EV Battery Recycling and Its Impact on Society

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Abstract

Recycling End-Of-Life (EOL) Lithium-Ion Batteries (LIBs) allows materials to be recovered for costs lower than by raw extraction, making it an attractive option for boosting the economy. Recycling LIBs reduces costs, energy, and greenhouse-gas (GHG) emissions, which are primarily based around the economy and environment, but there are also various social aspects that can be improved through this practice, which we focus on in this paper. The aim of this paper is to give information about the industrial recycling process currently being used globally, and to analyse how recycling LIBs benefits society through means of creating jobs in the Canadian job market.

Keywords: *electric vehicles, lithium-ion batteries, recycling ,recycling processes*

1. Introduction

Due to the rising industry of LIBs because of their usage in EVs, the number of EOL LIBs is currently increasing rapidly, and thus, correct handling of these batteries becomes a necessity. This includes safe disposal and the recycling of valuable metals, like lithium, copper, cobalt, and aluminum. Lithium in particular does not have a viable substitute in batteries, which would cause problems if supply were to become scarce. Recycling is therefore a feasible solution to such an issue. (Zeng, 2014; Vieceli et al., 2018)

Recycling itself is not as easy as it seems; however, as the many different materials in each battery cell make separation difficult, and since there is not a fixed recycling method for all batteries due to their varying cell designs and chemical compositions of active materials, the cathode in particular, (Elibama, 2014; Kwade and Diekmann, 2018; Gaines, 2014). Some safety concerns also exist when talking about the deactivation and dismantling of LIBs (Weiguang et al., 2018). The main LIB industrial recycling method at present consists of pyrometallurgical processes, which takes up a lot of energy and money (Diekmann et al., 2016), so our next step would be to find a way to recycle the valuable materials in LIBs while keeping costs as low as possible, thus providing a base for a more circular economy (Valio , 2017)

The purpose of this paper is to provide information about the industrial recycling process currently being used globally. Furthermore, this paper also intends to analyse how recycling LIBs benefits society through means of creating jobs in the Canada job market. The remainder of the paper is organized as follows: Section 2 presents a literature review about Lithium-Ion batteries, recycling, battery recycling steps, and Industrial recycling processes. Section 3 addresses EOL LIBs and calculates employment benefits. Finally, the conclusion is presented.

2. Literature Review

Lithium Ion Battery

Due to their high energy and power output per unit of battery mass, along with their comparatively great energy efficiencies, LIBs are the most feasible options of powering EVs (Low et al., 2010). One problem, however, is that since LIBs are degenerative, the criterion is that over 80% of a battery's original capacity must be available to be used in EVs, otherwise it is not permitted (Warner, 2013). Basically, when 20% of a battery's original capacity is lost, an LIB battery is said to have reached its end-of-life (Monsuru, 2012). When this criterion is met, the battery must be extracted from the EV for other uses. From Walker et al. (2015), we can conclude that the expected 8-year lifespan of LIBs can further be increased by almost 10 years when repurposed for stationary applications. Figure 1 displays the life cycle of an LIB from its conception to its recycling. It begins as a new battery, but over time it degrades until its EOL where it is remanufactured. Then this remanufactured battery is repurposed if it loses 20% of its capacity, and finally it is brought in for recycling when it can no longer be used elsewhere.

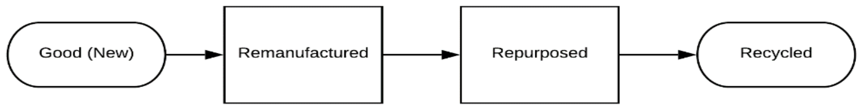

Figure 1: States of a LIB's Life Cycle (Akram, 2020)

Recycling

The definition of recycling as provided by Valio (2017) is retrieving and reincorporating materials into a material value chain by processing materials in products that have reached the end of their lifecycles. As environmentalism is becoming a point of interest for many countries, recycling has become an attractive means of cutting GHG emissions, with an added benefit of improving economies. As such, recycling products such as LIBs is a task that many governments have sought to implement, but that would also mean rules and regulations have to be put in place for this practice. The European Union (Green, 2017) has placed a goal of 50% recycling efficiency of LIBs by 2030. China has incorporated a tracking system for EVs, through which their batteries will be seen as they go from production to use to recycling (Jiao, 2018). But the US has no guidelines and rules to be followed for LIB collection and recycling (Murphy, 2017; Brown, 2016). While many countries are putting in effort to enact rules and enforce guidelines on the recycling of LIBs, many others still have room to improve. If a standardized set of regulations is implemented for countries to follow, the LIB recycling could become much more widespread; thus, creating a more sustainable global economy.

Battery Recycling Steps

The steps for recycling EOL LIBs usually consist of collecting, sorting, handling, eliminating, and distributing, all to recover valuable materials from them (Fleischmann et al., 2000). It is possible for an LIB manufacturer to process the batteries or take part in a cooperative recycling network, and steps for industrialized recycling for EV LIBs is shown in Figure 2.

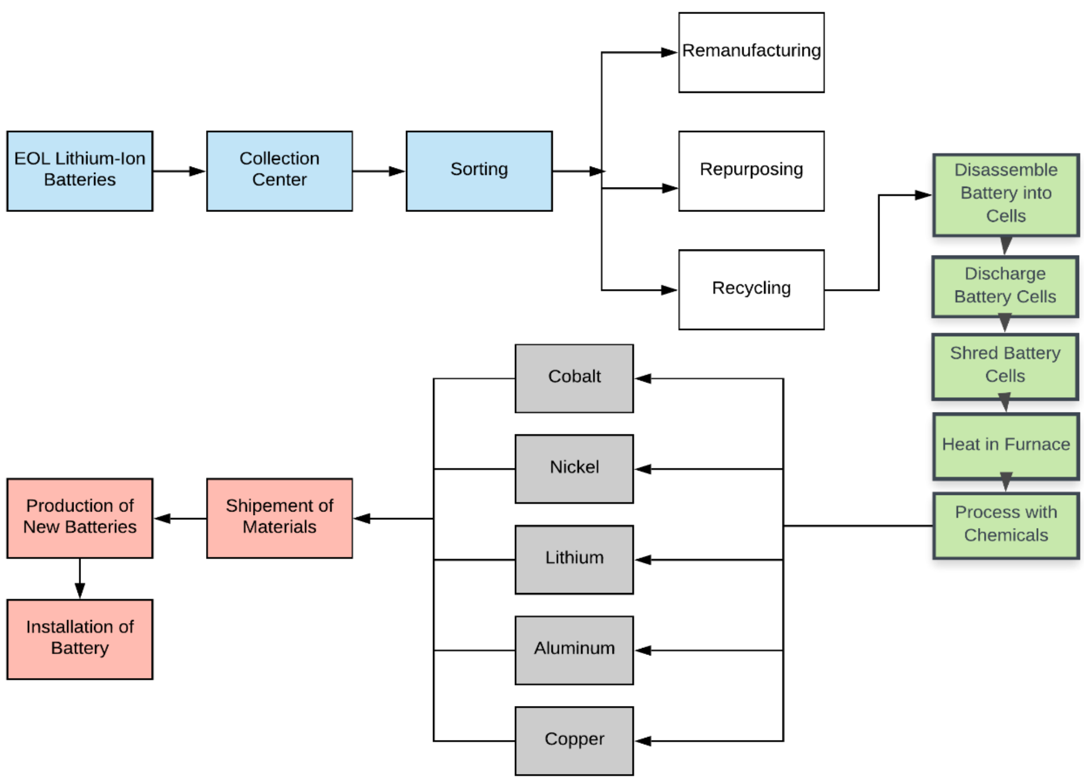

Figure 2: LIBs recycling (modified and adapted from Hoyer (2015))

The process begins with EOL LIBs being collected in a collection center. They are then sorted into three categories based on storing capacity: Good, Moderate, and Bad. The good batteries are remanufactured, the moderate batteries are taken for repurposing, and the batteries with little to no capacity left are recycled. The batteries in the third category are disassembled into their cells, and then discharged for safety. The cells are shredded, then heated in a furnace, and processed with chemicals, each recovering different materials. These materials are shipped to a battery production facility, where they are used for the production of new batteries and ultimately used in a new EV.

Industrial Recycling Processes

The current most popular and used recycling processes for batteries are Umicore VAL'EAS, Sony-Sumitomo, Retriev Technologies (Toxco), Recupyl Valibat and AkkuSer. They are explained in the following sections.

Umicore VAL'EAS (Belgium)

Through Umicore, many of the traditional processes of recycling batteries can either be omitted or simplified. This process focuses on recycling the battery materials that are deemed the most valuable, like cobalt and nickel. Umicore utilizes both pyrometallurgical and hydrometallurgical processes to extract these materials. By beginning with pyrometallurgical treatment in a single shaft furnace, there is not a need for releasing excess electricity left in a battery (discharging). Along with this, because aluminum and iron are basically viewed as excess materials, there is no need to separate them through crushing either, as they are slagged during the smelting process anyway (Georgi-Maschler et al. 2012; Cheret and Santén 2007).

First, the batteries are taken apart and put into a furnace with coke, slag formers and possibly limestone and silicon oxide; air is delivered into the furnace from the bottom (Vezzini, 2014; Cheret and Santén, 2007). Through gradual heating from 300°C, to 700°C, to 1200° - 1450°C, the electrolyte is evaporated, the plastic is pyrolyzed, and the materials inside the furnace are smelted respectively (Vezzini, 2014). After this treatment, the result is an alloy consisting of copper, cobalt, nickel, lithium, and a small amount of iron; and a slag consisting of aluminum, silicon, cadmium, manganese, lithium, the rest of the iron, and rare earth elements (Vezzini, 2014; CEC, 2015). From here, the slag is downcycled because the materials it is comprised of are not of interest (but it is possible to recover the lithium in the slag if needed). The focus of Umicore is on the alloy, and hydrometallurgical treatment takes place to extract its materials. There are two leaching phases: one to extract the copper and iron (though it is not publicly known what the leachant consists of), and another to extract nickel (II) hydroxide and cobalt (II) chloride (through hydrochloric acid).

Sony-Sumitomo (Japan)

The companies Sony and Sumitomo Metals Mining Company made a joint effort to create a process solely to recover the cobalt oxide inside Lithium-Ion batteries. The batteries are first heated in a furnace at 1000°C, and when the cells open, inflammable parts of the battery (like lithium, fluoride, organic solvents, and plastic casing) become fly ash. The result is an alloy consisting of iron, copper, and aluminum which can be separated magnetically (Sonoc et al., 2015). What is left from that is a powder that has the active cathode material along with either graphite or carbon (depending on the battery), and this is finally taken out through hydrometallurgical treatment to extract the cobalt (Ekermo, 2009).

Retreiv Technologies Toxco (Canada)

Combing mechanical and hydrometallugical processes, this process is owned by Retriev Technologies in the U.S. (Gaines and Dunn, 2014). First, any electrical energy that was previously in the batteries is taken out through cryogenically cooling them at around -200°C (Gerogi-Maschler et al., 2012). With this, any possible explosion hazard through lithium being at room temperature is mitigated. From this, the batteries are taken for shredding, and are crushed using a hammer mill. These small pieces are then brought to a shaker table, and then water is added. An alkaline solution is added in order to both neutralize the acid compounds and to hydrolyze the organic solvents, resulting in homogenates. The lithium salts that are created through this are separated from the plastic and metallic materials. Finally, this semiliquid-substance has sodium carbonate added to it, which allows the precipitation of lithium carbonate that can be purified and then recrystallized (Tedjar and Foundraz, 2010). As our focus is LIBs in EVs, recycling is a great way to recover and make use of materials in LIBs. Having said that, only about 5% of LIBs are recycled globally, leaving 95% that are either sent to landfills or not even collected (Heelan et al., 2016). Recycling is not only a viable option to reduce environmental damage, but it is also attractive in an economic sense due to cobalt becoming increasingly expensive (Li et al., 2013). Also, as cobalt and lithium are becoming less abundant in different sources, recycling LIBs can greatly reduce the sharp decrease in availability of these materials.

Recupyl Valibat

The Recupyl process was designed to combat the issues present in the Toxco and Sumitomo Sony processes, which included handling of gas emissions in the pyrometallurgical methods and the safety issues triggered by the HR 2R emissions from wet crushing. The aim was to allow the maximum recovery of materials through a low-temperature method (Tedjar and Foudraz 2010). Currently, plants using the Recupyl process are in operation in Singapore, France and UK (Vadenbo 2009, p. 31).

The process beings with crushing within an atmosphere consisting of argon and/or COR 2R; it is done to handle batteries that possibly have not been discharged correctly safely. The second step is comminution, and it is done in a low speed rotary shearing to free batteries' internal stresses. Right after, using an impact mill and a vibrating screen, the batteries are grinded to an optimal particle size of 3 mm at under 90 rotations per minute. Iron-based materials are removed using a high induction magnetic separator, and the remaining materials are processed using a densimetric table. The result is streams of metals that are high in density, non-magnetic, and non-ferrous, and a mix of paper and plastic with a relatively low density. (Tedjar and Foudraz, 2010). As an additional step, leaching is done to remove as much copper as possible from the metal oxide and the remaining copper comes down to below 0.3% after screening with a 500-µm mesh. (Tedjar and Foudraz 2010; Vezzini 2014, p. 548).

The remaining mixture is put in water and stirred heavily while increasing its pH level by adding lithium hydroxide. The hydrolysis reaction creates HR 2R, but any possibilities of harm are mitigated since the amount of mixture being processed at once is regulated, and a turbulence above the leaching bath is set. Through this reaction, lithium salts dissolve into water, while the other materials do not, which means through filtration, metal oxides and carbon can be separated, leaving a mixture of lithium salts and water. COR 2R gas from the previous milling step can be used to lower the remaining solution's pH to 9, which creates LiR 2RCOR 3R; i.e., lithium as a carbonate; solid/liquid separation can also be done to create LCO, thus retrieving cobalt. These last subprocesses are done only if of interest. (Tedjar and Foudraz 2010).

The scrap left from the LIBs is leached at 80 °C in HR 2RSOR 4R, copper is cemented with steel to reduce it to its purest form, and lithium is recovered if not done prior during the hydrolysis reaction by adding HR 3RPOR 4R and tweaking the pH to create LiR 3RPOR 4R. From here, cobalt recovery has two additional options, but none of three can be said to be better than the others: the first is to use NaCIO to create OTCo(OH)R 2R, and the second is to use a discrete electrolysis process to retrieve cobalt in its pure form (Tedjar and Foudraz 2010).

Theoretically, it is also possible to recover the constituent ions of the LiFePOR 4R cathodes (Tedjar and Foudraz 2010), but it is not known if this is implemented in practice (Vadenbo 2009, p. 33). It is additionally possible to create PFR 6 R– 42 from the electrolyte salt LiPFR 6R with ammonium salt in the hydrolysis step, but the presence of LiCl is needed due to its stabilizing effect on the electrolyte salt. (Tedjar and Foudraz 2010). As with LiFePOR 4 R treatment, the industrial execution of PFR 6 R recovery is not confirmed (Vadenbo 2009, p. 33), neither is the purity nor intended use of the product discussed.

AkkuSer (Finland)

The recycling technology developed by AkkuSer dry and low temperature, and it uses crushing, separating, and hydrometallurgical/pyrometallurgical processes to recover materials from battery components (Pudas et al. 2015; Vezzini 2014, p. 543).

The whole procedure falls under comminution of batteries: the batteries are first put through a cutting mill at 40-50°C and 100-400 rpm, with an optimal particle size of 1.25-2.5 cm; there is not a specialized protective atmosphere, but the low temperature mitigates the chance of fire. Since the crushing process releases HR 2R and OR 2R, a cyclonic air remover is installed for their removal. The gases are taken out and filtered two times, the first separates light plastics and cardboard, and the second allows any other particle to be withdrawn, thus making it safe to release the gases into the atmosphere. There is also a chance for the plastics from the first filtration to be mixed with metals, by which nickel and cobalt can be retrieved (Pudas et al. 2015).

The next phase, again, falls under comminution. At room temperature and cutting speeds of 1000-1200 rpm, the feed is sent to a second crusher through an air-tight tube which has an added benefit of cooling the feed itself; the optimal particle size is under 6mm. Another cyclonic air remover is used to keep fine particles from entering the atmosphere. Iron and other magnetic materials are removed with a magnetic separator, which can then be taken elsewhere. What is left is a powder containing cobalt and copper, which can then be refined through pyrometallurgical or hydrometallurgical procedures. (Pudas et al. 2015).

3. End of Life LIBS and Weight

A report by Transport Canada (2020) projects the annual number of Zero Emission Vehicles (ZEVs) coming into the market. Walker et al. (2015) says that the 8-year lifespan of LIBs can be increased by about 10 years if repurposed for stationary applications. Thus, the EVs' batteries will be available for recycling after an 18-year lifecycle (8 years in EV, and 10 years in stationary applications). We also collected information on the weights of the batteries used in EVs and PHEVs, namely Tesla Model 3 (2020), Chevy Bolt (2020), the Kia Soul (2020), and Kia Niro (2019) , each having batteries weighing 478 kg (Brooks, 2020), 430 kg (Chevrolet, 2020), 457 kg (EVSpecifications, 2020), and 117 Kg (Kia, 2019) respectively. We then found the average weight of an EV battery using these four models of EVs, which was 370 kg.

A study done by Foster et al. (2014) assumed that 85% of LIBs that have been removed from EVs (at their EOL) can be repurposed for a stationary applications. On this basis, we are making an assumption that 10% of batteries do not come to recycling facilities due to reasons such as batteries being damaged, landfilled, or improperly collected and transported. Furthermore, if we take EVs and PHEVs entering the market in 2020, 2025, 2030, 2035, and 2040 as example years, their batteries will be available for recycling in 2038, 2043, 2048, 2053, and 2058 respectively, as shown in Figure 3. With the assumption in mind and the example years picked, the calculations for the number of batteries available for recycling for each year and their combined weights are done below, as shown in Table 1.

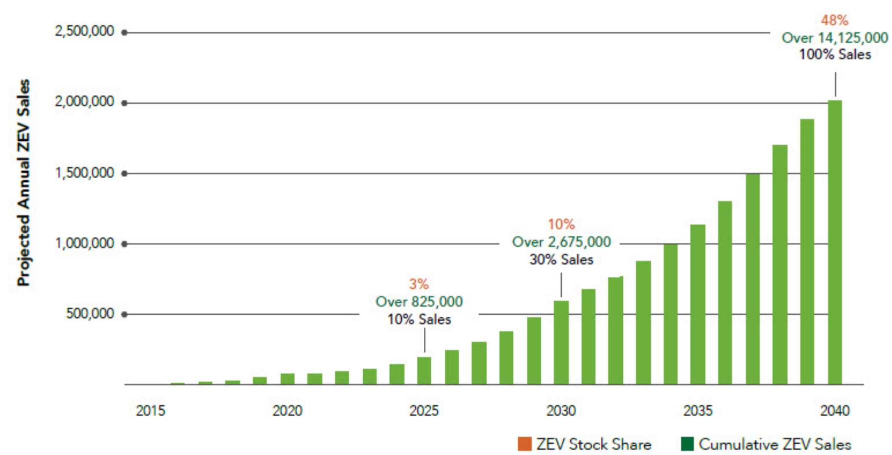

Figure: 3 Projected Annual Zero-Emission Vehicle Sale in Canada
(Source Transport Canada 2020)

Table 1: Total number of LIBs and Weight

Years	Total number of LIBs	Weight (Tons)
2038	112,500	41,625
2043	225,000	83,250
2048	567,000	209,790
2053	990,000	366,300
2058	1,800,000	666,000

Employment Benefits

Using information from Transport Canada, our focus is calculating the number of Canadian jobs created by recycling LIBs. Drabik and Rizos (2018) state that for every 1000 tonnes of EOL LIBs as waste, 15 jobs are created for the collection, dismantling and recycling of said batteries. From these 15 jobs, 12 would be focussed on collection and dismantling, as they are more labour intensive tasks, and 3 would be focussed on recycling since it is a more capital intensive task. Due to this being current data, it cannot take into account any technological advancements that may occur in the future, meaning these values are subject to change. Using the information of Table 1 and these values, we calculate the total number of potential jobs that can be created from recycling LIBs in coming years, and it is presented in Table 2 and graphed in Figure 4.

Table 2: Employment Benefits

Years	2038	2043	2048	2053	2058
Calculations	$\frac{41{,}625 * 15}{1000}$	$\frac{83{,}250 * 15}{1000}$	$\frac{209{,}790 * 15}{1000}$	$\frac{366{,}300 * 15}{1000}$	$\frac{666{,}000 * 15}{1000}$
No. of Jobs	624	1,249	3,147	5,494	9,990

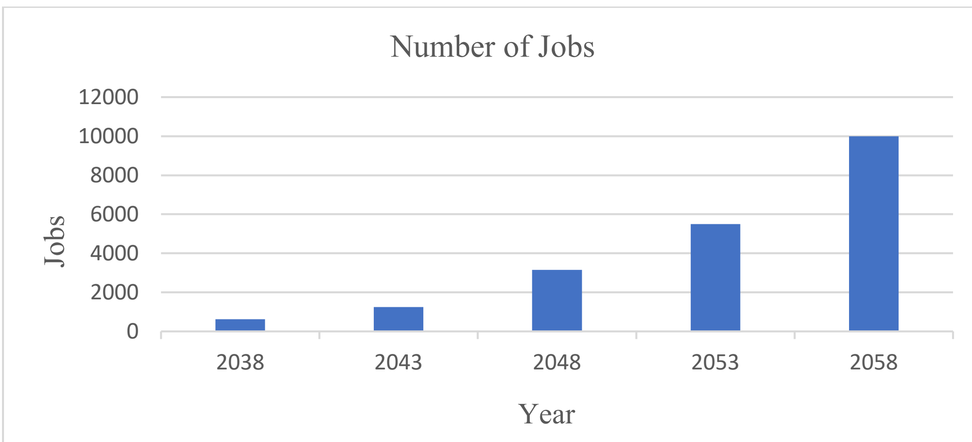

Figure 4: Number of Jobs Created through Recycling LIBs

4. Conclusion

Recycling LIBs is a practice that can benefit many aspects globaly. This paper presented and explained the types of industrial recycling processes that exist in the world today, and focussed at recycling LIBs Canadian job market. Using reverse logistics processes, we can bring batteries to recycling facilities. By using the years 2038, 2043, 2048, 2053, and 2058 as examples, we found that if Canada recycles its own batteries, the number of jobs created for each respective year is 624, 1,249, 3,147, 5,494, and 9,990. Many of the benefits that exist when recycling LIBs are environmental, but the creation of jobs benefits society, which further improves the reputation of recycling LIBs.

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