the sperm production organs.

Lead in the environment

Lead does not break down, but compounds of lead are altered by sunlight, air, and water. Lead that is released into the air may travel long distances before falling to the ground. Once lead falls to earth, it usually sticks to soil particles. Lead may move from soil to groundwater, depending on the type of lead compound and the characteristics of the soil.

Federal regulations or recommendations regarding lead

Lead was one of the first substances to be added to the "List of Toxic Substances" (Schedule 1) of the original *Canadian Environmental Protection Act* (CEPA). Several regulations regarding lead exist, and these cover the mining of lead, its use in fuel, its use in children's toys, the contamination of drinking water by lead, and many other matters.[9]

Silver (Ag)

Silver is 31%, by weight, of silver oxide button cell batteries. Four tonnes of silver was sold within these batteries in Canada in 2011.

What is silver?

Silver is a naturally occurring element. It is found in the environment combined with other elements such as sulfide, chloride, and nitrate. Silver is often found as a by-product during the retrieval of copper, lead, zinc, and gold ores. Silver is used to make jewellery, silverware, electronic equipment, and dental fillings, and it has many other uses.

Exposure to silver

One can be exposed to silver by breathing low levels in air (particularly while making jewellery with silver) or by ingesting it in drinking water, food, or medicines.

How silver affects humans

A condition called argyria, a blue-gray discoloration of the skin and other body tissues, may happen when one is exposed to high levels of silver for a long period of time. Argyria is a permanent effect, but it appears to be a cosmetic problem that may not be otherwise harmful to health. Lower-level exposures to silver may also cause silver to be deposited in the skin and other parts of the body; however, this is not known to be harmful.

Exposure to high levels of silver in the air can result in breathing problems, lung and throat irritations, and stomach pains. Skin contact with silver can cause a mild allergic reaction, such as a rash.

No studies are available on whether silver affects reproduction or causes developmental problems in people.

Silver in the environment

Natural processes such as the weathering of rocks or soil can cause silver to be released into the air and water. The burning of fossil fuel, the processing of ores, and cement manufacture are human activities that may release silver into the air. Silver does not appear to concentrate to a significant extent in aquatic animals.

The EPA has determined that silver is not classifiable as to human carcinogenicity.

Federal regulations or recommendations regarding silver

There are none.

Mercury (Hg)

Mercury is present in small amounts in zinc air button cell batteries, and trace amounts are in silver oxide button cell batteries. Overall, less than half a tonne of mercury was sold into Canada within batteries in 2011.

What is mercury?

Metallic mercury is a shiny, silver-white, odourless liquid. Heated, it becomes a colourless, odourless gas. Mercury can combine with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or "salts," usually white powders or crystals. Mercury can also combine with carbon to make organic mercury compounds. The most common organic mercury compound is methyl mercury, produced mainly by microscopic organisms in the water and soil. More mercury in the

[9] Lead, *List of Toxic Substances Managed Under CEPA* (Schedule 1), http://www.ec.gc.ca/toxiques-toxics/Default.asp?lang=En&n=98E80CC6-1&xml=D048E4B9-B103-4652-8DCF-AC148D29FB7D.

environment can increase the amounts of methyl mercury that these small organisms make.

Exposure to mercury

One could be exposed to mercury by eating fish or shellfish contaminated with methyl mercury; by breathing vapours in air from spills, incinerators, and industries that burn mercury-containing fuels; through the release of mercury used in dental work and medical treatments; and by breathing contaminated workplace air or through skin contact during mercury use at work.

How mercury affects humans

The nervous system is very sensitive to all forms of mercury. Methyl mercury and metallic mercury vapours are the most harmful forms because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing foetus. Effects on brain functioning may result in memory loss or other problems. Short-term exposure to high levels of metallic mercury vapours may cause effects including lung damage, nausea, vomiting, diarrhoea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

The EPA has determined that mercuric chloride and methyl mercury are possible human carcinogens.

Mercury in the environment

Inorganic mercury can enter the air from mining ore deposits, burning coal and waste, or manufacturing plants. It enters the water or soil from natural deposits, the disposal of wastes, or volcanic activity. Methyl mercury may be formed in water and soil by small organisms called bacteria, and this compound builds up in the tissues of fish. Larger and older fish tend to have the highest levels of mercury.

Federal regulations or recommendations regarding mercury

Mercury is on the "List of Toxic Substances" managed under CEPA (Schedule 1). On February 26, 2011, Environment Canada published a proposed regulation under Part 5 of the *Canadian Environmental Protection Act* outlining proposed prohibitions on the import, manufacture, sale, and offer for sale of mercury-containing products. The final regulation is expected sometime in 2012.

Alkali

Alakali is present in zinc carbon, alkaline, nickel cadmium, nickel metal hydride, zinc air button cell, and silver oxide button cell chemistries. In 2011, 1,076 tonnes of alkali were present in batteries that reached end of life in Canada.

What is alkali?

The adjective alkaline is commonly used in English as a synonym for "base," especially for a soluble base. This broad use of the term is likely to have come about because alkalis were the first bases known to obey the Arrhenius definition of a base and are still among the more common bases.

The alkaline battery gets its name because it has an alkaline electrolyte of potassium hydroxide, instead of the acidic ammonium chloride or zinc chloride electrolyte of the zinc carbon batteries. Other battery systems also use alkaline electrolytes, but they use different active materials for the electrodes.

Potassium hydroxide is an inorganic compound with the formula KOH, commonly called caustic potash. It is used in batteries because of its reactivity toward acids and its corrosive nature.

Exposure to alkali

Exposure to potassium hydroxide could occur by breathing in contaminated air, through ingestion, or by skin or eye contact.

How alkali affects humans

When inhaled, potassium hydroxide is a respiratory tract irritant, and it may cause serious burns on acute contact. Severe injury is usually avoided by self-limiting coughing and sneezing symptoms. When ingested, it is corrosive to mucous membranes and may cause perforation of the oesophagus and stomach. Abdominal pain, nausea, vomiting and general gastrointestinal upset can be expected.

Skin contact will create irritation, soreness, and redness; the destruction of skin may result. Eye contact will result in irritation to eye tissues, tearing, redness, pain, and impaired vision.

Chronic exposure and prolonged contact with potassium hydroxide could lead to defatting dermatitis, a medical condition involving the chemical dissolving of dermal lipids from the skin. Continued irritation may lead to increased susceptibility to respiratory illness.

Sulfuric Acid (H_2SO_4)

Sulfuric acid is present in small sealed lead acid batteries. Roughly 63 tonnes of H_2SO_4 were contained in SSLA batteries that reached end of life in Canada in 2011.

What is sulfuric acid?

Sulfuric acid is a clear, colourless, oily liquid that is very corrosive. It is also called sulphine acid, battery acid, and hydrogen sulfate. It is used in the manufacture of fertilizers, explosives, other acids, and glue; in the purification of petroleum; in the pickling of metal; and in lead acid batteries (used in most vehicles).

Exposure to sulfuric acid

One may be exposed to sulfuric acid working in the chemical or metal plating industry; producing detergents, soaps, fertilizers, or lead acid batteries; or working in printing and publishing or photography shops. Breathing outdoor air where coal, oil, or gas are burned; touching the material that forms on the outside of a car battery; or breathing air near a hazardous waste site where SO_3 is disposed of could also lead to a risk of exposure.

Sulfuric acid in the environment

Sulfuric acid dissolves in the water contained in air and can remain suspended in air for varying periods of time. It is removed from the air in rain. Sulfuric acid contributes to the formation of acid rain.

How sulfuric acid affects humans

Touching sulfuric acid will burn skin. Breathing sulfuric acid can result in both tooth erosion and respiratory tract irritation. Drinking sulfuric acid can burn ones mouth, throat, and stomach. It can result in death. It will cause watering and burning of the eyes.

People who have breathed in large quantities of sulfuric acid have shown an increase in cancers of the larynx. However, most of the people were also smokers who were exposed to other chemicals as well. The ability of sulfuric acid to cause cancer in laboratory animals has not been studied. The International Agency for Research on Cancer (IARC) has determined that occupational exposure to strong inorganic acid mists containing sulfuric acid is carcinogenic to humans.

Federal regulations or recommendations regarding sulfuric acid

There are none specifically about H_2SO_4, but all lead acid batteries are subject to the requirements of the Workplace Hazardous Materials Information System (WHMIS).[10]

Closing Note

Managing Canada's Waste Batteries was created to provide clarity and transparency to governments, industry, and the public on information relating to battery recovery and recycling in Canada. We hope that this report has helped inform the reader and illustrate the importance of data collection and independent reporting, as well as the differences in environmental impact of recycling and disposing of batteries.

The report aims to educate and promote best practices and encourage more recycling through enhanced collection and the high-value recovery of metals and elements.

Special Thanks

The gathering of accurate and detailed information, analysis, and peer review could not have been achieved without the generous assistance of certain individuals whose work supports battery and metals recycling in Canada.

A very special thank you to the following individuals:

Tamara Burns, Stewardship Ontario
David Pearce, Stewardship Ontario
James Ewles, Raw Materials Company
Heather Lee, Call2Recycle®
Maria Kelleher, Kelleher Environmental
Duncan Bury, Duncan Bury Consulting
Robert Sinclair, Natural Resources Canada
Amy C. Tolcin, United States Geological Survey
Doug Panagapko, Natural Resources Canada
Ali Alavi, Horseheads

[10] Health Canada, Workplace Hazardous Materials Information System (WHIMS), http://www.hc-sc.gc.ca/ewh-semt/occup-travail/whmis-simdut/index-eng.php.