Accelerating Clean Growth
Newfoundland & Labrador

Exploring Opportunities to Address Future EV Battery Waste in Newfoundland & Labrador

Discussion Paper

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Abbreviations

ECCC	Environment and Climate Change Canada
EPR	Extended Producer Responsibility
EV	Electric Vehicle
Hydromet	Hydrometallurgical
Li	Lithium
Cu	Copper
Co	Cobalt
Mn	Manganese
ZEV	Zero Emissions Vehicle

1.0 Introduction

The *Canadian Net-Zero Emissions Accountability Act* became law on June 29, 2021 and ensures Canada's commitment to achieve net-zero emissions by 2050. One of the many pathways to net-zero are electric vehicles (EVs), which operate on battery power instead of fossil fuels, thus reducing greenhouse gas (GHG) emissions. The increased production and adoption of EVs will result in the a corresponding increase in manufacturing, use, and disposal of EV batteries.

Although there are several commonly used batteries (alkaline, nickel-metal hydride and lithium-ion), the most common used for EVs are lithium-ion. This discussion paper will focus on lithium-ion batteries used in EVs – exploring the new challenges that they will present from a waste management perspective in the Newfoundland and Labrador (NL) context.

In December 2022, the Government of Canada published proposed regulations for Zero Emission Vehicles (ZEV) that set the following sales targets (ECCC, 2022):

- 2026 – 1 in 5 cars sold in Canada to be a ZEV
- 2030 - at least 60% will be ZEVs
- 2050- 100% of sales will be ZEVs

ZEVs are defined as "vehicles that do not produce polluting exhaust, including battery-electric, plug-in hybrid electric, and hydrogen fuel cell electric vehicles".

It's well established that ZEV's will reduce GHG emissions, however, there has been recent concerns about the downstream environmental impacts of ZEV, particularly with the disposal of EV batteries. This concern stems from 2 things:

(a) Many of the critical minerals (lithium, cobalt, nickel, manganese, and graphite) used to manufacture an EV battery are finite natural resources mined only in particular parts of the world. Not withstanding the environmental impacts of raw mineral mining itself, there is a need to draw out the supply of the critical mineral reserves. One way to accomplish this is to recapture and reuse critical minerals by recycling EV batteries and reusing them again to make more batteries.

(b) If EV batteries are not disposed of properly and are simply landfilled, there will be environmental impacts. Concerns with simply landfilling EV batteries include leaching of harmful chemicals into the environment, leaking of poisonous gas, and/or explosion.

To put the importance of proactive waste management strategies for EVs into perspective, here is an excerpt from a white paper produced by the International Council on Clean Transportation (ICCT):

> *"Battery recycling practices will have a profound effect on long-term ZEV battery material supply. The analysis indicates that developing recycling streams to recover approximately 90% of the critical battery materials can significantly reduce the need for raw material mining from 2040 on. When accounting for second-life use of batteries after electric vehicle end-of-life, recycling can reduce the need for new material mining by 20% in 2040 and 40% in 2050. With recycling, the cumulative use of lithium and nickel could reach 25% of known global reserves by 2050, and 30% for cobalt. This is approximately a 25% reduction in the cumulative use of materials as a percentage of known global reserves in 2050 compared to a no-recycling case. Without recycling, cumulative use of these three key materials for global passenger electric vehicles could reach 30% to 40% of global proven reserves by 2050. Beyond 2050, as greater volumes of batteries become available for recycling, the need for new mining can be further reduced."*

Taking a circular approach to waste management of EV batteries makes environmental and economic sense. From a local standpoint, e.g., within NL, the province can anticipate the increasing prevalence of EV batteries 'waste' and begin to plan how spent EV batteries are collected, dismantled, recycled and/or reused.

In general, the economics of waste management in NL are challenging due to the small and often rural/remote nature of its population which is spread across a large geography.

Currently in NL, batteries are removed from end-of-life vehicles that are processed as scrap metal my Newco Metals and Auto Recycling (Newco). EV batteries are removed from vehicles and the battery is removed prior to crushing. Removal happened at the garage, or by Newco staff. The batteries are then placed on pallets with wood or cardboard between layers (for protection) and secured to the pallet. The pallet is then shrink wrapped. Once volumes allow, the batteries are shipped to locations in mainland Canada for processing and recycling if possible. Ones that cannot be presently recycled are stored at a mainland Canada location for future processing. Standard lead acid batteries can be shipped together. The new EV batteries may have to be shipped separately.

Presently in NL, only a small number of batteries are being disposed of (e.g., less than 100 per year), yet just three years ago that value would be less than 10. As the sales of both EVs and hybrid vehicles increase, these numbers will climb quickly. NL can expect the number of batteries to be disposed of to fall in line with the number for EV sales following about 5 to 7 years from the date of sale. Statistics list an increase of EV sales from 2023 to 2027 of about 20.64%. EV unit sales are expected to reach 194,600 vehicles by 2027 nationwide in Canada.

In 2019, Newfoundland Power and NL Hydro completed a study on expected EV sales in the province (NL Power and NL Hydro, 2019). By 2034, the cumulative amount of EV in NL is projected to be approximately 40,000. As of 2022, cumulatively there were less than 2500 EVs purchased in the province. This study was completed prior to the Federal sales targets for EVs being released, so it is likely that this projection will be higher. An updated study is being completed which will provide more valid projections, however, regardless of the projections an exponential increase in the number of EVs (and therefore the number of end-of-life EV batteries) will take place in NL over the next couple of decades.

2.0 How an EV Battery is Built

In order to understand how EV battery waste management problems can be solved, it is important to know how an EV battery is built. Batteries are complex technologies and thus managing their end of life can be equally complex.

In its basic form, an EV battery is a grouping of approximately 10 modules, and each module is made up of 10-15 cells. The cells are what contain the critical minerals, anode, cathodes and electrolyte solution that make the chemical reaction to produce electricity. Each cell and module are usually encased in an aluminum cover, and the group of modules along with the electronics for battery management are encased in a plastic cover to make the battery pack (See Figure 1). Batteries typically weigh anywhere from 500-1000lbs and run the full wheelbase of a car, so, they are quite large. The typical life span of an EV battery for use in an EV is 8-15 years (75% spent). The battery itself is still functional for energy storage for 10-15 years following removal from an EV (National Renewable Energy Laboratory, 2022).

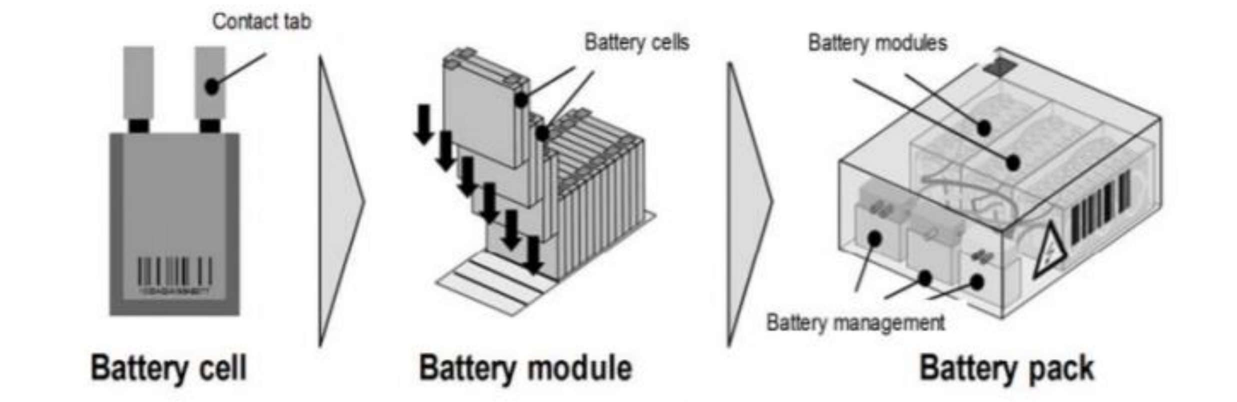

Figure 1: Components of a Typical EV Battery *(Source: EV Experts, 2022)*

Inside the battery cell is where most of critical minerals are located. It houses the aluminum cathode, the graphite separator, the copper anode and the electrolyte solution (See Figure 2). The electrolyte solution is a liquid that contains a combination of lithium, cobalt, manganese and/or other critical elements.

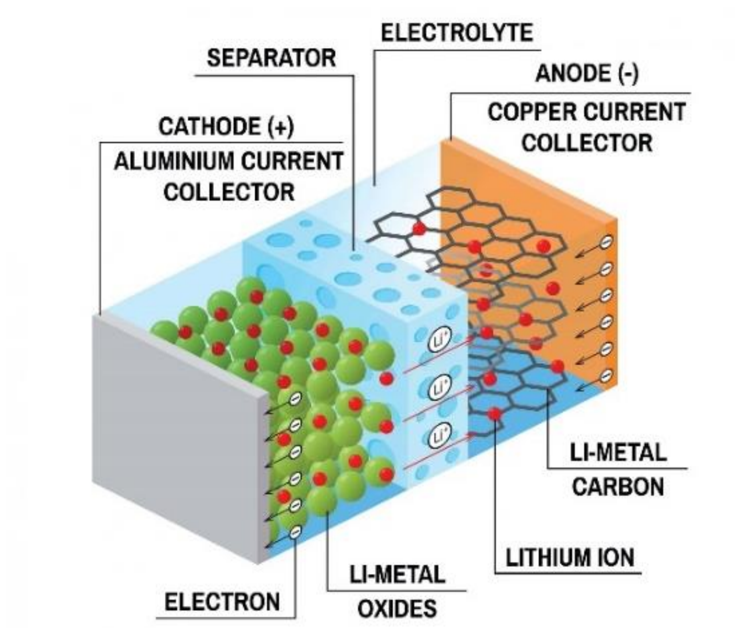

Figure 2: Components of a typical battery cell *(Source: Misumi Mechanical Lab, 2022)*

When looking at recycling a battery, the generalized percent breakdown of the components and their value are presented in Table 1.

Table 1: Percent Breakdown of Battery Components and their Recycling Value

Battery Components	Percent Breakdown	Recycling Value
Plastics used to make outer casing, electronics, steel	30%	Low
Aluminum/Copper used to make module casings	40%	Intermediate
Lithium (Li), colbalt (Co), nickel (Ni) and copper (Cu) used in the composition of the battery cells	30%	High

Source: Zhou et al., 2020

Recycling can include breaking down and separating all components, or just specific parts of the EV battery based on their value, market access and other considered variables.

3.0 Methods for EV Battery Recycling and Reuse

Recycling EV batteries fall into two main categories as discussed below: physical and chemical. It is important to note that for each recycling methods, the battery needs to be discharged before being processed. Discharging the battery reduces the risk of casualties through explosion, combustion, and the release of poisonous gas during the recycling process.

Advantages, disadvantages and challenges of each recycling approach are summarized in Table 2. The process/methodology are shown in Figure 3.

3.1 Recycling – Direct Physical Process

Direct physical recycling involves workers or machines deconstructing the batteries and separating them into their components. Batteries are usually separated into waste piles of 3 categories based on component value (Table 1). Battery cells need to be removed before processing (i.e., shredding) occurs. The separated battery cells can either be processed further to remove and separating the electrolyte solution, cathode and critical minerals solutions, or they can be shipped to a chemical processing facility for higher recovery. Due to the traditional assembly line set up, direct recycling of EV batteries has high operational and equipment costs. As well, battery construction is not standardized, so batteries from different manufactures may be built differently, including what type of material the modules and battery cell are encased and the critical minerals in the battery cell. This is important to consider, as it may be more or less labour intensive to dismantle a battery depending on who manufactured it.

3.2 Recycling – Chemical Processes

Two types of chemical processes include hydrometallurgical and pyrometallurgical.

Hydrometallurgical, also referred to as hydromet, uses water and acid leaching to separate the critical minerals. The battery is physically dismantled and the cathode and anode (which make up the battery cell) are separated. The anode (usually graphite) along with useful electrical components and metals from the casing (aluminum, copper) are separated and stored to be recycled in one stream. It is the components of the product of the cathode in the battery cell that are put through the hydromet process. Pre-treatment of the cathode components converts it into a powdery substance called black mass. The black mass is dissolved in water and varying mixed acid compounds attract the ions of the critical minerals, separating them back into their raw elemental form. The products are metal ion solutions that can be re-used by a battery manufacturing facility.

Pyrometallurgical involves burning the battery components, usually in a two-part process. The first process is to remove the plastic waste and the second is to smelt the critical minerals. The battery cell components are crushed and sifted to separate the anode and cathode pieces, and then smelted (Jena and Alfantazi, 2021). The slag produced through smelting process can be handled at a hydromet facility, separating it back into the critical mineral components. Pyrometallurgical is included in this conversation because it is a recognized method, however, the waste gas produced through the process and low recovery rates of original elements basically eliminates it from consideration as a viable recycling option. It may be worth exploring this option if the waste gas produced through the recycling process can be captured and converted to renewable fuel (known and plastic pyrolysis).

Note that the hydromet is the same process used by Vale to process nickel from Voisey's Bay at their Long Harbour processing plant in NL. Hydromet is an established technology in the mining field to separate metals from ores. Partnerships with mining companies may be worth exploring. The process also requires skilled labour (chemical engineers and technicians), so partnerships would be beneficial from a labour sharing perspective as well.

Table 2: Battery Recycling Methods with Advantages, Disadvantages, and Challenges

Process	Advantages	Disadvantages	Challenge
Hydrometallurgical process	High recovery rate High purity product Low energy consumption Less waste gas High Selectivity	More wastewater Long process	Wastewater treatment Optimize the process
Pyrometallurgical process	Simple operation and short flow No requirement for categories and the size of inputs High efficiency	Li and Mn are not recovered High energy consumption Low recovery efficiency More waste gas and the cost of waste gas treatment	Reduce energy consumption and pollution emissions Reduce environmental hazards Combine hydrometallurgy well
Direct physical recycling process	Short recovery route Low energy consumption Environmental friendly High recovery rate	High operational and equipment requirements Incomplete recovery	Reduce recovery costs Lower the requirements for categories Further optimize product performance

Source: Zhou et al., 2020

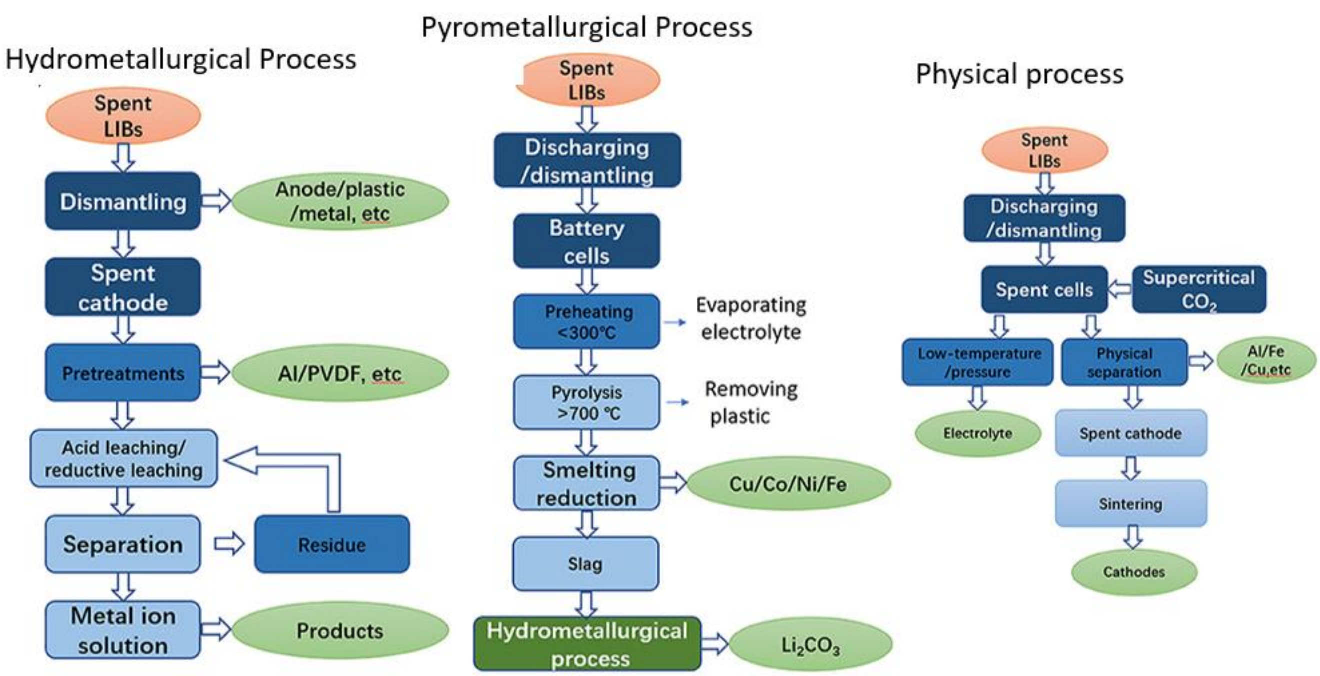

Figure 3: Generalized steps for each Recycling Method *(Source: Adapted from Zhou et al., 2020)*

3.2 Re-Use

Another consideration is the re-use of EV batteries for other industrial uses. An EV battery is at the end of its life for EV use when it can no longer hold 75% of it's charge. This is mainly because the length of time it can hold a charge is important for EV use. However, the battery itself is still functional as an energy storage unit and can be re-purposed for another use that does not depend on charge length. Re-using batteries is mainly done by joining together many batter packs until the desired kWh of stored energy is reached. Some opportune uses may include:

- A back up energy source - During power outages, EV batteries could provide a back-up to produce electricity for critical infrastructure (hospitals, warming shelters etc.), replacing combustion generating plants.
- As a power management technique to match supply and demand from variable renewable energy projects, such as wind power.
- Solar arrays - Re-purposed EV batteries can be used as the batteries for solar arrays.

4.0 Current Outlook in Canada

There is a Canadian start-up company called LiCycle in Kingston, ON which discharges and dismantles batteries to recover waste. The company's two main product streams are black mass and mixed copper/aluminum. The black mass is shipped to a hydromet facility in Rochester, NY to be processed and separated into their original elements and reinserted back into the EV battery supply chain to make new batteries. The recovery of elements in this process is 95%. The company advertises "closed loop resource recovery" on their website, but only mentions black mass and copper/aluminum. It is not clear or stated what happens to the lower value plastic and electronic waste.

Ontario appears to be the only jurisdiction in Canada with infrastructure for EV battery recycling. In 2021 British Colombia released a report (Kim et al., 2021) Identifying the importance of a local solution for EV battery critical mineral recycling. Some manufacturers, such as Tesla, have their own recycling facilities and pay to have the spent/defective EV batteries shipped from service centers. This is an example of industry proactively leading what is essentially an Extended Producer Responsibility (EPR) program. The batteries are either recycled or refurbished. Tesla also works with third party companies to recycle their batteries, the main one being Redwood Materials in Nevada.

GM has a dedicated website (https://www.recyclemybattery.com) for vehicle dismantlers who recycle automobiles at the end of their life (GM, 2022). The website has video instruction on how to properly disconnect and remove the battery. As with Tesla, GM collects spent/defective EV batteries at service centres. Most current GM EVs are repaired with refurbished packs when they experience a battery problem (GM, 2021). In Canada, GM works with LiCycyle as a third-party company to recover critical minerals from their EV batteries.

Companies already established for EV battery recycling seem to be:

- Logistics companies focused on collecting, sorting, and shipping batteries from end-of-life automobiles;
- Logistics companies focused on collecting and/or dismantling spent/defective EV batteries from manufacturing service centres;
- Companies focused on physically dismantling EV batteries and shipping battery cells to a hydromet facility. Sometimes, crushing and separating battery cells into black mass and aluminum/copper metal occurs, other times this step takes place at the hydromet facility; and/or
- Chemical / mining companies focused on high value recovery of critical elements at a hydromet facility.

5.0 Considerations

Below is a list of considerations that were highlighted often in in reports, articles and other literature during an initial review:

- More detailed analysis is required to better quantify projected EV car adoption in NL and how this will correlate to increasing EV battery waste.

- It is foreseeable that, over time, EV batteries will present increasing challenges and opportunities as a waste stream NL. There is time for NL to explore what the best options for recycling and/or reuse for this waste stream are, and to delineate approaches to acquisition, storage, and collection.

- Due to the size and weight of an EV battery, it makes sense to find a local solution to EV battery recycling or re-use that partially or fully reduces the amount of material that is processed outside of NL. Capitalizing on already existing bulk shipping supply chains and market connections for recycling materials may present advantages.

- Storage costs should be considered as part of the equation when considering EV battery recycling options, both for the batteries and the separated components. Depending on the selected recycling/re-use type, batteries may need to be stockpiled until there are enough to process and make a profit. Separated components may also need to be in storage until there is enough stock to make shipping it to a secondary processing facility off island economical.

- Complexities of repurposing batteries from multiple manufacturers, storing the batteries until there are enough to group together and finding end users/buyers in the local market are some things to consider when looking at EV battery reuse. There is also a need to inspect, test and guarantee the batteries for reuse re-use.

- Extended Producer Responsibility (EPR) approaches for battery disposal should be examined. This would include understanding voluntary programs already in place from manufacturers, and also a broader look at the existing Electronic Waste EPR in NL and how proposed EV battery recycling methods may be able to incorporate recycling of Lithium Ion batteries from other electronics (phones, laptop, e-bikes etc).

- Finding uses and markets for low and intermediate value components is key to making EV battery recycling truly circular. If only the high value product (approx. 30%) of the battery is recycled because just the portions that will make the most profit, that leaves 70% to be landfilled.

- The re-use of EV batteries for energy storage purposes presents an interesting area of exploration for NL that may align with broader clean energy priorities.

- It is expected that as the EV market matures, that there will be more research and development time spent on EV battery innovation. This means that there is an expected evolution on how the batteries are built and what they are made of, to make the recycling process easier and/or promote full recovery of all battery parts. It's important that the chosen battery recycling process is adaptable to these market changes.

- Federal and provincial regulations regarding the storage and transportation of batteries should be reviewed, as EV batteries may be considered a hazardous material. Considerations around current regulation regarding the disposal of e-waste may also come into play. Certain storage and containment procedures may need to be accommodated for transporting and shipping black mass and slag, if those methods are considered.

6.0 Conclusion and Recommendation

Stakeholders in NL have the lead time to proactively explore solutions to impending EV battery waste management challenges. To inform next steps, further research is required that will accomplish the following:

- Quantify expected EV battery waste in NL to the year 2050;
- Define best approaches to acquisition, storage, and collection of EV batteries in NL;
- Understanding the role that EPR may play for EV batteries in NL;
- Defining opportunities for EV battery processing and maximizing economic value for NL;
- Explore what opportunities hydromet processing of EV batteries may provide for NL;
- Better defining re-use opportunities for batteries in NL; and
- Regulatory review to understand barriers that may exist to recycling / re-use activities.

Such research would provide excellent value for NL by strategically mitigating a future waste management challenge.

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