UNIVERSAL WASTE MANAGMENT

BATTERY RECYLING PROGRAMS IN NOVA SCOTIA

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Acronyms

ATSDR: Agency for Toxic Substances and Disease Registry

CAP: Canada-wide Action Plan

CBA: Canadian Battery Association

CCME: Canadian Council of Ministers for the Environment

CFL: Compact Fluorescent Lamps

CFR: Code of Federal Regulations

DTSC: Department of Toxic Substances Control

HHW: Household Hazardous Wastes

ICI: Institutional, commercial and industrial

EABM: European Association of Batteries Manufacturers

EGPSA: Environmental Goals and Sustainable Prosperity Act

EPBA: European Portable Battery Association

EPR: Extended Producer Responsibility

ERP: European Recycling Platform

MSW: Municipal Solid Waste

PPM: Parts per million

SOx: Sulphur oxides

UNEP: United Nations Environmental Programme

USEPA: United States Environmental Protection Agency

WHO: World Health Organisation

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Purpose

This study focuses on the management of batteries, which is a common type of universal waste. Universal waste is a waste stream that contains materials that are not designated hazardous but do contain enough hazardous materials that they require special disposal. Battery recycling programs aim to minimize environmental contamination from improper disposal, increase recycling rates, increase waste diversion from landfills, and support the retrieval of valuable components that may be reused. The status of the battery recycling programs within Nova Scotia is reviewed in this report and opportunities for improvement identified.

Executive Summary

Currently, in Nova Scotia, battery recycling programs are not required by law and thus are not standardized across the province. The focus of this report is to understand battery recycling best practices across the country and compare this to what is happening in Nova Scotia.

Interview data and online survey results obtained from municipal employees, provincial employees and a Call2recycle expert were utilized in this study. In addition, a survey question regarding battery disposal was asked in the 2017 Fall Annual Dalhousie Sustainability and Commuter Survey. The data gathered provided information about how batteries are currently being managed in Nova Scotia.

Key findings include:

- There is no regulation for universal wastes as a waste stream in Canada;
- Batteries contain hazardous materials that have the potential to cause adverse environmental and health effects;
- The use of batteries is growing globally, hence the need for managing its end-of-life;
- A standardized battery recycling program (beyond automotive battery recycling) offered across Nova Scotia would increase diversion rates;
- Collection of batteries is key to a successful battery recycling program; therefore, it should be convenient for members of the public; and
- Batteries currently make up less than 1% of the waste stream in Nova Scotia by weight.

There are several opportunities identified to improve battery recycling rates in Nova Scotia. Some strategies will require more upfront investment in regulatory changes and program development but would likely realize higher diversion rates. The opportunities identified are as follows:

- Developing regulations to ban all battery types from the landfill in conjunction with a province-wide recycling program;
- Creating a product stewardship program that transfers responsibility for the end-of-life management of batteries to suppliers and manufacturers;
- Exploring curbside collection for household batteries;
- Implementing direct consumer incentives for batteries diversion such as a deposit-refund model;
- Provision of more battery collection centers at government service locations, thus making battering collection easier and convenient;
- Provision of battery collection boxes at Enviro Depots, to create convenience for the public and reduce travel time;
- Promoting the use of rechargeable batteries and batteries that contain less hazardous materials; and
- Creating more public awareness about battery suitability, safety, and methods of disposal.

1.0 Introduction

Universal waste is a type of waste stream that contains small amounts of hazardous materials such as antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, PCBs (Polychlorinated biphenyl), and zinc which are detrimental to human and environmental health (DTSC, 2010). Even though their quantity may be low, these materials can accumulate over time to reach unsafe levels contaminating the environment. Universal wastes have specific disposal and processing requirements in many jurisdictions. Items that commonly fall under the universal waste category include, fluorescent bulbs/lamps, paint, vehicle and equipment fluids, cellphones, batteries (all types), small appliances, mercury-containing devices/equipment, non-empty aerosol cans (such as propane, butane, pesticides), photovoltaic modules/solar panels, and electronic devices (DTSC, 2010) printer cartridges (Office of Sustainability, 2016), antifreeze, cathode ray tubes (CRTs), ballasts, oil-based finishes, and hazardous waste pharmaceuticals (USEPA, 2017a).

According to USEPA (2017a), universal waste regulations Title 40 of the Code of Federal Regulations (CFR) part 273 applies to four types of universal waste namely, batteries, mercury-containing equipment, pesticides, and lamps. The universal waste management rule was developed by USEPA in 1995 (40 CFR 273). The rule was established to reduce hazardous waste in the municipal solid waste stream, boost recycling, protect the environment and public health and reduce the regulatory issues for businesses that generate these wastes (USEPA, 2017a). Universal wastes are wastes that are neither categorized as solid wastes nor hazardous wastes in Canada (Figure 1.). In the US, universal wastes have less stringent storage, transportation, and collection standard compared with hazardous wastes, however, it must comply with hazardous waste requirements for final recycling, treatment or disposal (USEPA, 2017a).

Figure 1. Categorization of universal wastes.

This research focuses on management of one type of universal waste; batteries. There has been an increase in the use of batteries globally, due to the growing market for electronics and cell phones. In 2015, the annual global market for batteries was worth $33 billion (Battery University, 2017a - * *The Battery University is an educational site sponsored by a battery manufacture Cadex Electronics with its headquarters' in British Columbia*). Batteries contain potentially hazardous components namely mercury, lead, copper, zinc, cadmium, manganese, nickel, and lithium, hence the need for proper disposal. Some of these components such as nickel, cadmium, mercury, lead, and zinc are classified as toxic, persistent and bio-accumulative under the *Canadian Environmental Protection Act, 1999* (Schedule 6 section 9). When batteries are disposed into landfills the hazardous components may leak into the ground as the battery corrodes, thereby contaminating the environment (ERP, 2017). To minimize the concern for the environmental impacts of batteries, different jurisdictions have developed regulations and product stewardship programs to manage the end-of-life of batteries.

Battery recycling programs cover collection, handling, disposal, transportation, and the recycling process. Battery recycling helps to reduce environmental impacts and energy associated with extracting raw materials from the earth. For example, during smelting of sulphide ores sulphur oxides (SOx) containing copper, nickel, and cobalt can be released (Gaines, 2014). If batteries are incinerated with household waste materials, the heavy metals components may cause air pollution (ERP, 2017). The process of recycling batteries helps to recover valuable materials and saves energy by reducing the need for raw materials. The following are some valuable materials that can be recovered from batteries, such as ferromanganese concentrate can be reused by steel producers, pure mercury can be re-used in metric instruments and fluorescent lighting, zinc concentrate can be reused by zinc smelters and for electrolysis in industries, silver recovered can be reused by jewelers, nickel recovered can be used to manufacture stainless steel, and lead and cadmium can be recovered to manufacture new batteries (ERP, 2017).

This research will examine opportunities for a comprehensive battery recycling program in Nova Scotia, with the view of minimising environmental and health impacts, increasing public participation, increasing recycling rates, and increasing waste diversion from the landfills. Nova Scotia has been progressive in its solid waste management since the early 1990s. Even though the province has achieved and continued to surpass its solid waste diversion target of 50%, there are still opportunities for improvement (Nova Scotia, 2014a). Nova Scotia currently has seventeen items banned from the landfills and eight product stewardship programs in place (Nova Scotia, 2014a). The opportunities identified will also support the provinces' commitment to generating less than 300kg per capita waste disposal target stated in the Environmental Goals and Sustainable Prosperity Act (EGSPA) (2007). The goal of 300kg per capita can be achieved through innovative programs and product stewardship regulations (Nova Scotia, 2014).

2.0 Background

2.1 Universal waste management in Canada and Nova Scotia

According to Giroux (2014), municipal solid waste (MSW) consists of hazardous and special wastes found in the residential and Industrial, Commercial, and Institutional (ICI) sectors such as batteries, cleaners, or flammable material. The ICI sector includes businesses, hospitals, and schools. In Canada, about 33% wastes disposed are from the residential sector while the remaining 67% are from the ICI sector (Giroux, 2014). Municipal solid wastes are disposed in landfills, or diverted through recycling or composting in Nova Scotia. The seven landfills in

Nova Scotia are located in Chester, Colchester, Cumberland, Guysborough, Halifax, Queens, and West Hants counties. Waste diversion protects the environment, reduces energy used for extracting raw materials, boosts the economy and provides employment (Nova Scotia, 2014a).

The management and regulations of wastes are shared among federal, provincial, territorial and municipal governments in Canada. In Canada, universal wastes are not explicitly defined and regulated. Many materials such as batteries, compact fluorescent lights (CFLs) and fluorescent tubes, electronics such as cell phones and televisions, unwanted engine oil or anti-freeze, electronic wastes, paints and solvents, and medication, are usually categorized as household hazardous wastes and special wastes (Statistics Canada, 2012) as opposed to universal wastes. Household hazardous wastes (HHW) contain hazardous materials that require special disposal methods to prevent environmental pollution. There are several programs across the provinces and territories for collection and handling materials that fall under the category of universal wastes. For example, the electronics recycling program across Canada have diverted over 955,000 tonnes of end-of-life electronics from landfills in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, Prince Edward Island, New Brunswick, and Newfoundland since 2004 (Electronics Product Stewardship Canada, 2017).

In Nova Scotia, some of the materials termed universal waste are already banned from the landfills such as electronics, automotive antifreeze, paints, cellphones and lead-acid batteries. Other materials such as batteries (except lead-acid batteries), non-empty aerosols are collected through the municipal HHW program (Divert NS, 2017). These HHW programs are not available to the ICI sector and are often run on an occasional basis at a set location. The province through its waste management strategy in 1995 focused on the diversion of waste from residential homes and the ICI sector. In 2014, the ICI sector made up 56% (203,388 tonnes), of the total waste disposed of in Nova Scotia (Statistics Canada, 2016).

2.2 Types, uses and sources of batteries

According to Bernardes et al. (2004), a battery is an "electrochemical device that has the ability to convert chemical energy to electrical energy". Batteries are made up of an anode, a cathode, an electrolyte, separators and an external case. Batteries differ in function, specific characteristics, and application due to the materials used as the electrodes and electrolyte

(Bernardes et al., 2004). The world demand for batteries is estimated to increase by 7.7% annually reaching US$120 billion by 2019 (Battery University, 2017a). There are two main types of batteries namely, primary and secondary batteries. Primary batteries are used once and discarded for example alkaline batteries, while secondary batteries are rechargeable batteries with a longer lifespan, for example, lead-acid batteries and lithium-ion batteries (Dell et al., 2001).

Primary batteries are lightweight with low-cost and are used by households to power devices such as flashlights, alarm clocks, calculators, flashlights, TV remote controls, or toys (Pistoia et al., 2001). Primary batteries can be Alkaline, Zinc-carbon, Zinc air button cell, Lithium (P), Silver oxide button cell, and Mercuric oxide button cells. Primary batteries come in numerous sizes such as AAA, AA, C, D, and 9V (Bernardes et al., 2004). Secondary batteries are made up of Nickel Cadmium (Ni-Cd), Nickel Metal Hydride (NiMH), Small Sealed Lead Acid (SSLA/Pb), Lithium Ion (Li-Ion), and Nickel Zinc (Ni-Zn). The zinc-carbon and alkaline-manganese batteries are the most commonly used primary batteries (Pistoia et al., 2001). The household battery is a US$ 2.5 billion industry with annual sales of almost 3 billion batteries in the United States of America (Bernardes et al., 2004). In Europe, zinc-carbon accounts for 39% while the alkaline cells account for 51% of the portable battery market (Bernardes et al., 2004). Apart from the environmental pollution of the hazardous components of batteries, the Lithium-ion battery has the potential to cause a fire when exposed to moisture during corrosion of cells (Bernardes et al., 2004). The most common batteries with high revenue contributions are lithium-based (37%), lead-based (20%), and alkaline (15%) (Figure 2.).

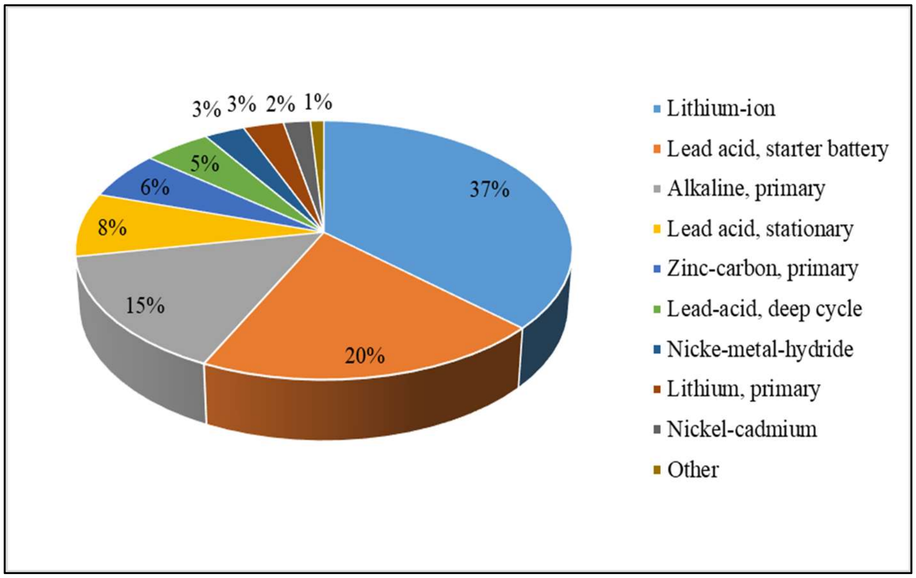

Figure 2. Revenue contributions by different battery chemistries (Adapted from Battery University, 2017a).

In Europe, the disposal of primary batteries became an environmental issue as early as the 1980s, due to the accumulation of mercury from batteries disposed of in landfills. Mercury from batteries may leak into the environment causing hazardous concentrations in soil, crops and freshwater fish (Pistoia et al., 2001). Due to the toxic nature of mercury, legislation was developed to reduce the concentration of mercury in batteries. The US developed Mercury-Containing and Rechargeable Battery Management Act, passed in 1996 and European Community legislation was passed in 1991(91/157/EEC—Batteries and Accumulators Directive). These legislations were created to reduce the concentration of mercury, cadmium, and lead in the batteries, and to regulate the identification of recyclable batteries (Espinosa et al., 2004). The *Mercury-Containing and Rechargeable Battery Management Act 1996* that contains regulations "to phase out the use of mercury in batteries and provide for the efficient and cost-effective collection and recycling or proper disposal of used nickel-cadmium batteries, small sealed lead-acid batteries, and certain other batteries, and for other purposes". The European Directive also had objectives of developing a battery collection system so that at least 75% of portable batteries and 95% of industrial batteries are collected. The European Association of Batteries Manufacturers (EABM) agreed in limiting the quantity of Hg in batteries to 5 ppm and to collect all types of batteries in 2003 (Espinosa et al., 2004).

There are still batteries that contain mercury such as button-cell batteries and mercuric oxide batteries. Mercury is used by battery manufacturers to reduce the accumulation of internal gases that cause batteries to bulge and leak (USEPA, 2017c). According to the *Mercury-Containing and Rechargeable Battery Management Act of 1996, "*mercuric oxide button-cell batteries are no longer sold in the U.S. for personal or commercial use". However, mercuric oxide batteries are still manufactured for military and medical equipment (USEPA, 2017c). The Federal law and some State laws in the US also allow the sales of mercuric oxide cells based on the condition that the manufacturers will manage their end-of-life to prevent environmental contamination.

Rechargeable lithium batteries are preferable for portable electronics, electric cars, military and aerospace applications due to its energy density and slow discharge mode (Kang et al., 2013). According to Kang et al. (2013), it was projected that the global market for lithium batteries will increase from $7.9 billion in 2008 to $8.6 billion in 2014. Lithium batteries contain potentially toxic materials including metals, such as copper, nickel, and lead, and organic chemicals, such as toxic and flammable electrolytes containing LiClO4, LiBF4, and LiPF6 (Kang et al., 2013).

2.3 Environmental and health impacts of batteries

Batteries are useful; however, care should be taken when handling damaged batteries. As mentioned earlier, batteries contain hazardous materials such as mercury, lead, copper, zinc, cadmium, manganese, nickel, and lithium, hence the need for proper disposal (Table 1.). When batteries are disposed of in the landfill, they may corrode thereby releasing its hazardous content into the environment. Damaged batteries may also contaminate the waste stream if disposed of in the garbage.

The following briefly describes the environment and health impacts of the major potentially hazardous components found in batteries,

- **Mercury:** Mercury is one of the most toxic elements released into the environment (Rice et al., 2014). The level of mercury toxicity varies depending on its form in the environment (WHO, 2017). Mercury can exist as elemental, inorganic, or methylmercury. Once mercury contaminates soil and water, it bioaccumulates in the food chain leading to consequences in the ecosystem. According to Rice et al. (2014), batteries are one of the sources of human exposure to mercury, other sources include dental amalgam, thermometers, sphygmomanometer, barometers, fossil fuel emissions, fluorescent lights, and the incineration of medical waste. Methylmercury (MeHg) is the usual form of mercury found in the environment. It easily bioaccumulates in fish which are the main source of human exposure (Rice et al., 2014). Exposure to mercury may cause death, mental retardation, dysarthria, blindness, neurological deficits, hearing loss, developmental defects, and abnormal muscle tone in humans (Rice et al., 2014). The most susceptible groups to effects of mercury are fetuses and people that are exposed due to their occupation (WHO, 2017). Fetuses are affected though their mothers from contaminated fish and shellfish consumption. Mercury affects the neurological development of fetuses thereby causing impairment of cognitive thinking, memory, attention, language, and fine motor and visual spatial skills in children (WHO, 2017). Some birds and animals feed on fish such as loons, eagles, otters, mink, kingfishers, and ospreys. Mercury exposure may lead to death and reduced birth rates affecting the existence of these species (Government of Canada, 2013a).

- **Lead:** According to World Health Organisation (WHO) (2016), the manufacture of automotive lead-acid batteries consumes over three quarters of global lead resource. Humans can be exposed to lead through inhalation of lead particles or ingestion of lead contaminated dust, water or food (WHO, 2016). The development of young children and fetuses are highly susceptible to lead exposure. Lead exposure may cause behavior and learning problems, low IQ, hyperactivity, delayed growth, hearing problems, and anemia in children (USEPA, 2017b). Lead poisoning may cause the increased risk of high blood pressure, kidney damage, cardiovascular effects, and reproductive problems (USEPA, 2017b). Pregnant women may suffer miscarriage, stillbirth, premature birth, malformations, and low birth weight due to lead exposure (WHO, 2016).

- **Cadmium:** Cadmium is a toxic and persistent element, found in zinc, lead and copper ores (UNEP, 2010). The cadmium extracted from the earth is majorly used to produce nickel-cadmium batteries, for instance, in 2004, 81% of cadmium was used to manufacture batteries (UNEP, 2010). Cadmium is released into the environment from anthropogenic activities such smoking, mining, smelting and refining of nonferrous metals, fossil fuel combustion, incineration of municipal waste (particularly cadmium-containing batteries and plastics), manufacture of phosphate fertilizers, and recycling of cadmium-plated steel scrap and electric and electronic waste (WHO, 2010). Human kidney, liver and bones are targets for cadmium. The accumulation of cadmium in the kidney may lead to renal tubular dysfunction with irreversible effects (WHO, 2010). Cadmium becomes carcinogenic by inhalation and may cause lung cancer (UNEP, 2010). Cadmium bioaccumulates in the kidneys and liver of vertebrates, aquatic invertebrates, and algae (UNEP, 2010). Vegetation can absorb cadmium from contaminated soils, leading to negative impacts on the food chain (Dokmeci et al., 2009).

- **Nickel:** Humans are exposed to nickel through inhalation, ingestion and adsorption. Nickel found in the air is due to combustion of coal, diesel oil and fuel oil, the incineration of waste and sewage (Cempel and Nikel, 2006). Human exposure to high doses of nickel may cause skin allergies, lung fibrosis, cancer of the respiratory tract, and nickel poisoning illnesses (Cempel and Nikel, 2006). Nickel exposure may cause haematotoxic, immunotoxic, neurotoxic, genotoxic, hepatoxic, nephrotoxic, reproductive toxic, pulmonary toxic, and carcinogenic effects in animals and humans (Das et al., 2008).

- **Lithium**: According to Aral and Vecchio-Sadus (2008), lithium does not bioaccumulate but toxic to the environment at high levels. There is risk of fire and explosion when lithium mixes combustibles and water. Lithium may cause coughing, burning sensations, breathlessness and sore throat. On contact with skin may cause redness, blisters, burns, ingestion may cause abdominal cramps, nausea vomiting and weaknesses (Aral and Vecchio-Sadus, 2008).

- **Zinc:** Humans are exposed to zinc through inhalation, ingestion or skin contact. The reversible metal fume fever (MFF) is the most common effect of inhaling zinc-containing smoke. Symptoms of MFF zinc include fever, muscle soreness, nausea, fatigue, and respiratory effects like chest pain, cough, and dyspnea. Ingestion of high doses of zinc may cause abdominal pain, nausea, and vomiting, lethargy, anemia, and dizziness (Plum et al., 2010).

- **Copper:** Exposure to copper can be through inhalation of particulate copper (typical of occupational exposure), drinking copper-contaminated water and eating copper contaminated food. The toxicity of copper to humans is relatively low compared to other metals such as mercury, cadmium, lead, and chromium (Solomon, 2009). Long-term exposure to copper dust can irritate your nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea (ATSDR, 2004). Copper ingestion in high doses can cause liver and kidney damage and even death (ATSDR, 2004).

- **Sulfuric Acid**: The sulfuric acid is highly corrosive, which can become explosive in concentrated form. Contact with eyes causes burns and may lead to blindness, ingestion damages internal organs that may lead to death. It can cause severe skin burns, can irritate the nose and throat and cause difficulties breathing if inhaled (ATSDR, 1998). Sulfuric acid may damage plants and burn animals exposed to it. It has acute and chronic toxicity to aquatic life. In high does can change alkalinity of aquatic systems thereby affecting growth and abundance of aquatic life (Commonwealth of Australia, 2014).

Table 1. Chemical composition of common batteries.

S/N	Battery Types	Chemical composition	Hazardous elements
1	Nickel Cadmium (Ni-Cd)	Fe - 40%; Ni - 22%; Cd - 15%; Plastic - 5%; KOH - 2%; others – 16% (EPBA, 2017)	Nickel, Cadmium
2	Nickel Metal Hydride (Ni-MH)	Ni - 33%; Fe - 30%; Lanthanides - 10%; H_2O - 8%; Co - 3%; Plastic – 5%; KOH - 2%; Mn - 1%; Zn - 1%; others – 7% (EPBA, 2017)	Nickel, Zinc
3	Nickel Zinc (Ni-Zn)	Limited literature to discern composition	Nickel, Zinc
4	Alkaline/Single-Use	Fe – 24%, Mn – 22%, Zn – 15% (Battery University, 2017b)	Zinc
5	Lithium Ion (Li-Ion)	Fe – 22%, Li – 3%, Co – 18%, Al – 5% (Battery University, 2017b)	Lithium
6	Small Sealed Lead Acid (SSLA/Pb)	Pb – 65% (Battery University, 2017b)	Lead, acid
7	Lithium Primary button cells	Fe - 50%; MnO_2 - 28%; Cr – 10%; Plastic - 3%; Li - 3%; Dimethoxyethane - 2%, C - 2%; Ni - 2% (EPBA, 2017)	Lithium, Nickel
8	Zinc Carbon	MnO_2 - 27%; Zn - 23%; H_2O - 18%; C - 10%; ZnCl/NH_4Cl - 5%; Fe - 4%; Others – 13% (EPBA, 2017)	Zinc
9	Alkaline Manganese	MnO_2 - 37%; Fe - 23%; Zn - 16%; H2 O - 9%; KOH - 5%; C - 4%; Brass - 2%; Others – 4% (EPBA, 2017)	Zinc
10	Zinc Chloride	Limited literature to discern composition	Zinc
11	Button cell batteries – Mercuric oxide button cells	Hg- 30 – 40% (NEMA, 2003)	Mercury
12	Zinc air button cell	Fe - 42%; Zinc - 35%; H_2O - 10%; Plastic - 4%; KOH - 4%; C – 1%; Hg - 1%; Others – 3% (EPBA, 2017)	Zinc, Mercury
13	Wet-cell batteries	Lead (incl. Lead oxides) – 72%, Electrolyte (H_2SO_4) – 17%, Plastics – 9%; others – 2% (EPBA, 2017)	Lead, acid
14	Lead-acid batteries	Lead (incl. Lead oxides) – 72%, Electrolyte (H_2SO_4) – 17%, Plastics – 9%; others – 2% (EPBA, 2017)	Lead, acid
15	Silver oxide batteries	Fe - 42%; Ag_2O - 33%; Zn – 9%; Cu - 4%; MnO_2 – 3%; H_2O - 2%; Plastic - 2%; Ni - 2%; KOH - 1%; C - 0.5%; Hg - 0.4%; Others – 1,1% (EPBA, 2017)	Zinc, Mercury, Nickel, Copper

Key:

Chemical compounds/elements: Fe - Iron, Ni -Nickel, Cd - Cadmium, KOH - Potassium Hydroxide, H_2O - water, Co - Cobalt, Mn -Manganese, Zn - Zinc, Li -Lithium, C - Carbon, MnO_2 - Manganese Oxide, Cr- Chromium, ZnCl - Zinc Chloride, NH_4Cl - Ammonium chloride, Hg -Mercury, H_2SO4 - Sulphuric acid, Ag_2O -Silver oxide, Cu -Copper

2.4 Environmental impact of battery recycling

The batteries with the most significant environmental impacts are lead and cadmium based batteries (Battery University, 2017c). Lead-acid batteries are not yet banned due to lack of a suitable replacement for them (Battery University, 2017c). At least 50% of lead is retrieved from recycled batteries (Battery University, 2017c). Recycled lead can also be used for sporting goods, construction materials, x-ray and medical radiation protection, and automotive parts (Gopher Resource, 2017). Due to the toxic nature of mercury, it was banned from use in batteries since the 1990s except for button cells. In North America, battery manufacturers have reduced mercury content in batteries by 95% (Government of Canada, 2013b).

Lithium-ion batteries are the most commonly used in portable electronic devices with an estimated double increase from 2013 to 2020. The process of recycling batteries is energy intensive. The processes for recycling portable batteries involves mechanical, pyrometallurgical and hydrometallurgical processes. The mechanical processes involve, dismantling the batteries by crushing and shredding and sorting materials according to their physical properties. The mechanical process may be by magnetic separation, air ballistic separation, and sieving (Bernardes et al., 2004). The hydrometallurgical processes help to recover metals using acids or bases to leach metals into a solution, which undergoes purification to extract the materials (Bernardes et al., 2004). The pyrometallurgical processes use high temperatures to recover materials. These processes may include pyrolysis, smelting, distillation, and refining (Bernardes et al., 2004).

In Canada, batteries are often sent for disposal (incineration) or recycling through hazardous waste companies or industry supported battery recycling programs such as Call2recycle. At Call2recycle batteries are sorted into different chemistries before being shipped to appropriate recycling facilities to extract valuable components for reuse (Figure 3.). These recycling facilities are located across North America. Waste from the facilities used by Call2recycle is disposed according to Responsible Recycling (R2) and Basel Action Network (BAN) standards (Call2recycle, 2016a). Integrating the collection of these batteries with other waste streams may minimise environmental impacts from transportation. For example in Sweden, battery collection boxes are attached to paper collection containers which are collected by the same truck (Bernardes et al., 2004).

According to a life cycle assessment of lithium-ion batteries by Boyden et al. (2016), environmental impacts of the battery recycling process may be minimised by reducing the distance traveled between collection sites and recycling facilities. This study also revealed that for pyrometallurgical processes, the largest impacts are caused by plastics incineration due to its global warming potential, and power while for the hydrometallurgical processes, the largest impacts are caused by landfill due to its global warming potential and power.

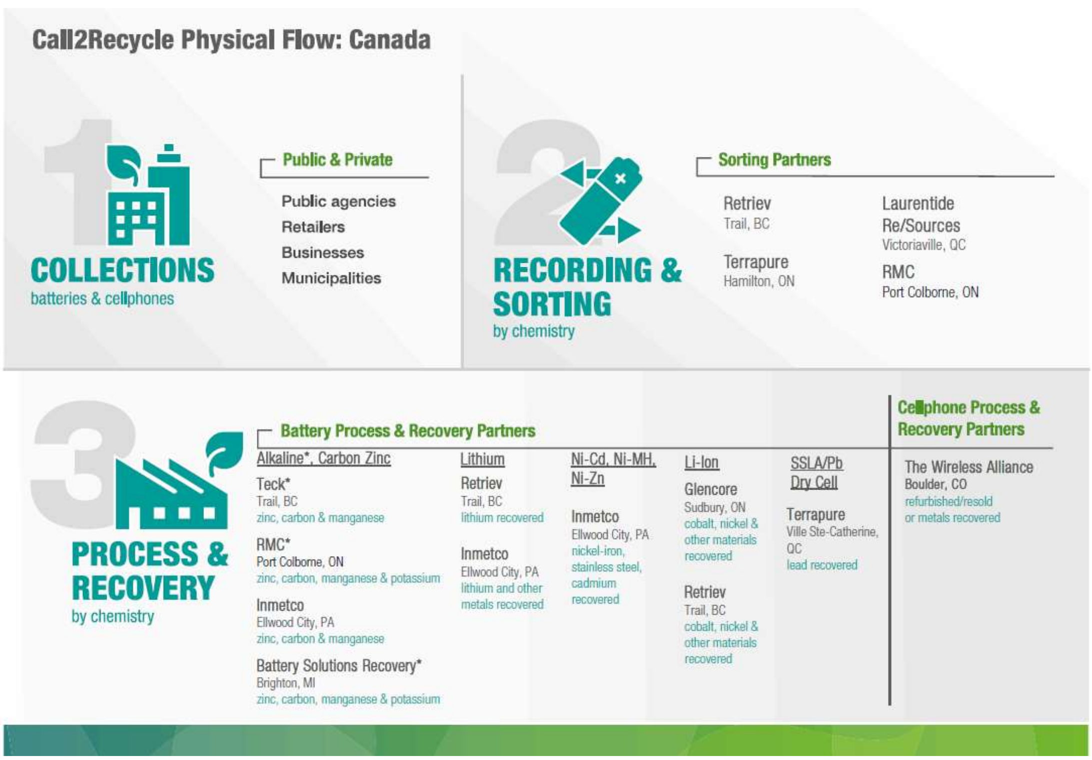

Figure 3. Process flowchart for Call2recycle program (Call2recycle, 2016).

In addition to environmental impacts of battery recycling, the recycling process itself can be detrimental to human health. For example, the lead recycling process may put workers at risk of lead poisoning (Figure 4.). This has led to strict regulations by USEPA on lead-acid recycling requirements such as recycling plants must be sealed, and the smokestacks fitted with scrubbers and surrounding the facility with lead-monitoring devices to prevent the escape of lead particles

(Battery University, 2017b). In China, lead battery production and recycling facilities are a significant source of human exposure. According to IPE (2011), children living near these facilities and workers are exposed to higher lead concentrations than the average exposure levels recommended by the World Health Organization (WHO).

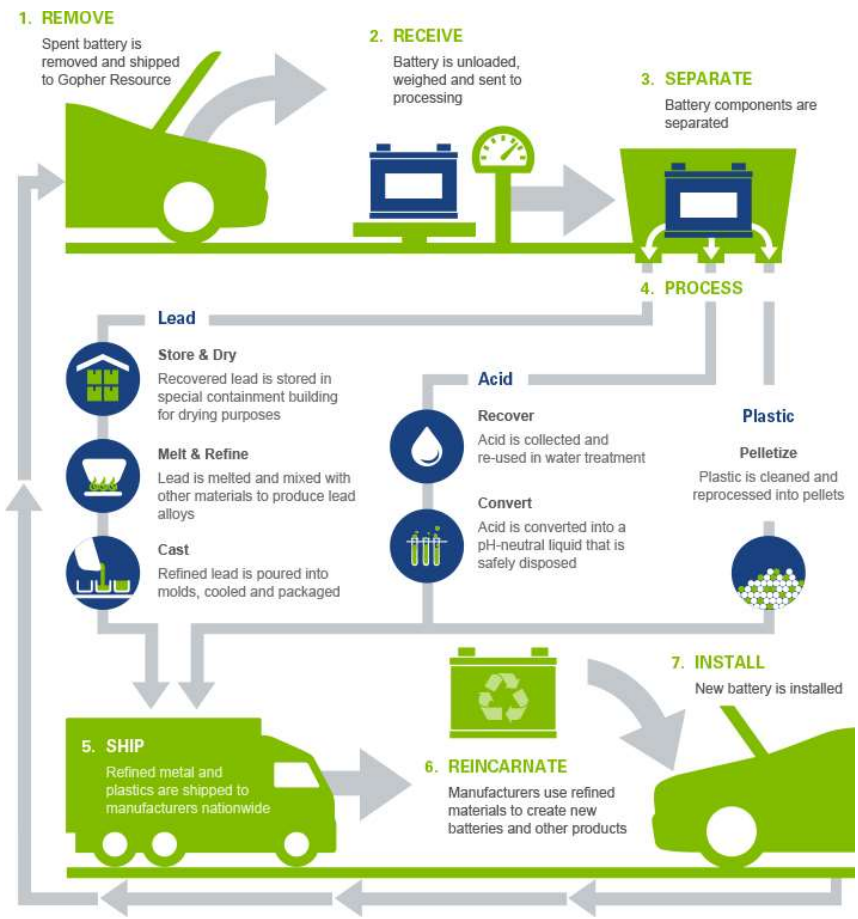

Figure 4. Lead-based batteries recycling process (Gopher Resource, 2017).

2.5 Battery recycling programs

A battery recycling program covers collection, handling, transportation and the recycling process itself. According to Espinosa et al. (2004), battery collection is the most challenging phase of the battery recycling program due to its reliance on the participation of the public, government and business/organizations. In Sweden, the voluntary Ni-Cd batteries recycling program in 1993 had a collection target of 90% by 1995, however, achieved only 35%. Battery collection largely depends on consumer behaviors. Studies in Germany, The Netherlands and Belgium revealed that 80–90% of the public are aware of the battery collection programs but only 30–50% complies with the rules (Bernardes et al., 2004). The product stewardship programs adopted by certain jurisdictions have helped to curb the challenges of battery collection since the responsibility has been shifted to the manufacturers (Espinosa et al., 2004). The collection process should be easy, convenient and cost-effective.

Product stewardship programs are used to manage products end-of-life to minimize adverse environmental impacts. Product stewardship is the "act of minimizing the health, safety, environmental, and social impacts of a product and its packaging throughout all lifecycle stages, while also maximizing economic benefits" (Product Stewardship Institute, Inc., 2016). The product stewardship program can be voluntary or mandatory. Extended Producer Responsibility (EPR) is a mandatory type of product stewardship that helps to shift responsibility away from the public to manufacturers, and it provides incentives for manufacturers to consider the environment in the design of products and packaging (Product Stewardship Institute, Inc., 2016). EPR is a form of polluter-pays principle that allows producers to be accountable end-of-life management of their products.

2.5.1 Canada

In Canada, household batteries that are recycled are often recycled through the Call2recycle program. Members of the public drop off batteries to collection boxes often found at ICI locations. The ICI sector itself may collect batteries and ship to Call2recycle locations. The Call2recycle program is mandatory and regulated in provinces, such as British Columbia, Manitoba, and Quebec while the program is voluntary in other jurisdictions (Government of Canada, 2017). The Call2recycle program in regulated provinces requires Call2recycle to produce an annual report with performance measures.

Call2recycle is an international recycling program with operations within Canada and the United States. The recycling program aims to collect and recycle batteries (weighing up to 5kg) and cell phones (with or without rechargeable battery) at no fee to consumers. The batteries collected are found in cordless power tools, mobile devices, and cordless phones, laptop computers, digital cameras, two-way radios, camcorders, portable printers, cordless toys (remote control), etc. Consumers drop off their batteries and cell phones at designated drop-off locations across Canada. The program is run by Call2recycle Inc., functioning in Canada as Call2recycle Canada

Inc. and formerly known as the Rechargeable Battery Recycling Corporation (RBRC) (Government of Canada, 2017). In British Columbia (B.C), Call2recycle has diverted at least 2.9 million kilograms of batteries since 2010 when the program commenced. The diversion rate in B.C was 20% in 2016 for batteries. Even though battery recycling is regulated there are no targets for batteries sold and collected in B.C and all batteries are not banned from the landfill (Call2recycle, 2016b). Regulated provinces for battery recycling such as British Columbia, Manitoba, Ontario, and Quebec are leading in the growth of batteries diverted from the landfill (Call2recycle, 2016b).

For lead-acid batteries, the Canadian Battery Association (CBA) was established as a national stewardship program to recycle lead-acid batteries. The lead-acid batteries are banned from the landfills and have been managed by Canadian Battery Association (CBA) across the country. The CBA members collect used lead-acid batteries through reverse-distribution collection system where used batteries are exchanged with new ones at the retailer by a distributor (McKean, 2016). The used lead-acid batteries are either recharged, revamped or discarded. The program recycles all parts of the battery including the metal, electrolytes, and plastics and sells the resulting products as commodities on the market. In 2013, the CBA members recycled over 12.7 million kg of lead-acid batteries.

2.5.2 Nova Scotia

In Nova Scotia, batteries are mainly recycled through the Call2recycle program, however, this is neither required nor regulated. Nova Scotia does not currently have an EPR for all batteries. The EPR requires battery producers to participate in a product stewardship plan. Batteries (with the exception lead-acid (automotive) batteries) have been recommended to be covered in a framework for product stewardship in Nova Scotia and will be banned from landfills once the stewardship program is in place (Nova Scotia, 2015). Lead-acid batteries have been banned from Nova Scotia landfill since 1996 (Nova Scotia, 2015). In 2009, Nova Scotia endorsed the Canadian Council of Ministers of the Environment (CCME) Canada-wide Action Plan (CAP) for the Extended Producer Responsibility, EPR in goal 5 (Nova Scotia, 2011). The EPR scorecard for Nova Scotia has decreased from a C in 2013 to a C- in 2015 (EPR Canada, 2015).

2.6 Battery recycling program implementation

Different jurisdictions have implemented battery recycling programs to divert batteries from landfills. A management table defining levels of battery implementation has been developed for further comparison (Table 2.) For example, at Dalhousie, batteries are handled through the Call2recycle program. The Call2recycle boxes are ordered as required. The filled boxes are shipped to Call2recycle on a bi-monthly basis. Battery waste has been disposed of responsibly by Dalhousie since the 90s. Batteries were collected in buckets at buildings and sent to hazardous waste hauler for proper disposal. In 2013, Dalhousie changed management approaches and joined the Call2recycle program. They also divert other batteries such as lead-acid according to the provincial ban. For Dalhousie these efforts correlate with level four type implementation as outlined in Table 2. The Levels of Battery Recycling Implementation (Table 2.) is compared to battery recycling initiatives in provinces and territories across Canada.

Table 2. Levels of battery recycling program implementation.

Levels of battery implementation programs		**Description**
1	No action	• No product stewardship program for batteries • Batteries not banned from the landfill
2	Organization/community interest based	• No product stewardship program for batteries • Batteries not banned from the landfill • Organization/community decides to divert batteries from the landfill through local initiatives, example Dalhousie University before 2013
3	Self-regulation/ organization interest	• Voluntary participation in available battery recycling programs
4	Partially regulated/organization interests	• Product stewardship program exists for some types of batteries such as, lead-acid batteries • Not all batteries are banned from the landfill • Voluntary participation in available battery recycling programs
5	Formal and voluntary agreements/partial regulation	• Product stewardship program exists for all battery types • Not all batteries are banned from the landfill
6	Fully regulated	• Product stewardship program exists for all battery types • All battery types banned from the landfill

Table 3. Battery recycling program implementation in Canada. Information used for the Table assessment was gleaned from Call2recycle.

Levels	AB	BC	MB	NB	NL	NS	NU	NWT	ON	PE	QC	SK	YK
1. No Action													
2. Org. Interest													
3. Self Reg.													
4.Partially Reg.	√			√	√	√	√	√		√		√	√
5. Formal Vol. Agr.		√	√						√		√		
6. Fully Reg.													

3.0 Methods

This study was carried out using a mixed-methods approach, both quantitative and qualitative research methods were adopted. Interviews were conducted to obtain qualitative data, while the quantitative data was obtained through an online survey. The mixed method approach was chosen to provide a comprehensive understanding of this study. According to Driscoll et al. (2007), a mixed methods approach in research helps to validate data collected qualitatively and quantitatively.

The ethics approval was obtained from the Research Ethics Officer of Faculty of Management at Dalhousie University (Appendix C) before embarking on the interviews and an online survey. The participants for interviews and the online survey were selected based on their knowledge about solid waste management and their roles. The participants consist of solid waste coordinators, landfill operators, municipal operators/solid waste managers, local waste reduction educators, and an expert from Call2recycle.

Recruitment emails were sent to a list of individuals requesting their contribution to this research (Appendix A). Once the participants indicated their interest and their availability, interviews were confirmed. The consent forms were sent and returned in person or via email before the interview (Appendix A). The list of interview questions (Appendix A) was sent to the interviewees before the interview for adequate preparation. The interviews were conducted either in person or by telephone. The interviews lasted between 15 and 40 minutes. Out of the anticipated eight individuals to be interviewed, five individuals were interviewed for this research. A completion rate of 63% was achieved for the interviews.

Information gathered from the interviews have been analyzed using thematic codes. Coding is an analytical process that helps to identify important concepts and themes. Coding involves preparing and translating the data for analysis. Codes provide meaning to information gathered during qualitative research (Basit, 2003). It involves documenting all responses from the interviews and putting them into a format that can be summarized and interpreted. Coding helps to break down data into manageable and meaningful segments.

Nova Scotia is divided into seven solid waste-resource management regions to effectively manage municipal waste collection. The online survey was sent to 33 participants with a 54.55% response rate (18 responses). The responses were received from at least one representative of the different waste regions in Nova Scotia for the online survey (Figure 5.). The participants for the online survey were asked to provide data and information about battery recycling programs in their jurisdictions (Appendix B). The online survey participants were sent regular reminder notifications to complete the survey by the closing date. Two of the interviewees also completed the online survey. The participants were asked for consent before carrying out the online surveys. In addition, data was captured from the Fall 2017 Annual Sustainability and Commuter Survey about campus community personal battery recycling practices.

4.0 Results

4.1 Findings from online survey

The online survey revealed that there is an ongoing battery recycling program in all waste management regions. The methods of collection, handling, processing, and transportation may vary slightly across the waste regions within the province.

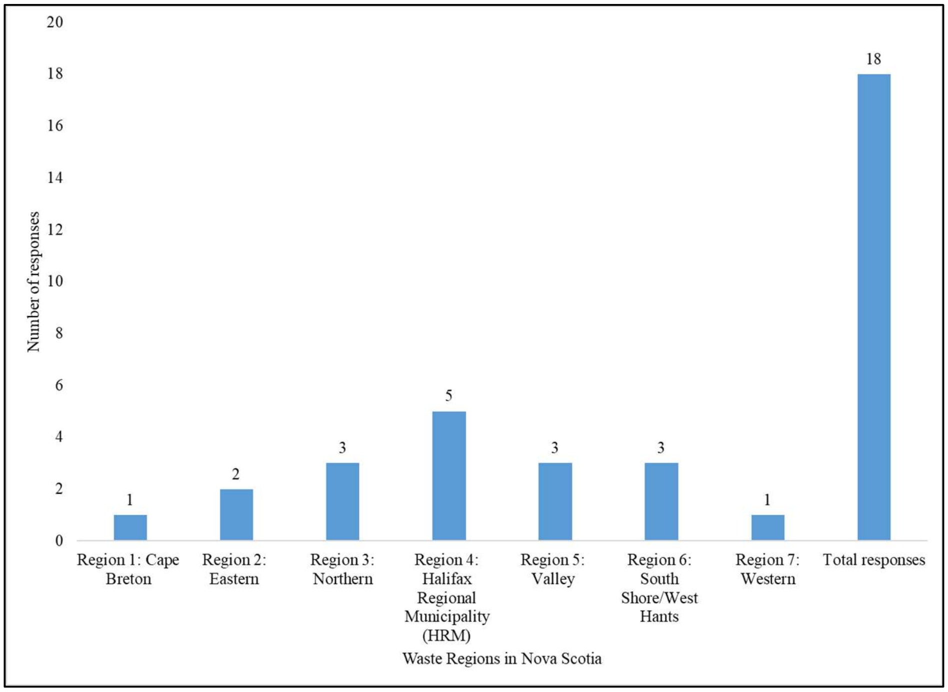

Figure 5. Number of responses received per waste region in Nova Scotia.

The most common method of collecting all batteries is through the HHW drop off locations with 51% for the waste regions excluding the ICI sector (Figure 6.). The Town of Antigonish is the only town that collects household batteries at curbside. The other programs used for battery collection are drop-off collection containers (such as, buckets and boxes) at retail stores, Enviro Depots, and organizations/businesses. The collection of batteries at curbside of businesses does not exist in any region (Curbside business). A wide range of both primary and secondary battery types are collected through the ongoing battery recycling program in the waste regions across Nova Scotia (Figure 7.).

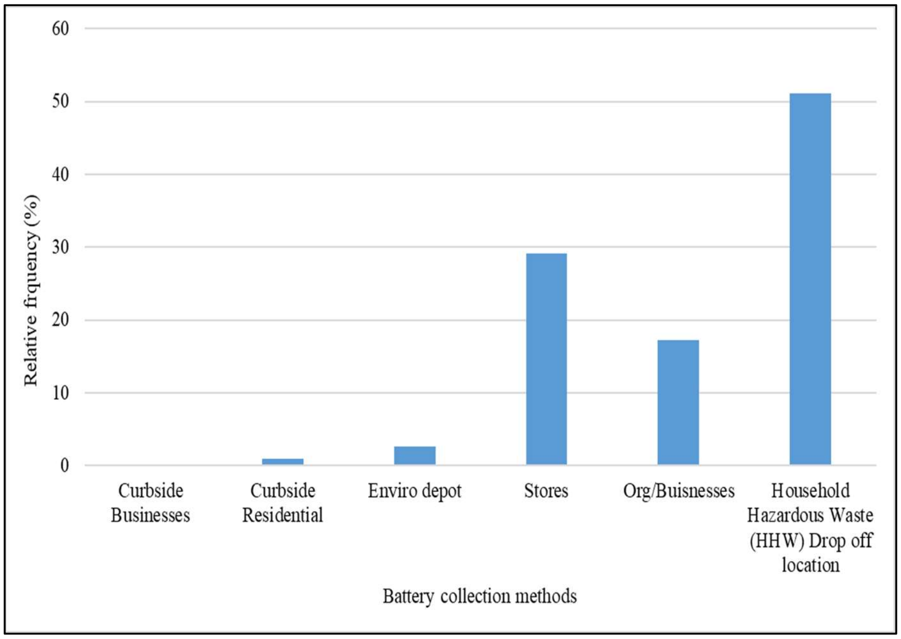

Figure 6. Percentage of battery collection methods for different battery types across waste regions in Nova Scotia.

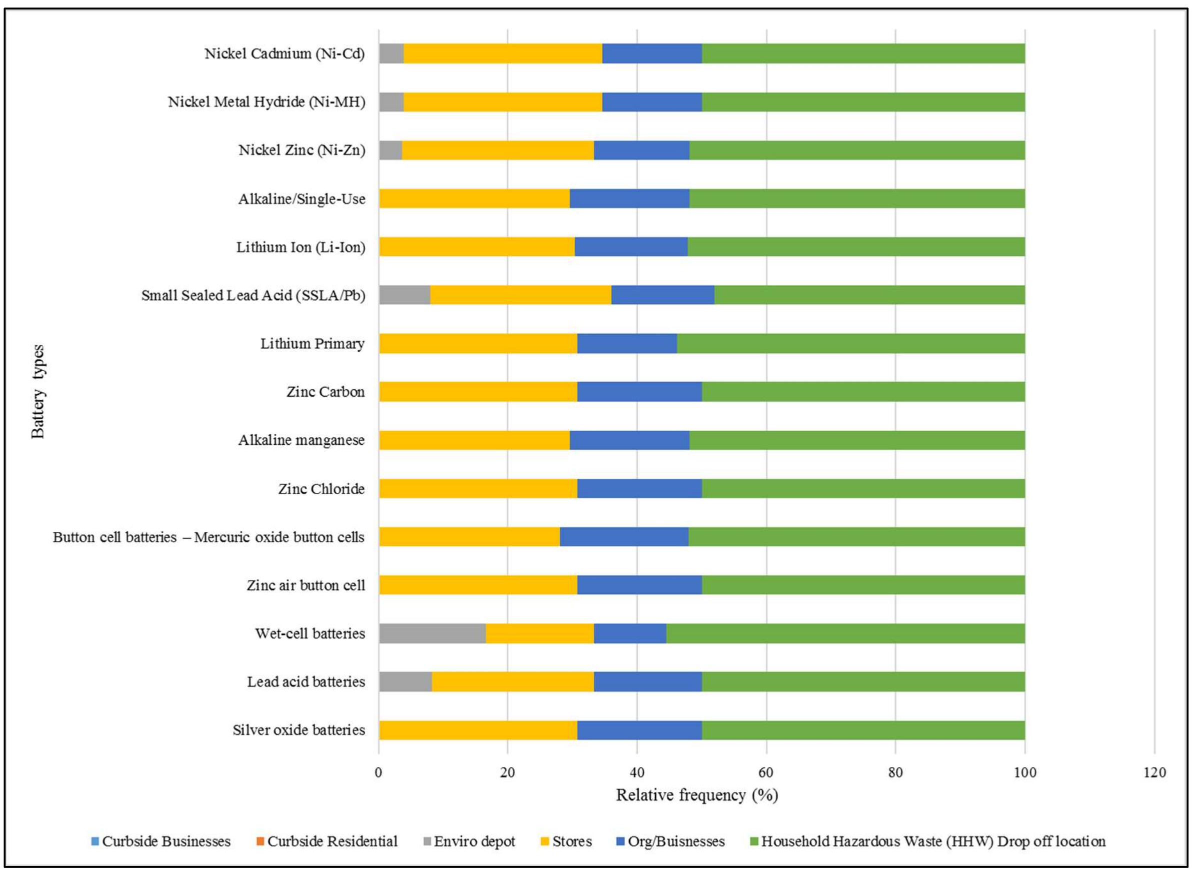

Figure 7. Battery collection methods for different battery types across waste regions in Nova Scotia.

In all the waste regions diverse types of batteries are commonly collected at the HHW drop-off locations (residential service only) and car batteries (lead acid) at Enviro Depots and car service businesses (ICI and residential). Battery collection is also available at public locations (ex. stores and government offices) and private locations (ex. at an organization).In the Valley Waste Resource Management area (Region 5), household batteries are also received at the municipal's two transfer stations where they are manually sorted to separate lithium batteries before transportation to Call2recycle. In the Town of Antigonish, batteries are collected at curbside (residential service).

The survey indicated that the batteries collected through curbside, Enviro Depots, stores, organisations/businesses and HHW drop off locations are mostly transported to Call2recycle in Nova Scotia with 48.28% (Figure 8.). All batteries that weigh less than 5kg are transported by road either through a third-party or organisations/businesses to Call2recycle for recycling. The other forms of battery recycling programs are managed by an organisation in conjunction with hazardous waste recycler and batteries are collected during Municipal special events for recycling.

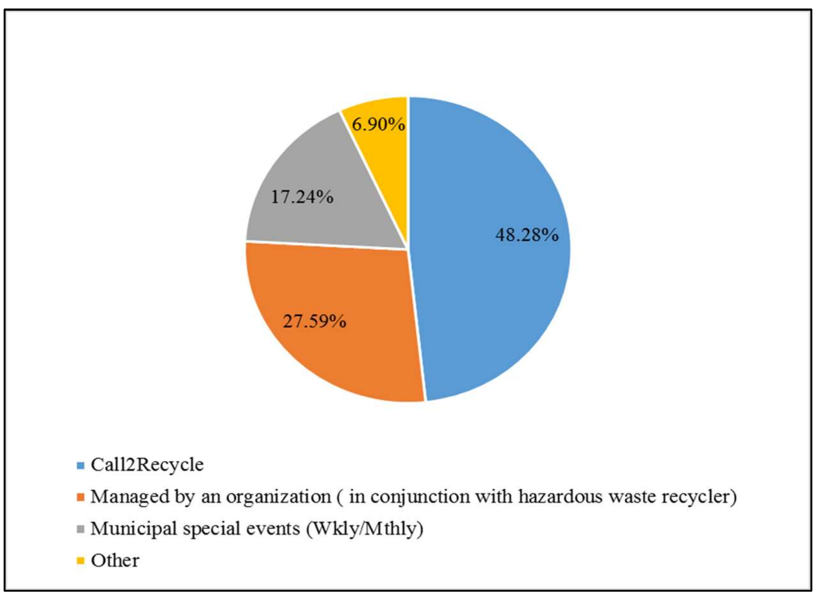

Figure 8. Battery recycling programs across waste regions in Nova Scotia.

The online survey revealed that Call2recycle boxes are commonly found in stores (Figure 9.). The Call2recycle boxes are also found in Enviro Depots, organizations/businesses, and municipal offices. The collection of batteries is key to achieve effective Battery recycling programs. The survey revealed 72% of the waste management regions advertise their battery recycling programs (Figure 10.).

Battery recycling programs are advertised through various communication tools such as, HHW brochures, municipal websites, waste management calendars, newsletter, local newspaper, educators responding to phone inquiries, community outreach education programs, and social media. There is no evidence across the regions of incentives to promote or encourage battery recycling programs (Figure 11.). The battery recycling programs are voluntary and free. The tracking of performance measures is not widely practised in Nova Scotia for batteries collected and transported for recycling. The survey revealed that 33.33% (Figure 12.) of regions keep records keep records of the quantity of batteries shipped to Call2recycle.

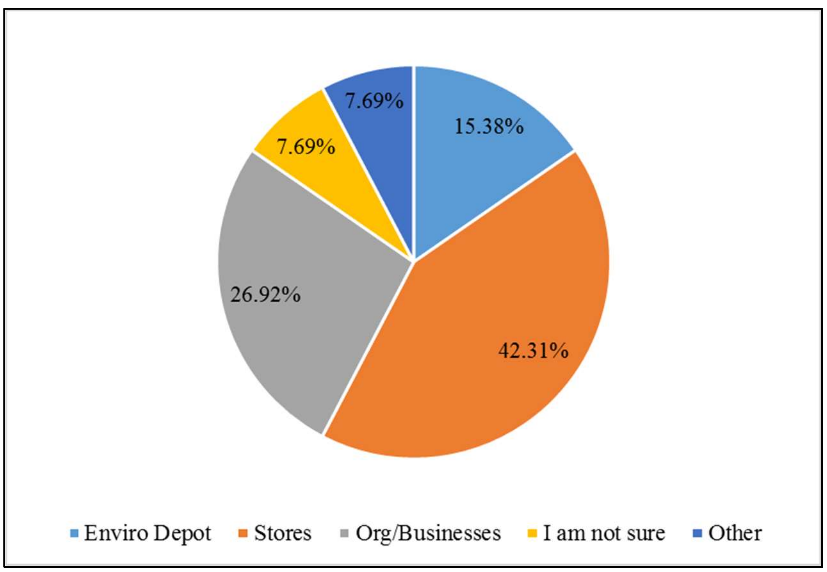

Figure 9. Locations with Call2recycle receptacles or boxes for battery collection.

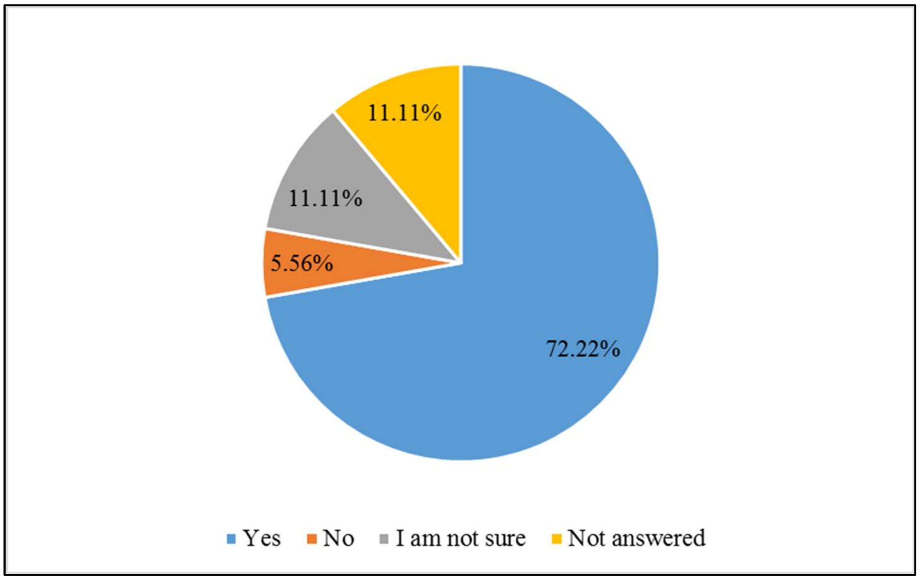

Figure 10. Percentage of waste regions that advertise battery recycling programs.

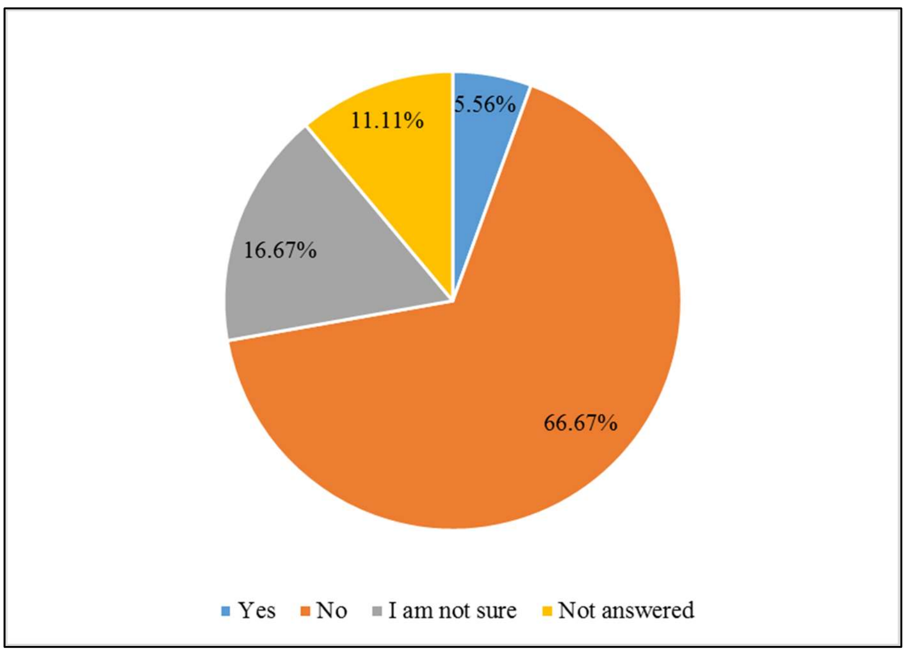

Figure 11. Percentage of waste regions that have incentive programs for battery recycling.

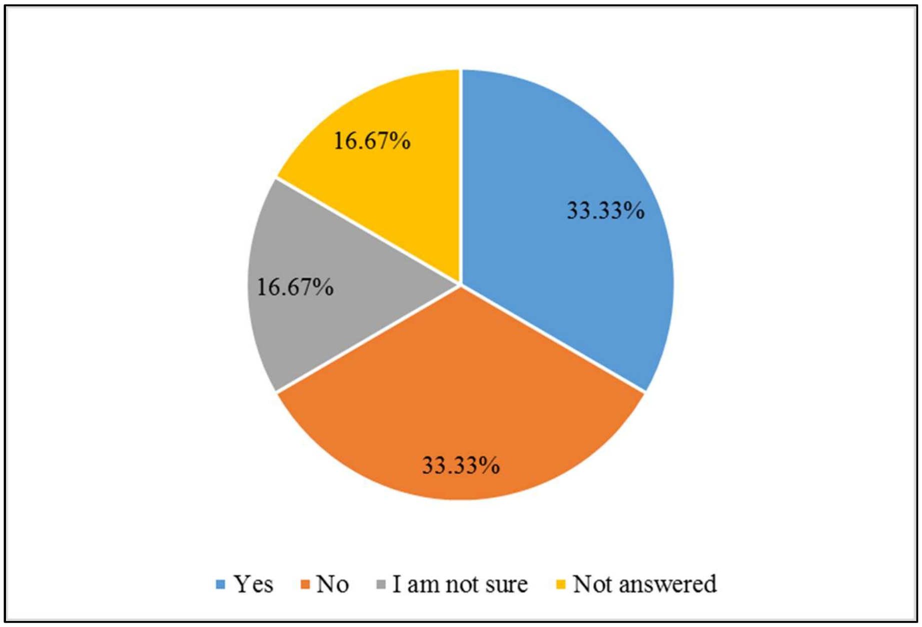

Figure 12. Percentage of waste regions that have performance measures for battery recycling program.

4.2 Annual Sustainability and Commuter Survey

The Annual Sustainability and Commuter Survey was conducted in November 2017 to help the Office of Sustainability improve its existing programs and implement new initiatives. The survey was open to Dalhousie students and employees. Question 3 asked "How do you manage your batteries at the end of their useful life?" There were 2883 out of 3137 responses received for question 3. Out of 2883 responses, 891 respondents (28.4%) indicated that their batteries are disposed in battery boxes located in Dalhousie, 709 respondents (22.6%) indicated that they dispose their batteries in the garbage, 586 respondents (18.68%) indicated they hold on to their batteries and 481 respondents (15.33%) dispose their batteries at the hazardous waste depot (Figure 13.).

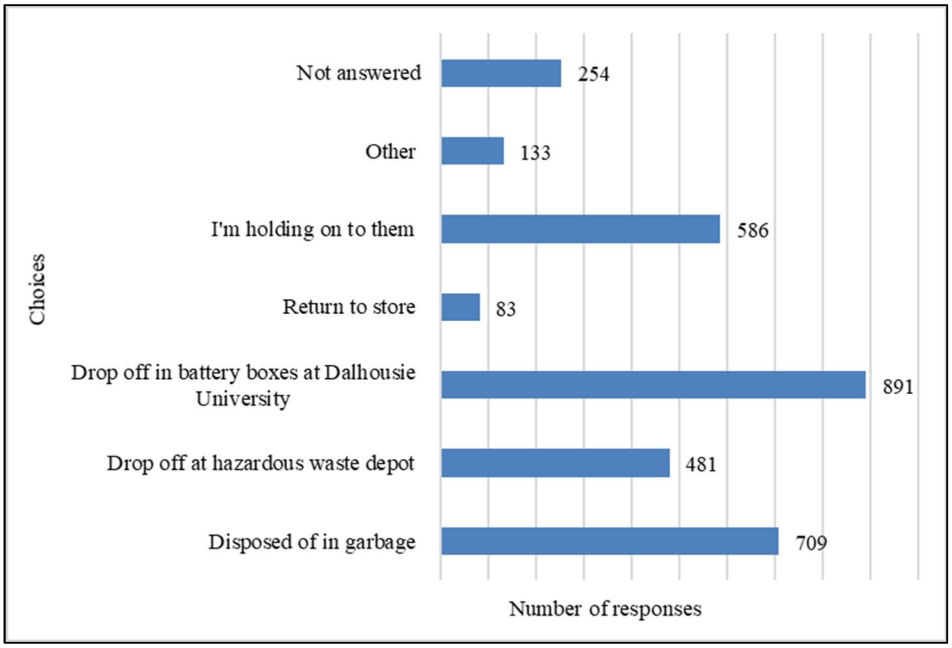

Figure 13. Total responses received per choices of end-of-life management of batteries**.**

4.3 Themes from interviews and survey

Battery collection and handling:

The online survey revealed that batteries are collected through residential curbside, Enviro Depots, retail stores, organisations/businesses, and HHW drop off locations. Once these batteries (rechargeable and non-rechargeable) are collected they are shipped to Call2recycle except automotive batteries, wet cell batteries, and industrial batteries. The automotive, wet cell, industrial, and lead-acid batteries are usually revamped, resold or recycled. According to Battery Council International (2017), recovered lead is sent to battery manufacturers to produce new batteries, plastic pellets are sold to producers of battery cases, and the sulfuric acid is neutralized before release into the public sewer system or converted to sodium sulfate used to produce laundry detergent, glass, and textiles.

The Call2recycle boxes are found in stores, organizations/businesses, and municipal buildings. These boxes are ordered by individual organizations/businesses and the municipality, which are shipped back to Call2recycle when full. The Call2recycle program is a free and voluntary program that commenced in Nova Scotia in the year 2000. The battery recycling program in Nova Scotia began with rechargeable batteries and moved on to the collection of non-rechargeable batteries. The Call2recycle program handles the recycling of batteries that are less than 5kg and cellphones. An interviewee from the provincial government mentioned that the electronics stewardship program in Nova Scotia removes any batteries found in electronics and ships them to Call2recycle.

Performance measures:

There is no obligation by the province to track performance of the battery recycling program, since it is not regulated. A provincial interviewee mentioned that it may be challenging to determine targets. There may be lack of compliance to disposal bans which makes the recycling and diversion rates are difficult to determine. Due to the small size of some batteries, consumers, may hold on to them or throw them in the garbage. In the Annual Sustainability and Commuter Survey, 586 respondents (18.68%) mentioned that they hold on to their batteries and 709 respondents (22.6%) still dispose their batteries in the garbage (Figure 13.).

Performance measures may help to indicate how efficient the battery recycling program is in the Province. For example, Call2recycle publishes annual report for regulated provinces such as British Columbia, Manitoba, and Quebec stating approved stewardship plan targets (collection rates, recycling rates), performance against targets, and strategies for improvement.

Regulatory framework:

Regulating the battery recycling program and having an EPR are opportunities for growth according to the Call2recycle expert. Though the rate of batteries collected through the Call2recycle program in Nova Scotia has increased from 7,000kg in 2010 to 70,000kg in 2016 there is room for improvement. Call2recycle has collection points in Nova Scotia but no agreement with the province. In 2014, there was a consultation about regulating batteries, however the implementation is still pending. The implementation of a regulatory framework requires time and resources. Regulating the battery recycling program may require developing laws/legislations, banning batteries from the landfills, developing a product stewardship program, creating initiatives and harmonizing performance metrics within the province.

Challenges affecting the battery recycling program:

The key challenge mentioned by most interviewees and online survey participants is the ease, convenience, and accessibility of drop-off locations for battery collection. Two of the municipal interviewees mentioned that there are not enough drop-off locations within their region. Some residents travel long distances to drop-off batteries. The battery collection in Nova Scotia is growing irrespective of the challenges according to the Call2recycle expert. Some other challenges mentioned by the interviewees are as follows:

- Not enough drop-off locations as it requires organizations to create a program with responsibilities and administrative work;
- Employee turn-over leading to inadequate handover procedures leading to lack of ownership for the Call2recycle boxes;
- There might be additional fee on batteries if regulated, that may lead to lack of acceptance by the public;
- Developing regulations for all types of batteries requires adequate time and resources, and;
- There may be push back from industries and businesses, due to the battery recycling program perceived as additional burden on the costs of operations.

<u>Improvement opportunities</u>:

Several improvement opportunities were suggested by the interviewees and online survey participants such as:

- The Government of Nova Scotia should provide more resources for battery recycling programs. There should be funding for different pilot projects by municipalities to develop best practices and encourage other municipalities to adopt best practices.
- Call2recycle should promote their programs more with retailers.
- Boxes should be in areas that are easily accessible and where it would generate volumes.
- There should be an EPR for all battery types.
- Creating more awareness among members of the public to increase participation.
- The need to provide incentives for businesses to take back the batteries. The areas that do not collect or encourage battery recycling would participate if the program was easier to implement as part of their HHW operations, that is, if they were compensated for the staff time and resources.
- Provision of more drop off locations.
- Industries should be required to compensate municipalities for handling batteries.

4.4 Nova Scotia active Call2recycle sites

Currently, out of 553 registered sites in Nova Scotia only 340 sites are actively sending their batteries to Call2recycle for recycling. Out of these 340 sites, 277 sites are designated private (Figure 13.). These private sites are mostly part of the ICI sector such as institutions, businesses, healthcare centres and other public services offices. The remaining 63 sites are public sites such as stores, retailers, municipal offices, and municipal buildings. The active sites in some wastes regions such as regions 1, 2,5,6,7 are few and clustered in certain areas and not widespread. This shows that individuals that do not live in the areas with active sites may need to drive long distances to deposit their batteries.

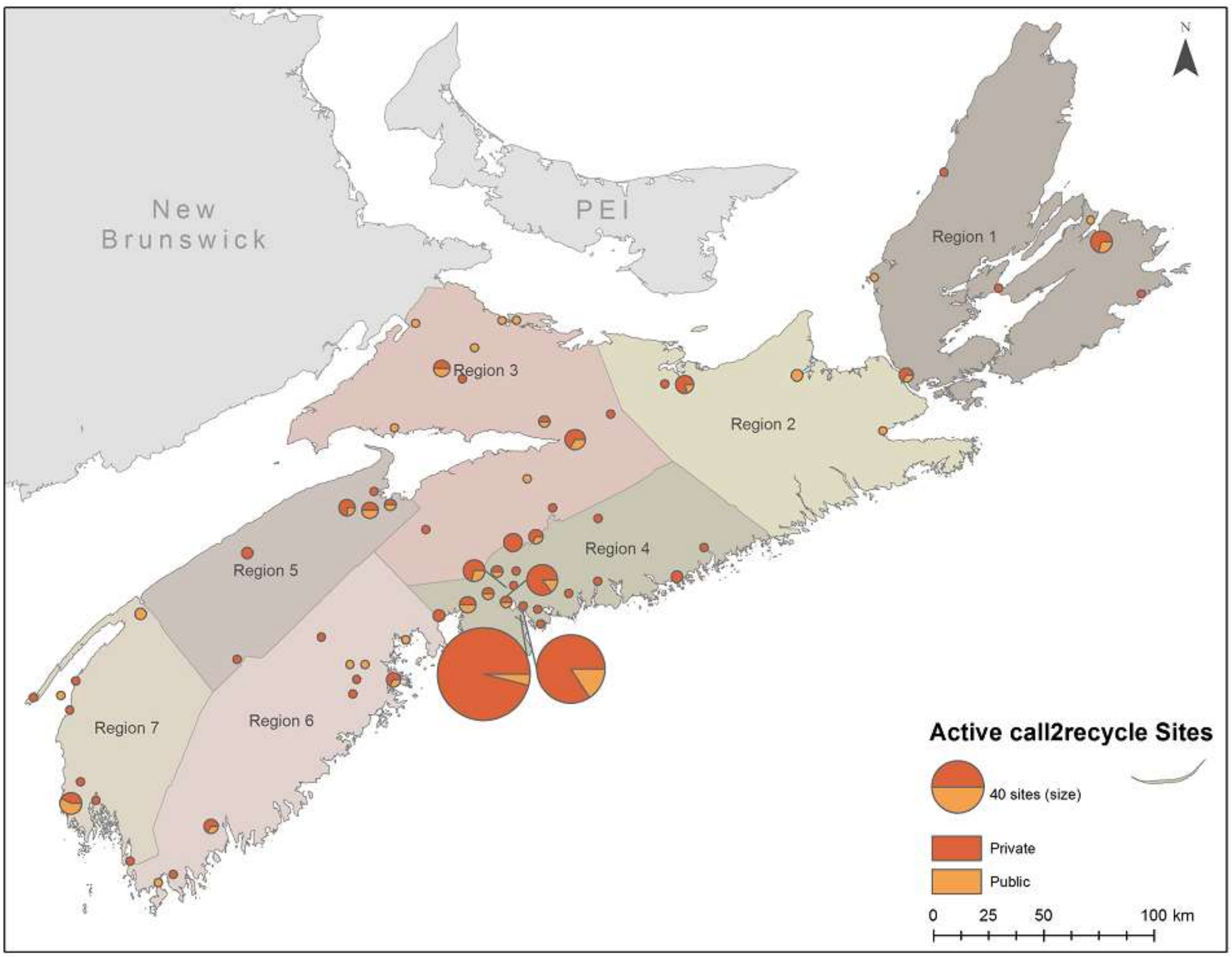

Figure 14. Map showing active Call2recycle sites in the seven solid waste-resource management regions in Nova Scotia (regions mapped based on municipal boundaries) (Data source: Statistics Canada (Census Divisions), 2011 and Call2recycle active site list, 2016).

5.0 Limitations

This study has limitations that affected data collection. The major limitation was lack of battery collection tonnage data from each waste region. This data would have been helpful to determine rates of diversion. Knowing the rate of diversion would inform the type of battery recycling program that may suit the province. The participants for the interviews and online survey have knowledge and skills on waste management due to their roles in the municipal and province. The data received is based only on the information received from municipal and provincial employees, a Call2recycle expert, and a campus survey. The data collected from Call2recycle only covers batteries that are less than 5kg. The data for automotive, wet cell, lead-acid and industrial batteries were not provided in this research. This information does not provide a complete picture of the battery recycling programs in Nova Scotia.

Batteries found in the landfill in the waste audit in 2012 represents less than 1% of the waste stream. Members of the public and the ICI sector were not part of this research. The effectiveness of battery recycling programs depends on participation and commitment of the public.

6.0 Opportunities for improving battery recycling in Nova Scotia

The surveys and interviews revealed that improvements can be made to managing the end-of-life of batteries. The following are opportunities that may lead to improvements in the battery recycling programs in the province:

- Developing regulations to ban all battery types from the landfill in conjunction with a province-wide recycling program;
- Creating a product stewardship program that transfers responsibility for the end-of-life management of batteries to suppliers and manufacturers;
- Exploring curbside collection for household batteries;
- Implementing direct consumer incentives for batteries diversion such as a deposit-refund model;
- Provision of more battery collection centers at government service locations, thus making battering collection easier and convenient;
- Provision of battery collection boxes at Enviro Depots, to create convenience for the public and reduce travel time;

- Promoting the use of rechargeable batteries which contain less hazardous materials than single use batteries, and,
- Creating more public awareness about battery suitability, safety, and methods of disposal.

7.0 Conclusions

Improper disposal of batteries may lead to environmental and health problems. Effective battery recycling programs can lead to diversion of batteries from the landfills and minimise its adverse impacts. It is important to have strict regulation and safety requirements for end-use recycling and incineration facilities so that contamination and health problem are not created at these locations, downstream from the collection process.

The online survey and interviews revealed that members of the public are interested in proper disposal of batteries, however current programs are not always convenient or accessible. The online survey further revealed that each waste management region within the province have been proactive in their individual battery recycling programs.

According to the representative from Call2recycle, the batteries collected from Nova Scotia has increased from 7,000kg in 2010 to 70,000kg in 2016. The NS waste audit conducted in 2012 revealed that 958 tonnes of batteries were found in the landfill. Another waste audit is scheduled to be conducted the fall of 2017. An average Call2recycle box filled with batteries weighs 30kg, this implies that approximately 31,933 boxes of batteries were found in the land fill that can fill up 266 standard bedrooms.

Regulating the battery recycling program for all battery types, a product stewardship program, including banning all batteries from the landfill may lead to higher diversion rates. Several battery manufacturers are already participating in product stewardship programs in other provinces such as British Columbia, Quebec and Manitoba. The economy of Canada cannot grow sustainably if manufacturers are not held accountable for the end-of-life management of their products. An EPR program, will not allow manufacturers to pursue sales without considering the environment impacts of the end-of-life of their products (McKerlie et al., 2006). With the growing demand for the use of batteries especially lithium-ion batteries, the province may need to develop proactive measures to minimize the environment and health impacts of end-of-life of batteries. Even though batteries are estimated to amount for less than 1% of the waste stream as at 2012, their cumulative effects may cause irreversible damages to the ecosystem in the future.

8.0 References

ATSDR (Agency for Toxic Substances and Disease Registry) (2004). Public health statement, Copper CAS#: 7440-50-8. Retrieved from, https://www.atsdr.cdc.gov/ToxProfiles/tp132-c1-b.pdf

ATSDR (1998). Public health statement sulfur trioxide and sulfuric acid, CAS#: Sulfur Trioxide 7446-11-9 Sulfuric Acid 7664-93-9. Retrieved from, https://www.atsdr.cdc.gov/ToxProfiles/tp117-c1-b.pdf

Aral, H. and Vecchio-Sadus, A. (2008). Toxicity of lithium to humans and the environment – A literature review. *Ecotoxicology and Environmental Safety, 70*, 349–356. Doi:10.1016/j.ecoenv.2008.02.026

Battery Council International (2017). Recycling Batteries. Retrieved from, http://batterycouncil.org/?page=Battery_Recycling

Battery University (2017a). BU-103: Global Battery Markets. Retrieved from, http://www.batteryuniversity.com/learn/article/global_battery_markets

Battery University (2017b). BU-705a: Battery Recycling as a Business. Retrived from, http://batteryuniversity.com/learn/article/battery_recycling_as_a_business

Battery University (2017c). BU-705: How to Recycle Batteries. Retrieved from, http://batteryuniversity.com/learn/article/recycling_batteries

Basit, T. (2003). Manual or electronic? The role of coding in qualitative data analysis. *Educational Research, 45* (2), 143-154. Doi: 10.1080/0013188032000133548

Bernardes, A.M., Espinosa, D.C.R., Tenório, J.A.S (2004). Recycling of batteries: a review of current processes and technologies. *Journal of Power Sources, 130*, 291–298

Boyden, A., Soo, V. K. and Doolan, M. (2016). The Environmental Impacts of Recycling Portable Lithium-Ion Batteries. *Procedia CIRP, 48*, 188 – 193 (23rd CIRP Conference on Life Cycle Engineering)

Call2recycle (2016a). How Call2recycle recycles your batteries. Retrieved from, http://www.Call2recycle.ca/physical-flowchart/

Call2recycle (2016b). Recycling regulations by province. Retrieved from, http://www.Call2recycle.ca/recycling-laws-by-province/

Cempel, M. and Nikel, G. (2006). Nickel: A review of its sources and environmental toxicology. *Polish Journal of Environmental Studies, 15*(3), 375-382

Commonwealth of Australia (2014). Sulfuric acid. Retrieved from, http://www.npi.gov.au/resource/sulfuric-acid

Das, K K., Das, S. N. and Dhundasi, S. A. (2008). Nickel, its adverse health effects & oxidative stress. *Indian Journal of Medical Research; New Delhi, 128* (4), 412-425.

Dell, R., Rand, D. A. J. and Royal Society of Chemistry. (2001). *Understanding batteries* (RSC paperbacks). Cambridge: Royal Society of Chemistry.

DTSC (Department of Toxic Substances Control) (2010). Universal Waste. Retrieved from, http://www.dtsc.ca.gov/HazardousWaste/UniversalWaste/

Divert NS (2017). Household hazardous waste. Retrieved from, http://divertns.ca/recycling/what-goes-where/hazardous-household-waste

Dokmecia, A. H., Ongena, A. and Dagdevirenb, S. (2009). Environmental toxicity of cadmium and health effect. *Journal of Environmental Protection and Ecology, 10*(1), 84–93

Driscoll, D. L., Appiah-Yeboah, A., Salib, P. and Rupert, D. J. (2007). Merging qualitative and quantitative data in mixed methods research: How to and why not. *Ecological and Environmental Anthropology (University of Georgia)*, *3* (1), 19-28. http://digitalcommons.unl.edu/icwdmeea/18

Electronics Product Stewardship Canada (2017). Home. Retrieved from, http://epsc.ca/#

EPR Canada (2015). BC's overall grade climbs to A in EPR Canada's 2015 scored report card on implementation of producer responsibility programs. Retrieved from, http://www.eprcanada.ca/reports/2014/2015-EPR-News-Release-EN.pdf

Espinosa, D.C.R, Bernardes, A.M., Tenório J.A.S (2004). Brazilian policy on battery disposal and its practical effects on battery recycling: Short communication. *Journal of Power Sources, 137*, 134–139

European Recycling Platform (ERP) (2017). How are batteries recycled? Retrieved from, http://www.erp-batteries.co.uk/

European Portable Battery Association (EPBA) (2017). Product information primary and rechargeable batteries. Retrieved from, https://www.epbaeurope.net/wpcontent/uploads/2016/12/EPBA_Product-Information_10112015.pdf

Gaines, L. (2014). The future of automotive lithium-ion battery recycling: Charting a sustainable course. *Sustainable Materials and Technologies, 1-2*, 2-7. http://dx.doi.org/10.1016/j.susmat.2014.10.001

Giroux, L. (2014). State of waste management in Canada, Prepared for:

Canadian Council of Ministers of Environment (CCME). Retrieved from, http://www.ccme.ca/files/Resources/waste/wst_mgmt/State_Waste_Mgmt_in_Canada%20April%202015%20revised.pdf

Government of Canada (2013a). Mercury in the Food Chain. Retrieved from, https://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=D721AC1F-1

Government of Canada (2013b). Batteries. Retrieved from, https://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=8E1CA841-1

Government of Canada (2017). Battery recycling program. Retrieved from, http://www.ec.gc.ca/gdd-mw/default.asp?lang=En&n=4F700CB1-1

Gopher Resource (2017). Our seven-step battery recycling process. Retrieved from, https://www.gopherresource.com/what-we-do/battery-recycling-process.html

IPE (Institute of Public and Environmental Affairs) (2011). Health and environmental impacts from lead battery manufacturing and recycling in China. Retrieved from, http://okinternational.org/docs/China%20Lead%20Battery%20Report%20IPE%20English%20Revised.pdf

Kang, D.H.P., Chen, M. and Ogunseitan, O.A (2013). Potential environmental and human health impacts of rechargeable lithium batteries in electronic waste. *Environmental Science &Technology, 47*, 5495−5503. dx.doi.org/10.1021/es400614y

McKean, C. (2016). Canadian Battery Association (CBA) Annual report to the director, 2015 Calendar Year. Retrieved from, http://recyclemybattery.ca/images/2015_CBA_Annual_Report_-_PEI.pdf

McKerlie, K., Knight, N. and Thorpe, B. (2006). Advancing extended producer responsibility in Canada. *Journal of Cleaner Production, 14*, 616 – 628. Doi:10.1016/j.jclepro.2005.08.001

NEMA (National Electrical Manufacturers Association) (2003). Button cell battery collection: why it does not make sense, Retrieved from, https://www.nema.org/Policy/Environmental-Stewardship/Documents/Buttoncellcollection.pdf

Nova Scotia (2011). Our path forward: Building on the success of Nova Scotia's solid waste resource management strategy. Retrieved from, https://www.novascotia.ca/nse/waste/docs/Solid.Waste.Strategy-Our.Path.Forward.2011.pdf

Nova Scotia (2014a). Environmental goals and sustainable prosperity act: Progress report, 2012–2014. Retrieved from, https://www.novascotia.ca/nse/egspa/docs/EGSPA-2012-2104-Progress-Report.pdf

Nova Scotia (2014b). Solid waste-resource management strategy. Retrieved from, https://www.novascotia.ca/nse/waste/swrmstrategy.asp

Nova Scotia (2015). Solid waste regulation, Public discussions: what we heard. Retrieved from, https://www.novascotia.ca/nse/waste/docs/Solid-Waste-What-We-Heard-Report-March-2015.pdf

Nova Scotia (2017). Municipal Collection Information. Retrieved from, https://novascotia.ca/nse/waste/muncollection.asp

Office of Sustainability (2016). Dalhousie guide to waste management on campus 2016. Retrieved from, https://www.dal.ca/content/dam/dalhousie/pdf/dept/sustainability/Waste/Waste%20Sorting%20Guide%20201617.pdf

Pistoia, G., Wiaux, J.-P. and Wolsky, S. P. (2001). Used battery collection and recycling (1st ed., Industrial chemistry library; v. 10). Amsterdam: Elsevier Science.

Plum, L.M., Rink, L and Haase, H. (2010). The essential toxin: Impact of zinc on human health. *International Journal of Environmental Research and Public Health, 7*, 1342-1365. Doi:10.3390/ijerph7041342

Product Stewardship Institute, Inc. (2016). Definitions: What is product stewardship, anyway? Retrieved from, http://www.productstewardship.us/?page=Definitions

Rice, K.M., Walker Jr. E.M., Wu, M., Gillette, C. and Blough, E.R. (2014). Environmental mercury and its toxic effects*, Journal of Preventive Medicine and Public Health*, *47*, 74-83. http://dx.doi.org/10.3961/jpmph.2014.47.2.74

Solomon, F. (2009). Impacts of copper on aquatic ecosystems and human health. *Environment & Communities*. Retrieved from, http://www.ushydrotech.com/files/6714/1409/9604/Impacts_of_Copper_on_Aquatic_Ecosystems_and_human_Health.pdf

Statistics Canada (Census Divisions) (2011). Retrieved from, http://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-eng.cfm

Statistics Canada (2012). Human activity and the environment: Waste management in Canada. Statistics Canada – Catalogue no. 16-201-X. Retrieved from, http://www.statcan.gc.ca/pub/16-201-x/2012000/part-partie3-eng.htm

Statistics Canada (2016). Waste disposal by source, province and territory (Newfoundland and Labrador, Prince Edward Island, Nova Scotia). Retrieved from, http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/envir25a-eng.htm

UNEP (United Nations Environment Programme) (2010). Final review of scientific information on cadmium –Version of December 2010. Retrieved from, http://drustage.unep.org/chemicalsandwaste/sites/unep.org.chemicalsandwaste/files/publications/GAELP_PUB_UNEP_GC26_INF_11_Add_2_Final_UNEP_Cadmium_review_and_apppendix_Dec_2010.pdf

USEPA (2017a). Universal waste. Retrieved from, https://www.epa.gov/hw/universal-waste

USEPA (2017b). Learn about Lead. Retrieved from, https://www.epa.gov/lead/learn-about-lead

USEPA (2017c). Mercury in Batteries. Retrieved from, https://www.epa.gov/mercury/mercury-batteries.

WHO (World Health Organisation) (2016). Lead poisoning and health. Retrieved from, http://www.who.int/mediacentre/factsheets/fs379/en/

WHO (2017). Mercury and health. Retrieved from, http://www.who.int/mediacentre/factsheets/fs361/en/

9.0 Appendices

Appendix A. Interview Script and interview questions

Interview Script – Municipal, Regional and Provincial staff

Good morning/afternoon, my name is Buky Adebambo and I am studying Masters in Resource and Environmental Management at Dalhousie University. With funding from the Divert Nova Scotia and support from the Office of Sustainability, I am completing a project titled *Universal Waste Management*. In Nova Scotia, currently there is no Extended Producer Responsibility (EPR) program in place for universal materials like batteries. There are over seven categories of battery types, the most widely used being Alkaline. The first section of this research would focus on understanding the types and volumes of battery waste in Nova Scotia, battery recycling programs employed across Canada and in Nova Scotia, and opportunities for the future. This research has been designed to understand the types and volumes of battery waste in Nova Scotia, recycling battery programs employed across Canada and in Nova Scotia, and opportunities for the future.

The objective of this interview is to review the status of the battery recycling program in your jurisdiction and develop strategies for improvement collectively for the province.

With your permission, I will record this session and the recording will only be accessible to my research supervisor and I. Notes and recordings from this session will be stored in a secure location at Dalhousie until December 2017, at which point all documents will be destroyed. If any question makes you feel uncomfortable, please let me know and we can move on to the next topic.

Interview Questions

1. What is the status of the battery recycling program in this jurisdiction?
2. When did the battery recycling program commence in this jurisdiction?
3. What types of batteries and respective volumes are collected? *Interviewer will have a complete list of types of batteries to be used as a prompt.
4. How are they handled, collected and disposed?
5. How do you encourage households to participate in the battery recycling program?

6. Do you have a performance measures (data, periodic tracking and targets) for battery recycling in this jurisdiction?
7. What are the current challenges?
8. How can these challenges be addressed?

Closing

That brings us to the end of our interview. Thank you so much for your time and contributions to this study. The recording from this meeting will be analyzed and will contribute to the preparation of a final report and presentation.

I would just like to reiterate that all information shared today is confidential. As noted in the consent form, if a direct quote is to be included in any report or presentation, it will remain anonymous. If you have any questions, please do not hesitate to contact me directly; my contact details are included in the consent form. Alternatively, please feel free to reach out to the Dalhousie Faculty of Management Research Ethics Officer.

Appendix B. Interview background with consent box for online survey

Universal Waste Management

CONSENT FORM

This survey is being conducted by Olubukola Adebambo, a Master of Resource and Environmental Management (MREM) student at Dalhousie University. It will contribute to a project titled Universal Waste Management, which is funded by Divert Nova Scotia and supported by the Office of Sustainability.

The objective of this survey is to review the status of the battery recycling program in your jurisdiction and develop strategies for improvement within the province.

Participants are free to withdraw from the research project at any time. During the online survey, participants may not click the submit button and thus not complete the online survey. Participants will be given an opportunity till the end of August 2017, to withdraw any information provided from the online survey responses. This information can be provided via telephone or email to the student researcher or the supervisor.

Information from this survey will be stored in a secure location at Dalhousie until December 2017, at which point all documents will be destroyed. The procedure involves filling an online survey that will take approximately 20 minutes. This survey will be open from 20th June to 21st July 2017.

ELECTRONIC CONSENT: Clicking on the "Start" button indicates that:

- You have read the information above, and
- You voluntarily agree to participate in the survey.

Online Survey Questions

1. Which waste region do you belong to?
   Please check the appropriate box.

Region 1	**Check**
Cape Breton Regional Municipality	
Inverness	
Victoria	
Richmond	
Port Hawkesbury	
Region 2	
Municipality of the District of Guysborough	
Municipality of the County of Antigonish	
Municipality of the Town of Antigonish	
Pictou County	
Region 3	
The Municipality of the County of Colchester	
Cumberland Joint Services Management Authority	
The Municipality of East Hants	
Region 4	
Halifax Regional Municipality (HRM)	

Region 5	
Valley Waste Resource Management includes, Annapolis, Kings, Berwick, Bridgetown, Hantsport, Kentville, Middleton, Wolfville	
Region 6	
South Shore/West Hants includes, Barrington, Bridgewater, Lockeport, Lunenburg, Mahone Bay, Shelburne, Windsor, West Hants, Chester, Lunenburg, Queens Region, Shelburne	
Region 7	
Town and County of Digby, Clare, Argyle, Town of Yarmouth, District of Yarmouth, Clark's Harbour	
Others (Please specify)	

2. Are batteries recycled in your region?

   Yes

   No

   I am not sure

   If yes, specify name (s) of the program (s)…………………………………………….
3. A list of common batteries has been provided. For every battery type being recycled in your region, please check as many applicable collection methods. If a method is not listed please provide additional information. Place your cursor on the battery pictures to show common uses.

S/N	**Battery Types**	Curbside Businesses	Curbside Residential	Enviro depot	Stores	Org/Buisnesses	Household Hazardous Waste (HHW) Drop off location	Other (Specify)
1	Nickel Cadmium (Ni-Cd)							
2	Nickel Metal Hydride (Ni-MH)							
3	Nickel Zinc (Ni-Zn)							
4	Alkaline/Single-Use							
5	Lithium Ion (Li-Ion)							
6	Small Sealed Lead Acid (SSLA/Pb)							
7	Lithium Primary							
8	Zinc Carbon							
9	Alkaline manganese							
10	Zinc Chloride							
11	Button cell batteries – Mercuric oxide button cells							
12	Zinc air button cell							
13	Wet-cell batteries							
14	Lead acid batteries							
15	Silver oxide batteries							

4. Please select which battery recycling program(s) is/are ongoing in your region (select all that apply):

   Call2recycle
   Managed by an organization (in conjunction with hazardous waste recycler)
   Municipal special events (Wkly/Mthly)
   I am not sure
   Other (please specify)…………….
5. Indicate which locations have the Call2recycle receptacles or boxes for battery collection (select all that apply):
   Enviro Depot
   Stores
   Org/Businesses
   I am not sure
   Other (please specify)…………….
6. Does your region advertise battery recycling programs?
   Yes

No

I am not sure

If yes, specify name (s) of the program (s)…………………………………………….

7. Do you have any incentive programs for battery recycling to encourage participation in waste prevention and diversion?

   Yes

   No

   I am not sure

   If yes, please specify…………………………….

8. Do you have any performance measures such as quantity of batteries sent to the recycling facility?

   Yes

   No

   I am not sure

   If yes, specify type of data collected………………………………….

9. Other comments?

10. Please provide email if we can contact you for further enquiries (optional)………..

Appendix C. Battery types and uses

S/N	Battery Types	Picture	Uses
1	Nickel Cadmium (Ni-Cd)		cordless power tools, cordless phones, digital cameras and video cameras, two-way radios, biomedical equipment, professional video cameras, alarm systems and emergency lighting
2	Nickel Metal Hydride (Ni-MH)		Cellphones, cordless power tools, digital cameras, two way radios, hybrid vehicles
3	Nickel Zinc (Ni-ZN)		Digital cameras, wireless keyboards, small electronics
4	Alkaline/Single-Use		Alarm clocks, calculators, flashlights, TV remote controls, remote control toys, MP3 players, torches or toys
5	Lithium Ion (Li-Ion)		Cellphones, cordless power tools, cordless phones, digital cameras, two-way radios, laptop computers, tablets and e-readers. cameras, MP3 players, laptops, and mobile phones.
6	Small Sealed Lead Acid (SSLA/Pb)		Mobility scooters, fire emergency devices, UPS systems, hospital equipment, emergency lighting
7	Lithium Primary		Car keyless entry remotes, watches, pacemakers, hearing aids, memory backup, fire alarm devices, military electronics, watches and in photographic equipment
8	Zinc Carbon		Clocks and radios
9	Alkaline Manganese		Alarm clocks, calculators, flashlights, TV remote controls, remote control toys, MP3 players, torches or toys
10	Zinc Chloride		Clocks and radios
11	Button cell batteries – Mercuric oxide button cells		Hearing aids, pacemakers and photographic equipment
12	Zinc air button cell		Hearing aids and radio pagers
13	Wet-cell batteries		Used to power vehicles, including cars, and in industry for standby power, lead-acid is the most common type of wet-cell battery
14	Lead acid batteries		Electric motors, electric scooters, electric wheelchairs
15	Silver oxide batteries		Hearing aids, watches, calculators

Appendix D. Ethics approval from the Research Ethics Officer of the Faculty of Management at Dalhousie University

DALHOUSIE
UNIVERSITY
Inspiring Minds
Faculty of Management

Faculty of Management Graduate Student Ethics Approval for a Course-based Project

June 19, 2017

Olubukola (Buky) Adebambo,

I am pleased to inform you that I have reviewed your project **"Universal Waste Management" (file no. 060517)**, for the course ENVI5501 (MREM Internship) under the supervision of Rochelle Owen and Michelle Adams, and have found the proposed research involving human participants to be in accordance with the *Faculty of Management Ethics Review Policy for Course-based Projects* and the *Tri- Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*. This project has received ethics approval.

This approval will be in effect until and not exceeding December 25, 2017 (fourteen days from the final date of classes for the 2017 Dalhousie Fall Semester). It is your responsibility to immediately report any adverse events involving participants to both your instructor and to the Research Ethics Officer. Please note that any significant changes to the research methodology, consent form or recruitment materials must be resubmitted to Research Ethics Officer for review and approval prior to their use.

Congratulations on your successful Faculty of Management Graduate Student Ethics Approval for your Course-based Project. I wish you all the best as you begin this next phase of your research. Should you have any questions regarding ethical issues at any point during your project, please do not hesitate to contact me.

Sincerely,

Ashley Doyle

Ashley Cummiskey (Doyle)
Faculty of Management Research Ethics Officer
Rowe 2029
Dalhousie University
PO Box 15000, Halifax, NS B3H 4R2
a.doyle@dal.ca

Appendix E. Nova Scotia Call2recycle report from 2015 till date

call2recycle® Recharging the planet. Recycling your batteries.™

Run Date:6/21/2017

Province Summary Report

NovaScotia

Batteries / Cell Phones Collected From 1/1/2016 To 12/31/2016

Rechargeable Batteries	Weight (kg)
Nickel Cadmium (Ni-Cd)	6,210.37
Lithium Ion (Li-Ion)	3,333.36
Nickel Metal Hydride (Ni-MH)	2,241.30
Small Sealed Lead Acid (SSLA/Pb)	4,559.51
Total:	16,344.54

Non-Rechargeable Batteries / Cell Phones	Weight (kg)
Alkaline	51,574.30
Lithium	1,588.34
Mercury	0.91
Cell Phone (Weight)	292.11
Wet Cell Nickel Cadmium	60.78
Cell Phone Accessories (Weight)	178.72
Total:	53,695.17

For the Reporting Period:

325 Sites Sent 2,714 Boxes (59% of 552 Enrolled Sites)

Totaling 70,040 kg

And Returned 1,808 Cell Phones