Environment Canada Environnement Canada

Battery Recycling in Canada – 2009 Update

Report

Submitted to

Environment Canada and Natural Resources Canada

Kelleher Environmental

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Canada

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Notice to Reader:

This document was completed under contract by Kelleher Environmental for Environment Canada and Natural Resources Canada. Reasonable efforts have been made to ensure the accuracy and the completeness of the information contained in this document. This included a technical review of the material by government and industry experts prior to its finalization and release.

Information contained within this document is provided for information purposes only, and intended to provide an overview of the quantities of spent batteries generated each year in Canada and the available battery recycling infrastructure and capacity in Canada and the USA. It may also help to assess the potential need for future policy development related to the management of spent batteries in Canada. Estimated quantities of spent batteries each year in Canada were based on best available information at the time.

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Executive Summary

A previous Environment Canada study - *Canadian Consumer Battery Baseline Study (February, 2007)* - was developed by RIS International Ltd. The study used 2004 as a baseline year, and made projections to 2010.

Environment Canada and Natural Resources Canada contracted Kelleher Environmental in January, 2008 to update the previous study and forecast quantities of batteries sold, recycled and disposed to year 2015, using 2007 as a baseline year; address automotive lead acid batteries (LABs); describe the infrastructure for processing batteries in Canada (including capacity and costs); and estimate the greenhouse gas (GHG) impacts of different recycling scenarios. A technical review and targeted consultation process was held with key stakeholders and industry contacts. The final report incorporates feedback and comments received through the technical review process.

The types and chemistries of batteries that were addressed in this project include:

PRIMARY BATTERIES

- Zinc carbon (ZnC)
- Alkaline ($ZnMnO_2$)
- Lithium primary
- Zinc air button cell (ZnO_2)
- Silver oxide button cell ($ZnAgO_2$)

RECHARGEABLE BATTERIES

- Nickel cadmium (NiCd)
- Nickel metal hydride (NiMH)
- Lithium ion (Li-ion)
- Lithium polymer (Li-poly)
- Small sealed lead acid (SSLA)
- Vehicular lead acid (automobiles, motorcycles, commercial vehicles)

Battery Sales

Over 95% (671 million of the approximately 707 million) of the batteries sold in Canada in 2007 were primary (non-rechargeable) batteries; the remaining 5% (36 million units) were secondary (rechargeable) batteries (including automotive lead acid batteries).

- Sales of primary consumer batteries are expected to increase from 671 million units (weighing an estimated 17,272 tonnes) in 2007 to 745 million units (weighing an estimated 19,122 tonnes) by 2015.
- In 2007, most of the primary batteries were alkaline batteries (418 million units) or zinc carbon (188 million units).
- Other primary batteries sold in 2007 include lithium primaries (28 million units), zinc air button cells (26 million units), or silver oxide button cells (10.3 million units). Zinc air primary batteries were a small fraction of the total at 148,000 units.
- Sales of secondary consumer batteries were estimated at 26 million units in 2007.
- Of this total, an estimated 16.45 million units were nickel cadmium (NiCd), and an additional 6.4 million units were nickel metal hydride (NiMH) batteries.
- Lithium ion and lithium polymer batteries made up about 2.8 million units of the total sales in 2007.
- Small sealed lead acid (SSLA) battery sales are estimated at 366,000 units.

- With available data on the decline of NiCd battery sales and the increase of lithium battery sales, it was estimated that 7.3 million units would be sold by 2015. This is considered an underestimate.
- An estimated 10.3 million vehicular lead acid batteries, weighing an estimated 209,000 tonnes were sold in Canada in 2007.
- Five million of the total units were for passenger vehicles, with 4.9 million units for commercial vehicles.
- The remaining 349,000 lead acid batteries were for motorcycles. By 2015, the total is expected to reach 11.5 million units weighing 231,000 tonnes.

Available sales projections for secondary consumer batteries indicate that NiCd batteries will remain in the Canadian market past 2015. There are certain applications where NiCd batteries remain necessary (e.g. medical equipment, power tools, emergency lighting, emergency and alarm systems). Many companies are moving to lithium ion and lithium polymer batteries where they are a viable option. Lithium ion battery sales projections to 2015 are considered low estimates.

Battery Lifespan, Hoarding and Unit Weights

Estimates of end of life batteries produced in Canada each year were developed using a Microsoft Excel computer based *Consumer Battery Flow Model*. Lifespan, hoarding[1] and unit weight assumptions in the model are summarized in the table below. Two hoarding assumptions of 5 and 15 years were used to show a range of end of life values and to test the sensitivity of the estimates to hoarding assumptions.

Table ES-1: Values for Lifespan, Hoarding and Unit Weight By Battery Chemistry Used for Consumer Battery Flow Modelling

Battery	Lifespan (years)	Hoarding Assumptions	Unit weight
PRIMARY			
Zinc carbon (ZnC)	3	30% for 5 and 15 years	27 grams
Alkaline ($ZnMnO_2$)	3	30% for 5 and 15 years	28 grams
Lithium primary	3	30% for 5 and 15 years	33 grams
Zinc air button cell (ZnO_2)	3	30% for 5 and 15 years	16 grams
Silver oxide button cell ($ZnAgO_2$)	3	30% for 5 and 15 years	1.2 grams
SECONDARY			
Nickel cadmium (NiCd)	5	60% for 5 and 15 years	203 grams
Nickel metal hydride (NiMH)	3	60% for 5 and 15 years	93 grams
Lithium ion (Li-ion)	1.75	60% for 5 and 15 years	40 grams
Lithium polymer (Li-poly)	1.75	60% for 5 and 15 years	40 grams
Small sealed lead acid (SSLA)	5	60% for 5 and 15 years	1045 grams
Vehicular lead acid (automobiles, motorcycles, commercial vehicles)	4.7	Hoarding assumed to be zero (minimal)	17.7 kg passenger cars 4.3 kg motorcycles 24.1 kg commercial vehicles

[1] Hoarding refers to consumers storing batteries for a period after end of life and before discard.

Battery Recycling

Battery Collection

The current collection rate for primary consumer batteries is 5% in Ontario, where many municipalities include batteries in their MHSW (municipal hazardous and special waste) programs. It is minimal in other provinces where programs are currently not in place.

The Rechargeable Battery Recycling Corporation of Canada (RBRCC) voluntary consumer battery recycling program targets selected rechargeable consumer batteries and was the only program for which collected tonnage information could be obtained. While this program does not reflect all consumer battery recycling in Canada, the tonnage collected was divided by the total estimated tonnage of consumer batteries discarded to estimate a minimum (lower bound) recycling rate for consumer batteries. The actual recycling rate is likely higher than this value, as the estimated recycling rate does not capture consumer battery recycling through other programs. Data could not be found for recovery through the other programs. The estimated overall collection rates for secondary consumer batteries through the RBRCC program alone in 2006/2007 were estimated, and vary somewhat depending on whether the batteries are hoarded for 5 years or 15 years after they are spent. Collection rate values for the 5 to 15 year hoarding assumptions respectively are: 8% to 9% for NiCd batteries; 7% to 8% for NiMH batteries; and 45% to 72% for lithium ion and lithium polymer batteries combined. Collection rates through the RBRCC program for all end of life small sealed lead acid (SSLA) consumer batteries were estimated at 10% for 5 year and 15 year hoarding assumptions. It should be noted that the RBRCC program only collects SSLA batteries which weigh less than 0.9kg (2 pounds). It should also be stressed that these figures do not take collection of secondary consumer batteries through other sources into account, and actual collection rates are likely higher than these values.

Battery collection rates in Canada will increase over time as various stewardship programs currently under consideration or being mandated in legislation are implemented.

Battery Processing Infrastructure

There is an existing battery processing infrastructure in Canada and the US which can process consumer batteries from the Canadian market. The current infrastructure has sufficient capacity to process all non-lead based consumer batteries currently disposed in Canada. The current infrastructure is significantly under-utilized for some battery chemistries. Processors of primary and secondary consumer batteries suffer from a lack of supply, and need more batteries for their operations. All processors contacted during this study indicated a willingness to add capacity or additional shifts as required to meet future processing demands.

Each company in the consumer battery recycling infrastructure has one or more specialties as shown in Table ES-2, which also shows the annual amounts of consumer batteries which reached end of life in 2007. The table shows that adequate processing capacity exists for consumer batteries in processing facilities in Canada and the US.

Table ES-2: Specialties and Capacities of Consumer Battery Recycling Facilities

Company	Specialty	Capacity (tonnes/year)	Batteries Reaching End of Life in Canada (2007), tonnes
Toxco, Trail, BC	Lithium batteries, all chemistries	4,550	47 lithium ion + 4 lithium polymer + 333 lithium primary
Teck Trail, BC	Alkaline batteries in zinc smelter	750	9,734 alkaline
RMC, Port Colborne, Ontario	Alkaline and zinc carbon	10,000	9,734 alkaline
Xstrata, Sudbury, Ontario	Cobalt bearing batteries	6,000 to 7,000	274 NiMH + 47 lithium ion
INMETCO, Pennsylvania	Nickel bearing batteries	6,000	274 NiMH
Toxco, Ohio (Kinsbursky Bros)	Cadmium batteries	15,600 to 19,200	1,915 NiCd

Recyclers charge a fee for processing of alkaline and zinc carbon batteries, because the small amounts of zinc and other materials in these consumer batteries are not of sufficiently high value to pay for the recycling cost.

Cobalt in lithium ion and to a lesser extent nickel metal hydride consumer batteries and nickel in nickel metal hydride batteries have traditionally been of sufficiently high value to offset the costs of recycling; and when market prices are sufficiently high, recyclers may actually pay for this feedstock.

There are four large lead smelters in Canada and one small lead smelter in British Columbia where lead acid batteries are recycled. Significant numbers of used lead acid batteries are exported to the US and are also imported from the US to Canada through existing commercial arrangements between smelters and battery manufacturers. The lead smelter operators interviewed for this project indicated that they were operating at capacity in 2007, and that they would establish additional processing capacity if a secure supply of lead acid batteries could be assured. The reported capacities of the five lead smelters in Canada are presented in Table ES-3. About 104,600 tonnes of lead are contained in the batteries researched in this study. There is sufficient capacity to process these batteries in Canadian lead smelters.

Table ES-3: Capacity of Canadian Secondary Lead Smelters

Company	Capacity (tonnes/year lead)	Lead From Lead Acid Batteries, tonnes
Teck, Trail, BC	95,000	30,000
Tonolli, Mississauga, ON	45,000	45,000
Newalta, Montreal, PQ	100,000	95,000
Xstrata, Belledune, NB	105,000	10,500
Metalex, BC	4,500	4,500
TOTAL	349,500	185,000

Lead acid batteries from automotive and other uses already have value in the marketplace and an existing efficient collection and recycling infrastructure. The combined recycling rate for lead acid batteries for the five year period from 1999-2003 was reported at 99.2% for the US by Battery Council International in 2005. The rate is calculated by adding all of the lead recycled across five years and comparing it to the lead contained in batteries sold in the appropriate prior years based on average life for different types of lead acid batteries. A similar recycling rate is probably also in place in Canada. It is unlikely that recycling levels higher than 99.2% could be achieved over a sustained period.

End-of-life Batteries

End-of-life batteries generated in Canada each year were estimated using the Canadian Consumer Battery Flow Model (2009). The Microsoft Excel computer based model estimates end-of-life batteries generated each year by combining historical unit sales information with the battery lifespan (by battery chemistry) and an assumption regarding how long spent batteries are hoarded before reaching their end-of-life. Two hoarding assumptions (5 and 15 years) were used in this study to show a range of values. Values for primary and secondary consumer batteries for 2007 and 2015 are presented in Table ES-4.

The estimated weight of consumer batteries that reached their end-of-life in Canada in 2007 was estimated at 16,637 to 17,138 tonnes for 15 year and 5 year hoarding assumptions respectively. The longer hoarding assumption results in a lower discard estimate because of the impacts of historical unit sales on consumer batteries discarded in any given year. Primary batteries make up the larger weight, at 14,056[2] to 14,898[3] tonnes of the discard estimates in 2007 compared to an estimated 2,311[4] to 2,563[5] tonnes for secondary batteries.

Table ES-4: Estimated Weight of Primary and Secondary Consumer Batteries Reaching End of Life in Canada in 2007 and 2015

	End of Life Primary Consumer Batteries (tonnes)		End of Life Secondary Consumer Batteries (tonnes)		End of Life Primary and Secondary Consumer Batteries (tonnes)	
Year	Scenario 1 5 year hoarding	Scenario 2 15 year hoarding	Scenario 1 5 year hoarding	Scenario 2 15 year hoarding	Scenario 1 5 year hoarding	Scenario 2 15 year hoarding
2007	14,898	14,056	2,563	2,311	17,461	16,367
2015	17,982	16,377	4,679	3,633	22,661	20,010

By 2015, the amount of end of life secondary batteries increases to a range of 3,633 to 4,679 tonnes, a 57% to 91% increase.

This estimate is likely low, as it is based on lithium ion and lithium polymer battery sales figures which are considered an under-estimate.

The amount of primary batteries at end-of-life increases substantially by 2015, to an estimated 16,377 to 17,982 tonnes, compared to 14,056 to 14,898 tonnes in 2007, representing a 17% to 21% increase over 8 years.

[2] 15 year hoarding assumption
[3] 5 year hoarding assumption
[4] 15 year hoarding assumption
[5] 5 year hoarding assumption

An estimated 9.1 million vehicular and small sealed lead acid batteries with a weight of 186,000 tonnes reached end-of-life in 2007. This value is expected to increase to 10.4 million lead acid batteries with a weight of 211,000 tonnes by 2015. No hoarding assumptions were used for the vehicular lead acid battery estimates.

Greenhouse Gas Benefits of Current and Potential Battery Recycling in Canada

The GHG emission benefit of current vehicular lead acid battery recycling is estimated to be over 250,550 tonnes of equivalent tonnes of CO_2 (eCO_2) savings in 2007. This value reflects the substantial energy savings achieved when secondary lead (from reclaimed vehicular and small sealed lead acid batteries) is used as a feedstock compared to using virgin lead in the same manufacturing process. The estimate was developed using an emission factor for lead developed by Natural Resources Canada staff that was based on energy process requirements for primary versus recycled feedstock. The emission factor needs to be developed in more detail in future research.

This study estimated the GHG benefits of non-lead based consumer battery recycling scenarios to provide a range of values. The GHG benefit of recycling 25% and 50% of primary consumer batteries in Canada is estimated at 7,263 to 14,527 tonnes of eCO_2. Current recycling levels have a benefit of 290 tonnes of eCO_2 savings in 2007. Current recycling of secondary consumer batteries has a GHG benefit of 955 tonnes of eCO_2 savings. If 25% and 50% of secondary consumer batteries were recycled, the GHG benefits are estimated to be 2,682 and 4,245 tonnes of eCO_2 savings.

Future Trends

Battery chemistry and design are developing rapidly to meet new consumer needs for smaller and lighter portable power, as well as the growing electric vehicle and hybrid car market. Various lithium battery chemistries are being developed at this time. The current limitation on broader adoption of lithium battery chemistries is a global limitation on lithium battery manufacturing capacity, as well as some concerns and debate regarding supplies of lithium. The lithium battery manufacturing capacity issue should be resolved over time.

Limitations of the Analysis

The analysis in this report was carried out using best available data. The Canadian Consumer Battery Flow Model (2009) has been designed to take various factors related to battery usage, lifespan and hoarding into consideration. The model can be updated as new information is identified.

Sales projections to 2015 are considered low for lithium ion and lithium polymer batteries. Some battery chemistry sales trends were estimated using sales projections expressed in million of dollars, and percentage increases applied to units sold in a particular baseline year, due to the lack of availability of unit battery sales forecast data. This is considered a limitation of the analysis.

Sales data purchased for the study are based on information collected at the manufacturer level and are presumed to include batteries shipped as part of products.

Current sales for zinc air, lithium primary, silver oxide button cell, and zinc air button cell batteries are based on pro-rating per capita German data to Canada. While there may be some limitations to this assumption, the German data were the best available at the time of the study.

The GHG calculations were carried out assuming emission factors for a number of materials (cobalt, cadmium, lithium, manganese, silver and mercury) for which GHG emission factors are not available.

1. Introduction and Background

1.1 Background

The increasing consumption of batteries has led to concerns that they undergo environmentally sound management with resource recovery where practical at the post-consumer stage. Diversion of end of life batteries to productive uses should be encouraged and supported where practical. The principal benefits of recycling of batteries are to recover reusable material and avoid disposal costs.

Some batteries are known to contain varying amounts of toxic substances under Schedule 1 of CEPA 1999, such as nickel[6], cadmium, lead and mercury. While Environment Canada maintains information regarding the estimated quantities of certain types of batteries recycled and disposed, additional information is required to update past studies, assess the fate of other (e.g. automotive) batteries, develop projections and foster a more complete understanding of the available recycling infrastructure for spent batteries.

Environment Canada's *Canadian Consumer Battery Baseline Study (February, 2007)* was developed by RIS International Ltd. The Baseline Study used 2004 as a baseline year, and made projections to 2010.

Environment Canada and Natural Resources Canada contracted Kelleher Environmental in January, 2008 to update and forecast quantities of batteries sold, recycled and disposed to year 2015; add automotive lead acid batteries to the study; describe the infrastructure for processing batteries in Canada (including capacity and costs); and estimate the greenhouse gas (GHG) impacts of different recycling scenarios. A technical review and targeted consultation process was held with key stakeholders and industry contacts. This report (2009) has been updated to incorporate feedback and comments received through the technical review process.

1.2 Objective of 2009 Battery Recycling in Canada Study

The project which was carried out in early-2008 and which was updated in January 2009 to incorporate technical review comments had three main objectives:

- to update existing and provide new recycling and disposal projections for various types of consumer and other (e.g. automotive) batteries marketed in Canada;
- to describe the currently available infrastructure, capacity, processes and costs to recycle spent batteries that are generated in Canada, and

[6] Schedule 1 of CEPA 1999 lists oxidic, sulphidic and soluble inorganic nickel compounds as toxic substances.

- to estimate greenhouse gas emission reductions that can be achieved by recycling resources recovered from spent batteries that are generated in Canada.

This project expanded upon the information gathered and the computer-based battery waste flow tool developed under Environment Canada's *Canadian Consumer Battery Baseline Study*. The Battery Flow Model uses a "lifespan" methodology based on the approach used by Environment Canada, a number of Canadian provinces and the US Environmental Protection Agency[7] to estimate recycling and disposal figures for waste electrical and electronic equipment.

This report is also intended to assist Environment Canada and Natural Resources Canada to evaluate the effectiveness of existing measures and programs in place throughout Canada to support the environmentally sound management and diversion of spent batteries.

1.3 Scope of the Project

The types and chemistries of batteries that were addressed in this project include:

PRIMARY BATTERIES

- Zinc carbon (ZnC)
- Alkaline ($ZnMnO_2$)
- Lithium primary
- Zinc air button cell (ZnO_2)
- Silver oxide button cell ($ZnAgO_2$)

RECHARGEABLE BATTERIES

- Nickel cadmium (NiCd)
- Nickel metal hydride (NiMH)
- Lithium ion (Li-ion)
- Lithium polymer (Li-poly)
- Small sealed lead acid (SSLA)
- Vehicular lead acid (automobiles, motorcycles, commercial vehicles) (LAB)

The project addressed the following three topics:

(1) Revising and Re-Populating the Battery Waste Flow Model

This activity involved:

- acquiring new and updated data on the unit numbers and cumulative weights for batteries (organized by type and chemistry) which are sold in Canada each year;
- revising Environment Canada's Microsoft Excel-based Battery Flow Model (2009);
- developing historic, current and projected quantities of batteries that are reused, stored and discarded (i.e. recycled and disposed) each year;
- identifying toxic and other substance or material content found in batteries that are marketed, reused, stored, recycled and disposed; and

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[7] Electronics Waste Management in the United States, draft report prepared by Eastern Research Group for the Office of Solid Waste, US Environmental Protection Agency, Washington, DC, April 2007 (EPS530-R-07-004a)

- summarizing any new or existing assumptions which are built into the Battery Flow Model (2009).

(2) Describing the Existing Recycling Infrastructure for End of Life Batteries

Identifying, for each battery type and chemistry, facilities in Canada, the USA and elsewhere that are considered to be realistic options for recycling end of life batteries from Canada, including a description of:

- The processes and recycling technologies used;
- Existing and maximum operational processing capacity;
- Current contribution of batteries as part of the overall “feedstock” used by the facilities (in %);
- Number of facility staff currently employed;
- Associated costs to have spent batteries recycled at these facilities (e.g. collection, sorting, transport, processing fees, etc.);
- On-going challenges related to battery recycling; and
- Describing overall and for each battery type and chemistry, any new and emerging technologies that are anticipated to help facilitate or revolutionize battery recycling.

(3) Estimating Greenhouse Gas (GHG) Emission Figures for Virgin and Secondary Materials Found in Batteries

- Estimating greenhouse gas emissions associated with processing both virgin and secondary materials and substances that are found in various types and chemistries of batteries.
- Summarizing any assumptions that are built in to the greenhouse gas emission estimates.

1.4 Report Structure

The report is organized in the following sections:

- Section 2 discusses consumer battery unit sales data and unit weights;
- Section 3 addresses some aspects of the battery recycling collection infrastructure;
- Section 4 describes consumer battery end of life estimates and metal loadings;
- Section 5 describes the major facilities which process primary and secondary consumer batteries;
- Section 6 describes some developments in battery chemistries;
- Section 7 presents GHG emission estimates related to consumer batteries and greenhouse gas estimates of different recycling scenarios;
- Section 8 presents automotive lead acid battery related information; and
- Section 9 presents conclusions.

Output sheets from the Battery Flow Model (2009) for both 5-year and 15-year hoarding assumptions for consumer batteries are presented in Appendix A. Appendix B contains Battery Flow Model (2009) output sheets for Vehicular Lead Acid Batteries. A hoarding sensitivity analysis was not carried out for vehicular lead acid batteries as sales are relatively steady from one year to the next and hoarding is expected to be minor.

2. Unit Battery Sales and Projections

Battery discard values presented later in this report were estimated using the Battery Flow Model (2009). Inputs to the model include unit sales data (discussed in this section) as well as lifespan and hoarding/storage assumptions discussed in Section 4 of this document.

This section outlines the approach used to develop estimates of historical battery unit sales in Canada from 2001 to 2007, and project unit sales estimates from 2008 to 2015. These estimates replace those developed in Environment Canada's *Canadian Consumer Battery Baseline Study* prepared by RIS International Ltd, dated February, 2007.

2.1 Data Sources Used

Extensive research was conducted to identify recent unit sales data for primary and secondary batteries. A comprehensive web search was conducted to identify data available for purchase from a variety of research houses. A number of recently published reports were identified as potential sources of battery sales information including:

- 2005/2006 Outlook for the Battery Market – Business Trend Analysis (August 2005);
- Consumer Batteries Report – Global Industry Analysis (February 2007);
- Rechargeable Batteries Report – Global Industry Analysis (July 2007);
- Lead Acid Batteries Report – Global Industry Analysis (July 2007);
- World Batteries to 2010 Report – Freedonia (August 2006); and
- Batteries: US Industry Study With Forecasts 2011 to 2016 – Freedonia (March 2007).

The key research houses were contacted by telephone to inquire about the relevance of the available data and to potentially identify additional sources of data. The following research houses were contacted and interviewed by a member of the study team:

- Global Industry Analysts (GIA);
- Freedonia;
- Frost and Sullivan;
- Business Trend Analysts; and
- Market Research.

2.2 Primary Consumer Battery Sales Data

A report published by Global Industry Analysis (*Consumer Batteries Report*, Feb. 2007) provides actual unit sales for alkaline and zinc carbon batteries in the US for the years 2001 through 2005, reported at the manufacturer level. These data have been pro-rated to the Canadian population using the factors presented in Table 2.1. National Electrical Manufacturers Association (NEMA) commented that it was more likely that zinc carbon batteries represented a smaller proportion of the total primary consumer batteries sold (in single rather than double digits). The GIA data was used for the analysis as it is a published source.

Table 2.1: Population of US and Canada, 2001 to 2005[8]

	2001	2002	2003	2004	2005
Canadian Population	31,592,805	31,902,268	32,207,113	32,507,874	32,805,041
US population	285,112,030	287,888,021	290,447,644	290,447,644	295,895,897
Ratio Canadian to US Population	11.1%	11.1%	11.1%	11.2%	11.1%
US Unit Sales – Zinc Carbon Batteries	1,370,000,000	1,458,000,000	1,594,000,000	1,704,000,000	1,878,000,000
US Unit Sales – Alkaline Batteries	2,824,000,000	2,994,000,000	3,139,000,000	3,300,000,000	3,517,000,000

Unit sales estimates for each type of battery are discussed below.

Zinc Carbon and Alkaline Battery Unit Sales

By pro-rating US unit battery purchases to the Canadian population, the annual units of zinc carbon and alkaline batteries sold into the Canadian marketplace from 2001 to 2005 was calculated. Canadian unit battery sales for these battery chemistries are presented in Table 2.2.

Table 2.2: Annual Sales of Zinc Carbon and Alkaline Batteries into the Canadian Market 2001 to 2005

(thousands of units)

	2001	2002	2003	2004	2005
Zinc Carbon	151,754	161,530	176,721	190,755	208,227
Alkaline	312,910	331,726	348,120	369,383	389,955

For the Canadian Consumer Battery Flow Model (2009), zinc carbon and alkaline battery unit sales prior to 2001 were estimated by assuming an annual growth rate of 2.5%. The annual growth rate for alkaline batteries was assumed to be 2.5% also prior to 2001, based on comments from NEMA that the primary battery industry is growing at 2-3% per year.

A report published by Freedonia (*World Batteries to 2010*, August 2006) provided long term Canadian sales projections for specific primary batteries (alkaline, zinc carbon, primary lithium and “other”, which combines silver oxide and zinc air) in US$ million for the years 2005, 2010 and 2015. The updated 2005 unit sales data were used as a baseline to project annual unit battery sales to 2015 by applying percentage sales increases or decreases per year to the number of units sold in 2005.

[8] All populations from *CIA World Factbook* so that relative populations came from the same source.

For 2005 to 2010, a 5% reduction in annual sales of zinc carbon batteries is projected by the Freedonia report. A 6.67% annual reduction in sales is projected from 2010 to 2015.

For alkaline batteries, a 3.53% increase in annual sales is projected by the Freedonia (August 2006) report 2005 to 2010. A 3.5 % annual increase in sales is projected from 2010 to 2015.

Zinc Air, Lithium Primary, Silver Oxide Button Cell and Zinc Air Button Cell Batteries

Canadian annual sales of zinc air, lithium primary, silver oxide button cell and zinc air button cell batteries were estimated by pro-rating unit sales of these batteries in Germany to the Canadian population for the years 2003 to 2006. The calculations, along with the estimates of Canadian battery unit sales figures are presented in Table 2.3.

Table 2.3: Annual Sales of Zinc Air, Lithium Primary, Silver Oxide Button Cell and Zinc Air Button Cell Batteries Sold into the Canadian Market (Pro-Rated on Per Capita German Data[9])

2003 to 2006
(thousands of units)

Primary Battery Type	2003	2004	2005	2006
Canadian Population (millions)[10]	32.21	32.51	32.81	33.10
German Population (millions)[11]	82.4	82.4	82,43	82.42
Proportion Canada: Germany	0.39	0.39	0.40	0.40
German Battery Sales Data (millions units)				
Zinc Air Primary Round Cell	372	107	338	359
Lithium Primary Round Cell	17,207	15,624	14,639	14,646
Lithium Primary Button Cell	38,043	43,236	52,661	60,456
Silver Oxide Button Cell	28,163	27,552	24,920	24,946
Zinc Air Button Cell	52,068	59,495	66,980	64,021
Canadian Battery Unit Sales Estimates (millions units)				
Zinc Air Primary	145	42	135	144
Lithium Primary	20,046	21,355	24,418	27,248
Silver Oxide Button Cell	11,008	10,866	9,917	10,018
Zinc Air Button Cell	20,352	23,465	26,656	25,709

Projections of annual unit sales beyond 2006 and before 2003 were based on an annual growth rate of 2.5% based on NEMA input.

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[9] Success Monitor (Stiftung Gemeinsames Rucknahmesystem) Batterien Hamburg, March 2007. Chapter 2, Volume of Batteries Put Into Circulation, Page 5 accessed through www.grs-battierien.de
[10] CIA World Facts
[11] CIA World Facts

2.3 Secondary Consumer Battery Sales Data

Nickel-cadmium, nickel-metal hydride, lithium and lithium-ion

Unit sales of four categories of rechargeable batteries (nickel-cadmium, nickel-metal hydride, lithium and lithium-ion) in Canada for the years 2001 to 2010 were purchased from Global Industry Analysts in 2005 which track sales at the manufacturer level. The vast majority of portable rechargeable batteries generally are sold as part of a product and therefore go from component manufacturer to battery manufacturer to product distributor and product retailer. As GIA no longer provides unit battery sales data for purchase (it is now reported as sales for each year in millions of dollars), the GIA 2005 battery unit sales data used in Environment Canada's 2007 *Consumer Battery Baseline Study* (presented in Table 2.4) were used for this study.

Another report by Global Industry Analysts (*Rechargeable Batteries Report*, July 2007) was also used to identify long term projections for Canadian sales (in US$ million) of four categories of rechargeable batteries (i.e. nickel-cadmium, nickel-metal hydride, lithium and lithium-ion batteries) for the years 2011, 2012, 2013, 2014 and 2015. The percentage increase in sales (expressed as millions of dollars) for each year (presented in Table 2.5) was applied to the 2010 unit sales data in Table 2.4 to project unit battery sales to 2015, which are presented in Table 2.6.

NiCd batteries have been phased out of a number of uses and have been replaced by other chemistries where viable. However they are fully expected to remain in the market for uses for which they are uniquely attractive, such as some kinds of power tools and back up lighting. Power tool users tend to keep their tools much longer and buy replacement batteries[12], which is not the case for other consumer goods which use rechargeable batteries.

In 2006, the dollar sales of rechargeable batteries worldwide consisted of approximately 7% NiCd, 8% NiMH and 85% lithium ion[13]. This does not reflect units sold because of the relative costs of the different batteries.

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[12] Rechargeable Battery Recycling Corporation
[13] NEMA

Table 2.4: Annual Shipments of Secondary Consumer Battery Units in Canada for the Years 2000 through 2010

(in Million Units)[14] Global Industry Analysts (GIA)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	% CAGR[15]
Nickel Cadmium (NiCd)	9.10	9.94	10.69	11.71	12.81	13.95	15.10	16.45	18.24	20.24	22.38	9.42
Nickel Metal Hydride (NiMH)	2.21	2.59	2.99	3.51	4.10	4.77	5.52	6.40	7.54	8.88	10.49	16.85
Lithium Ion (LI-ion)	0.74	0.89	1.07	1.29	1.54	1.84	2.16	2.53	3.04	3.64	4.29	19.21
Lithium Ion Polymer (Li-polymer)	0.06	0.09	0.09	0.12	0.14	0.16	0.21	0.25	0.28	0.33	0.36	19.62
Total	**12.11**	**13.51**	**14.84**	**16.63**	**18.59**	**20.72**	**22.99**	**25.63**	**29.10**	**33.09**	**37.52**	**11.97**

2004 & 2005: GIA Estimates 2006-2010: GIA Projections (*) All figures are at the Manufacturer's Level

Table 2.5: Projected Percentage Change in Sales of Secondary Batteries in Canadian Market, 2012 to 2015

Source: Global Industries Analysts - July 2007; Rechargeable Batteries

Secondary Battery Chemistry	2012	2013	2014	2015
Nickel Cadmium	-23.8%	-18.8%	-15.4%	-18.2%
Nickel Metal Hydride	-2.2%	-2.4%	-2.7%	-0.43%
Lithium Ion	3.3%	3.1%	2.9%	0.67%
Lithium Ion Polymer	6.3%	5.8%	5.2%	1.27%

Small Sealed Lead Acid Batteries

Data on small sealed lead acid (SSLA) batteries were not available for purchase from any of the research houses contacted by the study team. These batteries are used for a few specialized applications such as emergency lighting. German sales data for 2003 to 2006 were obtained from annual reports published by Stiftung Gemeinsames Rücknahmesystem Batterien Association[16] which manages the German battery recycling program and reports unit sales for various battery chemistries and recovered batteries on an annual basis[17]. The per capita rates calculated from the German data were applied to the Canadian population to estimate Canadian SSLA consumption rates for the years 2003 to 2006. Annual projections were estimated using Statistics Canada population figures for Canada to 2015.

There are some differences in the battery chemistries used from one country to another. Germany used NiCd batteries by code and Canada uses valve regulated lead acid (VRLA) batteries by code for emergency lighting, therefore applying the German data to Canada provides an underestimate of SSLA generation. However, the German data were the only data available to use for these estimates. This is a limitation of the study.

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[14] Battery units include individual batteries or battery packs of varying sizes and chemistries

[15] CAGR = compound annual growth rate

[16] Success Monitor (Stiftung Gemeinsames Rucknahmesystem) Batterien Hamburg, March 2007. Chapter 2, Volume of Batteries Put Into Circulation, Page 5 accessed through www.grs-battierien.de

[17] www.grs-batterien.de

2.4 Total Consumer Battery Sales Data.

Table 2.6 summarizes the total Canadian unit battery sales data (i.e. primary and secondary batteries) from 2007 to 2015.

Table 2.6: Battery Sales Data 2006 to 2015

(Thousands of Unit Sales Per Year)

	Unit Weight	2007	2008	2009	2010	2011	2012	2013	2014	2015
Primary Batteries										
Zinc Carbon	0.027	187,925	178,528	169,602	161,122	150,375	140,345	130,984	122,247	114,093
Alkaline	0.028	418,214	433,103	448,521	464,489	480,746	497,572	514,987	533,011	551,667
Zinc Air	0.033	148	151	155	159	163	167	171	176	180
Lithium	0.016	27,930	28,628	29,343	30,077	30,829	31,600	32,390	33,199	34,029
Button Cell Primary										
Silver Oxide	0.0012	10,268	10,525	10,788	11,058	11,334	11,618	11,908	12,206	12,511
Zinc Air	0.0009	26,352	27,011	27,686	28,378	29,088	29,815	30,560	31,324	32,108
Total Primary Batteries		670,837	677,946	686,096	695,283	702,535	711,116	721,000	732,164	744,588
Secondary Batteries										
NiCd	0.203	16,450	18,240	20,240	22,380	17,051	12,992	10,556	8,932	7,308
NiMH	0.093	6,400	7,540	8,880	10,490	10,263	10,041	9,796	9,530	9,489
Lithium Ion	0.04	2,530	3,040	3,640	4,290	4,434	4,582	4,723	4,859	4,891
Lithium Polymer	0.04	250	280	330	360	383	407	431	453	459
Total Secondary Batteries (Excluding SSLA and LAB)		25,630	29,100	33,090	37,520	32,131	28,022	25,506	23,774	22,147
SSLA	1.045	366	369	383	375	378	381	381	383	384
LAB - passenger cars	17.7	4,998	5,037	5,065	5,106	5,157	5,219	5,292	5,375	5,466
LAB - motor cycles	4.3	349	370	389	409	431	456	482	511	542
LAB - commercial vehicles	24.1	4,946	4,977	4,999	5,037	5,095	5,169	5,257	5,356	5,465
Total – Automotive LABs		10,293	10,383	10,453	10,552	10,684	10,843	11,031	11,241	11,473
Total Secondary Batteries including SSLA and Automotive LAB		36,289	39,852	43,926	48,447	43,193	39,246	36,918	35,398	34,004
Total Primary and Secondary Batteries		707,126	717,798	730,022	743,730	745,728	750,362	757,918	767,561	778,592

Note: Totals May Not Add Due to Rounding

Primary Consumer Batteries

The table shows that:

- Most of the unit sales are primary (non-rechargeable) batteries, at an estimated 671 million units sold in 2007 of which most were alkaline or zinc carbon.
- Sales of zinc carbon units are expected to decrease over time;
- Sales of alkaline units are expected to increase over time.
- Sales of primary batteries are expected to reach 745 million units by 2015.
- By 2015, sales of lithium primary batteries are expected to reach 34 million units per year, up from 28 million units in 2007.
- By 2015, sales of alkaline units are expected to reach 552 million units per year, and
- Sales of zinc carbon batteries are expected to be 114 million units by 2015, compared to 188 million units in 2007.

Secondary Consumer Batteries

Table 2.6 shows that an estimated 26 million secondary consumer batteries were sold in Canada in 2007. Of these:

- NiCd batteries make up the majority of this total, at 16.45 million units;
- NiMH batteries are next at 6.4 million units;
- Lithium ion batteries contribute the smallest unit count at 2.5 million units;
- Lithium polymer batteries make up a small proportion of the total at 250,000 units.
- SSLA battery sales are estimated at 366,000 units.

Sales of NiCd batteries are projected to increase to 22.38 million units by 2010, and then to sharply decline after that date, eventually reducing to 7.3 million units by 2015. Comments from the Portable Rechargeable Battery Association (PRBA) indicate that globally Li-ion dominated NiMH and NiCd in terms of units sold, with NiCd sales declining in the last five years. One would expect Canada's market to be similar to the world market in this regard, however the GIA projections show a somewhat different picture. The GIA projections were used for this study as they are based on manufacturer reports, and are considered to be a reputable source.

Available projections of NiCd battery sales continue to project a gradual decline in the use of this product. However, discussions with industry representatives indicate that many companies are phasing out or have phased out NiCd battery production[18]. Lithium ion batteries are rapidly replacing NiCd batteries for many applications, but production

[18] Personal communication Charlie Monahan, Panasonic, 9th April, 2008

capacity for lithium ion batteries is less than market demand, therefore lithium ion batteries cannot meet all needs at this time. The projections in this report do not reflect this trend. They are based on published projections by GIA, a reputable research house used by the battery industry and reported information is based on manufacturers reports.

Discussions with industry representatives indicate that lithium ion batteries will rapidly replace NiCd batteries for most applications, although NiCd will continue to be used for applications such as power tools, emergency lighting and various non-consumer medical applications, and in fact there are a number of unique applications where NiCd batteries are exempt from European Union and California bans[19]. See Section 6 for a discussion of predicted future trends in battery chemistries.

SSLA batteries are used for specialized applications such as emergency lighting and some medical applications. SSLA unit sales data from Germany did not show any particular trend; therefore growth is projected to match population growth in Canada (about 1.2% per year). Projections are based on a rolling 3-year average, adjusted for population growth. By 2015, sales in Canada are estimated at 384,000 units per year.

Total Canadian Consumer Battery Sales

Total Canadian consumer battery sales are projected to increase from 707 million units in 2007 to 779 million units in 2015, an increase of 10% in 8 years. The somewhat low growth rate is related to a projected decline in the sales of zinc carbon primary units (dropping by 74 million units between 2007 and 2015).

Figures 2.1 and 2.2 show the proportion of primary and secondary battery sales by different battery chemistry, and Figure 2.3 shows the proportion of the consumer battery market share captured by all of the battery chemistries addressed in this study.

Figure 2.1 shows that the vast majority of primary consumer batteries sold into the Canadian marketplace in 2007 were alkaline (62% of total) and zinc carbon (28%). Together these two chemistries accounted for 90% of unit sales in 2007. Zinc air button cell batteries and lithium primary consumer batteries each accounted for 4% of unit sales of primary consumer batteries in 2007. Silver oxide button cell batteries accounted for 2% of primary consumer battery sales, with zinc air batteries accounting for a very small proportion of the total (0.02%).

[19] PBRA comments

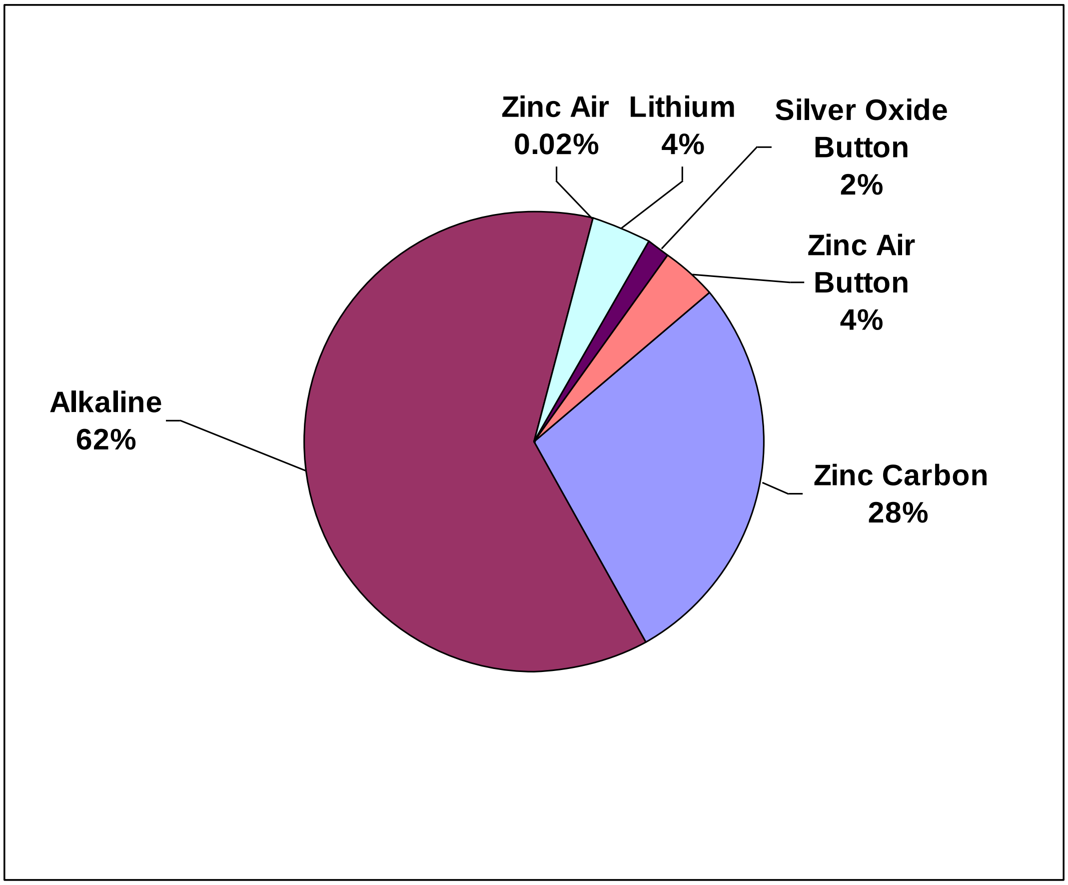

Figure 2.1: Primary Battery Unit Sales in Canada by Chemistry, 2007

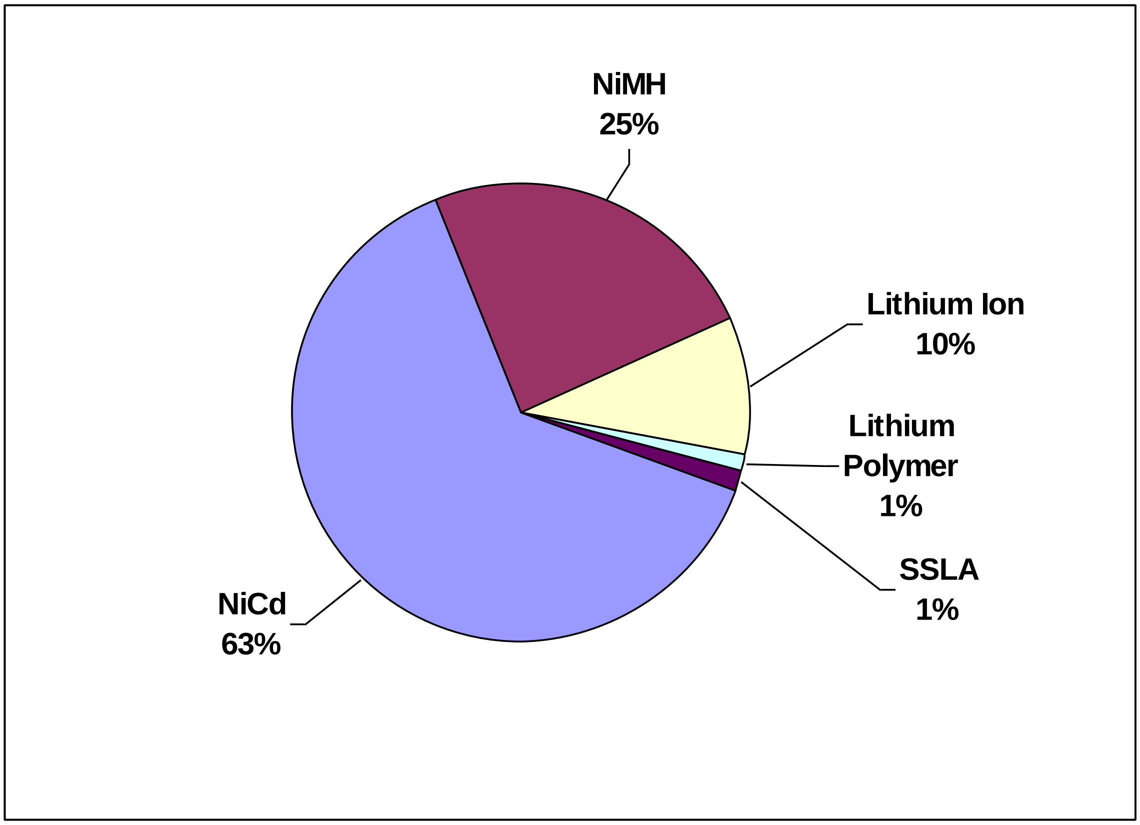

Figure 2.2: Secondary Battery Unit Sales in Canada, 2007

Figure 2.2 shows that NiCd battery sales dominated secondary consumer battery sales in 2007, followed by NiMH. Whereas lithium ion batteries are expected to dominate the secondary consumer market shortly, and unit sales are growing rapidly, the data on unit sales identified through this study showed a smaller market share than many industry observers would expect.

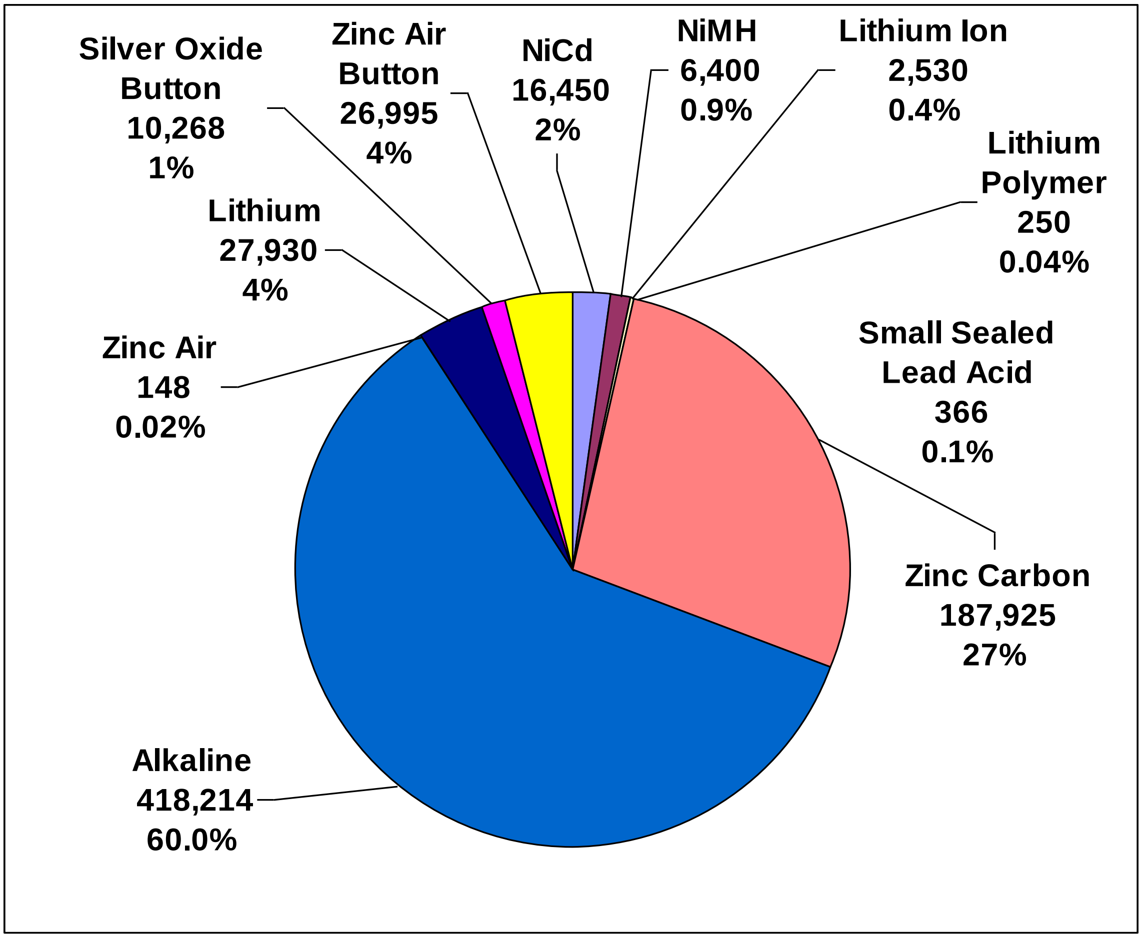

Figure 2.3: Proportion of Primary and Secondary Consumer Battery Sales By Chemistry in Canada, 2007

(Units in Thousands)

Figure 2.3 shows that alkaline primary batteries and zinc carbon battery units dominate consumer battery sales, at 87% of the total units sold in 2007. Secondary consumer batteries make up a small proportion of the total units sold in 2007.

2.5 Weight of Batteries Sold Into the Canadian Market

Battery weight data were needed to estimate the tonnage of batteries sold into the Canadian market each year. While battery manufacturers provided detailed tables containing dimensional data (i.e. weight and height) for each manufactured battery size (e.g. AA, AAA, etc.), very little information was found on the average weights for different battery chemistry groupings for which sales data were available (e.g. nickel cadmium, carbon zinc, etc) .
Several reports and sources were identified which provided information on individual weights for different battery sizes during preparation of the Environment Canada's *Canadian Consumer Battery Baseline Study* (2007):

- "Environmental Impacts of Household Battery Use in Canada" developed by the Institute for Risk Research, University of Waterloo in 1997 provided information on average battery weight by primary and secondary battery type and size[20];
- "Risk Assessment" prepared for the Belgium Federal Department of the Environment in May, 2003 focused on assessing the risks of cadmium used in NiCd batteries over different life cycle stages such as manufacturing, recycling and disposal[21]; and
- Material Safety Data Sheets (MSDS) on Original Equipment Manufacturer (OEM) websites.

All of this information was analysed to identify average unit weights used in Environment Canada's 2007 *Canadian Consumer Battery Baseline Study*. As no new information was identified during the 2008 update research of this follow-up study, original battery unit weight assumptions (presented in Table 2.7) have been retained for use in the battery waste flow tool. This information was used to estimate the weight of batteries sold into the Canadian marketplace.

Table 2.8 presents the weight of consumer batteries sold into the Canadian market from 2007 to 2015 (based on per unit weights from Table 2.7 and unit sales data from Table 2.6).

Primary Batteries

Primary batteries sold into the Canadian market in 2007 weighed an estimated 17,272 tonnes:

- Most were alkaline batteries weighing an estimated 11,710 tonnes, and
- Zinc carbon batteries, weighing an estimated 5,074 tonnes.
- Lithium primary batteries weighed an estimated 447 tonnes.
- Zinc air primaries, zinc air button cell and silver oxide button cell batteries weighed a small amount each, at 5, 24 and 12 tonnes respectively, in 2007.

[20] Institute for Risk Research. January 1997. *Environmental Impacts of Household Battery Use in Canada*. Report 34. Prepared for the Canadian Household Battery Association.
[21] Belgium Federal Department of the Environment. May 2003. Risk Assessment: Cadmium (oxide) as used in Batteries (response to final draft)

By 2015, an estimated 19,122 tonnes of primary batteries will be sold into the Canadian market. An estimated 15,447 tonnes of this total will be alkaline batteries, followed by 3,081 tonnes of zinc carbon batteries. Lithium primary batteries will make up 544 tonnes of the total.

The relative proportion of each primary battery chemistry to the total tonnes sold into the Canadian market in 2007 is presented in Figure 2.4.

Table 2.7: Unit Weights of Consumer Batteries

Battery Type	Weight Range from Various Sources (grams)	Average Weight Used (grams)	Source of Weight Data (See details at bottom of table)
Zinc Carbon (ZnC)	27-28	27	Germany
Alkaline ($ZnMnO_2$)	26-32	28	Average of France and Germany
Zinc air (ZnO_2)	33	33	One data source
Lithium Primary	3-40	16	Mean of data
Silver Oxide ($ZnAgO_2$) Button Cell	0.12-2.5	1.2	Averaging of data
Zinc air (ZNO_2) Button Cell		0.9	Mean of data
Nickel Cadmium (NiCd)	11-450	203	Average of France (all)
Nickel Metal Hydride (NiMH)	9-178	93	Averaging of data
Lithium- Ion (LI-ion)	11-75	40	Average of France (all)
Lithium-ion Polymer (Li-polymer)*	11-75*	40	Average of France (all)
Small Sealed Lead Acid (SSLA)	1015-1075	1,045	Average of Germany

* Note: Lithium-ion polymer battery unit weights were not available, therefore the model has assumed the weight for this battery chemistry is comparable to that of lithium ion batteries

<u>Sources of Unit Weights:</u>

RIS International Ltd. *Canadian Consumer Battery Baseline Study* Final Report to Environment Canada, February, 2007 which references the following original information sources:

Institute for Risk Research. January 1997. *Environmental Impacts of Household Battery Use in Canada.* Report 34. Prepared for Canadian Household Battery Association

Stifung Gemeinsames Rucknahmesystem Batterien (GRS). March 2005.*GRS Annual Report,* Germany

Agence do l'environnement et de la maitriese de l'Engerie. November 2003. *Obserevatoire des piles et accumujlateurs: La situation en 2002.*

Belgium Federal Department of the Environment. May 2003. *Risk Assessment: Cadmium (oxide) as used in Batteries.*

Review of Battery Material Safety Data Sheets (MSDS) for Energizer (E), Duracell (D), Rayovac (R), Sanyo, Panasonic, Toshiba

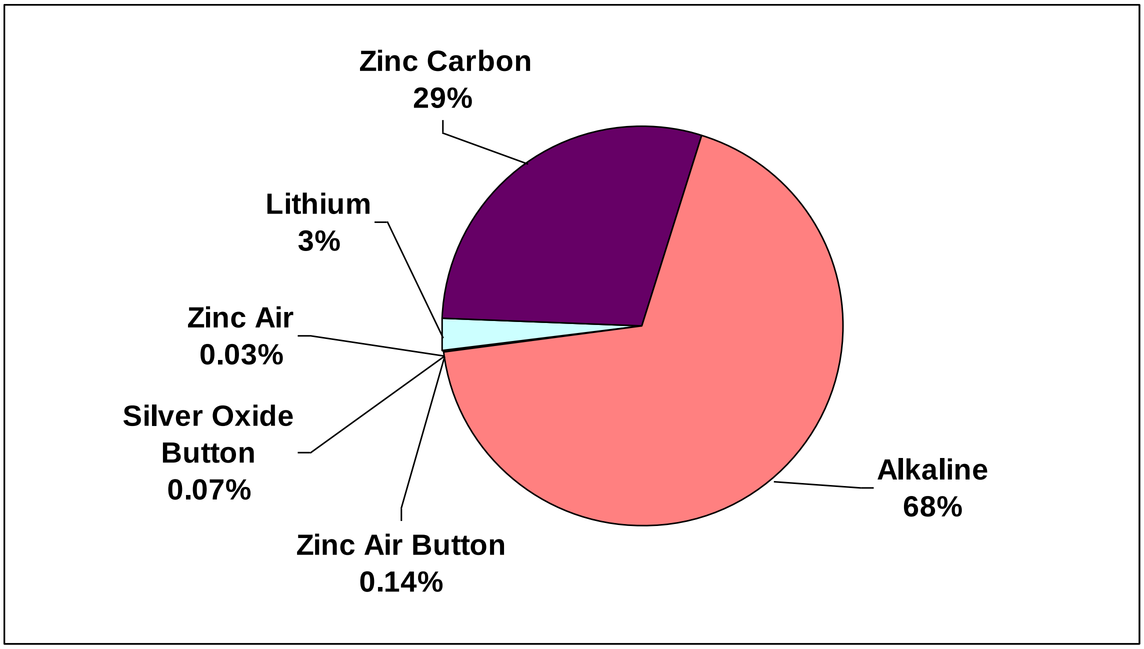

Figure 2.4: Contribution of Primary Consumer Batteries Sold Into the Canadian Market in 2007 to Total Battery Weight

Secondary Consumer Batteries

The weight of secondary batteries sold into the Canadian marketplace was 4,428 tonnes in 2007, most of which was NiCd batteries, according to available industry battery sales projections purchased for this study which indicate that NiCd batteries will be a strong player in the market until 2010, and that sales will decline rapidly after that time. The *EU Battery Directive* which among many other measures phases out the sale of NiCd batteries in the EU has had a significant impact on the global battery market. This may partially be due to an anticipated shift in NiCd battery sales from countries that have mandated phase-out schedules for NiCd batteries to countries that do not have similar restrictions in place (including Canada). Some of the original equipment manufactured in Asia that enters the Canadian market may already be equipped with batteries. Discussions with industry players indicate that NiCd is rapidly being replaced by lithium ion chemistry.

Based on an assumed unit weight of 1.045 kg/unit, about 382 tonnes of SSLA batteries were sold into the Canadian marketplace in 2007. This weight is not expected to change significantly between 2007 and 2015, when a projected 402 tonnes will be sold into the Canadian market.

By 2015, an estimated 2,982 tonnes of secondary consumer batteries are expected to be sold into the Canadian market. Based on the available data, most of this weight is projected to be NiCd (1,483 tonnes) and NiMH (882 tonnes). It has been stressed elsewhere in this report that the projections for lithium ion and lithium polymer batteries are considered to be underestimates.

Figure 2.5 presents the relative contribution of different secondary battery chemistries to the total tonnage sold in Canada in 2007.

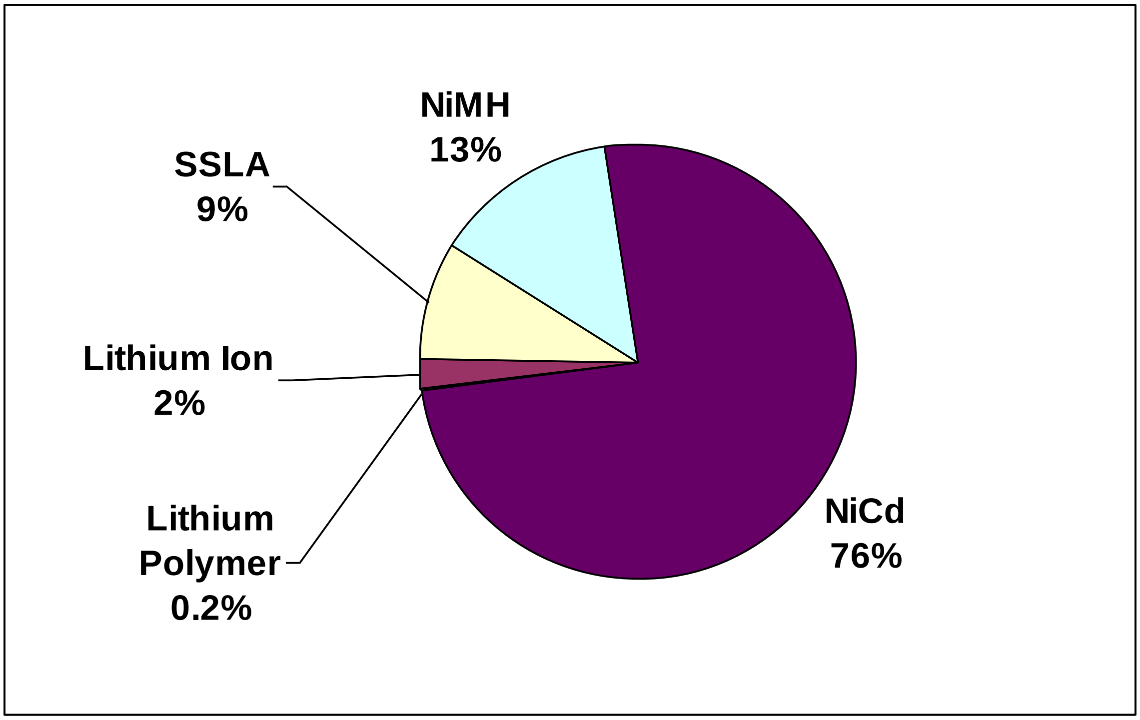

Figure 2.5: Contribution of Secondary Consumer Batteries Sold Into the Canadian Market in 2007 To Total

Table 2.8 shows the total weight of consumer batteries, primary and secondary, projected to be sold into the Canadian market between 2007 and 2015. An estimated 21,700 tonnes were sold into the Canadian market in 2007. Of this total most were primary batteries at 17,272 tonnes. Secondary batteries contributed 4,428 tonnes to the total.

Table 2.8: Weight of Consumer Batteries Sold in Canada, 2007 to 2015 (tonnes per year)

	Unit Weight	2007	2008	2009	2010	2011	2012	2013	2014	2015
Primary Batteries										
Zinc Carbon	0.027	5,074	4,820	4,579	4,350	4,060	3,789	3,537	3,301	3,081
Alkaline	0.028	11,710	12,127	12,559	13,006	13,461	13,932	14,420	14,924	15,447
Zinc Air	0.033	5	5	5	5	5	6	6	6	6
Lithium	0.016	447	458	469	481	493	506	518	531	544
Button Cell Primary										
Silver Oxide	0.0012	12	13	13	13	14	14	14	15	15
Zinc Air	0.0009	24	24	25	26	26	27	28	28	29
Total Primary Batteries		**17,272**	**17,447**	**17,650**	**17,881**	**18,059**	**18,273**	**18,522**	**18,805**	**19,122**
Secondary Batteries										
NiCd	0.203	3,339	3,703	4,109	4,543	3,461	2,637	2,143	1,813	1,483
NiMH	0.093	595	701	826	976	954	934	911	886	882
Lithium Ion	0.04	101	122	146	172	177	183	189	194	196
Lithium Polymer	0.04	10	11	13	14	15	16	17	18	18
SSLA	1.045	382	385	400	392	395	398	398	400	402
Total Secondary Consumer Batteries including SSLA		**4,428**	**4,922**	**5,493**	**6,097**	**5,004**	**4,169**	**3,658**	**3,312**	**2,982**
Total Consumer Batteries		**21,700**	**22,369**	**23,144**	**23,978**	**23,063**	**22,442**	**22,180**	**22,117**	**22,103**
LAB - passenger cars	17.7	88,469	89,151	89,657	90,379	91,285	92,377	93,671	95,132	96,755
LAB - motor cycles	4.3	1,502	1,591	1,671	1,759	1,855	1,959	2,072	2,195	2,328
LAB - commercial vehicles	24.1	119,195	119,937	120,487	121,397	122,796	124,569	126,699	129,078	131,713
Total – Automotive LABs		209,167	210,678	211,814	213,534	215,935	218,904	222,442	226,406	230,796

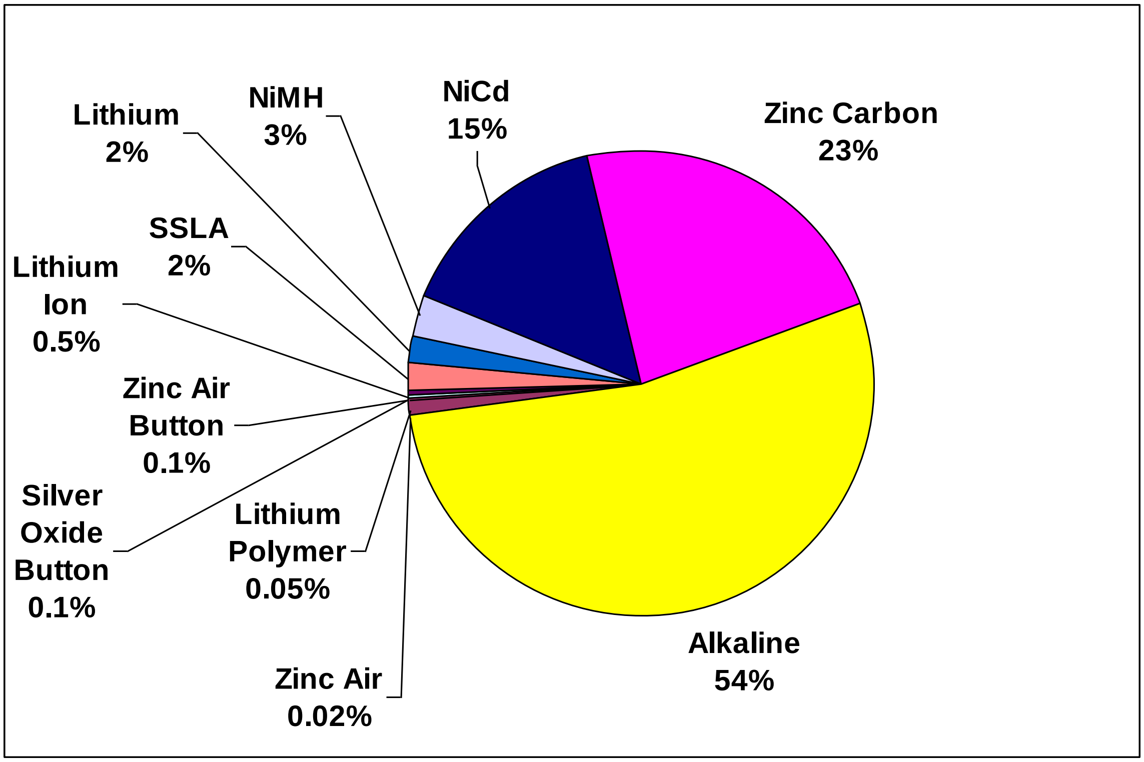

Figure 2.6: Contribution of Primary and Secondary Consumer Battery Chemistries to Total Weight of Consumer Batteries Sold Into the Canadian Market in 2007

The figure shows that alkaline and zinc carbon contribute most of the weight (77% of the total), followed by NiCd at an additional 15%.

2.6 Composition of Batteries Sold in Canada

The composition of the various consumer battery chemistries sold into the Canadian marketplace is presented in Table 2.9. This information is based on data contained in a report entitled, *Battery Waste Management Life Cycle Assessment,* which was completed for the UK Department of Environment, Food and Rural Affairs (Defra) by Environmental Resources Management (ERM) in October, 2006[22]. Since batteries consumed in Europe and North America are generally manufactured by the same companies, the use of European data in this study was considered appropriate.

Of note is the high cobalt content of lithium ion batteries (estimated at 18% in the Defra report) and the lower cobalt content of nickel metal hydride batteries (estimated at 4% in the same report, although interviews conducted for this research project indicated that the number can be as high as 10%[23]. The high global market demand for cobalt, and the very high value of cobalt in 2007 and early 2008 was one of the drivers behind battery

[22] The final report is dated 18th October, 2006.
[23] Personal communication Bob Sutherland, Xstrata Nickel, March, 2008

recycling industry efforts to increase the recycling of lithium ion and NiMH batteries in 2008 when the original project research was carried out.

Table 2.9: Battery Material and Substance Composition (expressed as a percentage by weight)

From Battery Waste Management Life Cycle Assessment completed for the UK Department of Environment, Food and Rural Affairs (Defra) by ERM (Environmental Resources Management) in October, 2006

Battery Type	iron & steel	Pb	Ni	Cd	Zn	Mn	Ag	Hg	Li	Al	Co	other metals	alkali	H_2SO_5	Other non-metals	H_2O	plastic, paper carbon
Primary																	
Zinc Carbon	16.8	0.1			19.4	15						0.8	6		15.2	12.3	13.9
alkaline	24.8		0.5		14.9	22.3						1.3	5.4		14	10.1	6.9
Zinc air																	
lithium primary	50		1			19			2						19		9
Button Cell																	
zinc air	42				35			1					4		3	10	5
silver oxide	42		2		9	2	31	0.4				4	1		4	2	2.5
Secondary																	
NiCd	35		22	15									2		11	5	10
NiMH	20		35		1	1					4	10	4		8	8	9
Lithium Ion	22								3	5	18	11			28		13
Lithium Polymer[24]																	
SSLA and Vehicular		65										4		16	5		10

Note: The materials in the table which are considered toxic under CEPA 1999 are: Oxidic, sulphidic and soluble inorganic nickel compounds; Inorganic cadmium compounds; mercury and lead.

[24] No data were provided on the composition of lithium polymer batteries in the DEFRA study

Table 2.10 presents the materials and substances contained in consumer batteries sold into the Canadian market in 2007 by battery type. In summary, the total materials contained in consumer batteries (excluding automotive lead acid batteries) sold into the Canadian market in 2007 were as follows:

Toxic Substances Under The Canadian Environmental Protection Act, 1999

- Lead: 248 tonnes in SSLA and 5 tonnes in Zinc Carbon
- Nickel: 1,006 tonnes
- Cadmium: 501 tonnes
- Mercury: 0.29 tonnes (240 kg from zinc air button cell batteries and 50 kg from zinc air primary batteries)

Other Substances / Materials

- Iron and steel: 5,306 tonnes
- Zinc: 2,745 tonnes
- Manganese: 3,464 tonnes
- Silver: 4 tonnes
- Lithium: 12 tonnes
- Aluminum: 5 tonnes
- Cobalt: 42 tonnes
- Other metals: 279 tonnes
- Alkali: 1,029 tonnes
- H_2SO_5: 61 tonnes
- Other non-metals: 2,960 tonnes
- Paper, plastic and carbon: 1,994 tonnes

Table 2.10: Materials Contained in Batteries Sold Into the Canadian Marketplace, 2007

(expressed in metric tonnes)

Battery Type	iron & steel	Pb	Ni	Cd	Zn	Mn	Ag	Hg	Li	Al	Co	other metals	alkali	H_2SO_5	Other non-metals	H_2O	plastic, paper carbon
Primary																	
Zinc Carbon	852.4	5.1	0.0	0.0	984.3	761.1	0.0	0.0	0.0	0.0	0.0	40.6	304.4	0.0	771.2	624.1	705.3
alkaline	2,904	0.0	58.5	0.0	1,745	2,611	0.0	0.0	0.0	0.0	0.0	152.2	632.3	0.0	1,639	1,183	808.0
zinc air	0.8	0.0	0.0	0.0	0.9	0.7	0.0	0.05	0.0	0.0	0.0	0.0	0.3	0.0	0.7	0.6	0.7
lithium primary[25]	223.4	0.0	4.5	0.0	0.0	84.9	0.0	0.0	8.9	0.0	0.0	0.0	0.0	0.0	84.9	0.0	40.2
Button Cell																	
zinc air	10.0	0.0	0.0	0.0	8.3	0.0	0.0	0.24	0.0	0.0	0.0	0.0	0.9	0.0	0.7	2.4	1.2
silver oxide	5.2	0.0	0.2	0.0	1.1	0.2	3.8	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.5	0.2	0.3
Secondary																	
NiCd	1,169	0.0	734.7	500.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.8	0.0	367.3	167.0	333.9
NiMH	119.0	0.0	208.3	0.0	6.0	6.0	0.0	0.0	0.0	0.0	23.8	59.5	23.8	0.0	47.6	47.6	53.6
Lithium Ion	22.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	5.1	18.2	11.1	0.0	0.0	28.3	0.0	13.2
Lead Acid SSLA	0.0	248.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.0	61.2	19.1	0.0	38.2
Lead Acid Automotive	0.0	135,958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,366.7	0.0	33,467	10,458	0.0	20,917
TOTAL	**5,306**	**136,212**	**1,006**	**500.9**	**2,745**	**3,464**	**4**	**0.3**	**12**	**5**	**42**	**8,646**	**1,029**	**33,528**	**13,418**	**2,025**	**22,911**

Note: The following four materials shown in the table are Toxic Substances under CEPA 1999[26]: Oxidic, sulphidic and soluble inorganic nickel compounds, inorganic cadmium compounds; mercury and lead.

[25] No data in the Defra report on composition of lithium polymer batteries – included in lithium ion category for this report

[26] www.ec.gc.ca/CEPARegistry/subs_list/Toxicupdate.cfm

3. Current Battery Collection Infrastructure in Canada

Available information on collection of consumer batteries in Canada is briefly described in this section.

3.1 General

For the most part, consumer battery collection programs are operated on a voluntary basis through municipally-operated household hazardous waste (HHW) or household special waste (HSW) programs, industry-operated point-of-purchase collection programs or non-profit collection programs. Several provinces have implemented extended producer responsibility (EPR) programs that either directly target lead-acid batteries or consumer batteries or indirectly target batteries found in waste electrical and electronic equipment. There is only one province, Prince Edward Island, which has implemented a voluntary province-wide program to directly collect consumer batteries.

3.2 Household Special Waste (HSW) Collection Programs

Many municipalities across Canada operate voluntary HSW (household special waste) drop off programs where residents are permitted to drop off various materials such as batteries, paint, anti-freeze, etc. In addition, municipalities will set up collection boxes for primary and secondary batteries at municipal building locations, such as city hall, libraries and recreational centres. In some cases, the HSW collection programs are supported with collection and disposal bans targeting HSW materials. These programs are supported financially to varying degrees by provincial programs and industry funding.

Some provinces refer to these programs as HHW (household hazardous waste) programs. For this discussion the term “special” is considered more appropriate when referring to batteries, given that many batteries are not considered hazardous under provincial legislation.

Three significant provincial programs which include consumer batteries are described below.

Prince Edward Island’s Re-Store Your Batteries Program
Funded by the province of PEI, the Island Waste Management Corporation, in partnership with two dozen participating PEI grocery retailers, introduced the voluntary “Re-Store Your Batteries” program in July 2005 enabling consumers to recycle their primary batteries at participating grocery stores. This service allows consumers and visitors to return alkaline/lithium batteries (D, C, AA, AAA, 9-volt, 12-volt, etc.) as well as button type batteries (watch, hearing aid batteries, etc.) at no charge. The batteries are shipped to the mainland to be broken down and recycled.

Ontario's Municipal Hazardous or Special Waste (MHSW) Program

Until recently, Ontario municipalities have been responsible for organizing and funding HHW collection programs, the most significant collection infrastructure is the Ontario municipal HHW collection system. Ontario is the only province that requests municipalities to annually report waste diversion data through the Waste Diversion Ontario (WDO) Municipal Datacall. Based on data reported in 2005, 89 municipalities operated 98 depots and 169 collection events serving 11.4 million Ontario residents (4,357,671 households).[27] Some of these communities collect dry cell batteries as part of the HHW program.

Quantities of consumer and automotive batteries collected by Ontario's Municipal Hazardous or Special Waste (MHSW) programs and reported to WDO are presented in Table 3.1

Table 3.1: Quantities of Consumer Batteries Collected By Ontario MHSW Programs

Year	Car Batteries (kgs)	Dry Cell Batteries (kgs)
2006	1,150,151	291,881
2005	1,203,739	249,776
2004	1,036,789	259,730
2003	1,085,139	296,776
2002	973,459	128,295

On December 11, 2006, the Minister of the Environment filed Ontario Regulation 542/06 under the *Waste Diversion Act* (WDA) designating Municipal Hazardous or Special Waste (MHSW). Batteries are defined as municipal special waste under this regulation. On December 12, 2006, the WDO Board of Directors received a Program Request Letter from the Minister of the Environment requesting a diversion program for MHSW, including batteries, and directing that Stewardship Ontario act as the Industry Funding Organization (IFO) for MHSW.

The Minister's Program Request Letter also permits IC&I (industrial, commercial and institutional) establishments to return small quantities of MHSW (not exceeding 100 kg per month) to a MHSW depot. The generator is not required to submit a generator registration report with respect to the waste under subsection 18(1) of Regulation 347 under the EPA (Environmental Protection Act).

On February 19, 2008, the Ontario Minister of the Environment approved the Municipal Hazardous or Special Waste Program Plan.[28]

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[27] Stewardship Ontario. Municipal Hazardous or Special Waste (MHSW) Program Plan. 26 November 2007.
[28] Ibid

Phase 1 of the program was launched province-wide on July 1, 2008 and targets a number of materials including primary consumer batteries. Specifically, the Ontario MHSW Program Plan addresses the following batteries:

Easily removable primary batteries that are designed and intended to be removable and replaceable by the consumer with the following chemistry:

Alkaline-Manganese (including batteries containing mercury)
Zinc-Carbon
Lithium batteries
Button Cells (a variety of chemistries such as those used in hearing aids, watches, etc)

The Plan has two targets for batteries – a collection target (batteries source separated from the waste stream) and a recycling target (batteries recycled after the battery has been collected – also referred to as the recycling efficiency rate). The Plan identifies phased collection targets for primary batteries ranging from 6% for Year 1 to 25% for Year 5, with annual program costs ranging from $630 K (Year 1) to $3 million (Year 5).[29] Throughout this period, annual diversion targets also require that one-half of the batteries collected be diverted from final disposal. Waste to energy is not an acceptable diversion practice in the province of Ontario. The MHSW plan is proposing a collection target of 25% for primary batteries, and a recycling target of 13% of primary batteries by Year 5. This value is the same as the EU Battery Directive target for 2012.

Under the MHSW program, industry will pay for about 80% of the program cost while municipalities will cover the balance. The MHSW plan estimates that the Year 1 fee required to collect single use/ primary batteries will be $0.13 per kilogram or $0.003 per unit.[30]

The Ontario MHSW Plan estimated that about 175 million primary batteries are sold into the Ontario market at an average weight of 28.8 grams, the total weight sold into the Ontario market is 5,040 tonnes. The Plan identified that 250 tonnes of primary batteries were collected by municipal programs in 2005. Based on the Association of Municipal Recycling Coordinators (AMRC) waste composition information, the Plan assumed that 46 tonnes of rechargeable batteries were removed, and therefore 204 tonnes of primary batteries were actually collected in 2005.

Based on discussions with one battery recycler, the Plan states that less than 7% (about 14 tonnes) of the collected primary batteries were recycled, with the remainder undergoing final disposal. This recycler provides a program to collect primary batteries from businesses and institutions. The processor charges a fee per pail (3,500 pails were distributed in 2006) and collected about 21 tonnes of primary batteries in 2006.[31]

The Ontario MHSW Plan estimated a collection rate of 5% based on collection of 225 tonnes and a quantity of 4,940 tonnes available for collection. Note that the Ontario MHSW Plan used an average unit weight of 28.8 grams per unit, whereas this study has used different unit weights for different primary battery chemistries; the weighted

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[29] The MHSW plan estimates that the Year 1 fee required to collect single use/ primary batteries will be $0.125 per kilogram or $0.003 per Unit – assuming that one battery had an average weight of 28.8 g. The per unit fee in Belgium is 0.1239 euros (about 20 cents Canadian per unit) (relates to 5 B francs). There is a plan to reduce the fee to 0.07-0.08 euros per unit.
[30] An average battery weight of 28.8 g was used for the calculation.
[31] Communication between Rick Unyi, Raw Materials Company and Stewardship Ontario, 21st March, 2007.

average is 25.7 grams per unit. Many of the unit weights used (presented in Section 2) are less than 28.8 grams.

On July 22, 2008 the Ontario Ministry of Environment requested Waste Diversion Ontario to develop a plan to address all MHSW in Ontario (including materials formerly categorized as Phases 1, 2, and 3 materials) and to develop a plan for 100% funding of the complete MHSW program by stewards with the *Addendum to the Minister's Request Letter to Waste Diversion Ontario for an amended Waste Diversion Program for Municipal Hazardous or Special Waste*. specifically addresses batteries in the following sections:

> *The scope of the program shall be expanded to include certain wastes from all industrial, commercial and institutional (IC&I) generators. Such wastes are generated from products typically used in either residential or IC&I applications, are indistinguishable from products used in residences and result in MHSW that is commonly not diverted from final disposal. The amended program shall address all batteries (excluding lead acid batteries from vehicles) and other wastes that may be deemed appropriate.*

Section 1(a) of the Addendum specifically states*:*

> *Waste Diversion Ontario (WDO) shall develop an amended Waste Diversion Program for MHSW (the program) incorporating Phase 2 and 3 wastes as specified below, in accordance with all legislative requirements of the Waste Diversion Act (2002) (the Act):*
>
> *The amended Program shall include the addition of the following wastes ("Phase 2"):*
> <u>*From residential and all IC&I generators:*</u>
> *i. all batteries, excluding lead acid batteries from vehicles.*

Batteries have clearly been identified as target materials for the Ontario MHSW program.

Manitoba's Hazardous Household Material Stewardship Program

The Province of Manitoba released a draft *Hazardous or Prescribed Household Material Stewardship Regulation* for public comment in June 2007 that generally requires manufacturers and sellers of designated products to establish collection and disposal systems for these products at the post-consumer stage. Designated materials targeted in the regulation include:

- Automotive antifreeze and lead acid batteries,
- Paint (Oil, Latex, Aerosols),
- Fluorescent lights & compact fluorescent lights,
- Pesticides, and
- Waste household hazardous materials.

It is anticipated that consumer and household batteries will fall under the category of waste household hazardous materials.

The regulation specifies that, a program operator must implement a province-wide management plan which is environmentally and economically sustainable. A phased in approach may be acceptable. Subject to the Minister's approval, the applicant is responsible for determining how materials are managed and how the affected industry and potential program partners will bear the costs, or fund the program. The cost of the stewardship program is the responsibility of the stewards and users of the designated material.

The regulation will enable stewards to partner with existing collection systems established by other stewards or to partner with another program plan for other designated materials. It is anticipated that some products, (e.g. rechargeable batteries) could also be returned primarily through return-to-retail systems, such as the Rechargeable Battery Recycling Corporation (RBRC) collection program.

Other Provinces

Quebec is currently developing umbrella extended producer responsibility (EPR) legislation for a range of products including primary and secondary batteries. The draft regulations may be posted in 2008, with implementation expected in 2009.

Manitoba's Minister of Environment announced that the province is developing long-term plans for introduction of a product stewardship regulation to establish an industry-operated, sustainable e-waste management program later in 2008 for residential and commercial electronic waste equipment, which includes rechargeable batteries. Primary and secondary batteries are addressed in the Provincial MHSW regulations currently under development.

In BC, primary and secondary batteries are among a list of candidate materials which can be regulated under the Recycling Regulation[32], and the province has signaled that they may move to EPR for consumer batteries in the future.

Nova Scotia has also signaled that they may move to mandate EPR for consumer batteries in the near future.

3.3 Waste Electronic and Electrical Equipment (WEEE) Collection Programs

WEEE programs were historically run by municipalities in Canada, starting in about the year 2000, partly in response to demands by their residents.[33] Many of the collection programs are tagged onto existing HHW programs with depots added to permanent HHW facilities or waste electronics included at local HHW events.

This situation changed rapidly since 2004, when Alberta was the first province in North America to launch an EPR program targeting end-of-life electronics. Canadian provinces have introduced mandatory EPR or producer responsibility regulations requiring collection and proper management of end of life electronics, including British

[32] www.env.gov.bc.ca/epd/epdpa/ips/resources/new_products.html

[33] Due to the nature of the program, the e-waste programs target specific battery waste comprising rechargeable batteries found in electronic equipment, such as laptops, cell phones, and hand-held computer game devices.

Columbia, Alberta, Saskatchewan, Ontario and Nova Scotia, with legislation pending in Manitoba and Quebec.

Provincial WEEE programs are of interest to the battery recycling issue as a number of targeted electronics (laptops and cell-phones in particular) contain rechargeable batteries. These programs should ensure that the rechargeable consumer batteries from the collected electronics are properly managed, as all programs require vendor qualification for processors.

In all operating e-waste collection programs in Canada to date (Alberta, British Columbia, Saskatchewan, Nova Scotia), provincial legislation requires brand owners and first importers of designated electronics products (usually televisions and computer related) to be responsible for end of life management. To date, each of these four programs imposes a fee on designated electronic products, which is paid by consumers at the point of purchase. The fees are used to pay the cost of collection and/or transportation and recycling of end-of-life electronics. Electronics are typically collected at existing and new drop-off sites, some of which are municipal; others are container deposit-return locations. The legislation covers a wide range of electronic products which may or may not be phased in over a stipulated period of time. Table 3.2 summarizes details of the existing end of life electronics programs by province.

Table 3.2: Waste Electrical and Electronics Equipment (WEEE) Legislation In Canadian Provinces and Territories

Jurisdiction	Key Dates	Consumer Fees	Products Targeted	Description
British Columbia	Enacted: Feb 2006 Phase 1 Effective: 2008 Extensive Phase 2 list of products announced December, 2008	Environmental Handling Fee paid by consumer (both residential and IC&I) ranging from $5 for notebook to $45 for TVs 46" and up	British Columbia, Saskatchewan and Nova Scotia Phase 1 list of designated products is identical to Alberta's list: computers, monitors, printers and TVs (see detailed list in Saskatchewan description).	Industry launched ESABC (Electronic Stewardship Association of British Columbia) program in August 2007. Consumers and IC&I generators can drop off end of life electronics at 73 collection sites throughout the province. The Western Canada Computer Industry Association (WCCIA) also collects e-waste.
Alberta	Enacted: 2004 Effective: Feb 2005	Advanced disposal surcharge paid at point of sale : Monitors $12, Computers $10, Laptops $5, Printers $8, TVs (size dependent) $15-$45	Televisions and computer equipment (Monitors, CPUs/servers (including keyboard, mouse, cables, speakers), laptops, notebooks & printers).	First province to implement a WEEE program in North America (followed by California 3 months later in January, 2005). Consumers pay an environmental fee which covers all costs for proper collection, transportation and management of the designated e-waste. Consumers and IC&I generators can take WEEE products to 249 drop-off locations
Saskatchewan	Enacted: Oct. 2005 Effective: Feb 2007	Environmental Handling Fee paid by consumer (both residential and IC&I) desktop $10, notebook $5, monitors $12, television $15 to $25, printers $8	Desktop computers (central processing units, mouse, keyboards, cables), notebook computers (notebook, laptop, tablet PCs), monitors (includes CRTs and flat panel display), televisions (includes CRT, flat panel or rear projection), printers (includes laser, LED, ink jet, dot matrix, thermal, dye sublimation, copy, fax, print, etc).	Industry launched SWEEP (Saskatchewan Waste Electronic Equipment Program) to manage end of life electronics. Consumers pay an environmental fee which covers all costs for proper collection, transportation and management of the E-waste. Consumers can take WEEE products to 71 drop off sites.

Jurisdiction	Key Dates	Consumer Fees	Products Targeted	Description
Ontario	Enacted: Dec 2004 Effective: Plan approved July 2008 Implementation expected April 2009 Phase 2 to be implemented within one year of Phase 1	Fees to be determined	Phase in approach 1st phase: Information Technology Equipment ▪ CD-ROM drive ▪ Computer disk drive, keyboard, mouse, terminals ▪ Microcomputer & minicomputer ▪ Monitors (CRT, LCD, plasma) ▪ Personal computers (desktop, laptop, notebook, notepad) ▪ Printer Telecommunications Equipment ▪ Fax machine Audio-Visual Equipment ▪ Televisions (CRT, LCD, plasma, rear projection)	Brand owners, manufacturers and first-importers of Phase 1 electronic and electrical equipment will be responsible for implementing the WEEE Program Plan. The industry will assume the cost and responsibility for transportation and handling of the WEEE, at an estimated Year 1 cost of $62 million.
Nova Scotia	Enacted: Jan 2006 Effective: Feb 2008 (Phase 1) and Feb 2009 (Phase 2)	Environmental Handling Fee paid by consumer (both residential and IC&I) ranging from $5 for notebook to $45 for TVs 46" and up	Phase 1: Computers, Laptops, Monitors, Printers and TVs.	Consumers pay an environmental fee. End of life WEEE can be dropped off at 33 drop off centres through out the province. Industry established ACES (Atlantic Canada Electronics Product Stewardship Program) to manage end of life electronics

3.4 Rechargeable Battery Recycling Corporation of Canada

The Rechargeable Battery Recycling Corporation (RBRC) was established by a group of leading portable rechargeable battery manufacturers[34] in 1994 in the United States to implement a voluntary take-back program for NiCd batteries. The voluntary program was established in response to pressure from state legislation on nickel-cadmium (NiCd) battery manufacturers to properly label and manage their NiCd batteries at the post-consumer stage. The voluntary collection program was launched throughout 50 US states in 1995. RBRC related activities in Canada are all undertaken through the subsidiary company Rechargeable Battery Recycling Corporation of Canada (RBRCC). Collection of NiCd batteries by RBRCC started in Canada in 1997. Initially the RBRCC program focused on voluntary collection of NiCd batteries but in 2001/2002 RBRCC expanded the program to accept all secondary batteries including NiMH, lithium-ion, lithium polymer and SSLA. The RBRCC voluntary program is the only national secondary consumer battery recovery program available in Canada.

Today RBRCC is supported voluntarily by 350 battery manufacturers/brand owners representing over 80% of the rechargeable power industry in North America[35]. The program is not mandated under either Canadian or US legislation. RBRC reports that 90% of manufacturers/brand owners of batteries and battery operated products comply with the program, by paying fees to RBRC.

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[34] The founding companies were also members of the Portable Rechargeable Battery Association (PRBA) but the two organizations are legally separate.

[35] http://strategis.ic.gc.ca/app/ccc/srch/nvgt.do?lang=eng&app=1&prtl=1&sbPrtl=&estblmntNo=234567014280&profile=cmpltPrfl

In 2004, the Call2Recycle program was launched by RBRC to recover cell phones and their batteries. The program (owned by RBRC) features over 7,000 collection locations across Canada where consumers can drop off used rechargeable batteries and old cell phones. Over 400 communities and almost 140 public agencies participate in the program. In February 2008, RBRC announced a partnership with Sony Electronics which has become the first manufacturer to insert branded Call2Recycle collection bags into product packaging. An individual Call2Recycle collection bag is now included with each custom, built-to-order Sony VAIO notebook.

All participants (retailers, communities, businesses, public agencies) receive the RBRC collection boxes free-of-charge. The boxes are shipped to the central processing facility when full. Shipping charges are paid by the RBRC.

RBRCC provided Environment Canada with information on the amount of each type of battery chemistry recycled in Canada for 2005-2007 in March 2008. Data for 2003 and 2004 had been provided previously by RBRC to Environment Canada by battery chemistry. Estimates for 2002 were allocated to each battery chemistry by pro-rating the percentage contribution from 2003 and 2004 data. Table 3.3 presents data for 2002 to 2007 by battery chemistry. The table shows that NiCd batteries currently account for the majority of the batteries collected in the RBRC program. Lithium ion and lithium polymer batteries have accounted for an increasing amount of the total, increasing from around 2% in 2002-2004 to 10% in 2007. Data for 2006 have a number of anomalies (low SSLA recovery and low NiMH recovery compared to other years) but the trend is generally towards increasing recovery of all rechargeable battery chemistries through the RBRC program. Other rechargeable battery programs are also available to Canadian consumers but data could not be found on the amounts of material collected through these programs. RBRCC was the only program which provided data to the study team during the study research.

Table 3.3: Weight and Percentage of Batteries Recycled by RBRCC in Canada, 2002 to 2007

	Tonnage Collected					Percentage of Total Collected			
Year	NiCd	NiMH	Li Ion & Polymer	SSLA	Total	NiCd	NiMH	Li Ion & Polymer	SSLA
2002	69	4	2	4	79	87.3%	5.1%	2.5%	5.1%
2003	101	6	2	6	115	87.8%	5.2%	1.7%	5.2%
2004	132	7	3	8	150	88.0%	4.7%	2.0%	5.3%
2005	141	12	7	17	177	79.7%	6.8%	4.0%	9.6%
2006	190	5	14	5	214	88.8%	2.3%	6.5%	2.3%
2007	155	20	23	33	231	67.1%	8.7%	10.0%	14.3%

This information formed the basis of recycling calculations for secondary batteries presented later in this study.

3.5 Cell Phone Collection Programs

Many cell phone companies and wireless service providers offer pre-paid return systems for used cell phones or collection programs in specific provinces such as Ontario, British Columbia, Alberta and Quebec. These include:

- Bell Mobility's Take Back Program (formally called Reduce, Reuse, Redial);
- Roger's Wireless and Fido Phones for Food Program; and
- Telus' 3R Take Back Program (linked to Tree Canada), among others.

Some non-profit and profit driven programs operating in Canada include:

- Charitable Recycling Program of Canada (formally the Wireless Source Canada);
- Pitch In Canada's National Cell Phone Collection Program; and
- ReCellular's cell phone recycling program.

Limited data is publicly available on the number and final destination of cellphones and batteries recovered through these programs.

The Phones for Food program was launched in 2003 as an initiative of the Canadian Association of Food Banks (CAFB). One donated wireless device, depending on its age and condition, can generate up to $5 for the Phones for Food Program.

As of October, 2007, 145, 980 used wireless devices had been donated to Fido (wholly owned by Rogers Wireless Inc), which has 7 million customers. The Phones for Food program had raised $400,000 since 2004.

Bell Mobility donates $1 to World Wildlife Fund-Canada for each unit collected through their program. The Bell Mobile Take-Back Program reuses or recycles the recovered phones. The program covers all mobile phone accessories, batteries and personal digital assistants (PDAs). In early April, 2007, the Bell website (www.bell.ca/support/PrsCSrvWls) stated that since 2003, more than 232,000 phones and 57 tonnes of batteries and accessories have been diverted from landfill.

On January 20, 2009 Canada's wireless telecommunications industry, launched Recycle My Cell, a new Web-based initiative designed to help Canadians to recycle their old cell phones. The national program lets users find out where and how to properly dispose of their cell phones and other wireless devices - regardless of carrier, brand or condition - at www.RecycleMyCell.ca. The web site identifies the ten sites (of 3,500 drop-off locations in Canada) which are closest to your location. A postage paid label is also generated from the website to allow consumers to return their cell-phones by mail. The website also contains instructions for clearing the device of all personal data before it is dropped off at a recycling site.

The free program, which incorporates numerous existing cell phone recycling initiatives across the country, is organized by the Canadian Wireless Telecommunications Association (CWTA) in conjunction with cell phone service providers, handset manufacturers and recycling companies. Sponsors and partners include Bell, GREENTEC, KYOCERA, Motorola, MTS, Nokia, ReCellular, Inc., Research In Motion, Rogers Communications Inc., Samsung, SaskTel, TbayTel, TELUS and Virgin Mobile Canada[36].

Many different items are accepted for recycling, including cell phones, smart phones, pagers, aircards, batteries, chargers and accessories. After the device is received, it is sent to a recycling plant where it can be taken apart for scrap or be refurbished. Proceeds from the sale of refurbished phones and scrap materials are donated to numerous national and local charities. All of the recycling companies involved with the Recycle My Cell program are ISO 14001:2004 certified.

3.6 Landfilling

While some types of primary and secondary consumer batteries may contain toxic substances under CEPA 1999 (see Table 2.10), spent consumer batteries generally do not pose risks to human health and the environment if they undergo environmentally sound management (ESM). In some cases, governments may discourage the landfilling of batteries to establish greater assurances of ESM for these products at end-of-life (e.g. incineration of batteries would raise concerns) and/or support enhanced resource recovery policies through the recycling of metals found in spent batteries.

The PRBA have cited a number of studies which have concluded that landfilling of batteries presents a minimal environmental risk. These include:

- A Solid Waste Management Association of North America (SWANA) study which showed that concentrations of heavy metals in leachate from landfills into which batteries are placed as part of household waste is generally low. The SWANA study reviewed data from 200 US landfills and found that the mean concentration of Resource Conservation and Recovery Act heavy metals averaged less than 1mg/l in all cases. These levels are less than one tenth of the TCLP (toxicity

[36] www.newswire.ca/en/releases/archive/January 2009

characteristic leachate procedure) regulatory levels that USEPA uses to determine if a waste is hazardous.

- A second study, conducted by Vest and Jantsch in 1999 reached the same conclusion about landfills operated to current standards in the developed world. It also pointed out that there is no significant risk from incineration of batteries in the developed world, because of the efficiency of the removal of Hg and Cd from flu gas. Fly ash must be either pre-treated or disposed of in hazardous waste landfills because of the presence of Cd and Zn.

- A third study conducted by Fukuoka University in Japan assessed the behaviour of mercury contained in landfilled batteries. The study looked at mercury migration rates across 0.5, 1, 2 and 7 year periods, and concluded that any mercury contained in household batteries would not escape from landfills.[37]

Landfilling of primary or secondary batteries is not encouraged because valuable metals contained in batteries are wasted rather than recycled.

[37] PRBA comments

4. Battery End of Life Estimates

An Excel Workbook based model (the Canadian Consumer Battery Flow Model (C2BFM)) was developed for Environment Canada as part of its 2007 *Canadian Consumer Battery Baseline Study* to estimate the flow of consumer batteries through the Canadian waste management system. This model was re-populated with more updated sales figures and assumptions to generate the output found in this report. The Battery Flow Model (2009) model includes the following key inputs:

- Annual unit sales data by battery type (described in Section 2);
- Weight data by battery type (described in Section 2);
- Lifespan of different battery types (discussed in this section); and
- The amount of time each battery type is likely to be held in storage (hoarded) before disposal (discussed in this section).

The model is constructed to reflect the typical flow of batteries through the Canadian waste management system as shown in Figure 4.1.

The model was run using two different "hoarding" assumptions to provide a range of end of life estimates at the recommendation of RBRC.

Data on consumer battery collection and recycling in Canada are very limited, therefore the approach for this study is to estimate the amount of consumer batteries at end of life each year, and compare these to reported tonnes collected and then estimate recycling rates.

Battery composition data are applied to the number of batteries recycled and at end of life to estimate amounts of material recovered and disposed. These values are used to estimate the greenhouse gas (GHG) benefits of battery management presented in this report.

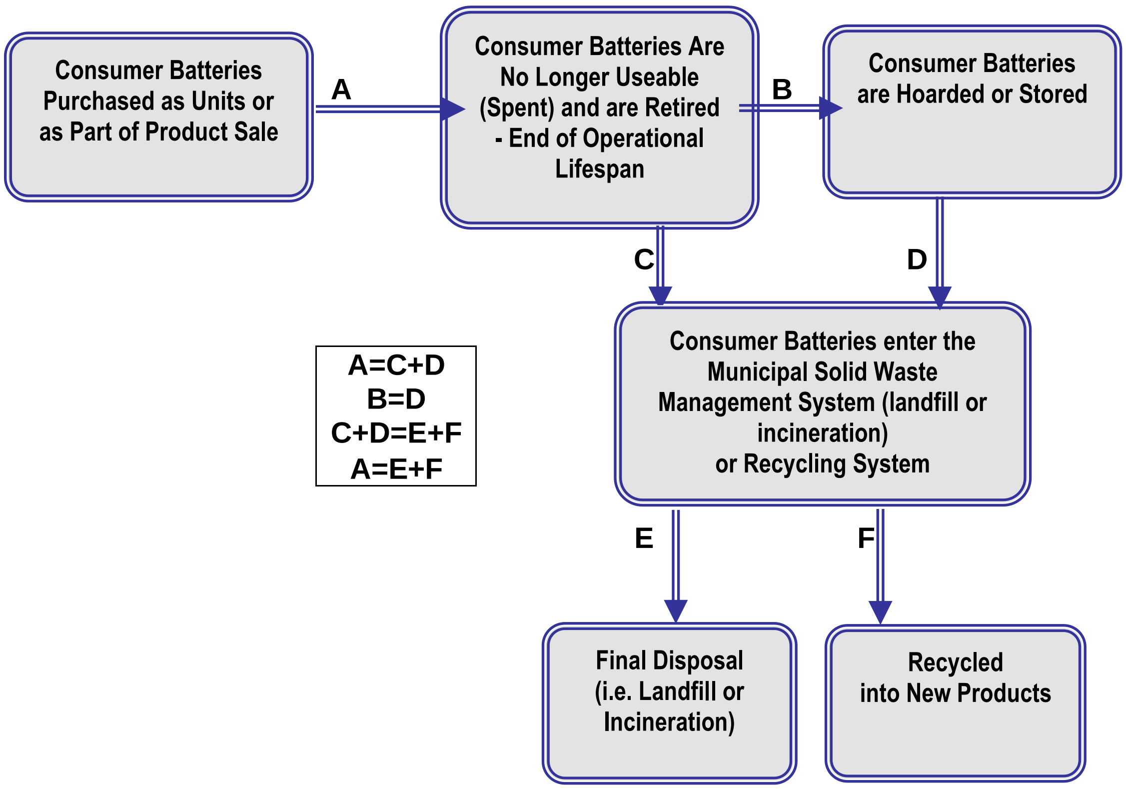
Various inputs to the Battery Flow Model (2009) as well as battery end of life estimates are described in this section.

4.1 Battery Flow Through the Canadian Waste Management System

The Battery Flow Model (2009) has been designed to take account of the various pathways through which consumer and other batteries can flow through the Canadian waste management system. The flow pathway is fairly simple. Once batteries are purchased, they are generally kept until spent. At that time the batteries are either hoarded (stored) or discarded. When discarded they are either directed to recycling or disposal.

As shown in Figure 4.1, the Battery Flow Model (2009) assumes that all end of life batteries will eventually be directed to either recycling facilities or final disposal facilities (i.e. landfill or incineration). In Canada, the majority of end of life consumer batteries which are disposed are sent to landfill (as opposed to incineration).

Figure 4.1: Mass Flow of Consumer Batteries Through The Canadian Waste Management System



The mass flow of consumer batteries is determined by the simple formulae shown above.

> "A" represents the tonnage of consumer batteries purchased. All of "A" tonnes will in time become retired, spent, or reach the end of their lifespan.
>
> "B" represents batteries that are stored or hoarded and eventually become discarded as well, but not immediately after they have been retired.
>
> "C" represents batteries that are sent immediately either to a recycling facility or a waste management facility for incineration or landfilling.
>
> All end-of-life batteries ("C" plus "D") are either recycled (i.e "F" in Figure 3.1) or they are sent to final disposal in a landfill or incinerator (E in Figure 3.1).

The sum of "E" and "F" will equal "A".

4.2 Battery Life-span and Unit Weight

The life-span of all batteries is linked to the capacity of the battery (e.g. in Ampere hours) and the amount of current (Amperes) drawn from the battery by the device which it powers. Temperature, humidity and other environmental factors also have an impact on battery life-span. The capacity of primary batteries cannot be replenished (or recharged) after being drained. Secondary batteries can be recharged many times depending on the battery chemistry. The recharging cycles vary depending on use and application. However, various battery charging behaviours (recharging a battery before it is fully discharged) considerably shorten the battery life (depending on the battery).

Various European reports have made the following assumptions about battery life-spans:

- Three years for general purpose batteries (UK)[38];
- One to five years for a nickel cadmium (NiCd) battery (Belgium)[39];
- Four to five years for a nickel cadmium (NiCd) battery (IEE)[40] ; and
- Three years for zinc air (ZnO_2) batteries (Duracell).[41]

In a report prepared for the European Commission[42] the following life-spans were used for different battery types:

- Three years for general purpose primary battery (i.e. alkaline, zinc carbon);
- Three years for button cell batteries;
- Three years for all other primary batteries;
- Five years for nickel cadmium (NiCd) batteries;
- Seven years for nickel metal hydride (NiMH) batteries;
- Five years for lithium-ion (Li-ion) batteries; and
- Five years for small sealed lead acid (SSLA) batteries.

The following assumptions were used in the Battery Flow Model. The assumed life-spans for NiCd, NiMH and Li-ion batteries were reviewed by the Canadian Household Battery Association (CHBA) and the RBRC during a review meeting held on 3 February, 2006 with Environment Canada staff. It was generally agreed by the meeting attendees that the assumed life spans were reasonable. These are:

- an average three year lifespan for primary batteries;
- an average five years lifespan for NiCd;

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[38] UK Department of Trade and Industry, August 2002. Batteries

[39] Belgium Federal Department of the Environment. May 2003. Risk Assessment.

[40] Institution of Electrical Engineers. June 2004. Recycling of Batteries

[41] Duracell report that it is best to use zinc air batteries within 3 years of manufacture

[42] Bio Intelligence Service, July 2003. Impact Assessment on Selected Policy Options for Revision of the Battery Directive, Prepared for the European Commission, Directorate General Environment

- an average lifespan of five years was originally used for Li-ion batteries but was changed to 1.75 years in the final version of this report based on comments from NEMA;
- an average lifespan of seven years was originally used for NiMH batteries but was changed to three years based on comments from NEMA that 7 years was too high by “at least a factor of 2” – a 3-year lifespan was therefore chosen for the estimates presented in this report; and
- an average five year lifespan for SSLA batteries.

The Battery Flow Model is designed so that it is easy to change life-span assumptions as new information becomes available.

Table 4.1 summarizes the assumptions for battery lifespan, reuse and hoarding used in the Battery Flow Model for primary and secondary batteries. Reuse of batteries was assumed to be zero (as discussed below), as batteries are generally discarded because they are spent, and no re-use infrastructure is in place to refurbish batteries. Recharging is not considered “reuse” in the Battery Flow Model which assumes that no reuse occurs for primary batteries that have been depleted. Secondary batteries are considered spent when they are unable to maintain a charge after successive cycling.

Unit weights used for each battery chemistry are also presented in Table 4.1. The research to support the unit weight data is described in Section 2.

Table 4.1: Battery Lifespan, Hoarding, and Unit Weight Assumptions in the 2009 Canadian Battery Flow Model

Battery	Lifespan (years)	Hoarding Assumptions	Unit weight
PRIMARY			
Zinc carbon (ZnC)	3	30% for 5 to 15 years	27 grams
Alkaline ($ZnMnO_2$)	3	30% for 5 to 15 years	28 grams
Lithium primary	3	30% for 5 to 15 years	33 grams
Zinc air button cell (ZnO_2	3	30% for 5 to 15 years	16 grams
Silver oxide button cell ($ZnAgO_2$)	3	30% for 5 to 15 years	1.2 grams
SECONDARY			
Nickel cadmium (NiCd)	5	60% for 5 to 15 years	203 grams
Nickel metal hydride (NiMH)	3	60% for 5 to 15 years	93 grams
Lithium ion (Li-ion)	1.75	60% for 5 to 15 years	40 grams
Lithium polymer (Li-poly)	1.75	60% for 5 to 15 years	40 grams
Small sealed lead acid (SSLA)	5	60% for 5 to 15 years	1045 grams
Vehicular lead acid (automobiles, motorcycles, commercial vehicles)	4.7 passenger cars	Minimal hoarding assumed to be zero	17.7 kg passenger cars
	2 motorcycles		4.3 kg motorcycles,
	3 commercial vehicles		24.1kg commercial vehicles

For alkaline batteries, research carried out by the European Portable Battery Association (EPBA) has identified that 80% of end of life alkaline batteries were 5 years old or less, and that virtually 100% of alkaline batteries were 10 years old or less when entering the waste or recycling stream. The age profile of alkaline batteries in The Netherlands is presented in Figure 4.2.

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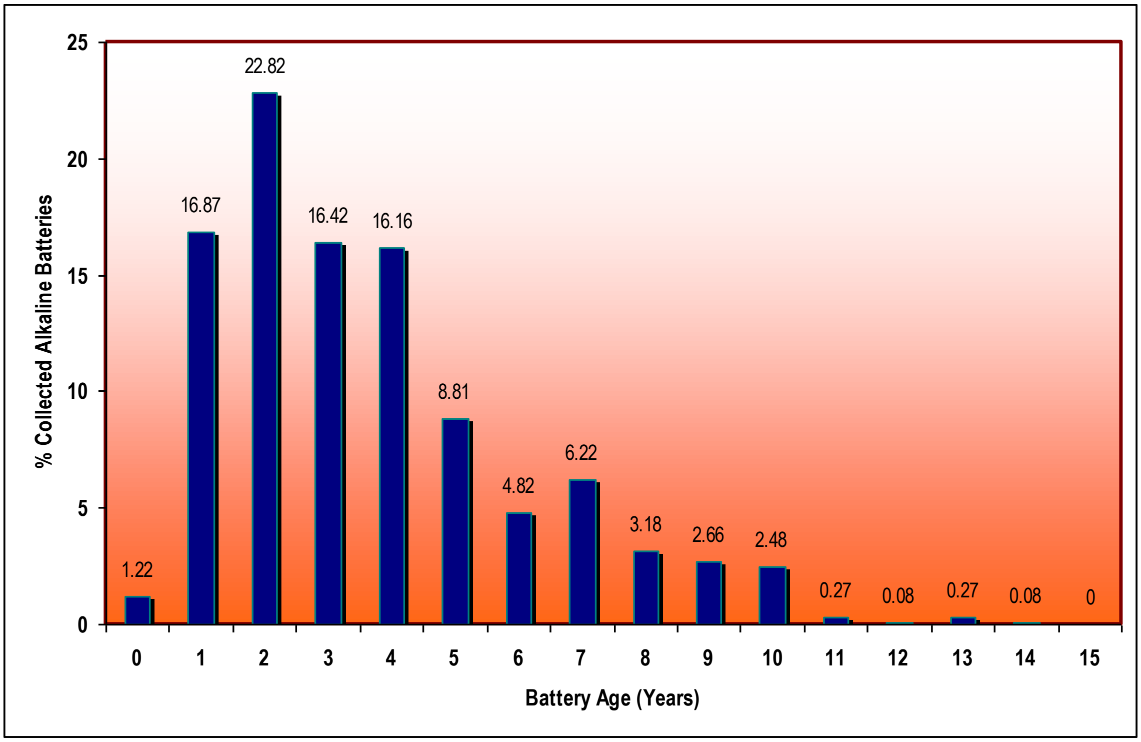

Figure 4.2: Age Profile of Discarded Alkaline Batteries in the Netherlands

Source: www.epbaeurope.net

4.3 Battery Hoarding

Hoarding (or storage) refers to the fact that consumers often store or hoard products (particularly electronics-related products that may or may not have reached their end-of-life) for a period of time before finally discarding them. Also referred to as hoarding and clearance rates, a number of reports attempted to estimate and identify hoarding rates for consumer batteries:

- The hoarding rate for portable NiCd batteries developed for the Belgian Federal Department of the Environment assumed a very slow clearance rate of only 5% after five years (after sale), 33% after 15 years with the remaining 62% being cleared by 25 years.[43]
- The NiCd industry in Europe claims that 65-95% of portable NiCd batteries sold over the last 10 years are still being hoarded.[44]

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[43] Belgium Federal Department of the Environment. May 2003. Risk Assessment

[44] Commission of the European Communities, November 2003. Draft Directive of the European Parliament and of the Council on Batteries and Accumulators and Spent Batteries and Accumulators (2003) 723

- The hoarding rate assumption used for primary (non-rechargeable) batteries is 30% and 60% for secondary (rechargeable) batteries in a report prepared for the European Commission.[45]

In its report, the Belgian Federal Department of the Environment acknowledges that "since both battery lifetime and hoarding behaviour are difficult to assess, calculating the amount available for collection will thus be subject to an error proportional to the uncertainty over these parameters" (see previous Belgian reference, pg 71).

For the purpose of the Battery Flow Model (2009), it has been assumed that 30% of primary batteries and 60% of secondary batteries are hoarded (stored) after the end of their operational life. The Battery Flow Model has been run for two hoarding assumptions:

- Scenario 1: a low hoarding rate of 5 years, and
- Scenario 2: a higher hoarding rate of 15 years.

The 15 year hoarding assumption is not considered likely for alkaline batteries based on the vintage analysis of alkaline batteries discarded in Belgium, which show that most alkaline batteries were 10 years old or less when discarded, but the scenario is presented as a sensitivity in this report, at the suggestion of RBRCC. The PRBA commented that,

> *It is well known that portable rechargeable batteries are hoarded by consumers after the end of their useful life. While the extent of this behaviour has not been studied, assuming that it does take place is quite reasonable, based on anecdotal evidence. The only way to establish a valid hoarding rate for portable rechargeable batteries would be to conduct a scientifically valid household survey which, to the best of PRBA's knowledge has not occurred.*[46]

The two scenarios show a range of values for end of life primary and secondary batteries.

4.4 Battery End of Life Estimates

In this report the term "end-of-life" refers to finally discarding a battery after it is spent, its lifespan is complete and hoarding is over. Batteries can then be directed to recycling or disposal (landfill or incineration). In Canada, the majority of spent portable batteries are still landfilled.

Tables 4.2 and 4.3 present estimates of the number of primary consumer battery units at end of life in Canada from 2007 to 2015, depending on whether a portion is hoarded for 5 years or 15 years. These estimates were developed using the Updated Battery Flow Model, the assumptions presented in Section 2 regarding battery sales, and the assumptions presented earlier in this section regarding battery lifespan, etc.

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[45] Bio Intelligence Service. July 2003. Impact Assessment on Selected Policy Options for Revision of the Battery Directive. Prepared for the European Commission, Directorate General Environment

[46] PRBA comments on March 2008 Report.

Table 4.2: Primary Consumer Batteries At End of Life in Canada, 2007 to 2015 (1,000 units)

Scenario 1: Assuming 5 Year Hoarding

Year	Zinc Carbon	Alkaline	Zinc Air	Lithium Primary	Silver Oxide Button Cell	Zinc Air Button Cell	Total Primary
2007	177,601	347,629	115	20,791	10,402	21,960	578,498
2008	183,632	362,917	115	22,611	10,248	23,351	602,874
2009	184,698	377,736	141	24,288	10,186	24,170	621,220
2010	180,645	392,106	146	25,417	10,409	24,402	633,124
2011	177,962	408,178	139	26,135	10,629	25,275	648,318
2012	176,378	424,796	141	27,124	10,731	26,429	665,599
2013	171,919	441,483	143	28,358	10,821	27,449	680,173
2014	164,810	457,810	157	29,541	10,955	28,235	691,507
2015	154,809	473,906	161	30,502	11,214	28,779	699,371

Table 4.3: Primary Consumer Batteries At End of Life in Canada, 2007 to 2015 (1,000 units)

Scenario 2: Assuming 15 Year Hoarding

Year	Zinc Carbon	Alkaline	Zinc Air	Lithium Primary	Silver Oxide Button Cell	Zinc Air Button Cell	Total Primary
2007	167,919	327,667	106	19,576	9,734	20,726	545,728
2008	173,703	342,443	106	21,364	9,563	22,086	569,265
2009	173,926	355,658	132	23,009	9,484	22,872	585,081
2010	167,903	367,594	136	24,105	9,688	23,070	592,497
2011	162,250	379,935	140	24,711	9,932	23,650	600,619
2012	156,950	392,698	143	25,331	10,182	24,244	609,549
2013	151,360	405,829	147	25,968	10,438	24,854	618,596
2014	145,537	419,341	151	26,620	10,701	25,478	627,828
2015	139,534	433,244	155	27,289	10,970	26,118	637,310

Tables 4.2 and 4.3 show that primary consumer batteries at end of life in Canada will increase steadily depending on the hoarding scenario chosen. The longer hoarding scenario delays the length of time between purchase and eventual discard of consumer batteries, therefore the impacts of historical unit sales are more pronounced:

- In Scenario 1 (Low, 5-Year Hoarding Assumption) primary batteries at end of life increase from 578 million units in 2007, to 699 million units in 2015.
- In Scenario 2 (High Hoarding Assumption) primary batteries at end of life increase from an estimated 546 million units in 2007 to 637 million units in 2015.

The wide range is sensitive to sales data for alkaline and zinc carbon batteries, which make up the lion's share of the total.

Tables 4.4 and 4.5 present estimates of the number of secondary consumer batteries that will be at end of life in Canada between 2007 and 2015, with 5-year and 15-year hoarding assumptions. The estimates are very sensitive to hoarding assumptions in 2007, but less so in 2015.

Secondary consumer batteries at end of life are estimated to range as follows:

- In Scenario 1 (short 5-year hoarding assumption) secondary batteries at end of life increase from 14 million units in 2007, to 31 million units in 2015.
- In Scenario 2 (long, 15-year hoarding assumption) secondary batteries at end of life increase from an estimated 12 million units in 2007 to 23 million units in 2015

Lithium polymer and SSLA batteries make up a small percentage of the total end of life secondary batteries for both hoarding scenarios. NiCd batteries make up most of the total end of life batteries, followed by NiMH units. As discussed in Section 2, sales of secondary batteries are considered to be significant underestimates, but they are based on available GIA data. Consultations are required with battery industry representatives who understand the marketplace dynamics to develop more reliable estimates of secondary battery unit sales into the future.

Table 4.4: Secondary Consumer Batteries at End of Life in Canada, 2007 to 2015 (1,000 units)

Scenario 1: Assuming 5-year Storage/Hoarding

	NiCd	NiMH	Lithium Ion	Lithium Polymer	SSLA	Total Secondary
2007	9,432	2,949	1,180	100	308	13,969
2008	9,928	3,311	1,398	138	313	15,087
2009	10,475	3,783	1,654	154	312	16,378
2010	11,171	4,412	1,990	184	332	18,089
2011	12,011	5,162	2,380	216	340	20,109
2012	13,105	6,063	2,820	240	334	22,562
2013	14,365	6,828	5,401	279	338	27,211
2014	15,807	7,443	5,534	313	338	29,435
2015	16,327	7,905	5,742	340	369	30,683

Table 4.5: Secondary Consumer Batteries At End of Life in Canada, 2007 to 2015 (1,000 units)

Scenario 2: Assuming 15-year Storage/Hoarding

	NiCd	NiMH	Lithium Ion	Lithium Polymer	SSLA	Total Secondary
2007	8,427	2,694	736	64	304	12,225
2008	8,901	2,985	864	84	310	13,143
2009	9,426	3,315	1,012	100	309	14,162
2010	9,972	3,709	1,216	112	329	15,339
2011	10,555	4,182	1,456	132	331	16,656
2012	11,229	4,752	2,114	176	337	18,607
2013	12,015	5,140	4,512	186	334	22,188
2014	12,907	5,322	4,432	197	336	23,193
2015	12,854	5,257	4,344	207	337	22,998

Table 4.6: Weight of Primary Consumer Batteries At End of Life in Canada, 2007 to 2015 (tonnes)

Scenario 1: Assuming 5 year hoarding

Year	Zinc Carbon	Alkaline	Zinc Air	Lithium Primary	Silver Oxide Button Cell	Zinc Air Button Cell	Total Primary
2007	4,795	9,734	4	333	12	20	14,898
2008	4,958	10,162	4	362	12	21	15,519
2009	4,987	10,577	5	389	12	22	15,991
2010	4,877	10,979	5	407	12	22	16,302
2011	4,805	11,429	5	418	13	23	16,692
2012	4,762	11,894	5	434	13	24	17,132
2013	4,642	12,362	5	454	13	25	17,499
2014	4,450	12,819	5	473	13	25	17,785
2015	4,180	13,269	5	488	13	26	17,982

Table 4.7: Weight of Primary Consumer Batteries At End of Life in Canada, 2006 to 2015 (tonnes)

Scenario 2: Assuming 15 year hoarding

Year	Zinc Carbon	Alkaline	Zinc Air	Lithium Primary	Silver Oxide Button Cell	Zinc Air Button Cell	Total Primary
2007	4,534	9,175	3	313	12	19	14,056
2008	4,690	9,588	4	342	11	20	14,655
2009	4,696	9,958	4	368	11	21	15,059
2010	4,533	10,293	5	386	12	21	15,249
2011	4,381	10,638	5	395	12	21	15,452
2012	4,238	10,996	5	405	12	22	15,677
2013	4,087	11,363	5	415	13	22	15,905
2014	3,929	11,742	5	426	13	23	16,138
2015	3,767	12,131	5	437	13	24	16,377

Table 4.8: Weight of Secondary Consumer Batteries At End of Life in Canada, 2007 to 2015 (tonnes)

Scenario 1: Assuming 5 Year Hoarding

	NiCd	NiMH	Lithium Ion	Lithium Polymer	SSLA	Total Secondary
2007	1,915	274	47	4	322	2,563
2008	2,015	308	56	6	327	2,711
2009	2,126	352	66	6	326	2,877
2010	2,268	410	80	7	347	3,112
2011	2,438	480	95	9	355	3,377
2012	2,660	564	113	10	349	3,695
2013	2,916	635	216	11	354	4,132
2014	3,209	692	221	13	353	4,488
2015	3,314	735	230	14	386	4,679

Table 4.9: Weight of Secondary Consumer Batteries at End of Life in Canada, 2007 to 2015 (tonnes)

Scenario 2: Assuming 15 Year Hoarding

	NiCd	NiMH	Lithium Ion	Lithium Polymer	SSLA	Total Secondary
2007	1,711	251	29	3	318	2,311
2008	1,807	278	35	3	323	2,446
2009	1,913	308	40	4	323	2,589
2010	2,024	345	49	4	344	2,767
2011	2,143	389	58	5	346	2,941
2012	2,279	442	85	7	352	3,165
2013	2,439	478	180	7	349	3,454
2014	2,620	495	177	8	351	3,651
2015	2,609	489	174	8	352	3,633

The estimated weight of consumer batteries at end of life in Canada from 2007 to 2015 is presented in Tables 4.6 and 4.7 for primary batteries (for two scenarios with 5 and 15 year hoarding assumptions), and for secondary consumer batteries in Tables 4.8 and 4.9 (for two hoarding scenarios - 5 year and 15 year hoarding assumptions). Table 4.10 summarizes the estimated range of weights at end of life.

Table 4.10: Estimated Weight of Primary and Secondary Batteries at End of Life in Canada in 2007 and 2015

5 and 15 Year Hoarding Assumptions

	Primary Consumer Batteries Discarded (tonnes)		Secondary Consumer Batteries Discarded (tonnes)		Primary and Secondary Consumer Batteries Discarded (tonnes)	
Year	**Scenario 1: 5 year hoarding**	**Scenario 2: 15 year hoarding**	**Scenario 1: 5 year hoarding**	**Scenario 2: 15 year hoarding**	**Scenario 1: 5 year hoarding**	**Scenario 2: 15 year hoarding**
2007	14,898	14,056	2,563	2,311	17,461	16,367
2015	17,982	16,377	4,679	3,633	22,661	20,010

Table 4.10 shows that primary batteries make up the larger weight of the batteries at end of life, at 14,898 to 14,056 tonnes in 2007 compared to an estimated 2,311 to 2,563 tonnes for secondary batteries. The lower weight in each case is for the longer hoarding scenario.

By 2015, the amount of secondary batteries at end of life increases substantially to a range of 4,679 tonnes for a 5-year hoarding scenario to 3,633 tonnes for a 15 year hoarding scenario. The end of life estimates are not significantly impacted by the sales figures from 2007 on (which are considered to be under-estimates for lithium ion batteries, because batteries sold in 2008 and later would not be discarded by 2015 or later (combining a lifespan of 5 years with hoarding of 5 years).

The amount of primary batteries at end of life also increases substantially by 2015, to an estimated 17,982 tonnes, representing a 17% to 21% increase over 8 years.

4.5 Battery Recycling Rates

Recycling rates need to be set in the Battery Flow Model so that disposal (which is discarded less recycled battery tonnages) can be identified. The assumptions on recycling rates are described by the broad battery groups below.

Primary Batteries

A primary battery collection rate of 5% is reported for Ontario (38% of Canada's population)[47] where a number of MHSW (municipal hazardous or special waste) programs collect batteries. Minimal collection and recycling of primary batteries occurs in other provinces, therefore it was assumed that the recycling of primary batteries which occurs in Ontario is the only recycling which occurs in Canada. A minimal amount of primary batteries collected in Ontario municipal programs are recycled; most are landfilled[48]. A recycling rate of 1% was used for this analysis, assuming that some IC&I generated batteries are recycled (rather than collected and landfilled). On the basis of the end of life estimates presented earlier, an estimated 140 to 149 tonnes of primary batteries were recycled in 2007, compared to 14,056 to 14,898 tonnes reaching end of life.

Secondary Batteries

RBRCC is the main program available in Canada for recycling of secondary consumer batteries.

RBRC provided data to Environment Canada on the tonnages of each secondary battery chemistry collected in Canada for 2005, 2006 and 2007 during meetings in March, 2008. Data for 2002-2004 were obtained through earlier discussions with RBRCC in 2006. These data were used to estimate a collection and recycling rate (in this case all batteries are recycled, so that the collection rate and the recycling rate are the same) for rechargeable batteries for two scenarios:

- Scenario 1: 5-year hoarding assumption, and
- Scenario 2: 15-year hoarding assumption.

While this report fully acknowledges that other battery recycling programs operate in Canada, data could not be found on the amounts of batteries recycled through the other programs. Therefore, even though there were a number of limitations to the approach, the RBRC data were used to develop some preliminary collection rate estimates.

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[47] Stewardship Ontario. Municipal Hazardous or Special Waste (MHSW) Program Plan. 26 November 2007.
[48] Ibid

The recycling rate for each battery chemistry for each year was estimated using the end of life amounts calculated by the Battery Flow Model, taking unit sales, lifespan and hoarding into consideration. This method is used by a number of jurisdictions including Environment Canada, the USEPA, the Province of Alberta and other groups to plan end of life management programs for a range of durable goods (goods with a lifespan of greater than six months).

The results are presented in Table 4.11 where it is shown that the calculation of recycling rates for NiCd and NiMH batteries is very sensitive to the hoarding assumption in the earlier years in the table, but less sensitive to the hoarding assumption by 2006 and 2007. The recycling rate achieved through the RBRC program alone is estimated at 10% to 12% and 8% to 9% for NiCd batteries in 2006 and 2007 respectively. Recycling rates for NiMH batteries are estimated at 2% (for both 5 year and 15 year hoarding assumptions) in 2006 and 7% to 8% in 2007.

Recovery rates are estimated at 30% to 50% for lithium ion and lithium polymer batteries combined in 2006 and 45% to 72% in 2007 if a 15-year hoarding assumption is used. This calculation shows that a 15-year hoarding assumption is not realistic for lithium ion or lithium polymer batteries, and that a shorter hoarding rate is actually occurring. Lithium based batteries were introduced into the market in the mid-1990's, and very few lithium based batteries were sold at that time. Where a hoarding rate of 15 years is assumed, the end of life batteries in 2007 would include 40% of the lithium batteries sold in 2002 and 60% of the batteries sold in 1987 (which would have lasted 5 years on average until 1992, and then be hoarded for 15 years to 2007). Because no lithium batteries entered the market in 1987, the hoarded contribution to the end of life total is zero.

Recovery rates for SSLAs vary from 2% in 2006 to 10% in 2007 for both the 5-year and the 15-year hoarding scenario. Amounts of SSLAs recovered vary significantly from one year to the next. As well, the RBRCC program only collects small SSLAs which weigh 0.9kg (2 pounds) or less. Battery Council International (BCI) commented that,

> *Many SSLA batteries are collected for recycling along with larger, automotive type batteries, and that the economics of lead battery recycling – the high value of lead and the high proportion of lead in SSLA batteries – provides an incentive for SSLA battery recycling outside of the RBRC program. SSLAs are used far more in business than consumer settings (e.g. to provide back-up power to computers, medical equipment and emergency alarm and lighting systems), etc.*

The RBRCC program focuses on batteries from consumers, so that the numerator in the recycling calculations is based on consumer batteries collected in the RBRC program only while the denominator is for all consumer batteries. The calculations therefore likely underestimate the actual recycling rate.

The PRBA commented that there may be several years of low recycling rates followed by years of higher recycling rates when large quantities of hoarded batteries are returned for recycling. Conditions contributing to such fluctuations may include, but are not limited to, increased consumer awareness of recycling opportunities, increased availability of recycling drop-off centres and collection of a critical mass of used batteries – that is, consumers will only hold on to a certain quantity of household batteries before seeking out recycling opportunities. PRBA commented that the only way to determine the accurate hoarding rate for consumer batteries is to conduct a scientifically valid household survey.[49]

4.6 Consumer Battery Disposal

End of life battery units and weights were presented earlier in this section. Table 4.12 presents the materials contained in primary and secondary consumer batteries which were disposed in Canada in 2007.

Tables 4.6 and 4.7 show the tonnes of primary batteries discarded for 5-year and 15-year hoarding scenarios, and Tables 4.8 and 4.9 show values for secondary consumer batteries for the two hoarding scenarios. The values in these tables are combined with the composition data by battery chemistry in Table 2.19 to estimate materials in batteries discarded in 2007.

The values for secondary batteries are likely an over-estimate as the recycling values include tonnages reported through the RBRCC program. Other IC&I secondary battery recycling is not included in these values.

[49] PRBA comments on March 2008 Report

Table 4.11: Estimated Recycling Rates for Rechargeable Batteries Collected in Canada Through RBRCC

For Five Year and Fifteen Year Hoarding Assumption (end of life and recycling in tonnes)

		NiCd		**NiMH**		**Li Ion & Lithium Polymer**		**SSLA**		**All Secondary Consumer Batteries**	
Year	Tonnes	5 yr store	15 yr store	5 yr store	15 yr store	5 yr store	15 yr store	5 yr store	15 yr store	5 yr store	15 yr store
2002	Disposed	1,625	948	189	168	30	13	324	131	**2,167**	**1,259**
	Recycled	69	69	4	4	2	2	4	4	**79**	**79**
	Recycling Rate	4%	7%	2%	2%	7%	16%	1%	3%	**4%**	**6%**
2003	Disposed	1,661	1,224	197	175	33	16	323	130	**2,214**	**1,545**
	Recycled	101	101	6	6	2	2	6	6	**115**	**115**
	Recycling Rate	6%	8%	3%	3%	7%	15%	2%	5%	**5%**	**7%**
2004	Disposed	1,697	1,506	210	187	37	19	324	194	**2,267**	**1,905**
	Recycled	132	132	7	7	3	3	8	8	**151**	**151**
	Recycling Rate	8%	9%	4%	4%	9%	17%	2%	4%	**7%**	**8%**
2005	Disposed	1,751	1,556	228	206	41	23	324	257	**2,345**	**2,041**
	Recycled	141	141	12	12	7	7	17	17	**176**	**176**
	Recycling Rate	8%	9%	5%	6%	16%	29%	5%	6%	**8%**	**9%**
2006	Disposed	1,821	1,622	250	226	46	27	329	325	**2,445**	**2,200**
	Recycled	190	190	5	5	14	14	5	5	**214**	**214**
	Recycling Rate	10%	12%	2%	2%	30%	50%	2%	2%	**9%**	**10%**
2007	Disposed	1,915	1,711	274	251	51	32	322	318	**2,563**	**2,311**
	Recycled	155	155	20	20	23	23	33	33	**230**	**230**
	Recycling Rate	8%	9%	7%	8%	45%	72%	10%	10%	**9%**	**10%**

Note: A 15-year hoarding assumption results in a lower discard estimates as the impacts of historical sales are more significant. This is particularly significant for lithium based consumer batteries which were only introduced into the market in 1995 and later.

Table 4.12: Estimated Metal and Material Loading From Disposed Consumer Batteries, 2007

	Iron & Steel	Pb	Ni	Cd	Zn	Mn	Ag	Hg	Li	Al	Co	Other Metals	Alkali	H_2SO_4	Other non-metals	Plastic Paper Carbon
PRIMARY CONSUMER BATTERIES (tonnes)																
Total End of Life 2007	3,400	5	8	0	2,389	2,954	3.87	0.25	7	0	0	165	814	0	2,156	1,370
Total Recycled 2007	33.3	0.05	0.5	-	23.5	29.1	0.04	0.001	0.1	-	-	1.6	8		21.2	13.4
Total Landfilled (Disposed) 2007	**3,367**	**5**	**8**		**2,366**	**2,925**	**3.8**	**0.2**	**7**			**164**	**806**		**2,135**	**1,357**
SECONDARY CONSUMER BATTERIES (Excluding Automotive Lead Acid based batteries) (tonnes)																
Total End of Life 2007	735.4	209.5	517.2	287.2	2.7	2.7	0.0	0.0	1.4	2.4	19.5	45.5	49.3	51.6	261.9	254.5
Total Recycled 2007	62.6	21	40.6	23	0.2	0.2	-	-	0.7	1.1	4.9	5.8	3.9		5.2	26.4
Total Landfilled (Disposed) 2007	**673**	**189**	**477**	**264**	**3**	**3**			**0.7**	**1.3**	**15**	**40**	**45**	**52**	**257**	**228**

5. Current Battery Processing Infrastructure for Canadian Consumer Batteries

5.1 Overview

Battery recycling is made up of a number of players:

- Companies who collect batteries;
- Companies that pre-process batteries and send them to larger specialized processing facilities;
- Specialized battery processing operations (described in this section); and
- Large refining and smelting operations which use batteries as one of a number of feed-stocks in their operations (described in this section).

This study focused on contacting all the major processors of consumer batteries across North America. Many of the companies are intricately linked and use each other's resources. Information obtained through interviews with each of the major players is described by company in this section. The last section summarizes key comments received regarding the challenges faced by battery recyclers, some related to the current regulatory environment, or related to the expected significant volume of batteries which will be recycled when hybrid cars currently on the road will require new batteries.

Overall, the processing of batteries is driven by the value of nickel, cobalt, lead and zinc:

- Nickel is used in a number of industries. Its value has varied from 90 cents per kilogram ($2 per pound) to $9.10 per kilogram ($20 per pound) in the recent past, and was about $5.45 per kilogram ($12 per pound) in March, 2008 when the study research was completed;
- Cobalt is used in the paint and coatings industry, and is a very valuable commodity, with a price of $22.72 per kilogram ($50 per pound) in March, 2008. Lithium and some other batteries contain cobalt, which is a driver for most battery recyclers;
- Zinc is recovered by some battery recyclers and is sold to the steel industry for galvanizing;
- Lead is generally a valuable commodity and is sold back to the lead acid battery business.

Battery processors use either hydrometallurgical or a range of pyrometallurgical processes:

Hydrometallurgical Processes (Alkaline, Zinc Carbon, Zinc Oxide, Lithium-ion Batteries)

Hydrometallurgy refers to the aqueous processing of metals. Hydrometallurgical processing of waste batteries involves a mechanical step and a chemical step. In the mechanical phase, the batteries are shredded in order to separate the metals, paper, plastic and the black mass. The black mass is further chemically processed to produce a solution, which undergoes electrolysis, or other treatment, in order to separate out the dissolved metals. NEMA commented that no battery processors are using hydrometallurgical processes in North America at this time to their knowledge, as they are not economically competitive. NEMA also commented that all primary battery processors in Europe and North America are using a combination of mechanical and pyrometallurgical processes. Natural Resources Canada staff visited facilities in Belgium in 2008 where hydrometallurgical processes are used to recycle alkaline consumer batteries.

Pyrometallurgy (Alkaline, Zinc Carbon, Zinc Oxide, , NiMH, NiCd and Li-ion Batteries)
Pyrometallurgy uses high temperatures to transform, separate and purify metals. There is no generic method for recycling batteries pyrometallurgically and each of the existing methods is unique.

Valuable Materials in Consumer Batteries
Table 5.1 summarizes the valuable constituents of various consumer batteries. In some cases, the presence of valuable metals such as nickel and cobalt in particular, drives the interest in collecting and recycling these items.

Table 5.1: Constituents of Consumer Batteries (percentage by weight)

Battery	Metal Constituents	Non-Metal Constituents	Plastic Paper and Carbon
Zinc carbon (ZnC)	16.8% iron and steel 0.1% lead 19.4% zinc 15% manganese	0.8% other metals 6% alkali 15% other non metals 12.3% water	13.9% plastic, paper, carbon
Alkaline ($ZnMnO_2$)	24.8 % iron and steel 14.9% zinc 22.3% manganese 0.5% nickel & 1.3 % other metals	5.4% alkali 14% other non metals 10.1% water	6.9% plastic, paper, carbon
Zinc air button cell (ZnO_2)	42% iron and steel 35% zinc 1% mercury	4% alkali 10% water 3% other non metals	5% plastic, paper, carbon
Silver oxide button cell ($ZnAgO_2$)	42% iron and steel 31% silver 9% zinc, 2% manganese, 2% nickel, 0.4% mercury and 4% other metals	1% alkali 4% other non metals 2% water	2.5% plastic, paper, carbon
Nickel cadmium (NiCd)	35% iron and steel 22% nickel 15% cadmium	2% alkali 5% water 11% other non-metals	10% plastic, paper and carbon
Nickel Metal Hydride (NiMH)	20% iron and steel 35% nickel 1% zinc and 1% manganese 4% cobalt & 10% other metals	4% alkali 8% other non-metals 8% water	9% plastic, paper and carbon
Small sealed lead acid	65% lead 4% other metals	16% $H_2 SO_4$ 5% other non-metals	10% plastic, paper, carbon
Lithium Ion	22% iron and steel 3% lithium 5% aluminum 18% cobalt & 11% other metals	28% other non-metals	13% plastic, paper and carbon

Source: From Battery Waste Management Life Cycle Assessment completed for the UK Department of Environment, Food and Rural Affairs (DEFRA) by ERM (Environmental Resources Management) in October, 2006

Lithium ion and some other batteries contain cobalt which is very valuable (the price was about $110 per kilogram ($50 per pound or $11,000 per tonne when the project research was carried out in March, 2008), and companies will pay to receive these batteries as feedstock.

NiCd and NiMH batteries contain nickel, which also had a high value ($44 per kilogram, $20 per pound or $4,400 per tonne when the project research was carried out in March, 2008). Companies also pay to receive this feedstock.

Alkaline and zinc carbon batteries contain zinc, which has a lower value, and therefore a fee is required for processing them.

5.2 Industry Interviews

Telephone interviews were conducted with the major consumer battery processors in Canada, and companies in the US which process Canadian batteries between January and March, 2008. These companies are listed in Table 5.2, along with their specializations and contact details. Information on Metalex Products in Richmond, British Columbia was obtained through e-mail correspondence.

Table 5.2: Companies Interviewed For Battery Recycling Study

Company	Specialty	Website and Contact Information	
Toxco Waste Management Ltd, Trail, BC	Lithium batteries, all chemistries	Mailing Address:	P.O. Box 232 Trail, British Columbia V1R 4L5
		Location Address:	9384 Hwy 22A Trail, British Columbia V1R 2Y8
		Telephone:	(250) 367-9882
		Toll Free Phone:	(877) 468-6926
		Fax:	(250) 367-9875
		Contact:	Cathy Bruce
		E-mail:	toxco@xplornet.com
		Website URL:	www.toxco.com
Teck Ltd., Trail, BC	Alkaline batteries in zinc smelter Lead batteries in lead smelter	Registered and Head Office Address:	600 - 200 Burrard Street Vancouver, British Columbia V6C 3L9
		Telephone:	(604) 687-1117
		Fax:	(604) 687-6100
		Contact:	David Goosen
		E-mail:	info@teck.com
RMC (Raw Materials Company), Port Colborne, ON	Alkaline and zinc carbon	Mailing Address:	P.O. Box 6 Port Colborne, Ontario L3K 5V7
		Site Address:	17 Invertose Drive Port Colborne, Ontario
		Toll Free:	(888) We-Reduce
		Telephone:	(905) 835-1203
		Fax:	(905) 835-6824
		Contact:	James Ewles jewels@rawmaterials.com
		E-mail:	admin@rawmaterials.com
		Website URL:	www.rawmaterials.com
Tonolli Canada Ltd., Mississauga	Lead acid batteries	Address:	1333 Tonolli Rd Mississauga ON, L4Y 4C2
		Telephone:	(905) 279-9555
		Fax:	(905) 279-5925
		Contact:	Ross Atkinson, President
		E-mail:	Ross@tonolli.ca

		No Website	
Xstrata, Sudbury	Cobalt bearing batteries	Xstrata Nickel Head Office Address: Toronto, ON Xstrata Operations: Sudbury, ON	
		Telephone:	(416) 775-1500
		E-mail:	info@xstrata.com
		Contact:	Bob Sutherland
		E-mail:	bsutherland@xtratanickel.ca
		Website URL:	www.xstrata.com
Nova Pb, Montreal	Lead acid batteries	Address:	1200 Garnier Street, Ville Ste-Catherine, Quebec, J5C 1B4
		Telephone:	(450) 632-9910
		Fax:	(450) 632-9090
		Contact:	Marc DeSautels
		E-mail:	service@novapb.qc.ca
		Website URL :	www.novapb.com
Xstrata Zinc Canada Brunswick Smelter, Belledune, New Brunswick	Lead acid batteries (breaker on site)	Mailing and Location Address:	692 Main St. Belledune, New Brunswick E8G 2M1
		Telephone:	(506) 522-7012
		Fax:	(506) 522-7089
		Contact:	Jay Hemenway
		Website URL:	www.xstratazinc.ca
INMETCO, Pennsylvania	Nickel bearing batteries	INMETCO is a subsidiary of "INCO" (The International Nickel Company)	
		Address:	Ellwood City, Pennsylvania 16117
		Telephone:	(724) 758-2800
		Fax:	(724) 758-2845
		Contact:	Marty Ellwood-Clark
		E-mail:	sales@inmetco.com
		Website URL:	www.inmetco.com
Toxco, Ohio	Cadmium batteries	Address:	Baltimore, Ohio, USA
		Toll free:	(877) 461-2345
		Telephone:	(740) 526-0334
		Contact:	Shane Thompson
		E-mail:	sthompson@kinsbursky.com
Metalex Products Ltd., Richmond, BC[50]	Lead acid battery breaking and smelting	Address:	2511 No. 5 Road Richmond, BC V6X 2S8
		Telephone:	(604) 2735487
		Fax:	(604) 273-4782
		Contact:	Robert Kamphiuis
		E-mail:	rob.metalex@telus.net
		Website URL:	www.metalexleadrecycling.com

The following sections describe each operation in more detail. The last section discusses various concerns expressed by battery recyclers. Table 5.3 summarizes the key information obtained from the battery recycling company interviews. Section 8 describes data for companies which specialize in lead acid battery recycling.

Battery recyclers recently formed an industry association to represent their direct needs separately from the scrap metal industry, which battery recyclers are also heavily involved with. BRANA (Battery Recycling Association of North America) is a non profit trade organization comprised of companies that handle, recycle, transport, and manage portable power batteries. Formed in the summer of 2007, members of BRANA imagined a trade association that would give a voice to the North American Battery Recycling Industry.

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[50] Not interviewed because of relatively small size of operation – see Section 8

Through cooperative dialogue with battery handlers, recyclers, manufacturers, and the regulatory community, BRANA seeks to establish guidance and training on the proper methods and regulations governing the safe handling of batteries throughout North America.[51]

Table 5.3: Summary of Canadian Consumer Battery Processor Data

Company	Specialty	Processing Technologies	Capacity and Current Through-put	Batteries as a % of Feed-stock	Employees	Markets for end products
Toxco, Trail, BC	Lithium batteries, all chemistries	Lithium primary: Wet process recovers lithium as lithium carbonate. Black slurry contains carbon, lithium chloride and sulphate salts. Secondary Lithium Batteries: wet process recovers lithium as lithium carbonate and produces a cobalt bearing filter cake.	Cap 90,900 kg per year (2 million pounds). Could handle 454,500 kg per year (10 million pounds).	Almost 100%	15	Produces a technical grade lithium carbonate for resale to the appliance coatings industry. Cobalt products are sent to cobalt refiners or appliance coatings industry.
Teck Trail Zinc Smelter	Can now take alkaline, zinc carbon and can take other primary if new technologies installed	Batteries a miniscule portion of their feedstock.	Want to process 750 tonnes per year of alkaline and zinc carbon batteries in 2008 – have put new process in	Miniscule – total capacity of zinc smelter is 300,000 tonnes per year of zinc 20 million ozs per year silver from ore Even at 10,000 tonnes per year would be only 3%	1,500 (lead and zinc)	Sold mostly to US Steel for galvanizing.
RMC, Port Colborne	Alkaline and zinc carbon their specialty. Also do lithium ion secondary in mechanical process.	Alkaline and zinc carbon through patented process. Process NiMH on site mechanically and produce nickel concentrate on site. Process lithium ion on site in similar process to NiMH – produce cobalt.	10,000 tonnes per year. capacity Running at 25% of capacity because of lack of feedstock	75% to 85%	85-100	Sell nickel concentrate to coatings industry across North America Lithium carbonate sold for cobalt recovery through cobalt industry Send mercury batteries to Bethlehem Apparatus for mercury recovery – residue returned for further processing.
Xstrata,	Cobalt	Smelter recovers nickel, cobalt	550,000	Miniscule	300 in	Cobalt sold to Glencor –

[51] www.brana-online.org/

Sudbury	bearing batteries	and copper. Introduce batteries directly to converter, or send to new rotary kiln ($30 million).	tonnes per year in smelter 6,000 to 7,000 tonnes per year in new rotary kiln	Niche market- cobalt bearing batteries	smelter	metal marketing company in Switzerland.
Inmetco, Pennsylvania	Nickel bearing batteries their specialty but handle others also	Alkaline and zinc carbon – rotary hearth furnace, zinc fumed off and recovered in wet scrubber. NiCd to cadmium recovery unit	Take all RBRC batteries from across North America		110	Ingots key output – to stainless steel industry - Consumed through steel making process Zinc to Horseheads, Pennsylvania Cadmium sold back to battery manufacturers. Nickel forms remelt alloy sold back to steel industry. Chrome, nickel and iron from spent batteries to stainless steel remelt alloy
Toxco, Ohio	Cadmium batteries	NiCd to Cadmium furnaces – temp 1,000 degrees – produce cadmium ingot 99.9999% pure NiMH – recover MISH metals, rare earth	15,600 to 19,200 tonnes per year (1,310 to 1,830 tonnes per month) nickel containing batteries	High 70's %	350 including all locations (excluding Toxco inTrail, BC	Ohio – steel mills use zinc and manganese, ferrous case Cadmium ingot to highest bidder – used to be battery companies, now colour and pigment enhancer

5.3 Toxco, Trail, BC

Toxco in Trail, BC operates a comprehensive lithium battery processing facility in North America. Their customers include the US military, and oil service companies throughout the globe. Directional drilling equipment used by oil companies uses lithium batteries which Toxco process and recycle.

Toxco is wholly owned by Toxco US, and has been in business for 15 years. Toxco accepts all batteries, then sort them and send the chemistries that they do not process at the site to other partners:

- Nickel based batteries are sent to Kinsbursky Brothers in Ohio (Toxco, Ohio), their parent company;
- Alkaline batteries are sent to Teck in Trail, BC; and
- Lead acid batteries are sent to KC Recycling Ltd, also located in Trail, BC. KC Recycling break the batteries and send them to Teck for lead recovery.

Toxco have an agreement to carry out QA (quality assurance) on loads of batteries destined for Teck to ensure that they do not contain any lithium batteries, which present a problem in the Teck facility.

The company started out processing lithium batteries only, mostly from the US military and navy. Much of their initial efforts were as a result of a contract to recycle large lithium batteries from nuclear weapons silos in the US which used large lithium batteries as their 4^{th} backup power system. Their business is still focused mostly on lithium batteries. They process all seven lithium battery chemistries.

Toxco have a contract with hybrid car manufacturers who are moving to lithium ion batteries. Most hybrid cars currently on the road now use nickel metal hydride batteries. People in the business currently feel that they will move to lithium batteries, and various chemistries of lithium are currently being explored. The lead acid battery business is also actively exploring re-design of lead acid batteries to power hybrid vehicles.

Primary Lithium Battery Recycling Process

All lithium batteries contain lithium metal and/or lithium salts and finely divided carbon. The process at Toxco BC involves the following steps (taken from literature provided by Toxco in February, 2008):

1. Batteries are de-packaged and prepared.
2. Alkali is added to the process solution in four tanks to maintain high alkaline pH.
3. Battery electrolytes are neutralized by the alkali and dissolve in the process solution.
4. Metallic lithium reacts with the water to dissolve and form hydrogen which is given off as a gas.
5. The hydrogen gas is burned and coupled with forced venting, the hydrogen concentration is thus kept below explosive limits.
6. Off gasses are sent to a scrubber and filter process and the cleaned air is vented to the atmosphere.
7. Large scrap metal and plastic fragments are recovered and separated into metallic and non-metallic fractions for recycling and or disposal.
8. The process solution has now increased in dissolved salts.
9. At near saturation point the solution, now containing large amounts of finely divided carbon and small metal and plastic fragments, is transferred to a large holding tank.
10. As the solution is moved to the tank it is screened to remove the bulk of the metal and plastic fragments.
11. Metal and plastic fragments are sent for disposal as non-hazardous fluff.
12. The remaining solution is now a black slurry containing:
    - Lithium Chloride,
    - finely divided carbon,
    - dissolved sodium and
    - Sulphate salts.

13. The carbon is removed by filtration to leave a water-clear salt solution.
14. Sodium carbonate is added to the clear solution in the amount chemically equivalent to the amount of lithium in the solution.
15. Sodium carbonate is soluble and dissolves, putting carbonate in the solution.
16. Lithium in solution combines with carbonate to form lithium carbonate Li_2CO_3 as a precipitate.

17. Li_2CO_3 precipitate is a snow white solid that is recovered by filtration and washed to remove contaminates.
18. Solid Li_2CO_3 is dried and packaged for sale.

Secondary Lithium Battery Recycling Process

The secondary lithium battery processing steps at Toxco, BC are listed below. The estimated recycling efficiency rate through the process ranges from 65% to 80% of the incoming battery weight depending on the batteries processed.

1. Batteries are sorted and fed via conveyor into a hammer mill crusher in a lithium brine process solution; dissolved electrolyte and lithium salts.
2. The process stream is then separated from the Lithium ion fluff.
3. Lithium ion fluff is a mixture of plastics and some steel. If the steel content is sufficient it is sent for steel recovery, otherwise it is disposed. The steel content may sometimes reach 65% depending on the feed-stock.
4. The process stream then passes through a shaker table to produce a copper cobalt product; a mixture of copper, aluminum and cobalt. This product is sold to primary metal producers.
5. The slurry is then added to a mix tank and /or holding tank.
6. The slurry is passed through a filter press to produce a cobalt filter cake; a mixture of cobalt and carbon. This product is sold to primary metal producers.
7. The remaining slurry is sent to the primary process line to recover lithium in the form of lithium carbonate.

Details on how different batteries are managed by Toxco at the Trail, BC facility are presented in Table 5.4. Facility operational details are presented in Table 5.5

Table 5.4: Processing of Batteries at Toxco, Trail, BC Facility

Battery	Processing
Zinc carbon (ZnC)	Part of alkaline battery stream sent to Teck in Trail, BC
Alkaline ($ZnMnO_2$)	Loads are sorted to remove lithium batteries. Alkaline batteries are sent to Teck in Trail BC for zinc recovery.
Lithium primary	Wet process recovers lithium as lithium carbonate for resale to the appliance coatings industry.
Zinc air button cell (ZnO_2)	Part of alkaline battery stream sent to Teck smelter in Trail, BC.
Silver oxide button cell ($ZnAgO_2$)	Part of alkaline battery stream sent to Teck smelter in Trail, BC
Nickel cadmium (NiCd)	Nickel based batteries are shipped to Toxco, Ohio. Retort furnaces are used to recover cadmium.
Nickel metal hydride (NiMH)-	Nickel based batteries are sent to Kinsbursky Brothers in Ohio.
Lithium ion (Li-ion) –	Wet process recovers lithium as lithium carbonate and produces a cobalt bearing filter cake. Cobalt is sold to cobalt refiners and to the appliance coating industry
Lithium polymer (Li-poly) –	Processed at Toxco Trail, BC site
Small sealed lead acid (SSLA) –	Sent to KC Recycling in Trail, BC Send heavy lead acid batteries to Kinsbursky facility in Anaheim California and to Toxco in Ohio
Vehicular Lead Acid Batteries (LAB)	Sent to KC Recycling in Trail, BC Send heavy lead acid batteries to Kinsbursky facility in Anaheim California and to Toxco, Ohio Kinsbursky processes lead in Anaheim and Baltimore
Mercury containing batteries	Mercury batteries are sent out for retorting

Table 5.5: Toxco, Trail, BC Battery Processing Facility Details

Sources of Batteries	US military, oil companies (directional drilling), other battery recyclers
Other feed-stocks processed	Lithium metals from battery manufacturers (this is a small amount of their business – drum might have 10 lbs).
Existing and Max Operational Processing capacity	Typically 91,000 kg (2 million lbs) per year batteries. Running one shift per day, 5 days per week They are nowhere near capacity and could process five times what they currently handle. Could process 454,500 kg per year (10 million lbs per year) Looking at very large capacity for bigger contracts
Batteries as a Percentage of Total Feedstock	Almost 100%, metal is a small amount of the total they process
Number of employees	15
Associated Costs	Charge by the pound for processing. Most lithium batteries have a tipping fee They will buy lithium ion rechargeable battery by the pound because of the cobalt content ($110 per kg $50 per pound in spring, 2008) – cobalt was $11 per kilogram ($5 per pound) 10 years ago. Nickel was $26 per kilogram ($12 per pound) in spring, 2008. Price was < $4 per kilogram ($2 per pound) in the past and was up to $44 per kilogram ($20 per pound) in 2007. Lead acid batteries –pay 6 to 9 cents per kilogram (3-4c/lb) They charge for recycling of alkaline batteries (they do not contain enough zinc to cover recycling costs)
End Markets for Processed Batteries	High grade lithium could go back to the pharmaceutical industry but Toxco do not produce this product at the Trail facility. Low grade lithium which is produced at the Trail facility is sold to the concrete industry Manganese dioxide ends up in the slag. There is a huge demand for manganese dioxide in the concrete business.

All electrolytes in lithium batteries are highly flammable. Incinerators used to handle lithium primary batteries, but one hazardous waste processing company reportedly had a fire a year ago and burned down. This incident resulted in others in the business being nervous about handling lithium primary batteries. Toxco works closely with a lot of battery manufacturers to incorporate recyclability as a design consideration in new batteries.

5.4 Teck Ltd, Trail, BC

Teck Ltd operates a zinc and lead operation in Trail BC. Batteries make up about 30% of the feedstock to the lead operation and less than 0.5% of the feedstock to the zinc operation. However, Teck tested the processing of consumer batteries and are interested in taking in more battery feedstock. They can easily develop capacity to process 10,000 tonnes per year of alkaline batteries if required. Details on the batteries which Teck recycles are presented in Table 5.6. Details of the Teck operation are summarized in Table 5.7.

Table 5.6: Processing of Batteries at Teck, Trail, BC Facility

Battery	Processing
Zinc carbon (ZnC)	Yes
Alkaline ($ZnMnO_2$)	Starting to process alkaline batteries in 2008 with Toxco. They use the same furnace for e-waste – it can also handle alkaline batteries. Teck fumes off the zinc and try to recover the copper. Manganese goes to the tail slag and to cement manufacturers. Teck wanted to process 750 tonnes of alkaline batteries in 2008 in advance of EPR tipping fees for batteries.
Zinc air button cell (ZnO_2)	Can process zinc air button cells but do not process a lot Teck are trying to put the secondary furnace after the slag furnace, they could then recover silver, aiming for 2011. Then zinc air button cells and other new products could be accepted and processed. Could recover 95% of the silver in a matt phase.
Silver oxide button cell ($ZnAgO_2$)	Silver oxide button cell ($ZnAgO_2$) batteries – use the same process, in the slag fuming furnace. Zinc fumes off and is collected as dust. Teck electro-win to recover the zinc, leach first. Fume zinc oxide. Silver oxide batteries are just another feedstock to what they always did –Teck always had slag furnaces
Nickel cadmium (NiCd)	It is not worth it to Teck to recycle NiCd batteries, because cadmium is a very poisonous metal. They used to sell to Saft Europe, but they shut down. Teck now deals with Toxco to handle large cadmium plates. They handle 1,200-1500 tonnes per year. They make 1,500 tonnes of cadmium metal, most goes to primary battery industry. All is made from new feedstock.
Small sealed lead acid (SSLA)	Teck do not recycle SSLAs themselves – they receive processed lead from KC Recycling, Trail, BC

Table 5.7: Teck, Trail, BC Zinc Smelter and Battery Processing Facility Details

Sources of Batteries	Teck process 30,000 tonnes/year (lead) of primarily lead acid batteries. Feedstock comes from the Pacific North West, all of the ULABs are 22.7 kg to 27.3 kg. (50-60 pounds) per unit. Some of that weight is plates, plastic, etc. Lead acid batteries come through KC Recycling after pre-processing (breaking) Teck sends batteries to KC Recycling in Trail, BC who shred the batteries and make lead paste. The plates and the paste come to Teck. Teck does not get the posts from the batteries, they go to someone else. Other batteries come through Toxco.
Other feed-stocks processed	Some CRT screens from monitors and televisions from the Alberta electronics programs are processed (to recover lead).
Processes On Site	Lead acid batteries are processed in the primary furnace which produces lead which is made back into batteries. Their main revenue comes from zinc – they are a zinc smelter. 50% of the feed to the lead furnace is zinc residues. The residues contain lead and some zinc. Most other locations the residues go to ponds. Teck put the residues through the lead smelting furnace with concentrates. Teck are trying to put the secondary furnace after the slag furnace, they could then recover silver, aiming for 2011. Then the zinc air button cells and other new products could be processed. Could get 95% silver in the matt phase.
Existing and Max Operational Processing Capacity	Make 300,000 tonnes/year zinc, and 95,000 tonnes/year of lead. Looking at putting in a secondary lead smelting furnace to treat more junk batteries - similar to the facility at Doe Run (US) which has primary and secondary furnaces. Alkaline batteries – could handle 10,000 tonnes/year, but they don't currently process any because of a lack of incentive. Processing 30,000 tonnes per year of lead was about at peak in early 2008. At that time Teck were considering installing another furnace to take an additional 35,000 tonnes of lead batteries.
Batteries as a Percentage of Total Feedstock	Lead smelting furnace is called KIVCET. Teck make 95,000 tonnes per year of lead; 30,000 tonnes per year from lead acid batteries, so less than one third (31.6% for lead process of feedstock is lead acid batteries). The percentage of the feedstock which comes from batteries is miniscule for zinc, even if they got to 10,000 tonnes per year of batteries, the total from batteries would be half percent.
Number of employees at the facility	1,500 people
Associated Costs	Can not share cost information, Teck is competing with other companies. To maximize profitability, Teck processes the most valuable materials.
End Markets for Processed Batteries	Zinc is sold mostly to US Steel for the galvanizing business. Teck produces 20 million ounces per year of silver, most of this is sold to Kodak for film (X-ray) Gold is sold to the mint; it is processed from ore. Germanium is sold for specialized applications (hot filling, stabilizing polymers, night vision equipment, etc). Indium is used in LCD manufacturing.

5.5 International Marine Salvage (Raw Materials Corporation - Port Colborne, Ontario

Raw Materials Corporation (RMC) is a private corporation which is a division of International Marine Salvage and is located in Port Colborne, Ontario. Raw Materials Corporation is a trade name retained by the company after purchasing an existing business.

RMC have a facility in Port Colborne, Ontario and one in the Buffalo NY, which acts as a shipping and receiving facility for US customers. Loads can be consolidated into one notice for Environment Canada reporting at the Buffalo, NY location and then shipped across the border to Port Colborne for processing.

Batteries are not categorized as a hazardous waste or a hazardous recyclable in Ontario or the US.

RMC handles primary alkaline batteries as well as some rechargeable batteries; 90% of the batteries they receive are processed on-site and 10% are outsourced. The company is mostly known for processing alkaline and zinc carbon batteries. They recycle zinc, manganese and steel.

RMC have a patented process for processing primary alkaline batteries. They are also in the midst of developing a process for manganese batteries which they hope to have in place by mid 2009 (crushing plus hydrometallurgical). All primary batteries which are manganese based and free of mercury can go through this process.

RMC reported that they still see some mercury containing batteries, which they send to an outside processor (Bethlehem Apparatus in the US) to recover the mercury. The mercury free components can then be shipped back to them for recycling.

Details on how various batteries are managed by RMC are presented in Table 5.8. Facility details are summarized in Table 5.9.

Table 5.8: Processing of Batteries at RMC, Port Colborne, Ontario Facility

Battery	Processing
Zinc carbon (ZnC)	Yes, through patented process
Alkaline ($ZnMnO_2$)	Yes, through patented process
Magnesium Batteries	New process being designed, in operation by 2009
Lithium primary	Send to Toxco, Trail, BC
Zinc air button cell (ZnO_2)	Yes, depending on the mercury content of the battery. If the zinc air batteries contain mercury they are treated as mercury batteries, then the mercury is extracted and recycled. The mercury free carcass is then returned to RMC for complete recycling. RMC have also designed and constructed customized equipment for the segregation button cell batteries by chemistry.
Silver oxide button cell ($ZnAgO_2$)	Silver oxide batteries are recycled – the silver is reclaimed for reuse. RMC have designed and constructed customized equipment for the segregation of button cell batteries by chemistry.
Nickel cadmium (NiCd)	Send NiCd batteries to Toxco in Ohio
Nickel metal hydride (NiMH)	Process NiMH batteries on site. RMC grinds and mechanically extracts nickel bearing materials, which are sold to the coatings industry. They use an all-mechanical process which includes milling, screening, drying, agitation. The material is sent through a piece of drying equipment. There are two processes to separate metal containing powder from the battery. A nickel concentrate is produced on site which is sold North America wide to the coatings and chemical industry for resist coatings and a variety of applications. RMC also produces some steel, some other components.
Lithium ion (Li-ion)	RMC processes lithium ion (Li-ion) on- site in a process similar to that used for NiMH batteries. They produce cobalt material which is sold for reclamation. Lithium carbonate cobalt is a reusble material where the lithium and cobalt are still combined. This is sent for cobalt recovery through the cobalt industry.
Lithium polymer (Li-poly)	RMC process lithium polymer (Li-poly) batteries which are similar to lithium ion, lithium primary are the only batteries they do not process.
Small sealed lead acid (SSLA)	RMC do not process small sealed lead acid (SSLA) batteries on-site, they send them off-site to lead smelters across North America.
Vehicular LABs	RMC accepts all sizes of lead acid batteries. There is no battery breaking on site, they bulk up the batteries and send off-site.
Mercury containing batteries	RMC send mercury containing batteries off-site for mercury removal (To Bethlehem Apparatus in US). The residue is returned for further processing.

Table 5.9: RMC Port Colborne, Ontario, Battery Processing Facility Details

Sources of Batteries	Most of feedstock is from the private industry – e.g photographic, automotive industry plus government agencies. They also receive stale-dated product from retailers
Other feedstock processed	Mercury wastes (including fluorescent lighting) and electronics, some scrap materials
Existing and maximum operational processing capacity	Existing capacity – can recycle on 3 shifts, 7 days per week, 10,000 tonnes, 20 million lbs of total mix. Tonnage available – 7,000 tonnes in Canada, mostly primary batteries Running 25% of production on one shift per day in early 2008 because of a lack of material. At that time RMC reported that they ramp up to 100% for one shift, then to 3 shifts per day. (Situation likely changed in July, 2008 with launch of Phase 1 of Ontario MHSW program which includes primary batteries)
Batteries as a Percentage of Total Feedstock	75% to 85% Balance – mercury wastes and electronics, some scrap materials
Number of employees at the facility	Company wide – 85 to 100 staff
Associated Costs	RMC can transport, sort and recycle batteries for less than $2.20 per kg ($1 per pound). Costs depend on the volume handled. The price can come down significantly if a high volume is involved.
End Markets for Processed Batteries	The coatings industry uses manganese, cobalt and lithium. There are lots of coatings manufacturers in Canada and the US Manganese – in a future process, manganese would go back to the coatings industry. Cobalt is mostly used by the coatings industry, for the blue colour as well as its instrinsic properties – blue barn paint and specialty applications use cobalt.

5.6 Xstrata, Sudbury, Ontario

Xstrata operate a very large copper and nickel operation in Sudbury, Ontario with a capacity of 550,000 tonnes per year. Batteries make up a "miniscule" part of the total processed at the site, but are a "niche market" for Xstrata which they want to grow. Their specialty is cobalt bearing batteries. Xstrata has recently invested $30 million in a rotary kiln incinerator at the Sudbury site which can process batteries in cell phones and laptops (the rotary kiln can accommodate high temperature incineration of plastics and meet emission limitations).

Xstrata has signed short term agreements with the German government to process Battery Directive related waste at their Sudbury facility. Xstrata pay for the recovered metals from the processed batteries, so they provide an attractive option for EU governments subject to Battery Directive requirements. In Europe, governments would have to pay to have the batteries handled, whereas Xstrata offers an option which may result in some net revenue.

Xstrata have stringent safety policies for evaluating new materials. Marketing staff identify where to sell nickel and cobalt, when the material is at end-of-life, and what strategies the company can use to get the material back to recycle. They have put pressure on large original equipment manufacturers (OEMs) to consider end-of-life when designing batteries and new battery chemistries. Details of the processing operation are presented in Table 5.10.

Table 5.10: Xstrata Sudbury Nickel Smelter – Battery Processing Facility Details

Sources of Batteries	End of life batteries Recall batteries – batteries that have gone to the market and been recalled. This source has been growing steadily in the last few years. Most batteries come from INMETCO. Battery production scrap is also a source. The industry has high reject rates because of their high quality needs.
Other feedstocks processed	Concentrate from ore from their own mines in Sudbury and Noranda, Quebec Xstrata buys mine concentrate from Africa and Australia
Processes On Site	The smelter recovers nickel, cobalt and copper. Batteries are broken into components. Xstrata can process batteries in two ways– they can introduce the batteries directly to a converter, or to a rotary kiln. If a load of end of life cell phone and laptop batteries arrives, or batteries packaged in plastic, processing options are limited by the flammability of the plastic. Then, batteries are directed to the rotary kiln where plastics are burned off, and all off-gases are treated through the afterburner to ensure that no dioxins are released. Feedstocks such as production scrap which could be finished in packaging or a powder component of a battery are directed to rotary kiln. The product is steel case with cobalt – this is then introduced to the converter. Some production scrap – there is no case, this can go directly into the converters. The converter is basically a big rotary vessel with a hole in the centre. As the temperature in the molten metal bath is 1300 degrees C, the battery components are broken down. Lithium is captured in the slag (and is lost), cobalt goes to the matt phase. Cobalt matt is produced through a hydrometallurgical chlorine process, cobalt metal output is sold to a metal broker in Switzerland.
Existing and Max operational Processing capacity	The Sudbury, Ontario smelter processes 550,000 tonnes of material a year. The new rotary kiln ($30 million investment) can treat 6,000 to 7,000 tonnes of end of life batteries.
Batteries as a Percentage of Total Feedstock	Batteries are a very small percentage of the feedstock, they are a niche market for Xstrata – their specialty is cobalt bearing batteries.
Number of employees at the facility	300 in smelter
Associated Costs	Xstrata do not want their operating costs or recoveries disclosed in the marketplace. They have a very efficient smelter, and are the cheapest globally. Xstrata have a niche in cobalt processing, and their recoveries are a step change higher than their competition. Xstrata charge a "treatment charge" for processing. They offer a significant cobalt credit back to customers who send batteries to them. When a load comes in, staff have a rough idea of what the cobalt content should be, but they pay based on an assay carried out at an on-site laboratory. End-of-life material – sometimes a battery comes in, there are small cell batteries from cell phones, these contain 18% to 22% cobalt if the plastic is taken away. If the processed batteries are in the original package, they have extra paper, etc. Xstrata will take the weight, but the load has a lower cobalt content when the weight of paper and packaging is taken away
End Markets for Processed Batteries	The cobalt matt is sold to Glencor which is a metal marketing company in Switzerland

5.7 INMETCO (International Metal Company)

INMETCO is located in Ellwood City, Pennsylvania, 35 miles north-west of Pittsburgh. The company is a subsidiary of Vale Inco (originally Inco, which was purchased by a Brazilian mining company in 2007) and has been in business since 1978. It is a fully permitted recycling facility with Part B hazardous waste storage status.

Although INMETCO does not process all battery types, it accepts all battery types at the site as a service to their clients. Batteries that are not processed at the site are sent to another reputable, properly permitted, recycling facility. Environmental audits of all third party sites are completed before any shipments are made.

INMETCO has always been the sole processing source for all batteries collected by the Rechargeable Battery Recycling Corporation (RBRC). Through RBRC, INMETCO receives batteries from across the US from sources which include municipalities as well as retailers such as Lowes, Walmart, etc.

Brokers procure batteries from across the US as far as the west coast. Some of the feedstock comes from hazardous material haulers such as Veolia, Clean Harbours, etc. Veolia brings in batteries by the truck-load, 40,000 lbs at a time. INMETCO also sell pre-paid boxes for smaller generators (Verizon, AT&T, etc) such as smaller battery companies, hospitals, or locations which do not have large numbers of batteries. These generators ship the boxes to INMETCO on a periodic basis. The generator is responsible for transportation.

The costing structure for battery recycling and processing depends on the battery and the value of the recovered metal. INMETCO charge or pay for batteries depending on the chemistry. They generally provide a credit for nickel bearing batteries because of the current value of nickel (which is their main focus), with a higher price paid for NiMH batteries than for NiCd batteries. They charge to process alkaline batteries.

INMETCO also process chrome solutions, and chrome or nickel sludges which come from steel mills. All feedstock produces a remelt alloy product which contains nickel with iron and copper and other metals from the solutions treated.

Processing of Batteries At the Site

There are seven cadmium furnaces at the INMETCO facility. The first three cadmium recovery furnaces were installed in 1995, followed by one additional furnace in 1996 and three additional units in 2000.

Cadmium furnaces reclaim cadmium from consumer cell and industrial cell nickel cadmium batteries. Recovered cadmium shot is called Cadmet®. It is drummed and mostly sent back to battery manufacturers for use in making new batteries. INMETCO also reclaims metals from nickel iron and nickel metal hydride batteries.

Nickel, chromium, iron and minor amounts of other metals are recovered in INMETCO's stainless steel recycling process, which produces a remelt alloy ingot that is remelted by the stainless steel industry for use in making new products.

Since INMETCO focuses on metal recovery, with primary attention to nickel, chrome, iron and cadmium, other materials are not processed at the site. Plastics and other battery packaging are separated and sent off-site to a properly permitted facility for incineration, or are consumed in the process furnaces. A hammermill and a thermal oxidizer remove plastic and contaminants before metal reclamation.

All INMETCO processes have appropriate pollution control devices, which are checked and monitored regularly by independent contractors and reported to the Pennsylvania Department of Environmental Protection.

Details on how specific batteries are processed are presented in Table 5.11

Table 5.11: Processing of Batteries at INMETCO, Pennsylvania

Battery	Processing
Zinc carbon (ZnC) primary	Zinc carbon (ZnC) batteries are handled like alkaline batteries. INMETCO removes the zinc and sends them to Horseheads in Palmerton, Pennsylvania where the zinc is recycled.
Alkaline ($ZnMnO_2$) primary	Alkaline batteries are consumed through the stainless steel recycling process. From these batteries, zinc, manganese and other metals are recovered while the carbon aids the steel making process as a reductant. Alkaline ($ZnMnO_2$) batteries are fed into the rotary hearth furnace and the zinc is fumed off and recovered in a wet scrubber system. Wastewater is sent to a treatment system and a cake is generated, pressed to remove water, then dried and sent to end markets.
Magnesium Batteries	The magnesium in magnesium containing batteries is used as a flux in the steel making process.
Lithium primary	INMETCO accepts lithium batteries and can process small amounts at the site. Some customers have large amounts of lithium primary batteries. INMETCO does not like to take large amounts (over 4,400 kg or 10,000 pounds) as they do not like to deal with lithium. They charge high fees because lithium primary batteries are so difficult to handle. They are directed into their process, for high temperature metal recovery.
Zinc air button cell (ZnO_2)	Zinc air button cell batteries are sent into the same process.
Silver oxide button cell ($ZnAgO_2$)	Silver oxide batteries are sent to a silver refinery for reclamation. They don't get very many silver oxide batteries because they don't process them at the site. They take silver oxide batteries as a courtesy to some customers. They manually sort them in the battery room to put them in the right piles and then send them to a silver refinery for reclamation.
Nickel cadmium (NiCd)	NiCd batteries go to the cadmium recover unit. Cadmium is sold back to battery manufacturers. The rest (nickel) goes to the main process. A remelt alloy ingot is sold to stainless steel companies.
Nickel metal hydride (NiMH)-	NiMH batteries go into the process, because INMETCO like the nickel.
Lithium ion (Li-ion) –	They sort and send lithium ion batteries to Xstrata Sudbury (formerly Falconbridge) who recovers the cobalt and recycles it.
Lithium polymer (Li-poly) –	Lithium polymer batteries are processed before being sent to a cobalt smelter for recovery of cobalt. INMETCO dont want to take lithium polymer batteries, as they contain vanadium. They send cobalt containing batteries to Xstrata Sudbury (formerly Falconbridge) where cobalt is recovered. The vanadium in lithium batteries is not good for their process, and cobalt is not good for their product.
Small sealed lead acid (SSLA)	SSLAs are sent to Newalta in Quebec (formerly Nova Pb).
Vehicular LAB	They take as courtesy for some customers but send them to Newalta in Quebec.

Mercury containing batteries are sent to a properly permitted mercury refiner.

Small amounts of lithium, silver oxide, zinc carbonate and every other battery type can be sent to INMETCO for recycling. These batteries are either consumed through the stainless steel recycling process, or are sent off-site if large quantities are involved.

Table 5.12: INMETCO, Pennsylvania Battery Processing Facility Details

Sources of Batteries	Sources of batteries include: the Rechargeable Battery Recycling Corporation (RBRC) from across the US (collected from municipalities and retailers such as Lowes, Walmart, etc); brokers, hazardous material haulers such as Veolia, Clean Harbours, etc.; smaller generators (Verizon, AT&T, etc) through pre-paid boxes; smaller battery companies; hospitals, locations which don't have large numbers of batteries.
Other feedstocks processed	Other feedstocks include: liquids by bulk tanker; chrome plating industries; other steel industries who use nickel or chrome in their processes; sludges in the form of cake and grindings and swarf (mill grindings) from steel industry manufacturing.
Existing and Max Operational Processing Capacity	NiCd batteries are probably the most limited in terms of available processing capacity because they have to go through the cadmium recovery process. The maximum capacity for NiCd batteries was estimated in early 2008 through cadmium recovery to be about 3,635 tonnes per year (4,000 tons per year). They operated at about 80% of that level in early 2008. The capacity for all other batteries processed is dependent on the received quantities but they average about an additional 1,820 tonnes (2,000 tons) per year of NiMH, alkaline, lithium, etc. that are run through their process. Lithium ion, lead, and mercury containing batteries are sent off-site for processing.
Batteries as a Percentage of Total Feedstock	The total waste processed through the plant is on the order of 63,640 to 72,730 tonnes per year (70,000 to 80,000 tons per year). Based on that number, batteries make up about 7-9% of the total raw materials processed.
Number of employees at the facility	110, this is the only location.
Associated Costs	Prices charged by INMETCO in February, 2008 reflected the comparative value or handling cost to the company for different batteries. They pay for some batteries based on the nickel content and the current value of nickel. They charge for other batteries (e.g. alkaline)
End Markets for Processed Batteries	Ingots are the key output from the recycling process – these go to the stainless steel industry. Cadmium goes to battery manufacturers. Nickel, chrome, and iron from spent batteries are recycled at INMETCO and are processed and reclaimed into their stainless steel remelt alloy product. Cadmium from NiCd batteries is recycled to produce up to 99.99% pure cadmium and is used to make new NiCd batteries.

5.8 Kinsbursky Brothers (Toxco), Ohio

Kinsbursky Brothers and Toxco are part of the same company which includes:

- Toxco Ohio
- Toxco Materials Management Centre
- Lithchem
- Big Green Box

Toxco Canada was discussed separately because it focuses on processing lithium based batteries. Kinsbursky Brothers Inc and Toxco Ohio are discussed in this section.

Toxco, Ohio operates two large battery processing facilities in Ohio:

- A universal waste facility in Baltimore, Ohio (consolidation site for all battery chemistries from all over the East Coast). When 40,000 lbs of batteries have been accumulated they are shipped to Trail, B.C. This facility also does some handling – staff go through each drum of batteries to make sure no lithium batteries are going into the furnace.

- Toxco Ohio operates a Part B permitted TSD (treatment, storage, disposal) facility in Lancaster, Ohio, 30 minutes outside Columbus, Ohio. The universal waste facility processes battery chemistries including lead, silver, nickel, mercury and others. The facility also consolidates and provides logistics support for East Coast and Southern US battery recycling. Lancaster is one of only two facilities in the US that has the Best Demonstrated Available Technology for cadmium recovery. Many Canadian battery recyclers send batteries to Toxco, Ohio for this service. The site has 6 retort furnaces and a lead breaking operation which handles 4 million lbs of lead per year.

The company perceives themselves to be battery recyclers first and foremost – that is where they want to grow the business and to excel. They have a corporate objective to be the best battery recycler in North America and they see battery recycling as their core business and a growth opportunity.

Details of the batteries processed at Toxco, Ohio are summarized in Table 5.13. Details of the processing operation are presented in Table 5.14.

Table 5.13: Processing of Batteries at Toxco, Ohio Facility

Battery	Processing
Zinc carbon (ZnC)	The facility accepts zinc carbon and zinc manganese batteries. They send them to RMC in Port Colborne – this is the recycling option they offer to customers. They charge a fee, mostly transportation costs, but customers get a volume discount. They also offer secure landfill, a lot cheaper at about one third of the cost of recycling, excluding volume discounts. Some customers want to recycle to be consistent with their corporate image.
Alkaline ($ZnMnO_2$)	Toxco, Ohio accepts alkaline batteries, they do not process at the site. Instead, they work with a partner and provide secure landfill. Alkaline batteries are sent to EQ, Bellvue, Michigan.
Lithium primary	Lithium primary batteries are consolidated and sent to Toxco, Trail, BC for lithium processing along with lithium ion batteries. Toxco, BC is the only facility in North America which handles all lithium chemistries.
Zinc air button cell (ZnO_2)	Toxco, Ohio do not process zinc air button cell (ZnO_2) batteries. They send anything containing zinc that the customer wants recycled to RMC in Port Colborne - all zinc batteries go to RMC. If they receive zinc carbon batteries with mercury they go to a mercury recycler.
Silver oxide button cell ($ZnAgO_2$)	Toxco, Ohio consolidates and bulks up silver oxide button cell ($ZnAgO_2$) batteries – silver is valuable, therefore they send these batteries to a precious metals recycling company, Met Tech in California and in Worchester, Mass.
Nickel cadmium (NiCd)	Nickel cadmium (NiCd) batteries are processed in Ohio. The batteries are processed at a temperature of up to 1,000 degrees. The furnaces were built by Energizer; they include condensation collection boxes; the cadmium vapourizes and goes to the condensation box where the cadmium is cooled and funneled into a tap to produce an ingot which is 99.9999% pure cadmium.
Nickel metal hydride (NiMH)-	Toxco, Ohio processes nickel metal hydride (NiMH) batteries and recovers lanthanum, yttrium (MISH metals) – rare earth elements. Each company is very tight lipped about the amounts and volumes processed and used.
Lithium ion (Li-ion) –	Consolidate and send to Toxco, Trail, BC.
Lithium polymer (Li-poly)	Consolidate and send to Toxco, Trail, BC.
Small sealed lead acid (SSLA)	Toxco, Ohio accept from very small to very large lead acid batteries. They provide a range of preparation services for the batteries - automotive as-is, breaking, draining potassium to prepare for smelter, etc. They offer some value added work, and then feed the batteries to the lead smelters; the services offered depend on commodity prices and relationships.

End Markets	Toxco, Ohio picks end markets which are well established – some companies or brokers are good at industrials, automotive, they use RSR (Granite). Their end markets prefer to work with Toxco and Kinsbursky, who can supply large amounts (1.8 million kg (4 million pounds) per month of lead (Lancaster). Their permit in California has been expanded from 1,820 to 5,460 tonnes per month (4 million to 12 million pounds per month). Toxco, Ohio collects and sends batteries to recyclers which are considered best in the business; their companies have their own sales efforts.

Table 5.14: Toxco Ohio Battery Processing Facility Details

Sources of Batteries	Toxco, Ohio estimate that 80% of batteries come from 20% of their customers.
Other feedstocks processed	Catalytic converters; Xerox de-manufacturing
Processes On Site	Their Baltimore facility services the US domestic market and acts as their east coast consolidation facility. They bring all the batteries that they can manage, and some they can not manage themselves (e.g. mercury). Clients pay a handling fee and Toxco, Ohio will handle the batteries and send them to someone else for processing. Nickel based batteries are processed in Lancaster, where there are six retort furnaces on site to separate cadmium from nickel. Lithium based batteries are consolidated to send to Toxco BC. Lead acid battery breaking occurs at the Lancaster facility.
Existing and Max Operational Processing Capacity	Capacity is 1,310 to 1,830 tonnes per year for nickel containing batteries processed in Ohio. The capacity in early 2008 (6 furnaces x 5 days per week) was about 110 tonnes per month (120 tons a month) (both consumer and industrial cell batteries). This is expandable to 153 tonnes per month (168 tons per month) by adding shifts. The processing technology is scalable – Toxco, Ohio could add new furnaces each with capacity to process 910kg (one ton) of batteries per day (1 furnace roughly = 27 tonnes (30 tons) per month operating 7 days per week).
Batteries as a Percentage of Total Feedstock	Toxco – high 90's Kinsbursky – Batteries are a lower proportion of the total (high 70's to maybe 80%) as the site also provides catalytic converter recycling ($30 million per year); Xerox for de-manufacturing, and research and development.
Number of employees at the facility	People directly on batteries about 350. Toxco – 180 people; Kinsbursky – 100-150 people; 350-450 total for the company; Ohio – Lancaster 112-113; Baltimore 15 additional; 2 in Philadelphia research facility. The company also decontaminates radioactive material from Oak Ridge, Tennessee.
Associated Costs	Company representatives could not share costs. They have made investments and have purchased appropriate technology to bring about optimal environmental outcomes. They make a percentage on material they sell to nickel furnaces, but can not share costs because of competition. They have invested heavily in technology and equipment. They have six furnaces and have invested $1 million to make them efficient and competitive in the market. This ensures good environmental outcomes, when compared to a broker from outside taking batteries to China where environmental controls are less stringent.
End Markets for Processed Batteries	In Ohio, steel mills use zinc and manganese, as well as the ferrous case material. They sell cadmium ingot to the highest bidder. In the past the lion's share of cadmium would be sold to battery companies. Cadmium is now sold as a colour and pigment enhancer (red) and to specialty applications. They sell residual ferro-nickel which is very high grade scrap. They sell to rare earths, stainless steel or specialty alloy companies, e.g aerospace companies where corrosion resistance is essential, stainless steel contains 13% to 16% nickel (with 13% to 16% chromium)

5.9 Comments on Challenges to Battery Recyclers

Battery processors were asked to comment on on-going challenges related to battery recycling. The comments were received during interviews which took place between January and March, 2008 and were wide ranging with a number of consistent themes:

- Sorting of batteries is the most difficult step;
- In early 2008, processors reported a lack of battery feedstock (for lithium battery and alkaline battery processors) – this may change with the launch of the Ontario MHSW program in July, 2008 which included primary consumer batteries and which is being expanded to all consumer batteries in 2010;
- Mercury "knock-off" or counterfeit batteries, which refer to batteries that contain mercury but should not (creating a concern for air emissions);[52]
- Long transportation distances discourage battery recycling (Toxco Trail BC is far from most large generator sources – many batteries are landfilled rather than recycled);
- High commodity prices – disreputable companies enter the marketplace;
- Companies offer high prices or lower costs and ship to China where controls are lower – US and Canadian companies have invested heavily in pollution control but compete with high prices and low costs of disreputable companies;
- Overlap between battery recycling and electronics recycling – some products (e.g. cell phones and laptop computers) are very integrated;
- Future battery chemistries – some lithium chemistries concern recyclers because of lack of valuable material;
- Hybrid cars – there is a plan by some manufacturers to use lithium iron phosphate batteries in hybrid cars (GM, 2011) – these batteries do not contain materials of value to recyclers;
- A comment was made that battery recyclers need their own association to represent their own unique needs. The formation of BRANA (Battery Recycling Association of North America) was announced in March, 2008; and
- Importance of working with OEMs at product design phase to consider EOL (end of life) management.

[52] Environment Canada's risk management strategy for mercury-containing products outlines an approach to address this issue, by restricting the amount of mercury contained in products marketed in Canada, including batteries. Note that the North American battery manufactures have voluntarily stopped adding mercury to batteries since 1996.

6. Future Trends in Battery Design and Chemistries

6.1 Trends in Battery Design

Batteries are the essential power source in the operations of portable electronic and electrical devices and are essential as EV (electric vehicles) and HEV (hybrid electric vehicles) power sources. Consequently, increasing attention is being paid to new technologies and improvements in lifespan, power and the weight of the batteries. The battery industry is engaged in a fine balancing act between technology advances and quality control, resulting in an interesting period for battery innovation and trends.

Demands for higher energy density in smaller products such as iPods where weight is key to the product success, have led to numerous innovations which continue at an increasing speed.

Batteries become more expensive as they evolve into smaller, more compact designs which require lighter, more expensive materials such as lithium and cobalt.

The battery industry[53] has commented that the key trends they foresee for the coming years are:

- Newer batteries will enhance safety, energy density and other performance;
- Newer products will reduce costs (by moving to less expensive materials);
- Newer products will eliminate or reduce problematic materials; and
- Newer products will adapt technology for newer applications, such as the use of lithium ion batteries in power tools and hybrid electric and electric vehicles.

6.2 Secondary Lithium Battery Developments

Battery manufacturers are addressing a number of safety issues associated with rechargeable lithium batteries.

A significant recall of lithium batteries occurred in August, 2006 from portable product makers including Apple, Dell, Fujitsu, Hitachi, IBM, Lenovo, Panasonic, Sharp, Sony, Gateway, and Toshiba. More than 10 million units from multiple computer makers were recalled. According to a battery analyst, safety concerns are now the biggest and most immediate issue impacting the secondary lithium battery market.[54]

The US government has responded to the increased concerns over the safety of lithium batteries by banning the checking of loose lithium ion and lithium polymer batteries in

[53] PRBA comment during technical review

[54] Safety first for rechargeable lithium-ion batteries, February 17, 2008, at www. purchasing.com

luggage on flights starting in 2008.[55] In response, the battery industry has invested in potential alternative battery designs for laptop computers and other hand-held devices. There are a number of alternative lithium ion and lithium polymer battery and other battery chemistries under development that could reduce or eliminate the problem. These include non-cobalt-based lithium-ion alternatives from companies such as Toshiba, A123Systems and Valence. A non-lithium alternative includes Altair Technologies' NanoSafe rechargeable, nano titanate battery.[56]

Lithium ion dominates the batteries used in laptops at this time. Laptop makers do not foresee a successor in the near future that can rival lithium ion batteries in supplying more power to laptops without driving up the system's weight or size. Instead, the computer industry is focusing on optimizing laptops by analyzing user behavior and saving power consumption where possible.[57]

There have been a few widely publicized cases of thermal runaway in lithium batteries, which is very rare. When it occurs, it involves a failure during manufacturing or the charging of batteries in incompatible charging systems. For fixed energy density, as battery size decreases, so does the risk of thermal runaway.

Lithium primary and lithium secondary batteries have very different chemistries and separate risk profiles. Lithium ion batteries, unlike lithium metal batteries, are not manufactured from lithium metal, and a lithium ion battery fire does not present risks associated with exposing lithium metal to water (which will make the lithium metal burn). However, lithium ion batteries contain organic solvents, which are flammable. The failures of lithium ion batteries have been declining because manufacturers have improved their design and manufacturing techniques.

The battery industry feels that it also merits noting that billions of lithium ion cells have been manufactured and distributed worldwide – 3 billion in 2007 alone. The number of failures involving these batteries has been miniscule. When lithium ion batteries fail, it typically is because of a flaw during manufacturing leading to a short circuit with overheating and possible venting or ignition. However, many of the lithium ion failures – particularly in recent years, have occurred in counterfeit batteries that unlawfully carry major brand labels, or because the batteries were placed in incompatible charging systems.

Recalls of large numbers of products typically occur not because of widespread failures, but because of a small number of problems. When a problem is found with a handful of units in a production line, the manufacturer typically will voluntarily recall all of the products of the same type that could potentially have the same problem. This is done to ensure public safety, even though the likelihood is that most of the recalled products do not actually carry the product flaw.[58]

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[55] Building batteries that don't explode, February 28, 2008, CNET news

[56] Safety first for rechargeable lithium-ion batteries, Februrary 17, 2008, at www.purchasing.com

[57] What's next for notebooks? February 2008, Computer World

[58] PRBA comment

While the use of lithium ion and lithium polymer secondary batteries has become a staple in consumer devices such as digital cameras, camcorders, laptops, personal digital assistants (PDAs), MP3 players and cell phones, they have not penetrated the industrial market until relatively recently. Lithium ion and lithium polymer batteries have begun to make inroads in industrial equipment such as the cordless power tool market, data collection equipment, space and defense applications and medical applications. [59]

Other developments include:

- Titanate Anodes - Altairnano, a small firm based in Reno, Nevada, has announced a nano-sized titanate electrode material for lithium-ion batteries.[60] It has claimed that the prototype battery has three times the power output of existing batteries and can be fully charged in six minutes. However the energy capacity is about half that of normal li-ion cells. The company also states that the battery can handle approximately 20,000 recharging cycles, therefore durability and battery life are much longer, estimated to be around 20 years or four times longer than regular lithium-ion batteries. The batteries can operate from -50 °C to over 75 °C and will not explode or result in thermal runaway even under severe conditions because they do not contain graphite-coated-metal anode electrode material.
- In April 2006, a group of scientists at MIT announced a process which uses viruses to form nano-sized wires. These can be used to build ultra-thin lithium-ion batteries with three times the normal energy density[61].
- In November 2007, Subaru unveiled their concept G4e electric vehicle with a lithium vanadium oxide based lithium ion battery, promising double the energy density of a conventional lithium ion battery (lithium cobalt oxide and graphite)[62]. In the lab, Lithium vanadium oxide anodes, paired with lithium cobalt oxide cathodes, have achieved 745Wh/l, nearly three times the volumetric energy density of conventional lithium ion batteries.
- In December 2007, researchers at Stanford University reported creating a lithium ion battery with ten times the energy density (amount of energy available by weight) through using silicon nano-wires deposited on stainless steel as the anode.[63] The battery takes advantage of the fact that silicon can hold large amounts of lithium, and helps alleviate the longstanding problem of cracking by the small size of the wires.

6.3 Hybrid Cars

Car manufacturers have begun to address the need for more sophisticated batteries for use in hybrid vehicles. In February 2008, Daimler, Mercedes-Benz announced that it will introduce an S-Class hybrid equipped with a lithium-ion battery next year in what was a

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[59] World Emerging Battery Markets, May 2006. Frost & Sullivan

[60] www.**altairnano**.com/markets_energy_systems

[61] Science Express (preprint) www.sciencemag.org/cgi/content/abstract/1122716

[62] www.gizmag.com/go/8281/

[63] www.sciencedaily.com/releases/2007/12/07

crucial technological breakthrough. The concern over lithium battery's longevity and extensive heat build up in large applications, such as those required for passenger vehicles has deterred its design and application in vehicles. Mercedes-Benz claims to have overcome these problems by integrating the lithium-ion batteries directly into the cooling system of the car to allow them to operate at an optimum temperature of between 59 and 95 degrees Fahrenheit. [64]

The main advantages of the newly developed lithium-ion battery are its very compact dimensions and far superior performance compared to conventional nickel-metal hybrid batteries currently powering the Toyota, Prius and early GM hybrid vehicles. The new batteries provide 33% more power, but take up 24% less space and weigh 40% less than the nickel-metal hydride batteries. Furthermore, a lithium-ion battery has the same capacity but half the weight of a lead-acid battery, making the vehicle more fuel-efficient. [65]

General Motors has announced that it will introduce a lithium-ion-based plug-in hybrid Saturn Vue on the market in 2010. GM also plans to use lithium-ion batteries to power its electric vehicles based on the Volt concept. GM plans to deliver the electric cars, which store power in batteries that are charged by plugging into the power grid or by using small onboard gasoline or diesel engines or fuel cells to generate onboard power, in 2010 as well. Toyota announced in December 2007 that it was preparing to start mass-producing lithium-ion batteries for its low-emissions cars.[66]

Other companies have announced breakthroughs in the chemistry of lithium batteries. The development of the Lithium Iron Phosphate (LiFePO4) battery which can sustain a longer charge than traditional lead-acid batteries and uses safe chemistry that can be put into a car is a major breakthrough. With this development, the total cost of energy for electric transportation has for the first time become cheaper than the cost of fuel when calculated on a per kilometer basis.[67]

Another company, EEStor, of Cedar Park, Texas, claims that it solved the problem of battery degradation using a ceramic ultracapacitor with a barium-titanate insulator that can absorb higher amounts of energy per given unit of mass (called specific energy). The company claims that the "ultracaps" can be used and recharged for decades with almost no degradation; the downside is that they tend to hold about 25 times less energy per pound than lithium ion batteries, meaning that they have to be recharged fairly often. In 2007, Zenn Motors, which manufactures electrical vehicles, made a big investment in the company. According to Zenn, traveling 500 miles in an EEStor-powered midsized vehicle would use only $12 in electricity compared to $85 in gas for a combustion-engine at current U.S. gas prices.[68]

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[64] The Mercedes-Benz S400 BlueHybrid is expected to go on sale in the United States in the third quarter of 2009, with a lithium-ion battery pack. February 29, 2008 In Auto Week

[65] Mercedes to launch lithium-ion hybrid in 2009, February 29, 2008, REUTERS and The new batteries provide 33% more power, but take up 24% less space and weigh 40% less than the nickel-metal hydride batteries, March 4, 2008, Detroit Free Press and Lead still a contender for hybrid cars: industry, March 4, 2008, REUTERS

[66] GM says it has lithium-ion batteries for hybrids figured out, March 4, 2008, USA Today

[67] Future of Transportation - PART II By Shai Agassi, Founder and CEO, Project Better Place, February 11, 2008 at www.egovmonitor.com/node/17105/print

[68] Cracking The Battery Barrier, February 28, 2008, at www.Forbes.com

The battery recyclers interviewed during this project commented that the proliferation of hybrid cars will eventually have a big impact on their industry. Current hybrids use NIMH batteries, but there is a movement towards lithium based batteries. One processor expressed concern that some of the new lithium chemistries being considered are not of interest to recyclers.

One interviewee described a recent experiment where a battery consortium ran a car with a LAB side by side with a car running on a NiMH battery. Both cars ran for 100,000 miles. The cost per mile of the LAB powered car was far less expensive compared to the car using the NiMH battery. This led the interviewee to believe that LABs could have resurgence as a power source for hybrid or electric cars.

Traditional LAB did not need to meet performance requirements for hybrid cars. The original design for LABs was to achieve particular charging goals. Old LABs were designed for cranking and some small power requirements. LABs have not yet been re-designed to meet hybrid requirements but there have been a number of recent developments and breakthroughs in LAB design to meet future market requirements.

6.4 Other Battery Trends

Sharp Electronics Corp. is forming a partnership with Daiwa House Industry and Dai Nippon Printing to make home batteries that will be powered by small solar panels available for sale in Japan in 2009 or 2010. The solar panels will enable lithium ion batteries to store up to 18 kilowatt-hours of power, enough to run home electronics such as laptops.[69]

In February 2008, two of the largest U.S. toy companies, Toys ‘R’ Us Inc. and Mattel Inc., announced that they will phase out the use of nickel-cadmium batteries in toys. These announcements were made as more information is published about widespread environmental contamination and health problems in China associated with the production of nickel-cadmium batteries and health and safety concerns when children use the toys.[70]

[69] Green-tech news harvest: Solar batteries for home electronics, February 27, 2008, CNET news
[70] Toys 'R' Us, Mattel Phase Out Cadmium Batteries, February 19, 2008, Wall Street Journal

7. Greenhouse Gas Estimates

Greenhouse gas benefits of current and possible future recycling rates for primary and secondary batteries were developed for this study, using 2007 as the baseline year for calculations. Greenhouse gas benefits of achieving a 25% and a 50% recycling rate for primary and secondary consumer batteries were estimated and were compared to the greenhouse gas benefits of existing recycling rates in this section. The greenhouse gas benefits of lead acid battery recycling are presented in Section 8.

These estimates were developed using Canadian national GHG emission factors for recycling compared to landfill from the report *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update* by ICF Consulting prepared for Environment Canada and Natural Resources Canada, dated October, 2005. GHG emission factors used for the analysis represent the difference between refining metals and other materials to manufacturer-ready grade from raw inputs compared to the energy required to manufacture the same tonnage of material using recycled inputs. It is the comparison of energy requirements for the different inputs that is the basis for the development of the GHG benefits – typically manufacturing with recycled inputs saves considerable energy and this saved energy translates to GHG savings.

The ICF report provided GHG emission factors for:

- Ferrous metal (1.18); and
- Aluminum (6.49)

All GHG emission factors in this discussion are in units of tonnes of eCO_2 (equivalent tonnes of carbon dioxide) per tonne of each material recycled. The emission factors exclude the impacts of local collection, storage and transportation of batteries for recycling as these impacts are minor compared to the "upstream" benefits of recycling.

Emission factors were developed for lead (1.88), zinc (3.78) and nickel (14.45) by Natural Resources Canada staff, based on Henstock and ICF.[71]

For this analysis, no emission factors could be located for cadmium, manganese, silver, mercury, lithium or cobalt. An emission factor of 1.18 (the same as for iron and steel) was used for these metals as well as for "Other metals" in the analysis. This may be a low value, but cannot be verified within the scope of this analysis. The lowest emission factor for metals was used to provide a conservatively low GHG estimate.

Better emission factors need to be developed for each of these materials in order to do a proper GHG analysis of battery policy options. The estimate presented in this report provides an estimate which is considered conservatively low and which needs to be refined.

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[71] Michael Henstock, "The Recycling of Non-Ferrous Metals", ICME, 1996; and ICF Consulting, "Determination of the Impact of Waste Mgt Activities on GHG Emissions, 2005 Update", Environment Canada and Natural Resources Canada

An emission factor of 2.75 was used for “plastic, paper and carbon”. This is a blended rate for various plastics and papers in the ICF report. The GHG benefit calculations assumed that half of the “plastic, paper and carbon” was actually recycled.

The GHG estimates are developed for the 5-year hoarding scenario only, as this gives the higher value. A lower value would be estimated for a 15 year hoarding scenario, as lower tonnages are involved.

Table 7.1 presents the GHG benefit estimates for primary batteries. It was assumed that current collection rates are 1%, although the actual rate is probably below that level. Estimates of the GHG impacts of 25% and 50% collection rates for primary batteries are included in the table, to show a range of potential GHG benefits of higher recycling rates for batteries.

The estimates show that current recycling of primary batteries has a GHG benefit of 291 tonnes of eCO_2 per year. This would increase to 7,263 tonnes at a 25% recycling rate and to 14,527 tonnes at a 50% recycling rate.

Table 7.2 presents the GHG benefit estimates for secondary consumer batteries. The 2007 recycling rates provided by RBRCC were used as the baseline, and GHG benefits of 25% and 50% recycling scenarios were developed. The GHG calculations presented in Table 7.2 show that recycling of secondary consumer batteries currently has a GHG benefit of 955 tonnes of eCO_2 per year, partly due to the very high emission factor for nickel (14.45), which is present in NiCd and NiMH batteries. This figure would increase to a benefit of 2,682 and 4,245 tonnes of eCO_2 if 25% and 50% recycling levels were reached. 2007 has been used as the baseline year for all of these calculations.

It should be noted that the convention for presenting GHG calculations is to show savings in GHG (i.e. GHG which are not produced as a result of energy savings) as a negative number or in parenthesis. Therefore, in Tables 7.1 and 7.2, values shown as (1) or -1 tonnes of eCO_2 represent “negative emissions” (emissions not created) in tonnes of eCO_2.

Table 7.1: Estimated GHG Benefits of 25% and 50% Recycling Scenarios for Primary Consumer Batteries

(Scenario 1: 5-Year Hoarding), (tonnes carbon dioxide equivalent saved per year)

	iron & steel*	Pb***	Ni**	Cd***	Zn**	Mn***	Ag***	Hg***	Li***	*Al	Co***	other metals	alkali	Other non-metals	plastic, paper carbon	TOTAL GHG
Total End of Life 2007	3,392.7	4.8	52.2	-	2,383.0	2,953.3	3.9	0.1	6.7	-	-	165.4	813.6	2,155.4	1,368.6	
Total Recycled 2007	33.9	0.05	0.5	-	23.8	29.5	0.04	0.001	0.1	-	-	1.7	8.1	21.6	13.7	
Total Landfilled (Disposed) 2007	3,358.8	4.7	51.7	-	2,359.2	2,923.8	3.8	0.1	6.6	-	-	163.7	805.5	2,133.8	1,354.9	
GHG Emission Factor – Recycling vs Raw Materials eCO2/tonne	-1.18	-1.88	-14.45	-1.18	-3.78	-1.18	-1.18	-1.18	-1.18	-6.49	-1.18	-1.18	0	0	-2.75	
GHG Benefit of Current Recycling (1%)	(40.03)	(0.09)	(7.55)	-	(90.08)	(111.64)	(0.15)	(0.00)	(0.25)	-	-	(3.11)	-	-	(37.64)	**(290.53)**
25% Recycling																
Materials Recycled	848	1	13	-	596	738	1	0.02	2	-	-	41	203	539	342	
Materials Landfilled	2,545	4	39	-	1,787	2,215	3	0.1	5	-	-	124	610	1,617	1,026	
GHG Benefits of 25% Recycling	(1,000.84)	(2.25)	(188.73)	-	(2,251.96)	(2,790.90)	(3.66)	(0.08)	(6.29)	-	-	(77.74)	-	-	(940.91)	**(7,263.37)**
50 % Recycling																
Materials Recycled	1,696.3	2.4	26.1	-	1,191.5	1,476.7	1.9	0.0	3.3	-	-	82.7	406.8	1,077.7	684.3	
Materials Landfilled	1,696.3	2.4	26.1	-	1,191.5	1,476.7	1.9	0.0	3.3	-	-	82.7	406.8	1,077.7	684.3	
GHG Benefits of 50% Recycling	(2,001.69)	(4.51)	(377.47)	-	(4,503.92)	(5,581.80)	(7.31)	(0.17)	(12.57)	-	-	(155.47)	-	-	(1,881.82)	**(14,526.73)**

* indicates emission factors from ICF; ** indicates emission factors developed by Natural Resources Canada; *** indicates emission factor not available so value for iron and steel used

Table 7.2 Estimated GHG Benefits of 25% and 50% Recycling Scenarios for Secondary Consumer Batteries

(Scenario 1: 5-Year Hoarding), (tonnes carbon dioxide equivalent saved per year)

	iron & steel*	**Pb*** **	**Ni****	**Cd*** **	**Zn****	**Mn*** **	**Ag*** **	**Hg*** **	**Li*** **	***Al**	**Co*** **	**other metal**	**alka li**	**H_2 $S0_5$**	**Other non-metal**	**plastic, paper carbon**	**TOTAL GHG**
Total End of Life 2007	736.3	209.5	517.2	287.2	2.7	2.7	-	-	1.5	2.6	20.2	46.0	49.3	51.6	263.0	255.0	
Total Recycled 2007	66.1	21.0	43.3	23.0	0.3	0.3	-	-	1.0	1.6	6.8	7.5	4.2	5.2	29.5	25.1	
Total Landfilled (Disposed) 2007	670.2	188.6	473.9	264.2	2.5	2.5	-	-	0.6	1.0	13.4	38.4	45.1	46.4	233.5	229.9	
GHG Emission Factor – Recycling vs Landfill	-1.18	-1.88	-14.45	-3.78	-3.78	-3.78	-3.78	-3.78	-3.78	-6.49	-3.78	-1.88	0	0	0	-2.75	
GHG Benefit of Current Recycling	(78)	(39)	(626)	(87)	(1)	(1)	-	-	(4)	(10)	(26)	(14)	-	-	-	(69)	(955)
25% Recycling																	
Materials Recycled	184.1	52.4	129.3	71.8	0.7	0.7	-	-	0.4	0.6	5.0	11.5	12.3	12.9	65.8	63.8	
Materials Landfilled	552.2	157.2	387.9	215.4	2.1	2.1	-	-	1.2	1.9	15.1	34.5	36.9	38.7	197.3	191.3	
GHG Benefits of 25% Recycling	(217)	(98)	(1,868)	(271)	(3)	(3)	-	-	(1)	(4)	(19)	(22)	-	-	-	(175)	(2,682)
50 % Recycling																	
Materials Recycled	335.1	-	210.6	143.6	-	-	-	-	-	-	-	-	19.1	-	105.3	95.7	
Materials Landfilled	401.2	209.5	306.6	143.6	2.7	2.7	-	-	1.5	2.6	20.2	46.0	30.1	51.6	157.7	159.3	
GHG Benefits 50% Recycling	(395)	-	(3,043)	(543)	-	-	-	-	-	-	-	-	-	-	-	(263)	(4,245)

* indicates emission factors from ICF; ** indicates emission factors developed by Natural Resources Canada; *** indicates emission factor not available so value for iron and steel used

8. Vehicular Lead Acid Batteries

This section summarizes data for vehicular lead acid batteries in Canada under the general headings used for the consumer batteries throughout this report:

- Sales data;
- Flow estimates;
- Collection and Recycling infrastructure;
- Battery processing infrastructure;
- Future trends; and
- GHG impacts of recycling.

Data on consumer small sealed lead acid (SSLA) batteries were presented in previous sections of this report. Much of the descriptive text in this section is quoted directly from a recently released report *Practices and Options for Environmentally Sound Management of Spent Lead Acid Batteries within North America* released by the Commission for Environmental Cooperation (CEC) in December, 2007.

8.1 Lead-Acid Battery Uses

Lead-acid batteries (LABs) have many applications which may employ different voltages, sizes and weights. The batteries may be classified as[72]:

- **automobile** - those batteries used as the main energy source for starting, lighting and ignition (SLI batteries) in vehicles such as cars, trucks, tractors, motorcycles, boats, planes, etc.;
- **generic** - batteries used in portable tools and devices, domestic alarm systems, emergency lights, etc.;
- **industrial** - batteries for stationary applications such as telecommunications, electrical power stations, uninterrupted power supplies or no-breaks, load leveling, alarm and security systems, general industrial use and starting of diesel motors;
- **motive** - batteries used to transport loads or people: fork lift trucks, golf carts, luggage transportation in airports, wheelchairs, electric cars, buses, etc.;
- **special** - batteries used in specific scientific, medical or military applications, and those that are integrated in electric-electronic circuits.

This report addresses automobile lead acid batteries only.

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[72] Technical Guidelines for the Environmentally Sound Management of Waste Lead-Acid Batteries, Annex to United Nations Environment Programme Document, UNEP/CHW.6/22 8 August 2002

8.2 Sales Data and Sales Projections

Canadian lead acid battery unit sales for OEMs as well as after market sales from 2001 to 2015 were purchased from Global Industry Analysts (Lead Acid Batteries, May 2008).

The data include lead acid batteries for:

- original equipment markets (OEM); and
- after-market and replacement market for motorcycles, passenger cars and commercial vehicles.

Sales of automotive batteries are projected to increase at about 1.8% per year from 2011 to 2015 (GIA, 2008). About 10.3 million units were sold in 2007. Of these, about 5 million units were sold to the consumer automotive sector, and another 4.9 million units for commercial vehicles. About 349,000 units were sold in or for motorcycles. Sales are expected to increase steadily to a total of 11.5 million units by 2015.

Table 8.1 presents lead acid battery sales data for 2001 to 2015. The table shows that sales are steady from one year to another, and increase slowly over time.

Table 8.1: Vehicular Lead Acid Battery Sales Data 2001 to 2015

Canada Lead Acid Batteries Sales (1000's of Units)																2011 to 2015	2001 to 2010
End-Use Segment	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**% CAGR**	**% CAGR**
Original Equipment Market	**2,600**	**2,706**	**2,636**	**2,803**	**2,843**	**2,895**	**2,940**	**2,976**	**3,007**	**3,043**	**3,085**	**3,132**	**3,185**	**3,243**	**3,306**	**1.74**	**1.76**
Motorcycles	71	80	86	96	103	112	119	125	131	137	143	150	158	166	175	5.17	7.56
Passenger Cars	1,279	1,373	1,344	1,340	1,355	1,375	1,392	1,407	1,419	1,434	1,451	1,470	1,492	1,516	1,542	1.54	1.28
Commercial Vehicles	1,250	1,253	1,205	1,367	1,386	1,408	1,428	1,444	1,457	1,473	1,491	1,512	1,535	1,561	1,589	1.60	1.84
Aftermarket / Replacement Market	**6,580**	**6,859**	**6,698**	**7,118**	**7,216**	**7,284**	**7,354**	**7,407**	**7,446**	**7,509**	**7,599**	**7,711**	**7,847**	**7,999**	**8,167**	**1.82**	**1.48**
Motorcycles	138	155	167	184	196	214	230	245	258	272	288	306	324	345	367	6.19	7.89
Passenger Cars	3,291	3,555	3,482	3,474	3,522	3,572	3,606	3,630	3,646	3,672	3,706	3,749	3,800	3,859	3,924	1.44	1.23
Commercial Vehicles	3,152	3,149	3,049	3,460	3,497	3,499	3,518	3,532	3,542	3,564	3,604	3,657	3,722	3,795	3,877	1.84	1.38
OEM & Aftermarket	**9,180**	**9,565**	**9,334**	**9,920**	**10,059**	**10,179**	**10,293**	**10,383**	**10,453**	**10,552**	**10,684**	**10,843**	**11,031**	**11,241**	**11,473**	**1.8**	**1.56**
Motorcycles	208	235	254	280	299	325	349	370	389	409	431	456	482	511	542		
Passenger Cars	4,570	4,928	4,826	4,813	4,877	4,946	4,998	5,037	5,065	5,106	5,157	5,219	5,292	5,375	5,466		
Commercial Vehicles	4,402	4,402	4,254	4,827	4,883	4,907	4,946	4,977	4,999	5,037	5,095	5,169	5,257	5,356	5,465		

Note: % CAGR is Percent Compound Annual Growth Rate

The weight of lead acid batteries sold into the Canadian market was estimated using the following unit weights:[73]

- Passenger car lead acid battery: 17.7 kg
- Motor cycle battery: 4.3 kg
- Commercial lead acid battery: 24.1 kg

Automotive lead acid batteries account for by far the largest weight of batteries sold into the Canadian marketplace, at 209,167 tonnes in 2007, increasing to 230,796 tonnes in 2015, unless significant changes occur to automobile and commercial vehicle design between now and then. Batteries for commercial vehicles account for the greatest weight, followed by passenger vehicle LABs, with a small amount of the total for motorcycle batteries.

Table 8.2: Weight of Lead Acid Batteries Sold in Canada 2007 to 2015 (tonnes per year)

	Unit Weight (kg)	2007	2008	2009	2010	2011	2012	2013	2014	2015
LAB - passenger cars	17.7	88,469	89,151	89,657	90,379	91,285	92,377	93,671	95,132	96,755
LAB - motor cycles	4.3	1,502	1,591	1,671	1,759	1,855	1,959	2,072	2,195	2,328
LAB - commercial vehicles	24.1	119,195	119,937	120,487	121,397	122,796	124,569	126,699	129,078	131,713
Total Automotive LAB		209,167	210,678	211,814	213,534	215,935	218,904	222,442	226,406	230,796

[73] www.wasteage.com 1st March, 2006 Article on Lead Acid Batteries by Chaz Miller, State Programs Director, National Solid Waste Management Association, Washington DC.

8.3 Composition and Lifespan of Lead Acid Batteries

Lead acid battery manufacturing accounts for over 71-75% of all lead consumed in Canada and internationally.[74] In 1999, lead-acid batteries and battery oxides accounted for the largest quantity of lead used in Canada (15,220 tonnes of primary lead and 18,200 tonnes of recycled lead).[75] Virtually all of the lead in lead acid batteries is recovered and recycled (discussed later in this section).

A typical lead-acid battery is shown in Figure 8.1 and includes the following materials:

- Lead, metal and paste;
- Plastic, e.g. polypropylene or co-polymer, polyvinyl chloride, polyethylene;
- Sulphuric acid; and
- Minor components such as antimony, arsenic, bismuth, cadmium, copper, calcium, silver, tin, barium sulfate, lampblack and lignin, lead-antimony alloy.

The lead content of various lead acid batteries is presented in Table 8.3

Table 8.3: Average Weight of Lead in Different Types of Lead Acid Batteries (Battery Council International)

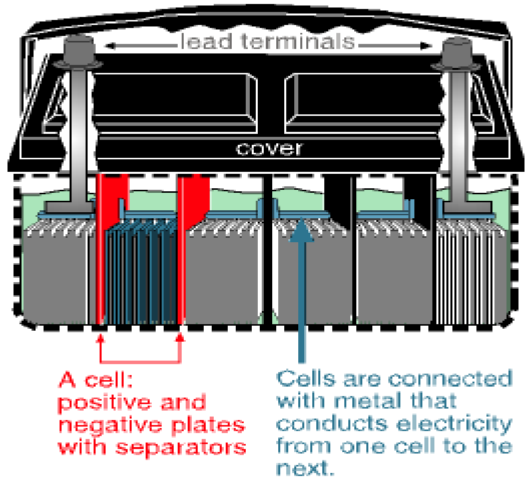
Automotive Battery Type	Average Lead Weight[76] (lbs)	Average Lead Weight (kg)	Assumed Battery Weight (kg)
Passenger Car	21.5	9.8	17.7
Truck & Heavy	38.7	17.6	24.1
Motorcycle	6.3	2.9	4.3

[74] See Lead chapter, 2005, Canadian Minerals Yearbook, NRCan at http://www.nrcan.gc.ca/mms/cmy/com_e.html; Nova Pb – Lead Recycling, http://novapb.com/lead_recycling.htm

[75] Public Consultation Draft, *Decision Document on Lead under the Process for Identifying Candidate Substances for Regional Action under the Sound Management of Chemicals Initiative*, prepared by the Substance Selection Task Force for the North American Sound Management of Chemicals Working of the Commission for Environmental Cooperation, June 2003

[76] BCI National Recycling Rate Study. By SmithBucklin Corp.Chicago June 2005

Figure 8.1: Diagram of a Typical Lead Acid Battery[77]



The materials are incorporated into the following constituents[78]:

(a) **positive and negative terminals**: made of lead, and where the external electricity consumer devices are connected;
(b) **plugs:** one for each battery element, (on older batteries) where distillated/deionized water can be replaced whenever needed and also to provide an escape route for gases formed in the cells; (new batteries are generally sealed);
(c) **connectors**: made of lead, that make electrical contact between plates of same polarity and also make electrical contact between separated elements;
(d) **cap and box**: originally made of ebonite, but now more commonly made from either polypropylene or co-polymer;
(e) **sulfuric acid solution**: the electrolyte of the battery;
(f) **element separators :** usually a part of the box and made of the same material, provide chemical and electrical isolation between the electrical elements;
(g) **plate separators**: made of PVC or other porous materials, avoid physical contact between two contiguous plates while allowing free movement of ions in the electrolyte solution;
(h) **negative plates**: a metallic lead grid covered by a lead dioxide (PbO_2) paste;
(i) **positive plates)**: metallic lead plates;
(j) **battery element**: a series of negative and positive plates, placed consecutively and isolated between each other with plate separators.

Source: **Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America**. December, 2007. Prepared for the Commission for Environmental Cooperation Secretariat

The battery plates consist of metallic lead structures covered by a lead dioxide paste, in the case of the negative plates, or by a porous metallic lead paste, in the case of the positive plates. The lead used in the plates may also contain several other chemical elements such as antimony, arsenic, bismuth, cadmium, copper, calcium, silver, tin and sometimes other elements. Expander materials, such as barium sulfate, lampblack and lignin are also used in the manufacture of plates.[79]

After being shaped, the battery plates are placed so that the negative and positive plates are alternated. Polyethylene, polyvinyl chloride or fibrous paper is used as separators between plates to avoid short circuiting. There are 6 to 20 pairs of negative and positive

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[77] From the Battery Council International, www.batterycouncil.org

[78] Technical Guidelines for the Environmentally Sound Management of Waste Lead-Acid Batteries, Annex to United Nations Environment Programme Document, UNEP/CHW.6/22 8 August 2002

[79] Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. December, 2007. Prepared for the Commission for Environmental Cooperation Secretariat

plates aligned and electrically isolated. The plates of same polarity are then electrically connected and the plate sandwiches, referred to as battery elements, are inserted into battery compartments. A standard battery element has 13 to 15 plates. The elements are connected in series with a lead-antimony alloy connector in order to provide a higher voltage. The higher the voltage, the higher the number of elements connected: a standard automobile battery has 6 elements in series producing (2V x 6 elements) 12 V. Finally, the battery is assembled and filled with electrolyte (sulphuric acid). The lid is then sealed and the product is examined for leaks, after which it will receive its first charge.

Vehicle Lead Acid Battery Lifespan

Battery life is defined as the period of time in which a battery is capable of being recharged and retains the charge applied. Once the battery is no longer capable of being recharged or cannot retain its charge properly, it reaches the end of its useful lifetime. The main cause of this “death” is the sulphation process.[80] This begins when lead sulphate precipitates over the battery plates, coating them and preventing the reactions which produce the electric energy.

Under ideal conditions, an automobile battery can last up to six years, but several factors decrease this optimal lifetime to from 6 months to 48 months. The Basel Guidelines[81] on environmentally sound management (ESM) of spent lead acid batteries (SLABs) suggests only 30% of all batteries last four years.

The life-span of all batteries is linked to the capacity of the battery (e.g. in Ampere hours) and the amount of current (Amperes) drawn from the battery by the device which it powers. Temperature, humidity and other environmental factors also have an impact on battery life-span.

Every five years since 1962, Battery Council International Technical Sub-Committee conducts a study to determine the failure modes of batteries removed from service. The results of the tests have been reported publicly since 1990.

Between September 2003 and December 2004, a total of 2,769 batteries were sampled in five locations in the US with each significant battery manufacturing company (Douglas Manufacturing Co., East Penn Manufacturing Co., Exide Technologies and Johnson Controls Inc.). selected samples of 12 volt batteries. Of the batteries sampled, half were from the southern US and half were from the northern US (Ohio and Rhode Island) and 2,681 batteries had both failure mode and battery date information reported.

The results showed that the average lead acid battery life is 50 months, compared to 41 months measured in 2000 and 44 months in 1995. Average life-spans measured through the failure mode studies have shown a steady increase in battery life through improvements in design. Batteries in the northern US had an average life of 56 months compared to those in the south which had an average life of 43 months. Lead acid

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[80] Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. December, 2007. Prepared for the Commission for Environmental Cooperation Secretariat

[81] Technical Guidelines for the Environmentally Sound Management of Waste Lead-Acid Batteries, Annex to United Nations Environment Programme Document, UNEP/CHW.6/22 8 August 2002

batteries last longer in cold climates as warm climates are hard on the system. Changes in lead acid battery life measured over time are presented in Table 8.4.

Table 8.4: Lead Acid Battery Life, 1962 to 2005[82]

Year	Average Battery Life (months)
1962	34
1995	44
2000	41
2005	50

Table 8.5 presents the lifespan assumptions which were used in the Canadian Consumer Battery Flow Model (2009).

Table 8.5: Lead Acid Battery Lifespans

Product	Average Lifespan	Estimated Variable Lifespan			% Units Lasting Lifespan		
		Low Life 2	Avg Life 2	High Life 2	1st	2nd	3rd
	years	years	years	years			
Passenger Cars	4.7	2.5	4.7	5	5%	60%	35%
Light Truck	4.7	2.5	4.7	5	5%	60%	35%
Heavy Truck	3.0	1	3.0	5	20%	60%	20%
Motorcycles	2.0	1	2.0	3	20%	60%	20%

8.4 End-of-Life Lead Acid Batteries

Estimates for end-of-life lead acid batteries were estimated using the Canadian Consumer Battery Flow Model and are presented in Table 8.6 by unit numbers and Table 8.7 by weight.

Table 8.6: Estimate of End-of-Life Vehicular Lead Acid Batteries (LAB) in Canada 2007 to 2015 (1,000 units)

	LAB Auto	LAB Motorcycle	LAB Commercial Vehicles	Total LAB
2007	4,543	213	4,352	9,109
2008	4,602	224	4,494	9,320
2009	4,622	234	4,654	9,510
2010	4,666	244	4,872	9,782
2011	4,780	260	4,912	9,951
2012	4,862	279	4,943	10,083
2013	4,926	302	4,973	10,201
2014	4,931	322	5,004	10,257
2015	4,971	345	5,043	10,359

[82] Failure Modes of Batteries Removed From Service – A Report of the BCI Technical Subcommittee on Battery Failure Modes, Battery Council International, 2005

Table 8.7: Weight of Lead Acid Batteries (LAB) Reaching End-of-Life in Canada 2007 to 2015 (tonnes)

	LAB Auto	LAB Motorcycle	LAB Commercial Vehicle	Total LAB
2007	80,415	916	104,892	186,223
2008	81,461	963	108,302	190,726
2009	81,817	1,004	112,166	194,987
2010	82,582	1,050	117,412	201,044
2011	84,606	1,117	118,369	204,092
2012	86,052	1,199	119,119	206,370
2013	87,196	1,297	119,861	208,353
2014	87,271	1,385	120,595	209,251
2015	87,982	1,482	121,548	211,011

8.5 Lead Acid Battery Recovery

Lead acid batteries are the largest uses of lead in Canada.[83] Much of the lead is recovered and recycled through secondary lead smelters for use in new lead acid batteries. The most recent BCI (Battery Council International) estimate (2005) is that 99.2% of lead acid batteries are recycled in the US. The value is expected to be similar in Canada.

There continues to be a strong market demand for recovered lead for two main reasons. Obtaining secondary lead from spent lead acid batteries has traditionally been economically attractive, with relatively stable and high market prices, and processing secondary lead requires about 25% less energy than mining primary lead. This has resulted in a well-established lead-acid battery recycling infrastructure in North America and internationally.

[83] CEC, 2007 and the Canadian Minerals Yearbook, Natural Resources Canada

8.6 Lead Acid Battery End-of-Life Management

A CEC report[84] describes three distinct stages involved in the recycling of spent lead acid batteries:

- Collection Storage and Transportation – involving collection and temporary storage of SLABs, transportation of collected SLABs to bulking facilities, temporary storage in bulking facilities and transportation of bulked quantities to recycling facility;
- Recycling – involving the dismantling and separation into recycling and disposal streams at the recycling facility; and
- Secondary Uses – which may involve, production of lead in lead reduction and refining facilities and use of the recycled materials as feedstock in the manufacture of new products.

Figure 8.2 shows the flow and management of end of life lead acid batteries.

Collection, Storage and Transportation Stage

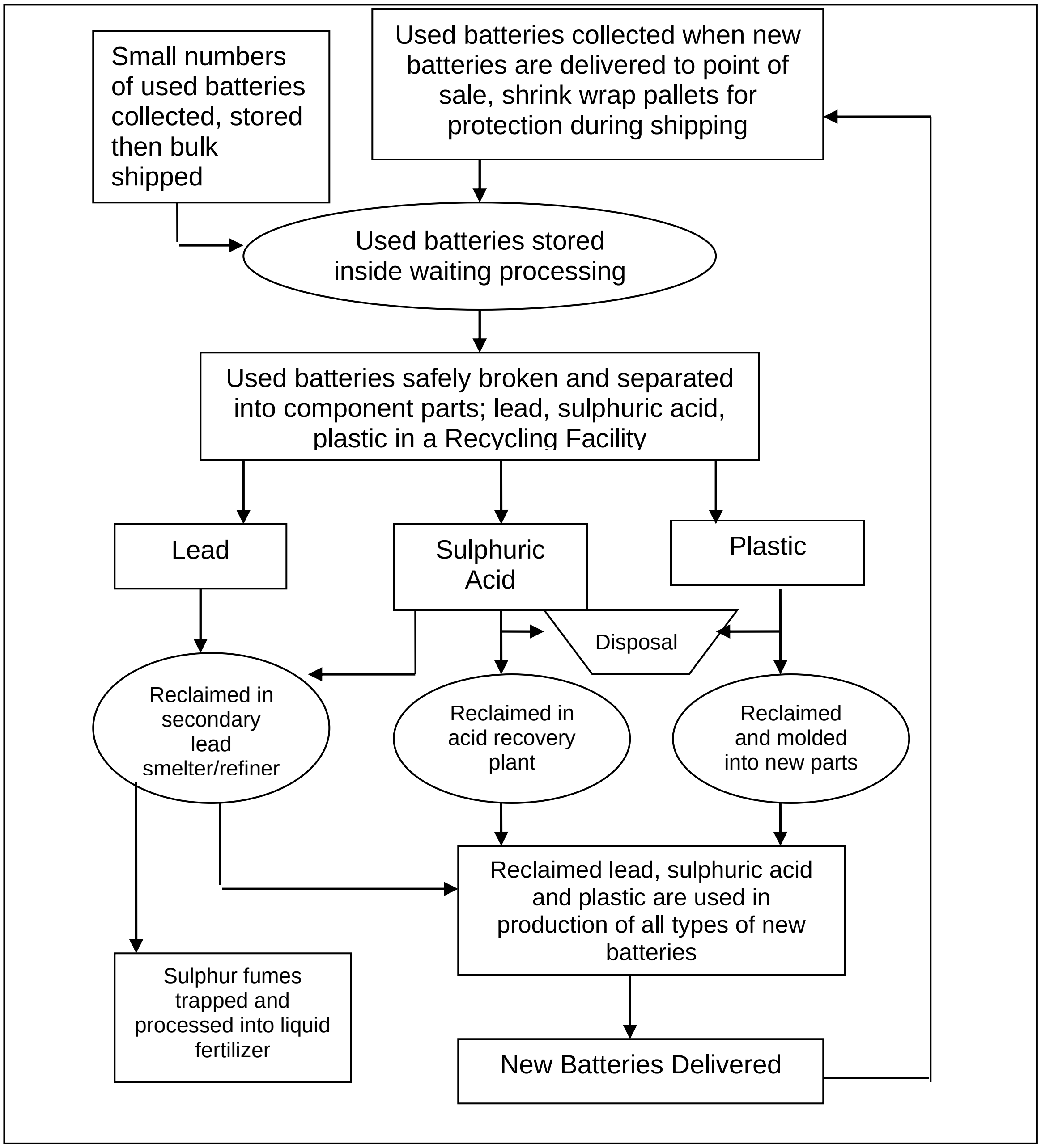
In general, the collection infrastructure for spent lead acid batteries involves the coordination of several different sectors including automobile service centers, waste transporters, scrap dealers, battery dealers, secondary lead processors and consumers. This infrastructure needs to be a well organized network that provides a safe and continuous flow of leaded scrap materials to the recycling process.[85]

In Canada, most provinces have an informal, voluntary, market-driven activity collection infrastructure in place for used lead acid batteries which relies on customers exchanging their spent lead acid batteries at local garages and automotive service centres for new batteries. Two provinces, British Columbia and Prince Edward Island, have introduced legislation requiring the implementation of a structured collection system for spent lead acid batteries.

[84] Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. 2004. Prepared for the Commission for Environmental Cooperation Secretariat

[85] Technical Guidelines for the Environmentally Sound Management of Waste Lead-Acid Batteries, Annex to United Nations Environment Programme Document, UNEP/CHW.6/22 8 August 2002

Table 8.8: End of Life Management of Lead Acid Batteries



Source: Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. 2004. Prepared for the Commission for Environmental Cooperation Secretariat

BC Used Lead-Acid Battery Collection Program

British Columbia launched the first lead acid battery collection program in Canada in 1991. The Program, managed by the BC Ministry of Environment, is funded from revenue collected from a $5 levy collected from the consumer upon purchase of the battery. The administration of this consumer levy is supported under the *Social Service Tax Act* and the *Sustainable Environment Fund Act*. Companies (referred to as brokers) that collect the batteries from various generators can register with the Battery Program in order to receive the Program's Transportation Incentive Payments (TIPs) which covers the cost of transportation of the batteries to a certified processor. The TIP rates vary depending on the location of the broker from the processor (the province is divided into 15 zones).

The BC Government estimates that today virtually 100% of the used lead-acid batteries generated annually in the province are recovered given the right market conditions. The Automotive Recyclers of Canada claims that the BC lead acid battery program captures about 98% of all end of life batteries.[86]

It is anticipated that the BC Ministry of Environment will replace this lead-acid battery program with an industry product stewardship program that is consistent with principles of producer responsibility, including industry financing and operation of the program[87].

Prince Edward Island's Lead Acid Battery Program

Prince Edward Island's (PEI) Lead Acid Battery regulations were enacted on April 1, 1993, requiring retailers to charge $5 on new battery purchases, unless an old battery is returned within 30 days. The regulations require retailers to send old batteries to appropriate facilities for recycling (the facility must be a licensed recycling outlet). A producer responsibility organization was not established. The regulations generally do not confer responsibilities upon manufacturers and brand owners of SLAB. All deposits not returned to customers in exchange for lead-acid batteries can be retained by the retailer.

The provincial aim was to eliminate lead acid batteries from being incinerated at the MSW Energy From Waste (EFW) facility in Charlottetown, in order to reduce lead emissions. Efforts are also made to reduce and eventually eliminate the disposal of lead acid batteries into landfills.[88]

In 1998, there was a 65% collection rate of batteries and battery-related materials, followed by a 70-75% capture rate in 1999, and a 107% rate in 2000. In 2005, the province achieved about 76% recovery rate and 73% in 2006. The decrease in collection rates may be partly due to the hoarding of spent lead acid batteries by collection facilities in anticipation of an increase in future lead prices.[89]

SLABs are generally temporarily stored in collection locations for transportation to bulking facilities (transfer stations), for bulking and eventual transportation to recycling facilities. Collection of non-vehicle LABs from industrial facilities is usually carried out by licensed waste service companies/transporters.

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[86] Automotive Recyclers of Canada, The Voice, Winter 2006 at http://www.autorecyclers.ca/news_files.php?news_id=14

[87] Personal communication Michael Vanderpol, Environment Canada, March, 2008

[88] Environment Canada's EPR website at http://www.ec.gc.ca/epr/default.asp?lang=En&n=8F32D718-1

[89] Communications with Glenda Peters of the Air and Hazardous Materials Waste Section, Prince Edward Island, March, 2008

8.7 Recycling Infrastructure for Lead Acid Batteries[90]

The recycling process for end of life lead acid batteries is considered to begin when they move from storage to the recycling plant and into processing. It can be divided into six main steps:

(a) Battery draining;
(b) Battery breaking;
(c) Separation into different fractions;
(d) Processing of acid electrolyte and lead paste prior to lead reduction;
(e) Lead reduction; and
(f) Lead refining.

Depending upon the location and circumstances, sometimes LABs are drained, broken and separated into different fractions at a bulker or scrap dealer. The different components are then transported to the appropriate facilities for recycling and/or disposal. More commonly today, these steps are carried out at the lead reduction facilities.

Battery Draining

LABs should always be drained before they enter the breaking process, since the acidic electrolyte produces several complications in the lead re-refining process. The acid may be neutralized to precipitate out lead in the form of lead hydroxide.

Battery Breaking

Once the LABs are drained they are delivered to the 'breaking machine', where the dismantling process begins.[91] The LABs are broken into small pieces in hammer mills or other crushing mechanisms. This ensures that all components, such as lead plates, connectors, plastic boxes and acid electrolyte can be easily separated in the subsequent steps. Figure 8.3 shows a generic battery breaking process and identifies the various materials generated/recovered from the LAB. Each of the components can be 'recycled' to a greater or lesser degree. This process may take place at a separate facility from the lead recovery process in a smelter or refinery or in a facility contiguous with a lead smelter (which has become the more usual case). Secondary lead smelters sometimes carry out battery breaking at their own site (e.g. Xstrata, Belledune). In other cases, a local company supplies the broken batteries already pre-processed. (e.g. KC Recycling in Trail BC supplies Teck in Trail, BC.) The relationship between KC Recycling and Teck in Trail, BC is an example of the latter arrangement. On the other hand, Xstrata, Belledune, New Brunswick is an integrated operation with battery breaking on-site.

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[90] Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. 2004. Prepared for the Commission for Environmental Cooperation Secretariat
[91] Technical Guidelines for the Environmentally Sound Management of Waste Lead-Acid Batteries, Annex to United Nations Environment Programme Document, UNEP/CHW.6/22 8 August 2002

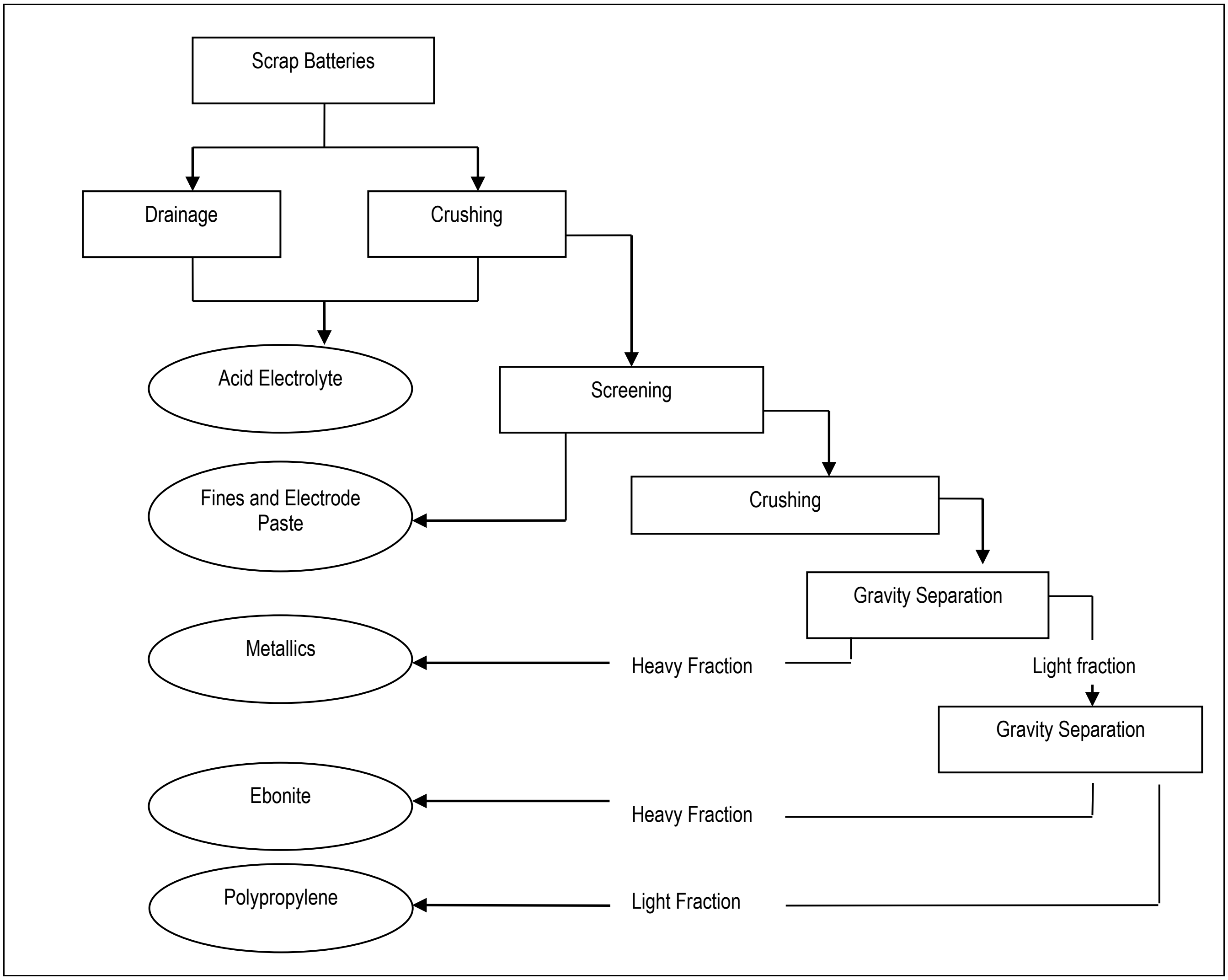

Figure 8.2: Battery Breaking Process [92]

Source: Practices and Options For Environmentally Sound Management of Spent Lead Acid Batteries Within North America. 2004. Prepared for the Commission for Environmental Cooperation Secretariat

Many of the components recovered from the spent lead acid batteries are used in the manufacture of new LABs, e.g. the lead recovered is used in the lead component of new lead-acid batteries and the plastic recovered is used to make battery casings. Some plastic which is not able to be separated from lead components in LABs may be used for energy in lead reduction and refining facilities.

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[92] Taken from United Nations Environment Programme, *Technical guidelines for the environmentally sound management of waste lead-acid batteries,* UNEP/CHW.6/22, 8 August 2002.

8.8 Lead Acid Battery Processor Interviews

Industry representatives for each of the four large secondary lead smelters in Canada were contacted by phone or email and asked a series of questions including:

- The batteries processed and the processes and recycling technologies used;
- Existing and maximum operational processing capacity;
- Current contribution of batteries as part of the overall "feedstock" used by the facilities (in %);
- Number of facility staff currently employed;
- Associated costs to have spent batteries recycled at these facilities (e.g. collection, sorting, transport, processing fees, etc.); and
- Ongoing challenges related to battery recycling.

Information on Metalex Products Ltd in Richmond, BC was obtained by email correspondence.

Results of the telephone and email survey are summarized in Table 8.9.

Table 8.9: Details for Secondary Lead Smelters Which Process Lead Acid Batteries

Company	Capacity (tonnes/year)	LAB as Percentage of Total Feedstock	Employees
Teck, Trail, BC	95,000 t/y lead	30,000 out of 95,000 – about 30% 50% is residue from zinc smelter	1,500 incl zinc smelter
Tonolli, Mississauga, ON	Capacity to process 80,000 t/y LABs; secondary smelter has capacity of 45,000 t/y lead	100% Accepted other feedstocks but stopped about 10 years ago	75[93]
Newalta, Montreal, QC	90,000 t/y lead	95% to 99% LAB Dentist office Counterweights for wheels Pipe	130
Xstrata, Belledune, NB	105,000 t/y lead	10% LAB 90% mine concentrate	430
Metalex, BC	4,550 t/y lead	99%	20
TOTAL	339,550 t/y lead[94]		

None of the secondary lead smelters would discuss their cost structure.

Lead acid batteries are pre-processed by battery breakers prior to entering the lead smelter. Sometimes the pre-processing is carried out by separate companies (such as

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[93]See Industry Canada, "Canadian Company Capabilities" database at http://strategis.ic.gc.ca

[94] Lead smelting capacity was determined to be 345,000 t/y in the 1994 CMY article "Recycled Metals", http://www.nrcan.gc.ca/mms/cmy/content/1994/72.pdf, Table 10

KC Recycling in Trail, BC). Some secondary lead smelters have integrated battery breaking at the smelter site (e.g. Xstrata, Belledune).

8.8.1 Newalta, Quebec

Newalta (formerly Nova Pb) is located in Quebec.[95] Lead acid batteries make up 95% to 99% of the feedstock to the lead smelter. Other feedstock varies widely and can include materials such as dentist office x-ray equipment, counterweights in wheels, pipes, etc. The facility employs 130 people. They could not share their costs for competitive reasons.

8.8.2 Xstrata, Belledune, New Brunswick

Xstrata have a large secondary lead smelter in Belledune, New Brunswick. The facility processes lead acid batteries and mine concentrate. Details are summarized in Table 8.10.

Table 8.10: Xstrata Belledune New Brunswick Lead Smelter Facility Details

Sources of Batteries	Battery feedstock comes from North Eastern US and from Ontario east in Canada. Also receive feedstock from scrap dealers and battery trading companies.
Other feedstocks processed	10% of the smelter feedstock is from batteries; 90% is from mine concentrate. Xstrata operate a lead mine 80km south of Belledune – most of the feedstock for the Belledune smelter comes from that mine. A supply of mine concentrate also comes from third party mines in Nova Scotia and New Brunswick. Xstrata used to get lead concentrate from a global supply but this was not as much a factor in early 2008. The Chinese entry into the smelting business had captured some of Xstrata's traditional supply (e.g. Peru) in early 2008. Until mid-2007, Chinese companies were buying from sources that Xstrata used to buy from, but this has slowed down since mid-2007. Lead residues from zinc plants (in North America and Europe) owned by Xstrata as well as other companies are also used.
Processes On Site	Lead acid batteries are received as whole units and are broken on-site. Xstrata has a full metal smelter on-site, breaking occurs on site and smelting is carried out in a pyrometallurgical process.
Existing and Maximum Operational Processing Capacity	The Xstrata Belldune facility can produce 105,000 tonnes of refined lead per year. The company's own internal processing capacity is a challenge and a limitation – they reported in early 2008 that they could do more business if they had more capacity. A decision on expansion at the Belledune site would be taken at a more senior level in the company.
Batteries as a Percentage of Total Feedstock	10%
Number of employees at the facility	430
Associated Costs	The company does not break battery processing costs out separately.
End Markets for Processed Batteries	Xstrata makes a refined lead product. This is sold mostly to battery manufacturers globally.

[95] www.newalta.com/views/NewsRelease.asp?compid=113540&releaseID=1115888

8.8.3 Teck Ltd, Trail, BC

TeckLed operates a zinc smelter and a lead smelter (KIVCET) at their facility in Trail, BC. Details are summarized in Table 8.11. The lead and zinc facilities are very integrated, therefore the table includes description of the zinc operation also.

Table 8.11: Teck Ltd, Trail BC Lead Smelter Facility Details

Sources of Batteries	Teck process 30,000 tonnes/year (lead) of primarily lead acid batteries. Feedstock comes from the Pacific North West, all of the used LABs (ULAB) weigh about 22.7 kg to 27.3 kg. (50-60 pounds) per unit. Some of that weight is plates, plastic, etc. Lead acid batteries come through KC Recycling after pre-processing (breaking). Teck sends batteries to KC Recycling in Trail, BC who shred the batteries and make lead paste. The plates and the paste come to Teck. Teck does not get the posts from the batteries, they go to someone else. Other batteries come through Toxco.
Other feed-stocks processed	Some CRT screens from monitors and televisions from the Alberta electronics programs are processed (to recover lead).
Processes On Site	Lead acid batteries are processed in the primary furnace which produces lead which is made back into batteries. Their main revenue comes from zinc – they are a zinc smelter. 50% of the feed to the lead furnace is zinc residues. The residues contain lead and some zinc. In most other locations the residues go to ponds. Teck puts the residues through the lead smelting furnace with concentrates. Teck is trying to put the secondary furnace after the slag furnace, they could then recover silver, aiming for 2011. Then the zinc air button cells and other new products could be processed. Could get 95% silver in the matt phase.
Existing and Max operational Processing capacity	Make 300,000 tonnes/year zinc, and 95,000 tonnes/year of lead. Looking at putting in a secondary lead smelting furnace to treat more junk batteries - similar to the facility at Doe Run (US) which has primary and secondary furnaces. Alkaline batteries – could handle 10,000 tonnes/year, but they do not currently process any because of a lack of incentive. Processing 30,000 tonnes per year of lead was about at peak in early 2008. At that time Teck was considering installing another furnace to take an additional 35,000 tonnes of lead batteries.
Batteries as a Percentage of Total Feedstock	Lead smelting furnace is called KIVCET. Teck makes 95,000 tonnes per year of lead; 30,000 tonnes per year from lead acid batteries, so less than one third (31.6% for lead process of feedstock is lead acid batteries). The percentage of the feedstock which comes from batteries is miniscule for zinc, even if they got to 10,000 tonnes per year of batteries, the total from batteries would be half percent.
Number of employees at the facility	1,500 people
Associated Costs	Can not share cost information, Teck is competing with other companies. To maximize profitability, Teck processes the most valuable materials.
End Markets for Processed Batteries	Zinc is sold mostly to US Steel for the galvanizing business. Teck produces 20 million ounces per year of silver, most of this is sold to Kodak for film (X-ray). Gold is sold to the mint; it is processed from ore. Germanium is sold for specialized applications (hot filling, stabilizing polymers, night vision equipment, etc). Indium is used in LCD manufacturing.

8.8.4 Tonolli, Mississauga, Ontario

Tonolli operates a lead battery breaking operation and secondary lead smelter in Mississauga, Ontario. Details are summarized in Table 8.12.

Table 8.12: Tonolli, Mississauga, Ontario Facility Details

Sources of Batteries	Battery feedstock is generally from a 500 km radius of the Mississauga, Ontario facility. About 50% of the feedstock is local, GTA (Greater Toronto Area) plus Boston, Chicago, Northern Ontario, Maritimes. Feedstock comes from specific operations – brokers they use; direct from scrap dealers or wholesale battery companies; returns from battery producers themselves – e.g. East Penn and other battery manufacturers have return systems (tolling). Tonolli deals with SSLAs –they don't pay for them generally, because they contain less lead. Tonolli pays a cost per pound for batteries.
Other feedstocks processed	All of their feedstock is batteries. They used to accept dross a long time ago – stopped 10 years ago.
Processes carried out at the site	The battery is run through a hammermill to break it into fine particles. They installed their current processing machinery (CX) in late 1980's – it was state of the art at the time. Batteries are sorted, put through the CX process, then shredded - components are separated into acid, plastics, etc. They wash the plastic and re-sell it. Lead is processed in furnaces and refined in kettles.
Existing and maximum operational processing capacity (tonnes per year)	Capacity is 45,000 tonnes of lead per year (50,000 short tons per year). They can process 90,000 tonnes of batteries per year – they do not generally reach this value, and run at about 80,000 tonnes per year. Tonolli considered that their plant was at capacity in early 2008; expansion might be limited by environmental factors and cost. In early 2008 they experienced a huge influx of batteries, and never experienced shortfalls of feedstock, - they would like to improve productivity. If they expand they need to meet environmental standards. Lead smelters – fugitive emissions are the biggest issue, they create lots of dust. Lead standards have become tighter every few years. A new standard will be in place in Ontario in February, 2010 – it will be the world's lowest standard for lead smelters. Ontario standards are already 50% lower than US requirements for air quality – this is the hardest and most difficult issue for smelters to address.
Batteries as a Percentage of Total Feedstock	100%
Number of employees	75
Associated Costs	The greatest cost is the cost of the feedstock itself (a very large proportion of operating costs - >50%). Buying chemicals (reagents for sulphur) are the next highest cost; then energy (natural gas, electricity and oxygen). Maintenance of the facility is a very significant cost – constant maintenance of the facility is required because they are handling acid and lead – this causes high wear and tear. Labour costs are a relatively low percentage of the total cost. They have highly paid workers with good benefits, very high environmental and health and safety costs. They spent $10 million upgrading the facility for environmental controls. They invested $12 million to handle slag inside and therefore minimize fugitive dust emissions. Two buildings and a new rotary furnace were required to process inside. There were process advantages, but they needed to move the operation inside anyway. They will spend another $4 million in next two years for environmental improvements.
End Markets for Processed Batteries	Lead is sold mostly to manufacturers of batteries as well as products that go into batteries. Lead also goes to traders who distribute the lead to battery manufacturers. They sometimes sell on the London Metal Exchange. Plastic is sold to two approved recyclers in the US – they extrude the plastic and make battery casings and other products

8.8.5 Metalex Products Ltd, Richmond, BC

Metalex Products Ltd operates a battery breaking operation and smelter in Richmond, BC. Details are presented in Table 8.13 below.

Table 8.13: Metalex Metal Products Ltd, Richmond, BC Facility Details

Sources of Batteries	Scrap dealers, battery retailers
Other feedstocks processed	99% of supply is lead acid batteries. Other feedstocks include lead drosses, lead pipes, wheel weights.
Processes carried out at the site	Battery decasing and component separation (acid, lead and plastic). Smelting furnace, lead refining department.
Existing and maximum operational processing capacity (tonnes per year)	4,545 tonnes (5,000 short tons) annually.
Batteries as a Percentage of Total Feedstock	99%
Number of employees	20
Associated Costs	No data available.
End Markets for Processed Batteries	Ammunition, replacement batteries, construction materials, radiation protection, ballast for boats and machinery, stained glass windows and artwork.

8.9 GHG Benefits of Lead Acid Battery Recycling

Table 8.14 presents the estimated GHG benefits of lead acid battery recycling in Canada, assuming a recycling rate of 99.2%. These were estimated using GHG emission factors from the ICF 2005 report, and an emission benefit factor of 1.88 for lead recycling developed by NRCan staff. If one tonne of lead is produced from raw materials, the estimated GHG emissions impact is 3.12 tonnes eCO_2. If lead scrap is used to produce new lead product, net GHG emissions are estimated to be between 0.90 and 0.75 tonnes eCO_2. Therefore, the amount of GHG emissions avoided by recycling lead is estimated to be 1.88 tonnes eCO_2 per tonne of lead.[96]

Given that the current recycling rate is over 99%, it is unlikely that additional recycling could be achieved.

Table 8.14: Estimated GHG Benefits of Lead Acid Battery Recycling in Canada in 2007,

(tonnes carbon dioxide equivalents)

	Lead (tonnes)	**Other metals (tonnes)**	**H_2S0_4 (tonnes)**	**Other non-metals (tonnes)**	**plastic, paper carbon (tonnes)**	**TOTAL GHG (tonnes eCO_2)**
Total End-of-life 2007	104,632	6,438	25,755	8,048	16,097	
Total Recycled 2007	103,585	6,374	25,498	7,968	15,936	
Total Landfilled	1,046	64	257	80	161	
GHG Emission Factor – Recycling vs Raw Material Extraction	-1.88	-1.88	0	0	-2.75	
GHG Benefit of Recycling	(194,791)	(11,984)	(0)	(0)	(22,000)	**(250,550)**

Based on the calculations shown in Table 8.7, it is estimated that by recycling lead acid batteries about 250,550 tonnes of eCO_2 were not emitted in 2007. This figure includes the GHG benefits of recycling about half of the paper, plastic and carbon from the batteries.

A more thorough emission factor development process needs to be carried out for lead to verify and refine these estimates since it not certain whether the energy factors used for primary versus recycled feedstock cover the full life cycle of production.[97]

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[96] The estimated GHG factor for lead reflects the benefit of producing lead (Pb) from recycled feedstock rather than raw materials. From an energy perspective, the production of primary Pb requires about 39 GJ for every tonne, whereas 10 GJ are needed if the feedstock is recycled Pb.

[97] The original source for the lead energy data is Michael Henstock, 1996, *The Recycling of Non-Ferrous Metals*, ICME

8.10 Lead Acid Battery Processing Capacity Conclusions

About 186,545 tonnes of automotive lead acid batteries containing approximately 104,632 tonnes of lead reached end of life in Canada in 2007. Capacity to process these batteries in Canadian smelters is presented in Table 8.15. The table shows that Canadian smelters have sufficient capacity to process all of the lead acid batteries reaching end of life in Canada which were addressed in this study.

Table 8.15: Capacity to Process Lead Acid Batteries in Canada

Company	Capacity (tonnes/year lead)	Lead From Lead Acid Batteries
Teck, Trail, BC	95,000	30,000
Tonolli, Mississauga, ON	45,000	45,000
Newalta, Montreal, PQ	100,000	95,000
Xstrata, Belledune, NB	105,000	10,500
Metalex, BC	4,500	4,500
TOTAL	351,000	185,000

Significant amounts of lead acid batteries are exported to the US and imported to Canada for processing and recycling through long standing commercial arrangements between manufacturers, brokers, battery breakers and smelters. The two countries therefore represent one market when discussing available processing capacity. Comparing Canadian capacity with the annual Canadian supply of used lead acid batteries does not necessary paint the true picture of available capacity, as Canadian lead acid batteries are exported to US facilities, and batteries originating in the US are processed in Canada.

When interviewed in January-February, 2008, some lead smelter company representatives indicated that they were operating at capacity, and could not process additional lead acid batteries without plant expansions. At the time, company representatives indicated that they would be willing to expand their capacity if a sufficiently large supply of feedstock was available could be secured.

The research concluded that there was sufficient capacity available in Canada to process lead acid batteries produced in Canada.

9. Conclusions

Battery Sales

Sales of primary consumer batteries are expected to increase from 671 million units in 2007 to 745 million units by 2015. Most of the primary batteries will continue to be alkaline or zinc carbon. Sales of zinc carbon primary batteries are expected to decline over time.

Sales of secondary consumer batteries were estimated at 26 million units in 2007. Of this total, 16.45 million units were NiCd, and an additional 6.4 million units were NiMH batteries. Lithium ion and lithium polymer batteries made up about 2.8 million units in 2007.

Available sales projections for secondary consumer batteries indicate that NiCd batteries will remain in the Canadian market past 2015. While use of these batteries has decreased substantially, there are certain applications of NiCd batteries that remain necessary and exempt from European Union and California bans (i.e. medical equipment, power tools and emergency and alarm systems, including emergency lighting).

An estimated 10.3 million vehicular lead acid batteries were sold in Canada in 2007. Of this total, 5 million were for passenger cars; 4.9 million were for commercial vehicles and the remainder were for motor cycles. Total sales are projected to increase to 11.5 million units by 2015.

End of Life Batteries

The estimated weight of consumer batteries which reached end of life in Canada in 2007 was 17,461 tonnes. Primary batteries make up the larger weight of the total, at 14,056 to 14,898 tonnes in 2007 compared to an estimated 3,633 to 4,679 tonnes for secondary batteries.

	End of Life Primary Consumer Batteries (tonnes)		End of Life Secondary Consumer Batteries Discarded (tonnes)	
Year	**Scenario 1 5 year hoarding**	**Scenario 2 15 year hoarding**	**Scenario 1 5 year hoarding**	**Scenario 2 15 year hoarding**
2007	14,898	14,056	2,563	2,311
2015	17,982	16,377	4,679	3,633

By 2015, the amount of secondary batteries at end of life is projected to increase to 3,633 to 4,679 tonnes, depending on the hoarding assumption applied. This estimate is likely low, as it is based on lithium ion battery sales figures which are considered to be under-estimates.

The amount of primary batteries at end of life also increases to an estimated 17,982 tonnes by 2015, compared to 14,056 to 14,898 tonnes in 2007, representing a 17% to 21% increase over 8 years.

An estimated 9.1 million vehicular lead acid batteries, weighing 186,545 tonnes, reached end of life in 2007. This value is projected to increase to 10.4 million units weighing 211,397 tonnes by 2015.

Battery Recycling

There is a well developed battery processing infrastructure in Canada and the US which can process consumer batteries from the Canadian market. Each company in the infrastructure has one or more specialties:

Table 9.1: Battery Processing Specialities

Company	Specialty
Toxco, Trail, BC	Lithium batteries, all chemistries
Teck, Trail, BC	Alkaline batteries in zinc smelter Lead batteries in lead smelter
RMC, Port Colborne	Alkaline and zinc carbon
Tonolli, Mississauga	Lead acid batteries
Xstrata, Sudbury	Cobalt bearing batteries
Nova Pb, Montreal	Lead acid batteries
Xstrata, Belledune, New Brunswick	Lead acid batteries (breaker on site)
INMETCO, Pennsylvania	Nickel bearing batteries
Toxco, Ohio	Cadmium batteries
Metalex, BC	Lead acid batteries

For some battery chemistries, processors of primary and secondary consumer batteries suffer from a lack of supply, and need more batteries for their operations. There is currently an adequate supply of used lead acid batteries and sufficient lead acid battery processing capacity in Canada.

All battery processors have indicated their willingness to expand the battery processing infrastructure should the demand for battery processing increase.

There is a charge for processing alkaline and zinc carbon batteries, because the small amounts of zinc and other materials they contain are not of sufficiently high value to pay for themselves.

Lithium ion and nickel metal hydride batteries which contain nickel and cobalt have a value in the marketplace, because the nickel and cobalt value provide sufficient revenues to cover processing costs and pay for supply.

Lead acid batteries already have value in the marketplace and an efficient recycling infrastructure. The current collection rate for primary consumer batteries is 5% in Ontario, where some MHSW (municipal hazardous and special waste) programs currently collect consumer batteries, and is minimal in other provinces, because primary batteries are not currently collected in any stewardship programs, and there are only two lead acid battery stewardship programs at this time. Most of the primary consumer batteries in Ontario are currently landfilled[98], with only a small amount recycled. A 1% recycling rate was assumed in this study.

End of life battery amounts were estimated using the Environment Canada Battery Flow Model (2009) which applies a lifespan methodology used in USEPA and other end of life models. Recycling was estimated as the recycled tonnage divided by the end of life tonnage. Recycling rates were estimated at 8% to 9% for NiCd batteries and 7% to 8% for NiMH batteries for hoarding assumptions of 5 years and 15 years. The longer hoarding assumption results in a higher estimated recycling rate. Recycling rates for SSLA batteries were estimated at 10%. Recycling rates for lithium batteries were estimated at 45% to 72%. Given that the product was only introduced to the commercial market in the mid-1990's, hoarding assumptions beyond 15 years are not realistic.

Battery Council International reports the combined recycling rate for the years 1999 to 2003 at 99.2% for the US. A similar recycling rate is probably also in place in Canada. It is unlikely that higher recycling levels than over 99.2% could be achieved.

Greenhouse Gas Benefits of Current and Potential Battery Recycling in Canada

Recycling of batteries generates GHG savings in comparison to the manufacture of materials from virgin feedstock. The GHG benefits of recycling 25% and 50%[99] of primary consumer batteries in Canada are estimated at 7,263 and 14,527 tonnes of eCO_2 respectively. Current recycling levels have a benefit of an estimated 290 tonnes of eCO_2 in 2007. The GHG estimates were developed using emission factors (expressed as tonnes of eCO_2 per tonne of managed material) in the ICF 2005 study for Environment Canada and Natural Resources Canada. Natural Resources Canada developed emission factors for lead (1.88), zinc (3.78) and nickel (14.45). The emission factor for plastic and paper is 2.75. A default value of 1.18 (the value for iron and steel) was used for all metals for which emission factors were not available. Separate emission factors need to be developed in detail for cobalt, lithium and a number of other materials to refine the analysis.

Current recycling of secondary consumer batteries has a GHG benefit of 955 tonnes of eCO_2. The GHG benefits of recycling 25% and 50% of secondary batteries are estimated at 2,682 and 4,245 tonnes of eCO2 respectively.

The GHG benefits of current lead acid battery recycling were estimated at over 250,550 tonnes of eCO_2 in 2007. This estimate was developed using an emission factor for lead developed by Natural Resources Canada staff. The emission factor needs to be developed in more detail to confirm the estimate.

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[98] Stewardship Ontario – Municipal Hazardous or Special Waste (MHSW) Program Plan, 2007
[99] 25% and 50% were chosen as theoretical values to illustrate a range of benefits

Future Trends

Battery chemistry is developing rapidly to meet new consumer needs for smaller and lighter portable power, as well as the growing electric vehicle and hybrid car market.

Recyclers are engaging battery designers to consider end of life recyclability when designing new products.

Various battery recyclers are developing new technologies to process batteries, but would not discuss details because of competitiveness of the business.

Appendix A

Battery Flow Model 2009 Output Sheets for Consumer Primary and Secondary Batteries

5 Year Hoarding Assumption

Zinc Carbon Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	133710	3,610	33%	33%	33%	0%	3	123,945	3,347	37,183	1,004	119,523	3227
1997	137139	3,703	33%	33%	33%	0%	3	127,123	3,432	38,137	1,030	122,588	3310
1998	140655	3,798	33%	33%	33%	0%	3	130,382	3,520	39,115	1,056	125,731	3395
1999	144261	3,895	33%	33%	33%	0%	3	133,725	3,611	40,118	1,083	128,955	3482
2000	147960	3,995	33%	33%	33%	0%	3	137,154	3,703	41,146	1,111	132,262	3571
2001	151754	4,097	33%	33%	33%	0%	3	140,671	3,798	42,201	1,139	135,653	3663
2002	161530	4,361	33%	33%	33%	0%	3	144,278	3,896	43,283	1,169	139,131	3757
2003	176721	4,771	33%	33%	33%	0%	3	147,977	3,995	44,393	1,199	142,699	3853
2004	190755	5,150	33%	33%	33%	0%	3	153,733	4,151	46,120	1,245	147,731	3989
2005	208227	5,622	33%	33%	33%	0%	3	163,319	4,410	48,996	1,323	155,469	4198
2006	197815	5,341	33%	33%	33%	0%	3	176,318	4,761	52,895	1,428	165,624	4472
2007	187925	5,074	33%	33%	33%	0%	3	191,882	5,181	57,565	1,554	177,601	4795
2008	178528	4,820	33%	33%	33%	0%	3	198,913	5,371	59,674	1,611	183,632	4958
2009	169602	4,579	33%	33%	33%	0%	3	197,969	5,345	59,391	1,604	184,698	4987
2010	161122	4,350	33%	33%	33%	0%	3	188,071	5,078	56,421	1,523	180,645	4877
2011	150375	4,060	33%	33%	33%	0%	3	178,667	4,824	53,600	1,447	177,962	4805
2012	140345	3,789	33%	33%	33%	0%	3	169,734	4,583	50,920	1,375	176,378	4762
2013	130984	3,537	33%	33%	33%	0%	3	160,350	4,329	48,105	1,299	171,919	4642
2014	122247	3,301	33%	33%	33%	0%	3	150,599	4,066	45,180	1,220	164,810	4450
2015	114093	3,081	33%	33%	33%	0%	3	140,554	3,795	42,166	1,138	154,809	4180

Alkaline Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	275703	7,720	33%	33%	33%	0%	3	255,567	7,156	76,670	2,147	246451	6901
1997	282773	7,918	33%	33%	33%	0%	3	262,120	7,339	78,636	2,202	252770	7078
1998	290023	8,121	33%	33%	33%	0%	3	268,841	7,528	80,652	2,258	259251	7259
1999	297460	8,329	33%	33%	33%	0%	3	275,735	7,721	82,720	2,316	265899	7445
2000	305087	8,542	33%	33%	33%	0%	3	282,805	7,919	84,841	2,376	272717	7636
2001	312910	8,761	33%	33%	33%	0%	3	290,056	8,122	87,017	2,436	279709	7832
2002	331726	9,288	33%	33%	33%	0%	3	297,493	8,330	89,248	2,499	286882	8033
2003	348120	9,747	33%	33%	33%	0%	3	305,122	8,543	91,536	2,563	294237	8239
2004	369383	10,343	33%	33%	33%	0%	3	316,543	8,863	94,963	2,659	304300	8520
2005	389955	10,919	33%	33%	33%	0%	3	330,886	9,265	99,266	2,779	316461	8861
2006	403838	11,307	33%	33%	33%	0%	3	349,708	9,792	104,912	2,938	331813	9291
2007	418214	11,710	33%	33%	33%	0%	3	369,116	10,335	110,735	3,101	347629	9734
2008	433103	12,127	33%	33%	33%	0%	3	387,686	10,855	116,306	3,257	362917	10162
2009	448521	12,559	33%	33%	33%	0%	3	403,962	11,311	121,189	3,393	377736	10577
2010	464489	13,006	33%	33%	33%	0%	3	418,343	11,714	125,503	3,514	392106	10979
2011	480746	13,461	33%	33%	33%	0%	3	433,236	12,131	129,971	3,639	408178	11429
2012	497572	13,932	33%	33%	33%	0%	3	448,659	12,562	134,598	3,769	424796	11894
2015	514987	14,420	33%	33%	33%	0%	3	464,539	13,007	139,362	3,902	441483	12362
2014	533011	14,924	33%	33%	33%	0%	3	480,887	13,465	144,266	4,039	457810	12819
2015	551667	15,447	33%	33%	33%	0%	3	497,718	13,936	149,315	4,181	473906	13269

Zinc Air Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	122	4.0	33%	33%	33%	0%	3	112.9	3.7	33.9	1.1	108.9	3.6
1997	125	4.1	33%	33%	33%	0%	3	115.8	3.8	34.7	1.1	111.7	3.7
1998	128	4.2	33%	33%	33%	0%	3	118.8	3.9	35.6	1.2	114.5	3.8
1999	131	4.3	33%	33%	33%	0%	3	121.8	4.0	36.5	1.2	117.5	3.9
2000	135	4.4	33%	33%	33%	0%	3	124.9	4.1	37.5	1.2	120.5	4.0
2001	138	4.6	33%	33%	33%	0%	3	128.1	4.2	38.4	1.3	123.6	4.1
2002	142	4.7	33%	33%	33%	0%	3	131.4	4.3	39.4	1.3	126.7	4.2
2003	145	4.8	33%	33%	33%	0%	3	134.8	4.4	40.4	1.3	130.0	4.3
2004	42	1.4	33%	33%	33%	0%	3	138.2	4.6	41.5	1.4	133.3	4.4
2005	135	4.4	33%	33%	33%	0%	3	141.8	4.7	42.5	1.4	136.7	4.5
2006	144	4.8	33%	33%	33%	0%	3	109.8	3.6	32.9	1.1	115.3	3.8
2007	148	4.9	33%	33%	33%	0%	3	107.4	3.5	32.2	1.1	114.6	3.8
2008	151	5.0	33%	33%	33%	0%	3	106.9	3.5	32.1	1.1	115.3	3.8
2009	155	5.1	33%	33%	33%	0%	3	142.1	4.7	42.6	1.4	141.0	4.7
2010	159	5.3	33%	33%	33%	0%	3	147.8	4.9	44.3	1.5	146.0	4.8
2011	163	5.4	33%	33%	33%	0%	3	151.5	5.0	45.4	1.5	139.0	4.6
2012	167	5.5	33%	33%	33%	0%	3	155.3	5.1	46.6	1.5	140.9	4.6
2013	171	5.7	33%	33%	33%	0%	3	159.1	5.3	47.7	1.6	143.5	4.7
2014	176	5.8	33%	33%	33%	0%	3	163.1	5.4	48.9	1.6	156.8	5.2
2015	180	5.9	33%	33%	33%	0%	3	167.2	5.5	50.2	1.7	161.4	5.3

Lithium Primary Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	16,790	269	33%	33%	33%	0%	3	15,564	249	4,669	75	15,009	240
1997	17,221	276	33%	33%	33%	0%	3	15,963	255	4,789	77	15,393	246
1998	17,662	283	33%	33%	33%	0%	3	16,372	262	4,912	79	15,788	253
1999	18,115	290	33%	33%	33%	0%	3	16,792	269	5,038	81	16,193	259
2000	18,580	297	33%	33%	33%	0%	3	17,223	276	5,167	83	16,608	266
2001	19,056	305	33%	33%	33%	0%	3	17,664	283	5,299	85	17,034	273
2002	19,545	313	33%	33%	33%	0%	3	18,117	290	5,435	87	17,471	280
2003	20,046	321	33%	33%	33%	0%	3	18,582	297	5,574	89	17,919	287
2004	21,355	342	33%	33%	33%	0%	3	19,058	305	5,717	91	18,378	294
2005	24,418	391	33%	33%	33%	0%	3	19,547	313	5,864	94	18,849	302
2006	27,248	436	33%	33%	33%	0%	3	20,313	325	6,094	98	19,518	312
2007	27,930	447	33%	33%	33%	0%	3	21,937	351	6,581	105	20,791	333
2008	28,628	458	33%	33%	33%	0%	3	24,338	389	7,301	117	22,611	362
2009	29,343	469	33%	33%	33%	0%	3	26,529	424	7,959	127	24,288	389
2010	30,077	481	33%	33%	33%	0%	3	27,932	447	8,380	134	25,417	407
2011	30,829	493	33%	33%	33%	0%	3	28,631	458	8,589	137	26,135	418
2012	31,600	506	33%	33%	33%	0%	3	29,346	470	8,804	141	27,124	434
2013	32,390	518	33%	33%	33%	0%	3	30,080	481	9,024	144	28,358	454
2014	33,199	531	33%	33%	33%	0%	3	30,832	493	9,250	148	29,541	473
2015	34,029	544	33%	33%	33%	0%	3	31,603	506	9,481	152	30,502	488

Silver Oxide Button Cell Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	9220	11	33%	33%	33%	0%	3	8,547	10	2,564	3	8,242	10
1997	9457	11	33%	33%	33%	0%	3	8,766	11	2,630	3	8,453	10
1998	9699	12	33%	33%	33%	0%	3	8,991	11	2,697	3	8,670	10
1999	9948	12	33%	33%	33%	0%	3	9,221	11	2,766	3	8,892	11
2000	10203	12	33%	33%	33%	0%	3	9,458	11	2,837	3	9,120	11
2001	10465	13	33%	33%	33%	0%	3	9,700	12	2,910	3	9,354	11
2002	10733	13	33%	33%	33%	0%	3	9,949	12	2,985	4	9,594	12
2003	11008	13	33%	33%	33%	0%	3	10,204	12	3,061	4	9,840	12
2004	10866	13	33%	33%	33%	0%	3	10,466	13	3,140	4	10,092	12
2005	9917	12	33%	33%	33%	0%	3	10,734	13	3,220	4	10,351	12
2006	10018	12	33%	33%	33%	0%	3	10,868	13	3,260	4	10,518	13
2007	10268	12	33%	33%	33%	0%	3	10,596	13	3,179	4	10,402	12
2008	10525	13	33%	33%	33%	0%	3	10,266	12	3,080	4	10,248	12
2009	10788	13	33%	33%	33%	0%	3	10,067	12	3,020	4	10,186	12
2010	11058	13	33%	33%	33%	0%	3	10,269	12	3,081	4	10,409	12
2011	11334	14	33%	33%	33%	0%	3	10,526	13	3,158	4	10,629	13
2012	11618	14	33%	33%	33%	0%	3	10,789	13	3,237	4	10,731	13
2013	11908	14	33%	33%	33%	0%	3	11,059	13	3,318	4	10,821	13
2014	12206	15	33%	33%	33%	0%	3	11,335	14	3,401	4	10,955	13
2015	12511	15	33%	33%	33%	0%	3	11,619	14	3,486	4	11,214	13

Zinc Air Button Cell Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Reused[6]		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	17047	15	33%	33%	33%	0%	3	15,802	14	0	0	4,740	4	15,238	14
1997	17484	16	33%	33%	33%	0%	3	16,207	15	0	0	4,862	4	15,629	14
1998	17932	16	33%	33%	33%	0%	3	16,622	15	0	0	4,987	4	16,029	14
1999	18392	17	33%	33%	33%	0%	3	17,048	15	0	0	5,115	5	16,440	15
2000	18863	17	33%	33%	33%	0%	3	17,486	16	0	0	5,246	5	16,862	15
2001	19347	17	33%	33%	33%	0%	3	17,934	16	0	0	5,380	5	17,294	16
2002	19843	18	33%	33%	33%	0%	3	18,394	17	0	0	5,518	5	17,738	16
2003	20352	18	33%	33%	33%	0%	3	18,865	17	0	0	5,660	5	18,193	16
2004	23465	21	33%	33%	33%	0%	3	19,349	17	0	0	5,805	5	18,659	17
2005	26656	24	33%	33%	33%	0%	3	19,845	18	0	0	5,954	5	19,137	17
2006	25709	23	33%	33%	33%	0%	3	21,218	19	0	0	6,365	6	20,233	18
2007	26352	24	33%	33%	33%	0%	3	23,488	21	0	0	7,047	6	21,960	20
2008	27011	24	33%	33%	33%	0%	3	25,274	23	0	0	7,582	7	23,351	21
2009	27686	25	33%	33%	33%	0%	3	26,237	24	0	0	7,871	7	24,170	22
2010	28378	26	33%	33%	33%	0%	3	26,355	24	0	0	7,906	7	24,402	22
2011	29088	26	33%	33%	33%	0%	3	27,014	24	0	0	8,104	7	25,275	23
2012	29815	27	33%	33%	33%	0%	3	27,689	25	0	0	8,307	7	26,429	24
2013	30560	28	33%	33%	33%	0%	3	28,381	26	0	0	8,514	8	27,449	25
2014	31324	28	33%	33%	33%	0%	3	29,091	26	0	0	8,727	8	28,235	25
2015	32108	29	33%	33%	33%	0%	3	29,818	27	0	0	8,945	8	28,779	26

NiCd Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	8347	1,694	33%	33%	33%	0%	5	7,482	1,519	4,489	911	7,018	1425
1997	8535	1,733	33%	33%	33%	0%	5	7,651	1,553	4,591	932	7,176	1457
1998	8723	1,771	33%	33%	33%	0%	5	7,820	1,587	4,692	952	7,334	1489
1999	8912	1,809	33%	33%	33%	0%	5	7,989	1,622	4,793	973	7,493	1521
2000	9100	1,847	33%	33%	33%	0%	5	8,164	1,657	4,898	994	7,657	1554
2001	9940	2,018	33%	33%	33%	0%	5	8,346	1,694	5,008	1,017	7,828	1589
2002	10690	2,170	33%	33%	33%	0%	5	8,534	1,732	5,121	1,039	8,004	1625
2003	11710	2,377	33%	33%	33%	0%	5	8,722	1,771	5,233	1,062	8,181	1661
2004	12810	2,600	33%	33%	33%	0%	5	8,911	1,809	5,346	1,085	8,358	1697
2005	13950	2,832	33%	33%	33%	0%	5	9,316	1,891	5,590	1,135	8,625	1751
2006	15100	3,065	33%	33%	33%	0%	5	9,909	2,012	5,945	1,207	8,971	1821
2007	16450	3,339	33%	33%	33%	0%	5	10,779	2,188	6,467	1,313	9,432	1915
2008	18240	3,703	33%	33%	33%	0%	5	11,735	2,382	7,041	1,429	9,928	2015
2009	20240	4,109	33%	33%	33%	0%	5	12,822	2,603	7,693	1,562	10,475	2126
2010	22380	4,543	33%	33%	33%	0%	5	13,952	2,832	8,371	1,699	11,171	2268
2011	17051	3,461	33%	33%	33%	0%	5	15,165	3,079	9,099	1,847	12,011	2438
2012	12992	2,637	33%	33%	33%	0%	5	16,595	3,369	9,957	2,021	13,105	2660
2013	10556	2,143	33%	33%	33%	0%	5	18,308	3,717	10,985	2,230	14,365	2916
2014	8932	1,813	33%	33%	33%	0%	5	20,285	4,118	12,171	2,471	15,807	3209
2015	7308	1,483	33%	33%	33%	0%	5	19,888	4,037	11,933	2,422	16,327	3314

NiMH Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 2	3	4	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	2027	189	33%	33%	33%	0%	3	1899	177	1139	106	1781	166
1997	2073	193	33%	33%	33%	0%	3	1940	180	1164	108	1820	169
1998	2119	197	33%	33%	33%	0%	3	1983	184	1190	111	1860	173
1999	2164	201	33%	33%	33%	0%	3	2027	188	1216	113	1901	177
2000	2210	206	33%	33%	33%	0%	3	2073	193	1244	116	1944	181
2001	2590	241	33%	33%	33%	0%	3	2118	197	1271	118	1987	185
2002	2990	278	33%	33%	33%	0%	3	2164	201	1298	121	2030	189
2003	3510	326	33%	33%	33%	0%	3	2321	216	1393	130	2118	197
2004	4100	381	33%	33%	33%	0%	3	2596	241	1558	145	2255	210
2005	4770	444	33%	33%	33%	0%	3	3030	282	1818	169	2455	228
2006	5520	513	33%	33%	33%	0%	3	3533	329	2120	197	2684	250
2007	6400	595	33%	33%	33%	0%	3	4126	384	2476	230	2949	274
2008	7540	701	33%	33%	33%	0%	3	4796	446	2878	268	3311	308
2009	8880	826	33%	33%	33%	0%	3	5563	517	3338	310	3783	352
2010	10490	976	33%	33%	33%	0%	3	6486	603	3892	362	4412	410
2011	10263	954	33%	33%	33%	0%	3	7606	707	4564	424	5162	480
2012	10041	934	33%	33%	33%	0%	3	8969	834	5381	500	6063	564
2013	9796	911	33%	33%	33%	0%	3	9877	919	5926	551	6828	635
2014	9530	886	33%	33%	33%	0%	3	10264	955	6158	573	7443	692
2015	9489	882	33%	33%	33%	0%	3	10032	933	6019	560	7905	735

Lithium Ion Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 1.5	1.75	2	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	679	27	33%	33%	33%	0%	2	0	0	0	0	0	0
1997	694	28	33%	33%	33%	0%	2	663	27	398	16	265	11
1998	709	28	33%	33%	33%	0%	2	679	27	407	16	271	11
1999	725	29	33%	33%	33%	0%	2	694	28	416	17	278	11
2000	740	30	33%	33%	33%	0%	2	709	28	426	17	284	11
2001	890	36	33%	33%	33%	0%	2	725	29	435	17	290	12
2002	1070	43	33%	33%	33%	0%	2	740	30	444	18	694	28
2003	1290	52	33%	33%	33%	0%	2	890	36	534	21	763	31
2004	1540	62	33%	33%	33%	0%	2	1,070	43	642	26	844	34
2005	1840	74	33%	33%	33%	0%	2	1,290	52	774	31	942	38
2006	2160	86	33%	33%	33%	0%	2	1,540	62	924	37	1,051	42
2007	2530	101	33%	33%	33%	0%	2	1,840	74	1,104	44	1,180	47
2008	3040	122	33%	33%	33%	0%	2	2,160	86	1,296	52	1,398	56
2009	3640	146	33%	33%	33%	0%	2	2,530	101	1,518	61	1,654	66
2010	4290	172	33%	33%	33%	0%	2	3,040	122	1,824	73	1,990	80
2011	10263	411	33%	33%	33%	0%	2	3,640	146	2,184	87	2,380	95
2012	10041	402	33%	33%	33%	0%	2	4,290	172	2,574	103	2,820	113
2013	9796	392	33%	33%	33%	0%	2	10,262	410	6,157	246	5,401	216
2014	9530	381	33%	33%	33%	0%	2	10,040	402	6,024	241	5,534	221
2015	9489	380	33%	33%	33%	0%	2	9,795	392	5,877	235	5,742	230

Lithium Polymer Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units[1] (000s)	Tonnes	Share of Units Lasting (years)[2] 1.5	1.75	2	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	55	2.2	33%	33%	33%	0%	2	0	0.0	0	0.0	0.0	0.0
1997	56	2.3	33%	33%	33%	0%	2	54	2.2	32	1.3	21.5	0.9
1998	58	2.3	33%	33%	33%	0%	2	55	2.2	33	1.3	22.0	0.9
1999	59	2.4	33%	33%	33%	0%	2	56	2.3	34	1.4	22.5	0.9
2000	60	2.4	33%	33%	33%	0%	2	58	2.3	35	1.4	23.0	0.9
2001	90	3.6	33%	33%	33%	0%	2	59	2.4	35	1.4	23.5	0.9
2002	90	3.6	33%	33%	33%	0%	2	60	2.4	36	1.4	56.3	2.3
2003	120	4.8	33%	33%	33%	0%	2	90	3.6	54	2.2	69.0	2.8
2004	140	5.6	33%	33%	33%	0%	2	90	3.6	54	2.2	69.8	2.8
2005	160	6.4	33%	33%	33%	0%	2	120	4.8	72	2.9	82.5	3.3
2006	210	8.4	33%	33%	33%	0%	2	140	5.6	84	3.4	91.2	3.6
2007	250	10.0	33%	33%	33%	0%	2	160	6.4	96	3.8	100.0	4.0
2008	280	11.2	33%	33%	33%	0%	2	210	8.4	126	5.0	138.0	5.5
2009	330	13.2	33%	33%	33%	0%	2	250	10.0	150	6.0	154.0	6.2
2010	360	14.4	33%	33%	33%	0%	2	280	11.2	168	6.7	184.0	7.4
2011	383	15.3	33%	33%	33%	0%	2	330	13.2	198	7.9	216.0	8.6
2012	407	16.3	33%	33%	33%	0%	2	360	14.4	216	8.6	240.0	9.6
2013	431	17.2	33%	33%	33%	0%	2	383	15.3	230	9.2	279.1	11.2
2014	453	18.1	33%	33%	33%	0%	2	407	16.3	244	9.8	312.8	12.5
2015	459	18.4	33%	33%	33%	0%	2	431	17.2	258	10.3	340.3	13.6

SSLA Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units (000s)	Tonnes	Share of Units Lasting (years)[2] 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	310	324	33%	33%	33%	0%	5	307	321	184	193	305	319
1997	311	325	33%	33%	33%	0%	5	308	322	185	193	306	320
1998	316	330	33%	33%	33%	0%	5	309	323	185	194	307	321
1999	304	318	33%	33%	33%	0%	5	309	323	185	194	307	321
2000	315	329	33%	33%	33%	0%	5	310	323	186	194	308	322
2001	317	331	33%	33%	33%	0%	5	310	324	186	194	308	322
2002	335	350	33%	33%	33%	0%	5	312	326	187	196	310	324
2003	256	268	33%	33%	33%	0%	5	310	324	186	195	309	323
2004	357	373	33%	33%	33%	0%	5	312	326	187	195	310	324
2005	328	342	33%	33%	33%	0%	5	312	326	187	196	310	324
2006	406	424	33%	33%	33%	0%	5	322	337	193	202	315	329
2007	366	382	33%	33%	33%	0%	5	303	316	182	190	308	322
2008	369	385	33%	33%	33%	0%	5	316	330	189	198	313	327
2009	383	400	33%	33%	33%	0%	5	313	327	188	196	312	326
2010	375	392	33%	33%	33%	0%	5	363	380	218	228	332	347
2011	378	395	33%	33%	33%	0%	5	366	383	220	230	340	355
2012	381	398	33%	33%	33%	0%	5	380	397	228	238	334	349
2013	381	398	33%	33%	33%	0%	5	372	389	223	234	338	354
2014	383	400	33%	33%	33%	0%	5	376	392	225	235	338	353
2015	384	402	33%	33%	33%	0%	5	379	396	227	237	369	386

Appendix B

Battery Flow Model 2009 Output Sheets for Consumer Primary and Secondary Batteries

15 Year Hoarding Assumption

Zinc Carbon Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	133,710	3,610	33%	33%	33%	0%	3	123,945	3,347	37,183	1,004	86,761	2,343
1997	137,139	3,703	33%	33%	33%	0%	3	127,123	3,432	38,137	1,030	88,986	2,403
1998	140,655	3,798	33%	33%	33%	0%	3	130,382	3,520	39,115	1,056	91,267	2,464
1999	144,261	3,895	33%	33%	33%	0%	3	133,725	3,611	40,118	1,083	93,608	2,527
2000	147,960	3,995	33%	33%	33%	0%	3	137,154	3,703	41,146	1,111	96,008	2,592
2001	151,754	4,097	33%	33%	33%	0%	3	140,671	3,798	42,201	1,139	98,470	2,659
2002	161,530	4,361	33%	33%	33%	0%	3	144,278	3,896	43,283	1,169	111,114	3,000
2003	176,721	4,771	33%	33%	33%	0%	3	147,977	3,995	44,393	1,199	124,083	3,350
2004	190,755	5,150	33%	33%	33%	0%	3	153,733	4,151	46,120	1,245	138,758	3,746
2005	208,227	5,622	33%	33%	33%	0%	3	163,319	4,410	48,996	1,323	146,266	3,949
2006	197,815	5,341	33%	33%	33%	0%	3	176,318	4,761	52,895	1,428	156,185	4,217
2007	187,925	5,074	33%	33%	33%	0%	3	191,882	5,181	57,565	1,554	167,919	4,534
2008	178,528	4,820	33%	33%	33%	0%	3	198,913	5,371	59,674	1,611	173,703	4,690
2009	169,602	4,579	33%	33%	33%	0%	3	197,969	5,345	59,391	1,604	173,926	4,696
2010	161,122	4,350	33%	33%	33%	0%	3	188,071	5,078	56,421	1,523	167,903	4,533
2011	150,375	4,060	33%	33%	33%	0%	3	178,667	4,824	53,600	1,447	162,250	4,381
2012	140,345	3,789	33%	33%	33%	0%	3	169,734	4,583	50,920	1,375	156,950	4,238
2013	130,984	3,537	33%	33%	33%	0%	3	160,350	4,329	48,105	1,299	151,360	4,087
2014	122,247	3,301	33%	33%	33%	0%	3	150,599	4,066	45,180	1,220	145,537	3,929
2015	114,093	3,081	33%	33%	33%	0%	3	140,554	3,795	42,166	1,138	139,534	3,767

Alkaline Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	275,703	7,720	33%	33%	33%	0%	3	255,567	7,156	76,670	2,147	178,897	5,009
1997	282,773	7,918	33%	33%	33%	0%	3	262,120	7,339	78,636	2,202	183,484	5,138
1998	290,023	8,121	33%	33%	33%	0%	3	268,841	7,528	80,652	2,258	188,189	5,269
1999	297,460	8,329	33%	33%	33%	0%	3	275,735	7,721	82,720	2,316	193,014	5,404
2000	305,087	8,542	33%	33%	33%	0%	3	282,805	7,919	84,841	2,376	197,963	5,543
2001	312,910	8,761	33%	33%	33%	0%	3	290,056	8,122	87,017	2,436	203,039	5,685
2002	331,726	9,288	33%	33%	33%	0%	3	297,493	8,330	89,248	2,499	229,112	6,415
2003	348,120	9,747	33%	33%	33%	0%	3	305,122	8,543	91,536	2,563	255,853	7,164
2004	369,383	10,343	33%	33%	33%	0%	3	316,543	8,863	94,963	2,659	285,798	8,002
2005	389,955	10,919	33%	33%	33%	0%	3	330,886	9,265	99,266	2,779	297,485	8,330
2006	403,838	11,307	33%	33%	33%	0%	3	349,708	9,792	104,912	2,938	312,349	8,746
2007	418,214	11,710	33%	33%	33%	0%	3	369,116	10,335	110,735	3,101	327,667	9,175
2008	433,103	12,127	33%	33%	33%	0%	3	387,686	10,855	116,306	3,257	342,443	9,588
2009	448,521	12,559	33%	33%	33%	0%	3	403,962	11,311	121,189	3,393	355,658	9,958
2010	464,489	13,006	33%	33%	33%	0%	3	418,343	11,714	125,503	3,514	367,594	10,293
2011	480,746	13,461	33%	33%	33%	0%	3	433,236	12,131	129,971	3,639	379,935	10,638
2012	497,572	13,932	33%	33%	33%	0%	3	448,659	12,562	134,598	3,769	392,698	10,996
2015	514,987	14,420	33%	33%	33%	0%	3	464,539	13,007	139,362	3,902	405,829	11,363
2014	533,011	14,924	33%	33%	33%	0%	3	480,887	13,465	144,266	4,039	419,341	11,742
2015	551,667	15,447	33%	33%	33%	0%	3	497,718	13,936	149,315	4,181	433,244	12,131

Zinc Air Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	121.8	4.0	33%	33%	33%	0%	3	112.9	3.7	33.9	1.1	79.0	2.6
1997	124.9	4.1	33%	33%	33%	0%	3	115.8	3.8	34.7	1.1	81.1	2.7
1998	128.1	4.2	33%	33%	33%	0%	3	118.8	3.9	35.6	1.2	83.1	2.7
1999	131.4	4.3	33%	33%	33%	0%	3	121.8	4.0	36.5	1.2	85.3	2.8
2000	134.8	4.4	33%	33%	33%	0%	3	124.9	4.1	37.5	1.2	87.4	2.9
2001	138.2	4.6	33%	33%	33%	0%	3	128.1	4.2	38.4	1.3	89.7	3.0
2002	141.8	4.7	33%	33%	33%	0%	3	131.4	4.3	39.4	1.3	92.0	3.0
2003	145.4	4.8	33%	33%	33%	0%	3	134.8	4.4	40.4	1.3	94.3	3.1
2004	42.2	1.4	33%	33%	33%	0%	3	138.2	4.6	41.5	1.4	96.8	3.2
2005	134.5	4.4	33%	33%	33%	0%	3	141.8	4.7	42.5	1.4	128.3	4.2
2006	144.2	4.8	33%	33%	33%	0%	3	109.8	3.6	32.9	1.1	106.7	3.5
2007	147.8	4.9	33%	33%	33%	0%	3	107.4	3.5	32.2	1.1	105.8	3.5
2008	151.5	5.0	33%	33%	33%	0%	3	106.9	3.5	32.1	1.1	106.3	3.5
2009	155.3	5.1	33%	33%	33%	0%	3	142.1	4.7	42.6	1.4	131.7	4.3
2010	159.1	5.3	33%	33%	33%	0%	3	147.8	4.9	44.3	1.5	136.5	4.5
2011	163.1	5.4	33%	33%	33%	0%	3	151.5	5.0	45.4	1.5	139.9	4.6
2012	167.2	5.5	33%	33%	33%	0%	3	155.3	5.1	46.6	1.5	143.4	4.7
2013	171.4	5.7	33%	33%	33%	0%	3	159.1	5.3	47.7	1.6	147.0	4.9
2014	175.7	5.8	33%	33%	33%	0%	3	163.1	5.4	48.9	1.6	150.7	5.0
2015	180.0	5.9	33%	33%	33%	0%	3	167.2	5.5	50.2	1.7	154.5	5.1

Lithium Primary Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			**Operational Lifespan**					**Units Spent[5]**		**Units Hoarded[7]**		**Units at End of Life[9]**	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	16790	269	33%	33%	33%	0%	3	15564	249	4,669	75	10,895	174
1997	17221	276	33%	33%	33%	0%	3	15963	255	4,789	77	11,174	179
1998	17662	283	33%	33%	33%	0%	3	16372	262	4,912	79	11,461	183
1999	18115	290	33%	33%	33%	0%	3	16792	269	5,038	81	11,754	188
2000	18580	297	33%	33%	33%	0%	3	17223	276	5,167	83	12,056	193
2001	19056	305	33%	33%	33%	0%	3	17664	283	5,299	85	12,365	198
2002	19545	313	33%	33%	33%	0%	3	18117	290	5,435	87	12,682	203
2003	20046	321	33%	33%	33%	0%	3	18582	297	5,574	89	13,007	208
2004	21355	342	33%	33%	33%	0%	3	19058	305	5,717	91	17,251	276
2005	24418	391	33%	33%	33%	0%	3	19547	313	5,864	94	17,694	283
2006	27248	436	33%	33%	33%	0%	3	20313	325	6,094	98	18,333	293
2007	27930	447	33%	33%	33%	0%	3	21937	351	6,581	105	19,576	313
2008	28628	458	33%	33%	33%	0%	3	24338	389	7,301	117	21,364	342
2009	29343	469	33%	33%	33%	0%	3	26529	424	7,959	127	23,009	368
2010	30077	481	33%	33%	33%	0%	3	27932	447	8,380	134	24,105	386
2011	30829	493	33%	33%	33%	0%	3	28631	458	8,589	137	24,711	395
2012	31600	506	33%	33%	33%	0%	3	29346	470	8,804	141	25,331	405
2013	32390	518	33%	33%	33%	0%	3	30080	481	9,024	144	25,968	415
2014	33199	531	33%	33%	33%	0%	3	30832	493	9,250	148	26,620	426
2015	34029	544	33%	33%	33%	0%	3	31603	506	9,481	152	27,289	437

Silver Oxide Button Cell Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	9220	11	33%	33%	33%	0%	3	8,547	10	2,564	3.1	5,983	7.2
1997	9457	11	33%	33%	33%	0%	3	8,766	11	2,630	3.2	6,136	7.4
1998	9699	12	33%	33%	33%	0%	3	8,991	11	2,697	3.2	6,294	7.6
1999	9948	12	33%	33%	33%	0%	3	9,221	11	2,766	3.3	6,455	7.7
2000	10203	12	33%	33%	33%	0%	3	9,458	11	2,837	3.4	6,620	7.9
2001	10465	13	33%	33%	33%	0%	3	9,700	12	2,910	3.5	6,790	8.1
2002	10733	13	33%	33%	33%	0%	3	9,949	12	2,985	3.6	7,662	9.2
2003	11008	13	33%	33%	33%	0%	3	10,204	12	3,061	3.7	8,556	10.3
2004	10866	13	33%	33%	33%	0%	3	10,466	13	3,140	3.8	9,474	11.4
2005	9917	12	33%	33%	33%	0%	3	10,734	13	3,220	3.9	9,717	11.7
2006	10018	12	33%	33%	33%	0%	3	10,868	13	3,260	3.9	9,867	11.8
2007	10268	12	33%	33%	33%	0%	3	10,596	13	3,179	3.8	9,734	11.7
2008	10525	13	33%	33%	33%	0%	3	10,266	12	3,080	3.7	9,563	11.5
2009	10788	13	33%	33%	33%	0%	3	10,067	12	3,020	3.6	9,484	11.4
2010	11058	13	33%	33%	33%	0%	3	10,269	12	3,081	3.7	9,688	11.6
2011	11334	14	33%	33%	33%	0%	3	10,526	13	3,158	3.8	9,932	11.9
2012	11618	14	33%	33%	33%	0%	3	10,789	13	3,237	3.9	10,182	12.2
2013	11908	14	33%	33%	33%	0%	3	11,059	13	3,318	4.0	10,438	12.5
2014	12206	15	33%	33%	33%	0%	3	11,335	14	3,401	4.1	10,701	12.8
2015	12511	15	33%	33%	33%	0%	3	11,619	14	3,486	4.2	10,970	13.2

Zinc Air Button Cell Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			**Operational Lifespan**					**Units Spent[5]**		**Units Hoarded[7]**		**Units at End of Life[9]**	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	17047	15	33%	33%	33%	0%	3	15,802	14	4,740	4.3	11,061	10.0
1997	17484	16	33%	33%	33%	0%	3	16,207	15	4,862	4.4	11,345	10.2
1998	17932	16	33%	33%	33%	0%	3	16,622	15	4,987	4.5	11,636	10.5
1999	18392	17	33%	33%	33%	0%	3	17,048	15	5,115	4.6	11,934	10.7
2000	18863	17	33%	33%	33%	0%	3	17,486	16	5,246	4.7	12,240	11.0
2001	19347	17	33%	33%	33%	0%	3	17,934	16	5,380	4.8	12,554	11.3
2002	19843	18	33%	33%	33%	0%	3	18,394	17	5,518	5.0	12,876	11.6
2003	20352	18	33%	33%	33%	0%	3	18,865	17	5,660	5.1	15,819	14.2
2004	23465	21	33%	33%	33%	0%	3	19,349	17	5,805	5.2	17,515	15.8
2005	26656	24	33%	33%	33%	0%	3	19,845	18	5,954	5.4	17,964	16.2
2006	25709	23	33%	33%	33%	0%	3	21,218	19	6,365	5.7	19,029	17.1
2007	26352	24	33%	33%	33%	0%	3	23,488	21	7,047	6.3	20,726	18.7
2008	27011	24	33%	33%	33%	0%	3	25,274	23	7,582	6.8	22,086	19.9
2009	27686	25	33%	33%	33%	0%	3	26,237	24	7,871	7.1	22,872	20.6
2010	28378	26	33%	33%	33%	0%	3	26,355	24	7,906	7.1	23,070	20.8
2011	29088	26	33%	33%	33%	0%	3	27,014	24	8,104	7.3	23,650	21.3
2012	29815	27	33%	33%	33%	0%	3	27,689	25	8,307	7.5	24,244	21.8
2013	30560	28	33%	33%	33%	0%	3	28,381	26	8,514	7.7	24,854	22.4
2014	31324	28	33%	33%	33%	0%	3	29,091	26	8,727	7.9	25,478	22.9
2015	32108	29	33%	33%	33%	0%	3	29,818	27	8,945	8.1	26,118	23.5

NiCd Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 4	5	6	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	8,347	1,694	33%	33%	33%	0%	5	7,482	1,519	4,489	911	2,993	608
1997	8,535	1,733	33%	33%	33%	0%	5	7,651	1,553	4,591	932	3,060	621
1998	8,723	1,771	33%	33%	33%	0%	5	7,820	1,587	4,692	952	3,128	635
1999	8,912	1,809	33%	33%	33%	0%	5	7,989	1,622	4,793	973	3,195	649
2000	9,100	1,847	33%	33%	33%	0%	5	8,164	1,657	4,898	994	3,266	663
2001	9,940	2,018	33%	33%	33%	0%	5	8,346	1,694	5,008	1,017	3,338	678
2002	10,690	2,170	33%	33%	33%	0%	5	8,534	1,732	5,121	1,039	4,671	948
2003	11,710	2,377	33%	33%	33%	0%	5	8,722	1,771	5,233	1,062	6,030	1,224
2004	12,810	2,600	33%	33%	33%	0%	5	8,911	1,809	5,346	1,085	7,417	1,506
2005	13,950	2,832	33%	33%	33%	0%	5	9,316	1,891	5,590	1,135	7,664	1,556
2006	15,100	3,065	33%	33%	33%	0%	5	9,909	2,012	5,945	1,207	7,988	1,622
2007	16,450	3,339	33%	33%	33%	0%	5	10,779	2,188	6,467	1,313	8,427	1,711
2008	18,240	3,703	33%	33%	33%	0%	5	11,735	2,382	7,041	1,429	8,901	1,807
2009	20,240	4,109	33%	33%	33%	0%	5	12,822	2,603	7,693	1,562	9,426	1,913
2010	22,380	4,543	33%	33%	33%	0%	5	13,952	2,832	8,371	1,699	9,972	2,024
2011	17,051	3,461	33%	33%	33%	0%	5	15,165	3,079	9,099	1,847	10,555	2,143
2012	12,992	2,637	33%	33%	33%	0%	5	16,595	3,369	9,957	2,021	11,229	2,279
2013	10,556	2,143	33%	33%	33%	0%	5	18,308	3,717	10,985	2,230	12,015	2,439
2014	8,932	1,813	33%	33%	33%	0%	5	20,285	4,118	12,171	2,471	12,907	2,620
2015	7,308	1,483	33%	33%	33%	0%	5	19,888	4,037	11,933	2,422	12,854	2,609

NiMH Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 2	3	4	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	2,027	189	33%	33%	33%	0%	3	1,899	177	1,139	106	760	71
1997	2,073	193	33%	33%	33%	0%	3	1,940	180	1,164	108	776	72
1998	2,119	197	33%	33%	33%	0%	3	1,983	184	1,190	111	793	74
1999	2,164	201	33%	33%	33%	0%	3	2,027	188	1,216	113	811	75
2000	2,210	206	33%	33%	33%	0%	3	2,073	193	1,244	116	1,134	105
2001	2,590	241	33%	33%	33%	0%	3	2,118	197	1,271	118	1,464	136
2002	2,990	278	33%	33%	33%	0%	3	2,164	201	1,298	121	1,801	168
2003	3,510	326	33%	33%	33%	0%	3	2,321	216	1,393	130	1,885	175
2004	4,100	381	33%	33%	33%	0%	3	2,596	241	1,558	145	2,016	187
2005	4,770	444	33%	33%	33%	0%	3	3,030	282	1,818	169	2,211	206
2006	5,520	513	33%	33%	33%	0%	3	3,533	329	2,120	197	2,435	226
2007	6,400	595	33%	33%	33%	0%	3	4,126	384	2,476	230	2,694	251
2008	7,540	701	33%	33%	33%	0%	3	4,796	446	2,878	268	2,985	278
2009	8,880	826	33%	33%	33%	0%	3	5,563	517	3,338	310	3,315	308
2010	10,490	976	33%	33%	33%	0%	3	6,486	603	3,892	362	3,709	345
2011	10,263	954	33%	33%	33%	0%	3	7,606	707	4,564	424	4,182	389
2012	10,041	934	33%	33%	33%	0%	3	8,969	834	5,381	500	4,752	442
2013	9,796	911	33%	33%	33%	0%	3	9,877	919	5,926	551	5,140	478
2014	9,530	886	33%	33%	33%	0%	3	10,264	955	6,158	573	5,322	495
2015	9,489	882	33%	33%	33%	0%	3	10,032	933	6,019	560	5,257	489

Lithium Ion Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 1.5	1.75	2	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	679	27	33%	33%	33%	0%	2	0	0	0	0	0	0
1997	694	28	33%	33%	33%	0%	2	663	27	398	16	265	11
1998	709	28	33%	33%	33%	0%	2	679	27	407	16	271	11
1999	725	29	33%	33%	33%	0%	2	694	28	416	17	278	11
2000	740	30	33%	33%	33%	0%	2	709	28	426	17	284	11
2001	890	36	33%	33%	33%	0%	2	725	29	435	17	290	12
2002	1,070	43	33%	33%	33%	0%	2	740	30	444	18	296	12
2003	1,290	52	33%	33%	33%	0%	2	890	36	534	21	356	14
2004	1,540	62	33%	33%	33%	0%	2	1,070	43	642	26	428	17
2005	1,840	74	33%	33%	33%	0%	2	1,290	52	774	31	516	21
2006	2,160	86	33%	33%	33%	0%	2	1,540	62	924	37	616	25
2007	2,530	101	33%	33%	33%	0%	2	1,840	74	1,104	44	736	29
2008	3,040	122	33%	33%	33%	0%	2	2,160	86	1,296	52	864	35
2009	3,640	146	33%	33%	33%	0%	2	2,530	101	1,518	61	1,012	40
2010	4,290	172	33%	33%	33%	0%	2	3,040	122	1,824	73	1,216	49
2011	10,263	411	33%	33%	33%	0%	2	3,640	146	2,184	87	1,456	58
2012	10,041	402	33%	33%	33%	0%	2	4,290	172	2,574	103	2,114	85
2013	9,796	392	33%	33%	33%	0%	2	10,262	410	6,157	246	4,512	180
2014	9,530	381	33%	33%	33%	0%	2	10,040	402	6,024	241	4,432	177
2015	9,489	380	33%	33%	33%	0%	2	9,795	392	5,877	235	4,344	174

Lithium Polymer Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent[5]		Units Hoarded[7]		Units at End of Life[9]	
Year	Units[1] (000s)	Tonnes[2]	Share of Units Lasting (years)[3] 1.5	1.75	2	0	Weighted Avg[4] (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	55	2.2	33%	33%	33%	0%	2	0.0	0.0	0.0	0.0	0.0	0.0
1997	56	2.3	33%	33%	33%	0%	2	53.8	2.2	32.3	1.3	21.5	0.9
1998	58	2.3	33%	33%	33%	0%	2	55.0	2.2	33.0	1.3	22.0	0.9
1999	59	2.4	33%	33%	33%	0%	2	56.3	2.3	33.8	1.4	22.5	0.9
2000	60	2.4	33%	33%	33%	0%	2	57.5	2.3	34.5	1.4	23.0	0.9
2001	90	3.6	33%	33%	33%	0%	2	58.8	2.4	35.3	1.4	23.5	0.9
2002	90	3.6	33%	33%	33%	0%	2	60.0	2.4	36.0	1.4	24.0	1.0
2003	120	4.8	33%	33%	33%	0%	2	90.0	3.6	54.0	2.2	36.0	1.4
2004	140	5.6	33%	33%	33%	0%	2	90.0	3.6	54.0	2.2	36.0	1.4
2005	160	6.4	33%	33%	33%	0%	2	120.0	4.8	72.0	2.9	48.0	1.9
2006	210	8.4	33%	33%	33%	0%	2	140.0	5.6	84.0	3.4	56.0	2.2
2007	250	10.0	33%	33%	33%	0%	2	160.0	6.4	96.0	3.8	64.0	2.6
2008	280	11.2	33%	33%	33%	0%	2	210.0	8.4	126.0	5.0	84.0	3.4
2009	330	13.2	33%	33%	33%	0%	2	250.0	10.0	150.0	6.0	100.0	4.0
2010	360	14.4	33%	33%	33%	0%	2	280.0	11.2	168.0	6.7	112.0	4.5
2011	383	15.3	33%	33%	33%	0%	2	330.0	13.2	198.0	7.9	132.0	5.3
2012	407	16.3	33%	33%	33%	0%	2	360.0	14.4	216.0	8.6	176.3	7.1
2013	431	17.2	33%	33%	33%	0%	2	382.7	15.3	229.6	9.2	186.1	7.4
2014	453	18.1	33%	33%	33%	0%	2	407.0	16.3	244.2	9.8	196.5	7.9
2015	459	18.4	33%	33%	33%	0%	2	430.7	17.2	258.4	10.3	206.8	8.3

SSLA Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units (000s)	Tonnes	Share of Units Lasting (years) 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	310	324	33%	33%	33%	0%	5	307	321	184	193	123	128
1997	311	325	33%	33%	33%	0%	5	308	322	185	193	123	129
1998	316	330	33%	33%	33%	0%	5	309	323	185	194	123	129
1999	304	318	33%	33%	33%	0%	5	309	323	185	194	124	129
2000	315	329	33%	33%	33%	0%	5	310	323	186	194	124	129
2001	317	331	33%	33%	33%	0%	5	310	324	186	194	124	130
2002	335	350	33%	33%	33%	0%	5	312	326	187	196	125	131
2003	256	268	33%	33%	33%	0%	5	310	324	186	195	124	130
2004	357	373	33%	33%	33%	0%	5	312	326	187	195	185	194
2005	328	342	33%	33%	33%	0%	5	312	326	187	196	246	257
2006	406	424	33%	33%	33%	0%	5	322	337	193	202	311	325
2007	366	382	33%	33%	33%	0%	5	303	316	182	190	304	318
2008	369	385	33%	33%	33%	0%	5	316	330	189	198	310	323
2009	383	400	33%	33%	33%	0%	5	313	327	188	196	309	323
2010	375	392	33%	33%	33%	0%	5	363	380	218	228	329	344
2011	378	395	33%	33%	33%	0%	5	366	383	220	230	331	346
2012	381	398	33%	33%	33%	0%	5	380	397	228	238	337	352
2013	381	398	33%	33%	33%	0%	5	372	389	223	234	334	349
2014	383	400	33%	33%	33%	0%	5	376	392	225	235	336	351
2015	384	402	33%	33%	33%	0%	5	379	396	227	237	337	352

Appendix C

Battery Flow Model 2009 Output Sheets for Lead Acid Batteries

No Hoarding Assumption

Passenger Car LAB Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units (000s)	Tonnes	Share of Units Lasting (years) 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	4346	76,920	33%	33%	33%	0%	5	4,133	73,146	2,480	43,887	4,011	70,995
1997	4390	77,697	33%	33%	33%	0%	5	4,174	73,884	2,505	44,331	4,052	71,712
1998	4434	78,482	33%	33%	33%	0%	5	4,216	74,631	2,530	44,778	4,092	72,436
1999	4479	79,275	33%	33%	33%	0%	5	4,259	75,385	2,555	45,231	4,134	73,168
2000	4524	80,076	33%	33%	33%	0%	5	4,302	76,146	2,581	45,688	4,176	73,907
2001	4570	80,884	33%	33%	33%	0%	5	4,345	76,915	2,607	46,149	4,218	74,653
2002	4928	87,219	33%	33%	33%	0%	5	4,389	77,692	2,634	46,615	4,260	75,407
2003	4826	85,420	33%	33%	33%	0%	5	4,434	78,477	2,660	47,086	4,303	76,169
2004	4813	85,198	33%	33%	33%	0%	5	4,479	79,270	2,687	47,562	4,347	76,939
2005	4877	86,323	33%	33%	33%	0%	5	4,524	80,070	2,714	48,042	4,391	77,716
2006	4946	87,551	33%	33%	33%	0%	5	4,673	82,718	2,804	49,631	4,477	79,236
2007	4998	88,469	33%	33%	33%	0%	5	4,774	84,499	2,864	50,700	4,543	80,415
2008	5037	89,151	33%	33%	33%	0%	5	4,855	85,937	2,913	51,562	4,602	81,461
2009	5065	89,657	33%	33%	33%	0%	5	4,838	85,639	2,903	51,383	4,622	81,817
2010	5106	90,379	33%	33%	33%	0%	5	4,878	86,349	2,927	51,809	4,666	82,582
2011	5157	91,285	33%	33%	33%	0%	5	4,940	87,439	2,964	52,463	4,780	84,606
2012	5219	92,377	33%	33%	33%	0%	5	4,993	88,382	2,996	53,029	4,862	86,052
2013	5292	93,671	33%	33%	33%	0%	5	5,033	89,083	3,020	53,450	4,926	87,196
2014	5375	95,132	33%	33%	33%	0%	5	5,069	89,720	3,041	53,832	4,931	87,271
2015	5466	96,755	33%	33%	33%	0%	5	5,109	90,431	3,065	54,259	4,971	87,982

Motorcycle LAB Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units (000s)	Tonnes	Share of Units Lasting (years) 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	198	852	33%	33%	33%	0	5	307	1,321	184	793	305	1,313
1997	200	861	33%	33%	33%	0	5	308	1,323	185	794	306	1,316
1998	202	869	33%	33%	33%	0	5	309	1,327	185	796	307	1,319
1999	204	878	33%	33%	33%	0	5	309	1,329	185	797	307	1,321
2000	206	887	33%	33%	33%	0	5	272	1,171	163	702	293	1,259
2001	208	896	33%	33%	33%	0	5	236	1,013	141	608	279	1,198
2002	235	1,013	33%	33%	33%	0	5	200	861	120	516	265	1,138
2003	254	1,091	33%	33%	33%	0	5	202	869	121	522	266	1,144
2004	280	1,204	33%	33%	33%	0	5	204	878	123	527	267	1,149
2005	299	1,284	33%	33%	33%	0	5	206	887	124	532	246	1,057
2006	325	1,399	33%	33%	33%	0	5	217	932	130	559	228	981
2007	349	1,502	33%	33%	33%	0	5	233	1,000	140	600	213	916
2008	370	1,591	33%	33%	33%	0	5	256	1,103	154	662	224	963
2009	389	1,671	33%	33%	33%	0	5	277	1,193	166	716	234	1,004
2010	409	1,759	33%	33%	33%	0	5	301	1,296	181	777	244	1,050
2011	431	1,855	33%	33%	33%	0	5	324	1,395	195	837	260	1,117
2012	456	1,959	33%	33%	33%	0	5	348	1,497	209	898	279	1,199
2013	482	2,072	33%	33%	33%	0	5	369	1,588	222	953	302	1,297
2014	511	2,195	33%	33%	33%	0	5	389	1,673	233	1,004	322	1,385
2015	542	2,328	33%	33%	33%	0	5	410	1,761	246	1,057	345	1,482

Commercial Vehicle LAB Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			Operational Lifespan					Units Spent		Units Hoarded		Units at End of Life	
Year	Units (000s)	Tonnes	Share of Units Lasting (years) 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	4186	100,893	33%	33%	33%	0%	5	3,981	95,942	0	0	3,981	95,942
1997	4229	101,912	33%	33%	33%	0%	5	4,021	96,911	0	0	4,021	96,911
1998	4271	102,942	33%	33%	33%	0%	5	4,062	97,890	0	0	4,062	97,890
1999	4315	103,982	33%	33%	33%	0%	5	4,103	98,879	0	0	4,103	98,879
2000	4358	105,032	33%	33%	33%	0%	5	4,144	99,878	0	0	4,144	99,878
2001	4402	106,093	33%	33%	33%	0%	5	4,186	100,886	0	0	4,186	100,886
2002	4402	106,092	33%	33%	33%	0%	5	4,228	101,906	0	0	4,228	101,906
2003	4254	102,521	33%	33%	33%	0%	5	4,271	102,935	0	0	4,271	102,935
2004	4827	116,325	33%	33%	33%	0%	5	4,314	103,975	0	0	4,314	103,975
2005	4883	117,685	33%	33%	33%	0%	5	4,358	105,025	0	0	4,358	105,025
2006	4907	118,261	33%	33%	33%	0%	5	4,387	105,728	0	0	4,387	105,728
2007	4946	119,195	33%	33%	33%	0%	5	4,352	104,892	0	0	4,352	104,892
2008	4977	119,937	33%	33%	33%	0%	5	4,494	108,302	0	0	4,494	108,302
2009	4999	120,487	33%	33%	33%	0%	5	4,654	112,166	0	0	4,654	112,166
2010	5037	121,397	33%	33%	33%	0%	5	4,872	117,412	0	0	4,872	117,412
2011	5095	122,796	33%	33%	33%	0%	5	4,912	118,369	0	0	4,912	118,369
2012	5169	124,569	33%	33%	33%	0%	5	4,943	119,119	0	0	4,943	119,119
2013	5257	126,699	33%	33%	33%	0%	5	4,973	119,861	0	0	4,973	119,861
2014	5356	129,078	33%	33%	33%	0%	5	5,004	120,595	0	0	5,004	120,595
2015	5465	131,713	33%	33%	33%	0%	5	5,043	121,548	0	0	5,043	121,548

Total Automotive LAB Batteries Sold, Stored and End of Life in Canada from 1996-2015

New unit Sales			**Operational Lifespan**					**Units Spent**		**Units Hoarded**		**Units at End of Life**	
Year	Units (000s)	Tonnes	Share of Units Lasting (years) 4	5	6	0	Weighted Avg (Years)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)	Number (000s)	Weight (Tonnes)
1996	8,730	178,666	33%	33%	33%	0	5	8,302	142,794	2,664	44,680	8,302	142,794
1997	8,819	180,470	33%	33%	33%	0	5	8,386	144,236	2,689	45,125	8,386	144,236
1998	8,908	182,293	33%	33%	33%	0	5	8,471	145,693	2,715	45,575	8,471	145,693
1999	8,998	184,135	33%	33%	33%	0	5	8,556	147,165	2,741	46,028	8,556	147,165
2000	9,089	185,994	33%	33%	33%	0	5	8,643	148,651	2,745	46,390	8,643	148,651
2001	9,180	187,873	33%	33%	33%	0	5	8,730	150,153	2,749	46,757	8,730	150,153
2002	9,565	194,324	33%	33%	33%	0	5	8,818	151,669	2,754	47,132	8,818	151,669
2003	9,334	189,033	33%	33%	33%	0	5	8,907	153,201	2,782	47,608	8,907	153,201
2004	9,920	202,728	33%	33%	33%	0	5	8,997	154,749	2,810	48,089	8,997	154,749
2005	10,059	205,292	33%	33%	33%	0	5	9,088	156,312	2,838	48,574	9,088	156,312
2006	10,179	207,211	33%	33%	33%	0	5	9,277	159,566	2,934	50,190	9,277	159,566
2007	10,293	209,167	33%	33%	33%	0	5	9,359	160,972	3,004	51,300	9,359	160,972
2008	10,383	210,678	33%	33%	33%	0	5	9,606	165,215	3,067	52,224	9,606	165,215
2009	10,453	211,814	33%	33%	33%	0	5	9,770	168,044	3,069	52,099	9,770	168,044
2010	10,552	213,534	33%	33%	33%	0	5	10,052	172,888	3,108	52,587	10,052	172,888
2011	10,684	215,935	33%	33%	33%	0	5	10,176	175,027	3,159	53,300	10,176	175,027
2012	10,843	218,904	33%	33%	33%	0	5	10,284	176,887	3,205	53,927	10,284	176,887
2013	11,031	222,442	33%	33%	33%	0	5	10,376	178,462	3,241	54,403	10,376	178,462
2014	11,241	226,406	33%	33%	33%	0	5	10,462	179,946	3,275	54,836	10,462	179,946
2015	11,473	230,796	33%	33%	33%	0	5	10,562	181,669	3,311	55,315	10,562	181,669