Post-Consumer Management of Electric Vehicle Batteries

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Abstract

The end-of-life management of EV batteries is a significant issue. With the use of high-performance batteries on the rise, they have the potential to become the next global waste management challenge.

This Major Research Paper comparatively analyzes the policy structures for managing the end-of-lives for electric vehicle (EV) batteries in Canada, the European Union and the United States. Sociotechnical transition theory is used to understand the effects of large-scale technological transitions as they relate to electric vehicles. Emphasis is placed on the downstream consequences of technological transitions, and the lack of discussion in the transitions literature of downstream effects.

This paper utilizes a methodological framework that draws inspiration from the work of Dr. Mark Winfield and Hugh Benevides in the Walkerton Water Inquiry. It is used to comparatively analyze the policy structures in Europe and North America for end-of-life EV batteries. I conclude that based on existing policy structures, the European Union has developed a basic framework on this issue through the implementation of the 2006 Battery Directive. The United States and Canada, with the exception of Quebec, are falling behind on the issue.

Design for disassembly is explored as a potential method for alleviating the concerns with downstream effects. It also allows for the growth in markets for second-life applications of end-of-life EV batteries. Second-life applications, where possible, are preferred to direct recycling because of the potential development of undesirable waste streams.

Extended producer responsibility (EPR) is explored and chosen as the preferred model for countries to hold producers responsible for the waste they generate. This model, in conjunction with an emphasis on second-life applications, can incentivize producers to design their batteries for easier disassembly, reuse and recycling.

Foreword

This section describes the nature and role of the research presented in this paper in fulfilling the requirements of the Master of Environmental Studies degree. My Area of Concentration focuses on understanding environmental policy and the effects of federalism and law on policymaking. I was interested in this subject because of my undergraduate studies in political science. The MES program has allowed me to research various issues in Canadian environmental policy and understand the strengths and weaknesses of current approaches to environmental protection. My Major Research Paper (MRP) is linked to this, as it comparatively analyzes the current policies and practices for managing end-of-life electric vehicle (EV) batteries in Canada, the European Union and the United States of America. This has allowed me to understand where Canada needs to improve to respond to this future waste management challenge.

My Plan of Study (POS) includes three learning components: (1) Federalism & Constitutional Law; (2) Environmental Policy & the Policymaking Process; and (3) Carbon Pricing. My MRP directly relates to Component 1 and Component 2. Component 3 was fulfilled through coursework.

Concerning the first component, my MRP analyzed Canada’s ability to develop a joint federal-provincial extended producer responsibility system to manage the end-of-life for EV batteries. Specifically, my MRP details the jurisdiction of each level of government concerning the management of end-of-life EV batteries. It is here where the roles of each level are defined to ensure EV batteries are not disposed of in municipal landfills, which can lead to serious environmental harm.

Concerning the second component, there is a direct relationship because the primary objective of my MRP was to comparatively analyze global policy structures in relation to the safe management of EV batteries. I refer to the work performed by the European Union through the 2006 Battery Directive, in terms of what can be learned from the shortcomings of the European efforts to address this issue. Recommendations for the gaps that exist in European policy are outlined to ensure Canada avoids these issues when developing its strategies for the end-of-life management of EV batteries.

My MRP supports the learning objectives outlined in my POS that are developed from the learning components. I have accomplished all of them and the knowledge I have gained was crucial to understanding the environmental issues that affect Canada today.

Acknowledgements

Without the guidance and support of many people, this Master's degree would not have been possible. Firstly, I would like to thank my Supervisor, Dr. Mark Winfield, for his endless support throughout the development of this paper. His extensive knowledge of environmental policy was a massive inspiration for pursuing this topic. I would also like to express my gratitude towards Dr. Ute Lehrer for acting as my Advisor throughout my program and providing the guidance needed to complete this chapter of my education. I also want to extend a thank you to all of my professors and peers through these past two years. It was a gratifying experience meeting all of you and working together on various projects. Last but not least, I would like to thank my family and friends for their support and encouragement during my time in this program.

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List of Acronyms

CEETES = Center of Excellence in Transportation Electrification and Energy Storage
CÉPROCQ = Centre d'étude des proceeds chimiques du Québec
EPR = Extended Producer Responsibility
EU = European Union
ELV = End-of-Live Vehicle
EUR = Euro
EV = Electric Vehicle
HEV = Hybrid Electric Vehicle
ICE = Internal Combustion Engine
kWh = Kilowatt Hour
LIB = Lithium Ion Battery
MWe = Megawatt Electrical
NiMH = Nickel Metal Hydride
PHEV = Plug-in Hybrid Electric Vehicle
RBRCC = Rechargeable Battery Recycling Corporation of Canada
USB-C = Universal Serial Bus Type-C
WEEE = Waste Electrical and Electronic Equipment
WRAP = Waste Reduction and Pollution Prevention Act
WDA = Waste Diversion Act of 2002

Section 1: Introduction

As countries strive to meet the emissions targets set in various climate change accords for 2030 and beyond, the use of fossil fuels will need to be curtailed. One aspect of lowering global carbon emissions will be the adoption of electric passenger vehicles and the reduction of the use of vehicles based on the internal combustion engine (ICE). This is not a simple transition, as the ICE is embedded across society. From transportation to the machinery used for the production of material goods, the ICE is entrenched in our ways of life. However, technological innovations in the field of battery technology may allow for the electrification of transportation and other aspects of society.

Passenger electric vehicles are rising in popularity as consumers begin to adopt alternative forms of transportation over traditional ICE-powered vehicles. A growing number of vehicle manufacturers are committing to developing fleets of fully electric vehicles (CEC, 2015). The price of these vehicles is decreasing, allowing consumers from wider socioeconomic backgrounds to participate in the transition. The increasing adoption of electric vehicles has environmental benefits, including improved air quality and an overall reduction of environmental impacts (CEC, 2015). While the future for private passenger vehicles is increasingly looking electric, there are concerns related to electric vehicles.

The end-of-life management of the high-performance batteries that power electric vehicles is beginning to garner more significant attention amongst scholars and policymakers worldwide. Battery life for EV batteries averages between 8-10 years (Xu et al., 2017). Questions of what happens after batteries are removed from vehicles are emerging, but there are no clear pathways yet developed for tackling this problem on a large scale. In countries such as China, illegal dumping by unregulated lead-acid battery plants has contaminated the land and water in Eastern China, requiring millions of dollars in land rehabilitation costs (Chen, 2018).

Unregulated end-of-life management like this must be avoided, as there are concerns that this could become a significant waste management challenge especially with the rise in global EV sales. These reached 1,940,147 new EV sales in 2019 (Loveday, 2020). This means that almost two million high-performance batteries will require some form of end-of-life management in the future, with these figures expected to rise (CEC, 2015).

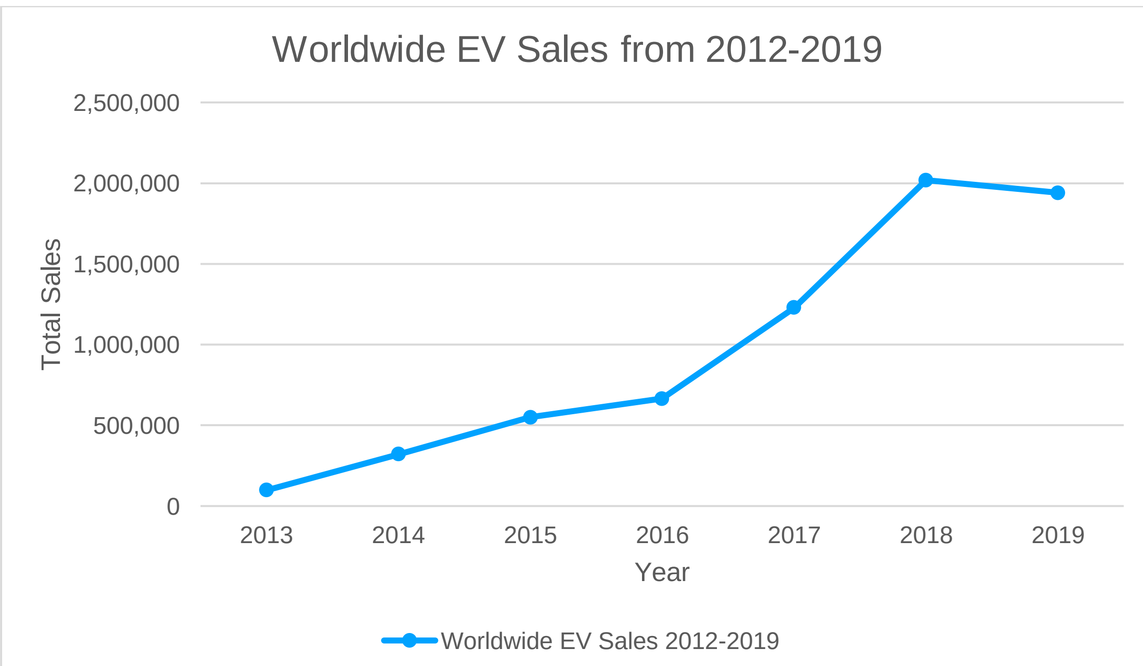

Figure 1: Components of a Consumer-Type NiMH Battery (Loveday, 2020)

Current management practices offer potential solutions for handling the future uptake of waste EV batteries, but they are not without their drawbacks. Current recycling technologies carry significant environmental risks including harmful emissions from re-smelting processes, and the development of undesirable waste streams from the use of powerful chemicals (Baltac & Slater, 2019). These outcomes are not desirable, but the future uptake of waste EV batteries will lead to a greater reliance on these methods.

Waste battery management regimes for spent batteries exist in the European Union, Canada and the United States. However, these regimes pre-date the emergence of high-performance batteries, which has left policymakers struggling to determine how to handle EV battery packs, with extender producer responsibility seen as one potential option.

Disassembly and reuse of high performance batteries is emerging as the best option in the place of direct recycling, but this does not align with how producers are designing their products (Ramoni & Zhang, 2013). Current trends in battery design are favouring performance over disassembly, including the use of stronger adhesives and welding to bond components and make disassembly more problematic.

This paper will focus on the following question: What policies and regulations currently exist to govern the post-consumer management of passenger electric vehicle batteries in Canada, the United States and the European Union? Are they sufficient to ensure the safe management of end-of-life batteries? The paper will engage in a comparative analysis between Canada, the United States and the European Union to evaluate how each has engaged on this issue. The paper will also shed light on options for Canadian policymakers to consider for handling this challenge. The paper focuses solely on electric passenger vehicles as we see a greater adoption of this form of transportation, and this presents the most immediate waste management challenge.

Section 2 of the paper outlines the methodological framework that is used to evaluate the policy structures in Canada, the United States and the European Union. Section 3 outlines the theoretical framework for the paper. Section 4 provides background and context on electric passenger vehicles and high-performance batteries. Section 5 includes a comparative analysis of the policy, regulatory and compliance structures in each country and organization. Section 6 will provide recommendations for Canadian regulatory structures based on what can be learned from the progress of other countries and organizations on the issue. The paper will also discuss the potential challenges for Canadian policymakers when determining how to best manage the end of life for EV batteries. Section 7 concludes and summarizes what has been learned over this exercise.

Section 2: Methodology

The purpose of this paper is to engage in a comparative analysis of the regulatory structures currently in place to manage the end-of-life for passenger EV batteries. The paper will compare the structures in the European Union, the United States, and Canada to determine the readiness of each country/organization to handle the issue. At the Canadian provincial level, the research will focus on British Columbia, Manitoba, Ontario, and Quebec, as these provinces either have general guidelines regarding electric vehicles or some pre-existing policies and regulations for waste management more broadly that could apply to high-performance batteries. At the federal level, the focus will be on the existing regulations for hazardous waste materials, and any other regulations that may play a role in end-of-life management. I will evaluate policies in the United States at the federal and state level along with those from the European Union.

In the European Union, there is a Battery Directive regarding end-of-life batteries. This will be analyzed in this paper, along with any relevant policies by the Member States. Member States were required to transpose the Directive into their legal frameworks, although each had the freedom to develop its own collection and recycling schemes for batteries. The focus will be on a select number of EU countries, including Germany, the United Kingdom, and France. It will also examine the Nordic countries. Although the United Kingdom is exiting the European Union, for the purposes of this paper, it is included as a part of the European Union as the UK has transposed the Battery Directive into its laws.

For this paper, consultations with various governmental and non-governmental stakeholders to understand their perspective on this issue were conducted. Primary research plays an integral part in the analysis and was gathered from the countries/organizations under scrutiny. This paper references various statutes and policies available from the relevant government websites and resources. Secondary research was used to help understand where weaknesses may exist in current regulatory structures and practices, along with providing the theoretical background on the broader issues that exist with new technologies and technological transitions.

For the analysis of regulatory structures, the following evaluative criteria will be used:

- **Policy & Regulatory Structures**
    - Are there implementation plans or policies in place relating to end of life electric vehicles more broadly?
    - What are the current regulatory structures focused on safe management of end-of-life batteries?
    - Are there gaps in existing legislation that require attention?
- **Performance & Impact**
    - Comprehensiveness in the scope and coverage of all aspects relating to battery recycling/re-use?
    - Potential impact on waste reduction and prevention of environmental damage from battery disposal and recycling processes?
- **Accountability & Oversight**
    - What are the measures in place to ensure compliance with policies and regulations?
    - Are there penalties in place for non-compliers and mechanisms for dispute resolution?

These criteria are a combination of process and performance criteria that draws inspiration from a number of scholarly sources and reports, such as the issue paper by Mark Winfield and Hugh Benevides on the comparison of direct and alternative delivery models as a part of the Walkerton Inquiry (Winfield & Benevides, 2001). The evaluative criteria used by the authors included Performance & Effectiveness considerations along with Governance, Accountability & Democratic Values. The framework for this paper utilizes the criteria by Winfield and Benevides in a slightly altered way. This allows for the relevant policy structures to be evaluated from a performance perspective, but also allows for other aspects such as oversight and accountability measures to be considered, allowing for a holistic evaluation of policy.

Section 3: Theoretical Framework

3.1 Socio-technical Transitions and Downstream Impacts

To understand the significance of end-of-life management of EV batteries and the shift towards electric vehicles more broadly, it is essential to analyze the overarching theoretical issues related to this topic. This section will review the literature on socio-technical transitions, the downstream impacts of transitions, and extended producer responsibility as a policy model for end-of-life management of EV batteries. These topics represent the broader discussions underlying end-of-life management and the adoption of new technologies.

Technological transitions are defined as significant transformations in the way certain societal functions are fulfilled (Geels, 2002). These functions can include transportation, methods of communication, housing and more. Technological transitions can also involve changes in non-technological elements, such as user practices and infrastructure. Transitions may consist of shifts from one socio-technical configuration to another, such as the transition from sail to steam-powered ships from the mid-19th to the early-20th centuries (Geels, 2002).

New technologies can experience obstacles in breaking through and gaining popularity or market share. This can be attributed to existing regulations, infrastructures, or user practices that favour or are more compatible with existing technologies (Geels, 2002). Innovations are developed in niches, which are separate from the standard market. Niches allow innovations to develop further, as they would not be capable of competing with established technologies. An example is the military, which stimulated innovations when they were still in their infancy, such as jet engines and radar (Geels, 2002). The military acted as an incubator for these new technologies and allowed users to develop learning processes such as learning by using.

Niches form a part of what Frank Geels calls the “multi-level perspective.” This refers to the landscape, the regimes and the niches which form the three levels of this perspective. Landscapes are the external factors and structures that help facilitate interactions between various actors, while regimes are the rules that govern activities (Geels, 2002). This perspective can be understood hierarchically, with landscapes at the top and niches at the bottom. The purpose of this perspective is to help understand the complex dynamics of socio-technical transitions (Geels, 2002). In order for a new technology to be successful under the multi-level perspective, developments must occur at each level. The development of processes at the niche level, combined with changes at regime and landscape-level, determines if a transition will occur (Geels, 2002).

Scholars find the socio-technical transitions perspective for new sustainable technologies appealing for two reasons. The first is that for new and cleaner technologies to emerge, social, economic and political change is necessary as existing practices are no longer suitable. The second reason is that scholars recognize that for larger environmental goals to be achieved, structural changes to socio-technical systems (i.e. energy infrastructure) are required to accommodate the needs of new technologies (Smith & Stirling, 2008). Thus, the perspective can help explain transitions, such as the increasing adoption of electric vehicles and how this transition can be facilitated more smoothly. Transitions do not occur by themselves; they are the result of interactions between various factors.

While socio-technical transitions theory explains the transition towards newer and cleaner technologies and changes in how certain functions are filled, there are several critiques with this theory. The question of who governs transitions is one such critique. The socio-technical perspective implies that various actors and institutions occupy roles and are involved in transitions (Smith & Stirling, 2008). However, having multiple actors can cause delays in achieving milestones or goals related to the transition or prevent the transition from happening at all.

One of the significant issues with socio-technical transitions theory is that it focuses solely on the early, front-end of transitions and not the downstream effects. The downstream effects of transitions are not greatly considered in transitions theory, and it is there where important environmental considerations are situated. For example, the literature on vehicle electrification considers the costs associated with purchasing and owning electric vehicles, and even the impact on electricity infrastructures (Boulanger et al., 2011), but is only beginning to engage on end-of-life issues for EVs and power systems.

However, the other significant impacts of socio-technical transitions tend to be forgotten. Current literature concentrates on the adoption of new technology, the benefits accruing from this adoption, and how to develop ways of increasing access to consumers. When new technologies are introduced, they rarely arrive fully formed and require further development, linking of various elements into operable arrangements (Smith & Stirling, 2008). A transition that may seem benign or promising may have significant drawbacks further down the line (Shove & Walker, 2007). For example, the spread of air conditioning units in areas where this technology was not used led to its normalization (Shove & Walker, 2007). The result was the new requirement that this technology be universally implemented even though it was not seen as a necessity in the past. Transitions are not always net-positive, and some may push behaviours and technologies in opposite directions (Shove & Walker, 2007).

Transitions theory tends to place new technologies within the assumption that development will occur naturally over time and that supporting infrastructure will be developed along the way. However, the downstream consequences need to be addressed early in the development to ensure future generations are not impacted by the lack of foresight on a technology by its adopters. An example of a lack of foresight is the waste generated from smartphones. The mobile phone has become an integral part of daily lives, and the market has seen substantial growth over the past 10 years (Bian et al., 2016). This has resulted in mobile phones and their components being disposed in municipal landfills, which pose serious health and environmental hazards. Countries have implemented prohibitions on mobile phone disposal in landfills, but these were adopted after significant quantities had already entered these sites (Bian et al., 2016).

The European Union has also begun to address the issue of power cables associated with mobile phones and personal computers appearing in municipal landfills. The European Union is attempting to mandate the USB-C cable as the single cable that can power all devices along with various other uses such as data transfer (Gold, 2020). This response is years after large quantities of charging cables have entered landfills.

Another example is nuclear waste management. Canada developed its first nuclear reactor in 1945, called the Zero Energy Experimental Pile at Chalk River, Ontario. The first power reactor was the 20-MWe Nuclear Power Demonstration

Reactor developed in 1962 (Ramana, 2013). It was not until 1969 that the Atomic Energy Control Board, now known as the Canadian Nuclear Safety Commission, requested a study be undertaken on the storage and disposal of nuclear waste (Ramana, 2013). Over 20 years had passed since the development of the first nuclear reactor in Canada before nuclear waste management was considered. As of 2020, Canada still lacked a strategy for managing nuclear waste. As of 2019, approximately 2.9 million used CANDU fuel bundles were in storage at reactor sites, and the total projected number of used fuel bundles in the future is 5.5 million (Gobien & Ion, 2019). While there have been talks of developing a deep geological repository in Bruce County, ON to store this waste, there has been significant opposition by residents and a strong possibility of this plan not being pursued (Butler, 2020).

The issue of downstream consequences applies to EV batteries and advanced energy storage more broadly. Concerns surround the development of complex waste streams once batteries have been thoroughly spent and marked for recycling or disposal (S. Brown et al., 2010). This relates to the idea that while transitions bring about the adoption of new technologies, they may also bring cascading impacts that affect various dynamics across systems (Rosenbloom, 2019). Transitions require the alignment of forces across systems since they are not isolated to single systems (Rosenbloom, 2019). In the case of EV batteries, the electricity and waste industries will need to adapt and change in response to the increasing adoption of EVs. These industries are essential to maintaining the power requirements for these vehicles, along with operating the waste management structures for end-of-life. However, this also expands further into the design of cities and broader built environments to ensure the required infrastructure is available (Rosenbloom, 2019). The literature on transitions does not address these concerns. Focus is placed on the barriers and the potential of new technologies, not downstream consequences.

3.2 Extended Producer Responsibility

The concept of extended producer responsibility (EPR) refers to a policy measure that emphasizes the role of producers in reducing the impacts of their products over their entire lifecycle (McKerlie et al., 2006). EPR policies transfer responsibility for waste management from consumers to the producers. It enforces the notion that producers, not consumers, have the most significant responsibility for the end-of-life management of products It also recognizes the ability of producers to influence the upstream, manufacturing, and downstream phases of a product's life (McKerlie et al., 2006).

Policymakers implement EPR through legislation. There is also a possibility of producers participating in voluntary EPR. Ideally, the additional costs associated with EPR will be internalized by the producer. Product pricing may also be adjusted to account for this additional responsibility (McKerlie et al., 2006).

EPR can be linked to design for disassembly. When producers are given greater responsibilities, they have more significant incentives to engage in environmentally sound management and design (McKerlie et al., 2006). The central idea is that transferring the post-consumer management costs back to the producers, who control the designs of their products, they will be given incentives to reconsider design in order to favour the efficient disassembly and reuse of components. It is also essential for second-life applications of EV batteries. When a battery is designated for a second-life, the battery pack will undergo disassembly and remanufacturing. It is here that the battery pack will undergo any necessary repairs, including the replacement of damaged components, to prepare it for its new use (Ramoni & Zhang, 2013). Second-life applications will be further explained in Section 4. An example of design for disassembly legislation is the European Directive for End-of-Life Vehicles, which stipulates in Article 4 that producers must prioritize "the design and production of new vehicles which take[s] into full account and facilitate[s] the dismantling, reuse and recovery, in particular the recycling, of end-of-life vehicles, their components and materials" (The End-of-Life Vehicle Directive, 2000).

Figure 2 represents the value chain or lifecycle for EV batteries, and this can also be attributed to other advanced energy storage options. The "Design & Manufacturing" stage is crucial for considering the downstream environmental impacts. This stage is where design for disassembly can be undertaken. Manufacturers must keep this in mind if they are considerate of the environmental consequences posed by EV batteries. EPR measures have incentivized producers to design vehicles for disassembly and similar results are possible through the use of EPR for end-of-life EV batteries. This is relevant because disassembly and reuse is considered the preferred approach, as will be later explained in this paper.

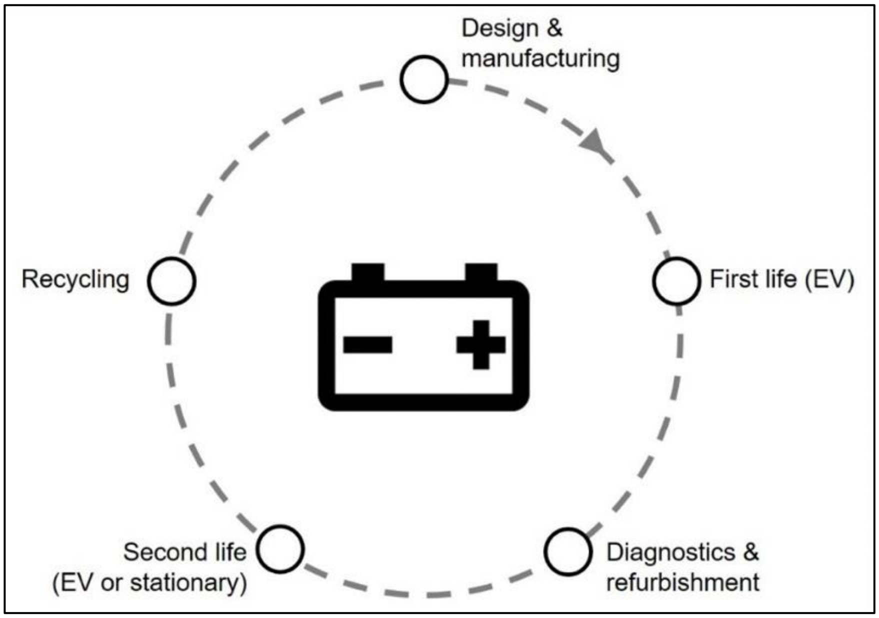

Figure 2: The Circular EV Battery Value Chain (Olsson et al., 2018)

EPR could be a policy model for the end-of-life management of EV batteries. The European Union has already implemented this policy for a variety of products. Automotive producers are responsible for the take-back of waste from their products (Mayers, 2008) – i.e. they have to take back their cars at end life. The model used by the European Union is for producers to develop national collective and compliance schemes known as producer responsibility organizations. These are organized to collect waste from designated collection points at no cost to the consumer (Mayers, 2008).

Sociotechnical transitions and extended producer responsibility provide the theoretical and normative frameworks for end-of-life management of EV batteries. The transitions literature highlights the failure of socio-technical transition theory to consider the downstream impacts of technological transitions. EPR is a potential policy model for end-of-life management because it places the responsibility on producers to collect, recycle and dispose of the products they produce.

Section 4: Passenger Electric Vehicles and Batteries

4.1. What Are Passenger Electric Vehicles and How Are They Powered?

An electric vehicle (EV) is a variation of the internal combustion engine (ICE) vehicle that occupies the vast majority of market share in the passenger transportation sector. Instead of the vehicle generating its power from the ICE, a high-performance battery is used for power and acceleration. EVs are not new in the transportation sector. Hybrid electric vehicles (HEV) have been available for over decades. HEVs make use of two power sources: a gasoline combustion engine and a battery. The engine is used to recharge the battery and to operate the vehicle when the battery is low (CEC, 2015). In 2000, the Honda Insight became the first mainstream HEV that was available to consumers in North America (CEC, 2015).

While sales were low during the early years of HEVs, improvements in technology have led to the increasing adoption of these vehicles. One development came in the form of the plug-in hybrid electric vehicle (PHEV), which entered the North American market in 2010. The PHEV utilized a similar set-up as to traditional HEV, with the exception that it could be plugged into a grid-provided electricity system in order to charge the battery (CEC, 2015). Both HEVs and PHEVs can have configurations where both the electric motor and the engine can drive the vehicle directly or where the ICE is used to generate the electricity for the electric motor, which drives the wheels (Elkind, 2014).

EVs differ from HEVs and PHEVs in that they are powered entirely by high-performance batteries and their electric drive-trains (CEC, 2015). Examples of these types of vehicles include the Nissan Leaf and the Tesla Model S. The batteries used in these types of vehicles are recharged by plugging into grid-powered electric systems, similar to PHEVs.

The batteries used to power EVs require a combination of power density and energy density. Power density refers to the amount of energy that can be delivered to the vehicle in a certain period of time, while energy density affects the capacity of the battery to store energy (CEC, 2015). As a result, power density affects the ability of the vehicle to accelerate, while energy density affects the range that a vehicle can reach on a single charge (CEC, 2015).

Currently, there are two main types of batteries used in EVs and hybrids: nickel-metal hydride (NiMH) and lithium-ion batteries (LIB). NiMH batteries are more commonly used in HEVs because of the power requirements, and because they are capable of being recharged from the engine (CEC, 2015). Examples of vehicles that utilize this form of battery include the popular Toyota Prius models. Some manufacturers such as Ford have used lithium-ion battery packs for some of their HEVs, including the Ford Fusion (CEC, 2015).

The application of LIBs is most commonly seen in EVs and PHEVs because of their capability to charge from the electric grid (CEC, 2015). One noticeable difference between batteries for HEVs and those used for PHEVs & EVs is the weight. Batteries for PHEVs and EVs are significantly heavier, weighing anywhere from 150 kilograms (kg) to 450 kg per unit depending on the specifications and design (CEC, 2015). This is because the energy requirements for powering PHEV/EVs are considerably higher due to the lack of a traditional combustion engine, and LIBs provide a superior energy output

(CEC, 2015). LIBs are used to power every function of the EV, where an ICE-powered vehicle or HEV utilizes a combustion engine.

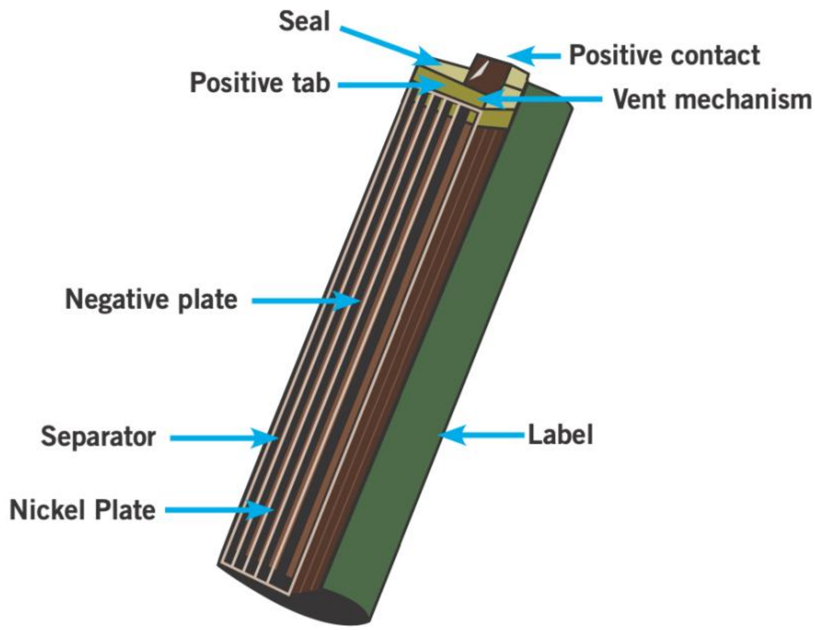

Figure 3: Components of a Consumer-Type NiMH Battery (CEC, 2015)

The composition of NiMH and LIBs varies and has a significant effect on disassembly and recycling, which will be discussed later in this paper. NiMH batteries are composed of a positive and negative electrode, an electrolyte and a separator (CEC, 2015). The positive electrode is usually composed of nickel hydroxide, while the negative electrode is made of metal hydride consisting of alloys such as palladium, zirconium, vanadium or titanium. (CEC, 2015).

Figure 4: NiMH Battery Pack from a HEV (CEC, 2015)

The chemical makeup of LIBs can vary, and the term lithium-ion battery is commonly used to refer to a number of battery chemistries (CEC, 2015):

- Lithium cobalt oxide (also known as lithium cobalt)
- Lithium manganese oxide
- Lithium iron phosphate
- Lithium nickel manganese cobalt oxide
- Lithium cobalt aluminum
- Lithium titanate

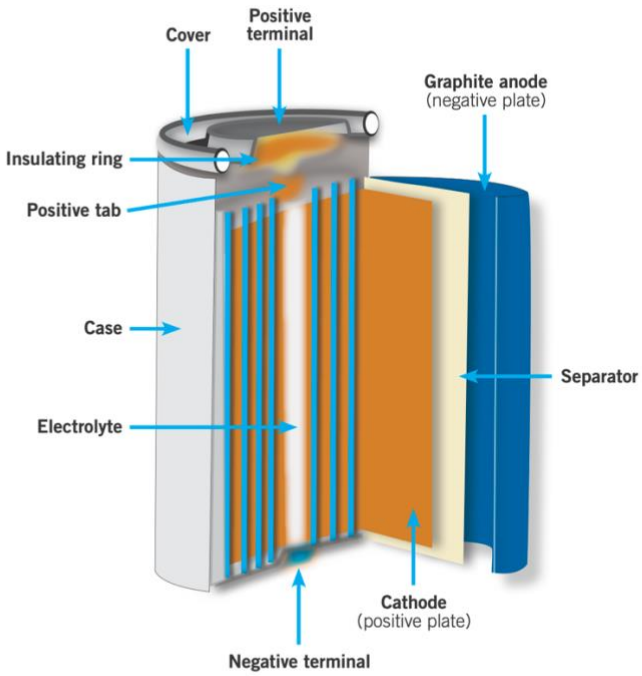

Figure 5: Components of a Lithium-Ion Battery (CEC, 2015)

An LIB is composed of four components: a cathode, an anode, an electrolyte separator (referred to as the separator), and an outer casing (Winslow et al., 2018). The cathode occupies 25-30% of the total weight, and a majority of the valuable materials contained within the battery are located here. The common materials found in the cathode are highly toxic and consist of 80-85% metal oxide powder, 10% polyvinylidene fluoride bunder, and 5% acetylene black (Winslow et al., 2018). The anode represents 15-30% of the total weight and is usually comprised of a copper current collector sheet; graphite is the common anode material which also stores lithium-ions during charging (Winslow et al., 2018). Due to the chemistry of LIBs, these types of batteries are ideal for energy storage and are increasingly being used in various applications.

Figure 6: Lithium-ion Battery from Chevrolet Volt (CEC, 2015)

Newer EVs are utilizing lithium-ion technology because of its superior energy density and lighter weight (Kurdve et al., 2019). Battery advancements have led to EVs now matching or exceeding the range output and overall efficiency of ICE-powered vehicles. Looking at average efficiency, ICE vehicles in the United Kingdom have an average performance of 18.2 kilometres (km) per litre, equating to 1.8 km per kilowatt-hour (kWh) of energy. In contrast, new EVs are capable of achieving 6.4 km per kWh, 3.5 times greater than an ICE-vehicle (Alhajii & Lewis, 2019). When comparing the levels of efficiency between ICE-vehicles and EVs, ICE-vehicles require higher levels of energy to operate (Alhajii & Lewis, 2019). This increased efficiency can provide numerous environmental benefits such as the reduction of greenhouse gas emissions and other pollutants,

Manufacturers are moving away from NiMH batteries because of these factors, in addition to the fact that LIBs are more compatible with plug-in charging methods. This has also led vehicle manufacturers to develop their own specific battery designs for their EVs, leading to a lack of uniformity. This effects the recycling processes for these batteries, as will be discussed later in this paper.

4.2 The Future of Passenger Electric Vehicles

With countries beginning to subsidize and encourage the adoption of zero-emission electric vehicles, the future of transportation is favouring EVs over traditional ICE-powered vehicles. Sales for plug-in electric vehicles in the United States increased over five times between 2011 and 2013 from approximately 18,000 to 100,000 vehicles sold per year (Sathre et al., 2015). Estimates are that by 2030, EVs will occupy 30% of all light-vehicle sales in the United States, with this figure rising to nearly 80% by 2050 (Sathre et al., 2015).

A report by the North American Commission for Environmental Cooperation (CEC) noted that global electric drive vehicle sales – which include P/HEVs and EVs – in 2011 were 244,064, rising to 592,432 in 2013 (CEC, 2015). While the figures show the growth of EVs in the United States, it should be noted that they still only comprise a small fraction of total sales in the United States. The total vehicle sales in 2013 were 15,531,609, with electric drive vehicles only representing approximately 3.8% of total vehicle sales. More current figures show that EV sales in 2019 were 329,528 vehicles in the United States (Loveday, 2020).

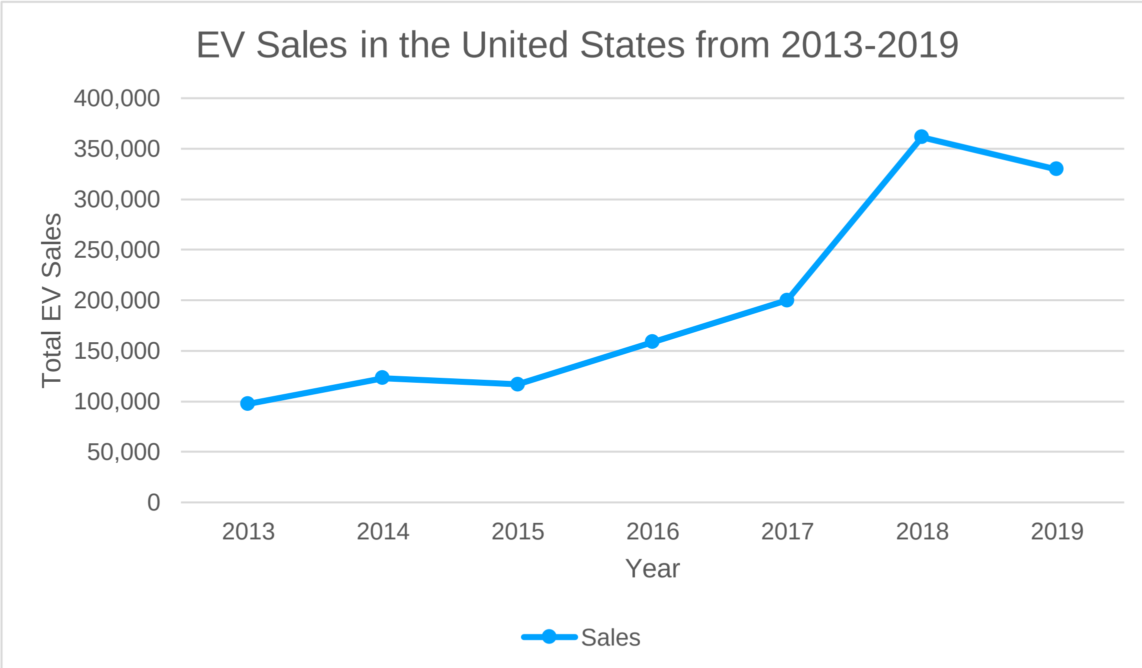

Figure 7: US EV Sales from 2013-2019 (Loveday, 2020)

While the United States boasts one of the largest vehicle markets in the world, electric drive vehicles sales are increasing on a global scale. The United States Energy Information Administration estimated that by 2020, global EV sales could reach 6.9 million units, with the Deutsche Bank predicting higher estimates of nearly 19.8 million for 2020 (Winslow et al., 2018). In 2017, estimates of EVs on the road globally were found to be over 1.15 million vehicles. The global stock of EVs was estimated at over 5 million for 2018 (IEA, 2019).

In addition to vehicles sold, the necessary infrastructure must be developed to support the increases in EVs, and the charging needs of consumers. The number of charging stations and points on a global scale was estimated to be 5.2 million by the end of 2018, an increase of 44% from 2017 (IEA, 2019). The IEA reported that 4.66

million chargers were private residential units, with 0.54 million being public chargers of either fast or slow charging capabilities.

The Canadian landscape for EVs differs from the United States and the European Union because Canada possesses a much smaller vehicle market. EV sales have been rising in Canada, and further growth is expected. In 2011, approximately 500 zero-emission vehicles were sold out of a total of 1.587 million vehicles for that year, which equates to 0.03%. The highest selling EV vehicle in 2011 was the Chevrolet Volt with 275 vehicles sold, and the only competition being the Nissan Leaf with 170 vehicles sold (Klippenstein, 2019). In 2018, zero-emission vehicle sales in Canada rose to 44,175, which was significantly higher than the 19,645 vehicles sold in 2017 (Klippenstein, 2019). The two most popular EVs in 2018 were the Chevrolet Volt and Nissan Leaf. It should be noted that vehicle manufacturers are not obligated to release sales information publicly, and thus any sales figures are the result of self-reporting. The growth in sales is significant for the Canadian market, considering the first wave of EVs did not arrive until 2011, and the sales figures in more recent years have been promising.

While the increase in EVs will assist in the reduction of transportation-related carbon emissions, the future growth of these vehicles also equates to an increase in the number of used EV batteries. Some projections are quoting a range of 0.33 to 4 million metric tonnes of used LIBs being generated between 2015 and 2040 (Winslow et al., 2018). This is in addition to the LIBs that will be removed from various other products, including smartphones, tablets and personal computers. China is home to over 1 billion cell phone users and will require some level end-of-life management once these LIBs are disposed (Bian et al., 2016). While end-of-life management may not be a present issue, the downstream impacts of delaying or avoiding the development of necessary policy structures could be severe. The future of passenger vehicle transportation is increasingly favouring electric drive vehicles, as the global growth in EV numbers is beginning to transition global vehicle markets away from traditional ICE-powered vehicles.

4.3 Current Approaches to the Management of High-Performance Batteries

When batteries reach their end-of-life, they are disposed or recycled. EV batteries have an average lifespan of 8-10 years for which they can be used to power an EV because they degrade over time due to use (Richa et al., 2014). As more consumers transition to EVs, higher numbers of spent batteries will begin appearing (Alhajii & Lewis, 2019). Estimates show that by 2020, North America will be the site of 268,000 NiMH batteries and 90,000 LIBs that have reached their end-of-lives (CEC, 2015). A battery that has reached the state of “end-of-life” is considered to be no longer useable for its original purpose. As a result, batteries must be either recycled or repurposed for second-uses. In both cases, EV batteries require some form of disassembly before undergoing any recycling process.

Depending on the chemical properties of the battery, several environmental risks emerge. When batteries are sealed, they pose minimal risk to the environment and human health. However, if the constituents are released during disassembly or due to a broken seal, there is a risk of adverse environmental impacts from contamination (CEC, 2015). While vehicle manufacturers are adopting LIBs for their EVs, NiMH batteries are still prevalent in some older models, such as the Toyota Prius. NiMH batteries present risks to the environment because of their chemical composition.

These batteries consist of several materials, including steel, zinc, manganese, nickel, cobalt, other metals, alkali, water and other non-metals (CEC, 2015). Many of these substances can pose significant risks to the environment and human health if released during recycling and disposal. Nickel is classified as a toxic substance under the *Canadian Environmental Protection Act*. If it is released into the environment it can accumulate in soil or sediment, attach to other particles such as iron or manganese, and seep into groundwater. This means that nickel is bio-accumulative, persistent and toxic; and can cause harmful effects on wildlife and human health (CEC, 2015).

Manganese is another significant compound in NiMH batteries. Like other metals, manganese does not break down in the environment, and it will attach to other particles. Exposure to high levels of manganese is toxic and has been seen to cause changes in brain development in younger children (CEC, 2015).

LIBs are being increasingly used in newer EVs, but their components can also cause adverse effects on the environment and human health. If combined with water, elemental lithium can be highly dangerous because of the generation of intense heat along with the formation of hydrogen gas, which can cause an explosion or fire (CEC, 2015). As a result, lithium metal can cause severe burns if combined with water. Another common compound within LIBs is cobalt, and there is evidence that it is carcinogenic in experiments with laboratory animals. Cobalt is categorized as toxic under the *Canadian Environmental Protection Act*. Humans can be exposed to cobalt through food and drinking water, and it will attach to soil particles if it is deposited.

Cobalt is usually not mobile, unlike other compounds, but the mobility will increase in more acidic conditions. (CEC, 2015).

One of the significant risks with the increase in end-of-life EV batteries is that they may enter municipal waste sites. The entry of chemicals into groundwater is a significant risk posed by batteries in waste landfills through leaching. The majority of leachable materials are contained within the cathode of the battery and protected by a casing. However, exposure of the inner contents can occur due to degradation or damage to the casing. The landfill leachate can act as a medium that transports pollutants outside the landfill, and potentially into the water supply of a region (Winslow et al., 2018). Municipal landfills are generally not equipped to handle hazardous waste materials, as they require specialized disposal methods and facilities. Thus, while batteries may not be inherently dangerous in their solid-state, any disruption in the integrity of the casing or other components can be harmful.

Another point of entry for hazardous materials from spent EV batteries can be if they are disposed of through incineration or waste-to-energy facilities. These facilities will burn waste products. Hazardous material contained in batteries entering these types of facilities may be released to the atmosphere in stack emissions or contained in bottom and fly ash. In addition, the ashes from incineration can return back to landfills leading to further potential environmental and health risks (Winslow et al., 2018).

4.4 Environmental and Social Impacts of Battery Development

While P/HEVs and EVs are considered low or zero-emission vehicles, the processes involved to develop these vehicles are not entirely emissions-free. Electric drive vehicles require specific components to develop the chemistries essential for their batteries, and the only way to find and utilize these minerals is through mining. Mining processes are not considered environmentally friendly, not only in the extraction but also in the refinement and preparation for use in batteries. For example, a large percentage of cobalt reserves are found in geographically concentrated areas, mainly the Democratic Republic of the Congo. Concerns regarding the processes used for mining, along with other social considerations such as the use of child labour, highlight the number of issues with this mineral (Harper et al., 2019).

Lithium is also a problematic mineral to produce, as one tonne of lithium requires 250 tonnes of the mineral ore spodumene when mined, or 750 tonnes of mineral-rich brine (Harper et al., 2019). Mining processes for the various raw materials can involve drilling, clear-cutting of forests, and pumping of mineral-rich solutions to the surface, which can disrupt local ecosystems and other activities in the region (Harper et al., 2019).

For example, a major center for lithium production is located in Chile's Salar de Atacama. 65% of the region's water supply is used towards mining activities, which not only strains the local water systems but forces local farmers to import water for their farming activities (Harper et al., 2019). As a result, high-performance batteries can pose a variety of adverse effects on the environment and human health. The effects of these batteries can occur across the lifecycle of the battery, from mining and development to end-of-life. While EVs are seen as zero-emission products, this only applies during the operation stage by the user. The Pre and Post-consumer stages cannot be placed under the zero-emissions category.

4.5 Current Recycling Methods & Second-Lives

EV batteries may be recycled, and processes have been developed to extract the valuable components in order to sell them to interested parties. The three main recycling methods for advanced batteries that exist are:

- Pyrometallurgical Recycling (Pyrometallurgy)
- Hydrometallurgical Recycling (Hydrometallurgy)
- Physical or Mechanical Recycling

4.5.1 Pyrometallurgical Recycling

Pyrometallurgical recycling, also known as pyrometallurgy, involves the use of heat to recover metallic battery components (Baltac & Slater, 2019). This process places the batteries within high-temperature furnaces, which causes certain materials in batteries to combust and burn. These materials include graphite anode, aluminum wires, paper, and plastic casing. Other chemical components, including copper, cobalt, nickel, and iron, are transformed into molten metals that are collected as alloys (Baltac & Slater, 2019).

Before EV battery packs are placed in these furnaces, some preliminary dismantling occurs to remove any components which may not have any significant use or value. The furnace slag houses the ashes from the burnt components and primarily contains lithium, aluminum, silicon, calcium and some iron compounds. Recovering the individual components from the slag is not economical. Recyclers sometimes dispose of the slag altogether. Some recyclers sell or re-use the slag in other products, such as in the form of a cement additive (Baltac & Slater, 2019). Pyrometallurgy is the most mature out of all battery recycling processes and has the advantage that all battery chemistries can be recycled at once (Baltac & Slater, 2019). The slags produced after the completion of the smelting process also contain ashes of elements that could damage the environment and must be treated as hazardous waste. Proper disposal protocols must be in place to prevent contamination of the surrounding environment.

Pyrometallurgy is an intense process that can produce various negative environmental impacts because it requires the use of high temperature furnaces to melt the components in batteries. This process generates high amounts of conventional and hazardous emissions, not only during the burning processes but with the energy required to operate the furnaces. The energy sources used to power these processes are likely to be coal or natural gas, as renewable sources cannot generate the required energy (Baltac & Slater, 2019).

4.5.2 Hydrometallurgical Recycling

Hydrometallurgical recycling, also known as hydrometallurgy, is a process that utilizes various acids to dissolve the metal components of the battery in a process called leaching. This method also requires some preliminary disassembly, with battery cells being fragmented through crushing or shredding processes (Baltac & Slater, 2019). As a result, hydrometallurgy is a two-step process that separates any metals, paper and plastic prior to acidification. Once the metals are dissolved into an acid solution, it is then put through solvent extraction, chemical precipitation or electrolysis to separate the various elements (Baltac & Slater, 2019). The recovery rate for components is very high due to the nature of the process that separates individual elements as inorganic salts (Baltac & Slater, 2019).

For hydrometallurgy, one advantage of this process is that it can be customized for each battery type. This can also be a disadvantage as multiple battery chemistries cannot be recycled at once. The source material must be known beforehand in order to sort batteries by their chemistry (Kushnir, 2015). This means that recycling sequences have to be optimized for each battery chemistry in order to ensure high recovery and favourable economics (Baltac & Slater, 2019).

The by-products from the leaching in hydrometallurgy include acidic liquid waste containing hazardous chemicals. The process involves the use of harsh chemicals such as sulfuric acid, which can be harmful to the environment and human health. Organic acids such as citric or malic acids have been proposed as more environmentally friendly alternatives but have yet to become the standard in this process (Winslow et al., 2018). Like pyrometallurgy, this process is energy-intensive, and the use of non-renewable energy sources is unlikely, but more chemical waste is generated through this method. As a result, while the recycling processes can reduce the amount of EV batteries that are sent for disposal, the potential for environmental harm is real.

4.5.3 Physical/Mechanical Recycling

The final recycling method is the physical or mechanical recycling of the batteries. Dismantling of the batteries can consist of manual and automated processes, with valuable components retrieved in their original state (Baltac & Slater, 2019). The process allows for some components (e.g. electrodes, wiring, casing) to be re-used in new batteries, and others can be recycled using pyro-or-hydro techniques (Baltac & Slater, 2019). The benefit of this method is the absence of chemical or heat usage in the recycling process, and for the components to be recovered in useable condition. For example, the re-use of mechanically separated graphite anodes has been successfully demonstrated (Harper et al., 2019). These processes have a much lower environmental impacts and risks than pyro- or hydro-processes. At the same time, disassembly of batteries in laboratory experiments is sometimes performed in Argon gas-filled gloveboxes, and high levels of technical expertise is required for large-scale EV battery disassembly (Ramoni & Zhang, 2013).

Other potential drawbacks include the performance of recovered components in new applications may not be 100%, and the risks of some components becoming obsolete in the future (Baltac & Slater, 2019). In addition, the efficiency of recycling through this method is dependent upon the state of health of the battery, as a low state of charge may render this method uneconomic (Harper et al., 2019). If the state of health for an end-of-life EV battery does not meet a certain standard, it may not be worthwhile economically to pursue a second-life because of the reduced return on investment. While this recycling method is still only used in pilots, the potential as an alternative is significant.

The three main recycling processes each provide unique ways of extracting valuable components from EV batteries. However, each process has various drawbacks. The increasing adoption of electric drive vehicles will result in higher numbers of batteries entering their end-of-lives. While recycling processes can recover valuable materials that can be resold, these methods can cause environmental harm through carbon emissions or through waste streams that are developed as a result of the by-products from the processes. Therefore, the development of second-life applications for EV batteries provides an alternative to recycling and can delay some of the adverse effects that hydro- and pyro-recycling methods can produce.

4.5.4 Second-Life Applications of EV Batteries

A second-life application is the re-use of a battery pack for a different purpose once the battery can no longer fulfill its original intention (Ramoni & Zhang, 2013). Second-life applications are favoured recycling because of the various uses that are possible. A second-life battery has several benefits, such as the ability to be fully utilized, as EV batteries are removed after 8-10 years, or the capacity reduces to 80% (Ramoni & Zhang, 2013). Repurposing batteries increases their total service life, which slows down the rate of resource extraction and waste disposal required (Jiao & Evans, 2016). Second-life applications for EV batteries also relate to the concept of the circular economy, which emphasizes re-using products in order to reduce the amount of waste generated through the creation of new products with the overarching goal to eliminate waste (Olsson et al., 2018). For example, we can reduce the need to develop new batteries, which will reduce the amount of mining undertaken to extract the required minerals.

The potential for second-life EV batteries to be used for grid energy storage is a growing field. One example includes the application in grid-based wind and solar power generation. For example, batteries can be used to provide power in the event of a blackout for residential or commercial purposes, to power server farms intended for a variety of services, or used for energy time-shifting (CEC, 2015). Second-uses for EV batteries also include telecommunication applications, such as the use in cellular towers during blackouts to maintain certain services (CEC, 2015). Research in second-life applications has been ongoing by various government and academic institutions such as the US Department of Energy and the University of California-Davis (Elkind, 2014).

In addition to Tesla, other vehicle manufacturers such as Nissan and Toyota have also begun researching recycling and second-life applications in order to develop reverse supply chains for their batteries. However, there does not appear to be a formal battery refurbishment or re-use business in operation as of yet.

Battery manufacturers have begun to research and develop their recycling systems. For example, Tesla Motors has developed a closed-loop recycling system at their Gigafactory 1, located in Sparks, Nevada (Evarts, 2019). This allows Tesla to recover valuable materials and utilize them for their new batteries, which can reduce the amount of new materials extracted and used for this process. There is not much information available on Tesla’s recycling practices as they have been reluctant to share how they are operating their closed-loop recycling program (Evarts, 2019). Therefore, we do not know if they are utilizing pyro-or-hydro techniques to extract the valuable components from their battery packs.

While second-life applications are promising, there are some barriers, such as the high costs associated with refurbishment, the uncertainty of degradation rates, and the perception of used batteries (CEC, 2015). In addition, second-life applications do not solve the ultimate problem of end-of-life, as batteries still require recycling and disposal once they are completely spent. Hydro- or pyro-processes will be required at that stage. In addition, the preparation for second-lives may require disassembly and processing, which can be dangerous. The associated risks include the need for discharging batteries before disassembly to prevent serious harm or death to workers, as these batteries can discharge 200 volts (CEC, 2015).

Legal questions surrounding ownership of second-live EV batteries currently exist and are potential barriers to widespread applications of second-life EV batteries. For example, what if an owner sells their EV before the battery has reached the end-of-life? EV batteries have an average lifespan of 8-10 years. If a consumer sells their vehicle after three years of ownership, the battery will theoretically have at least five years of use. There is a lack of clarity on the legal requirements of producers if purchased EVs are sold before reaching their end-of-life. If a consumer purchases an EV through the secondary market, would the consumer or the producer be responsible for financing the costs for collection and recycling?

The problem does not apply for EVs that are leased, as they are returned once the lease has expired. The issue also exists with producers in the European Union and has not yet been answered. This ambiguity must be addressed to avoid situations of producers not accepting end-of-life batteries due to grey areas in legislation. The ideal solution would be to move forward with EPR as the foundation for any future battery recycling policy, to ensure that producers are financing the waste they place on the market.

As EVs rise in popularity as alternatives to ICE-powered vehicles, EV sales will continue to rise. The necessary policy structures and practices must be in place to respond to the influx of end-of-life EV batteries. The preferred approach is for second-life applications, where possible, be prioritized for EV batteries that have reached their end-of-lives. Second-lives ensure the reuse of battery packs that retain value and can be used for several different purposes. After the second-life, disassembly and reuse of components for new batteries or other purposes can be undertaken. Reducing the need for new components is essential because of the resource intensity of this process. Finally, recycling processes such as hydrometallurgy and pyrometallurgy should be a last resort, and should only be considered once a second-life and disassembly/reuse of components has been undertaken. It is possible that after a second-life and reuse of components, recycling processes may not be required as the value for extracting minerals may not be worthwhile. This would be beneficial as these recycling processes can develop unfavourable waste streams, as mentioned in this section. Second-life applications should be pursued whenever possible.

Section 5: Comparative Analysis

The policy and regulatory landscape for end-of-life for EV batteries varies between the European Union, the United States, and Canada. This section will comparatively analyze the policy and regulatory structures developed for managing the end-of-life of EV batteries and will highlight the strengths and weaknesses of each of the actors. The analysis will follow the evaluative criteria outlined in Section 2 of this paper. This involves evaluating the Policy & Regulatory Structures, the Performance & Impact of current policies, and the Accountability & Oversight measures embedded within the structures for each actor. In virtually all cases, the existing regulatory regimes predate the emergence of advanced energy storage technology.

5.1 European Union

5.1.1 The Battery Directive

The European Union adopted a set of policies to manage the end-of-life for various battery types. On September 6, 2006, Directive 2006/66/EC of the European Parliament and the Council was enacted. The Directive, known as the Battery Directive, developed objectives, actions, and established further provisions to achieve the requirements set out in the document. The Directive replaced the previous Battery Directive, which had been in effect since March of 1991 because of its failure to achieve its original objectives (Stahl, 2018). The main objective of the Directive is to reduce the negative impacts associated with batteries and accumulators and waste batteries and accumulators on the environment. The intention was that reducing these types of environmental harms would contribute to the “protection, preservation and improvement of the quality of the environment” (CEC, 2015, p. 59).

The Directive stipulates several requirements related to battery recycling. For example, all collected batteries must be recycled, and certain components, such as mercury, are not to be used in further battery production. In addition, batteries are not permitted to be disposed of in landfills, and battery producers or third parties acting on their behalf cannot refuse to take back waste batteries (CEC, 2015). In order to facilitate the take-back of batteries, the Directive mandates various collection and recycling schemes along with targets. The Member States must develop collection schemes for the take-back of batteries that are separate from mixed municipal waste, and these collection schemes must allow end-users to dispose of their waste batteries conveniently and free of charge (Stahl, 2018).

According to the Directive, batteries are to be categorized under three distinct classifications. These are **Portable Batteries**, **Automotive Batteries**, and **Industrial Batteries**. Portable batteries are those used in various consumer electronics such as laptops and cellphones, while also including traditional AA and AAA batteries. Automotive batteries are those used for igniting a vehicle’s engine or lighting system (i.e., lead acid batteries). Finally, industrial batteries are high-performance batteries such as those used for energy storage purposes. Batteries for electric-drive vehicles fall into this category and are subject to its requirements as per paragraph 9 of the European Battery Directive:

> Examples of industrial batteries and accumulators include batteries and accumulators used for emergency or back-up power supply in hospitals, airports or offices, batteries and accumulators used in trains or aircraft and batteries and accumulators used on offshore oil rigs or in lighthouses. Examples also include batteries and accumulators designed exclusively for hand- held payment terminals in

> shops and restaurants, bar code readers in shops, professional video equipment for TV channels and professional studios, miners' lamps and diving lamps attached to mining and diving helmets for professionals, back up batteries and accumulators for electric doors to prevent them from blocking or crushing people, batteries and accumulators used for instrumentation or in various types of measurement and instrumentation equipment and batteries and accumulators used in connection with solar panel, photo-voltaic, and other renewable energy applications. Industrial batteries and accumulators also include batteries and accumulators used in electrical vehicles, such as **ELECTRIC CARS**, wheelchairs, bicycles, airport vehicles and automatic transport vehicles. In addition to this non exhaustive list of examples, any battery or accumulator that is not sealed and not automotive should be considered industrial. (The Battery Directive, 2006)

The central theme of the Battery Directive is the concept of extended producer responsibility, as described in section 3 of this paper. The Directive emphasizes the reduction of responsibility on the part of consumers to handle waste batteries and transfers these responsibilities back to the producers. The Directive outlines different concepts of producer responsibility depending on the battery classification. For example, producers of portable batteries have established organizations in all Member states for the collection, storage, transport and recycling of all batteries in this category (Stahl, 2018).

Users of industrial batteries are responsible for handling spent batteries, and the producers shall not refuse to take back waste industrial batteries. This means that end-users are responsible for the collection, storage and transport of industrial batteries to the producers or the recycling sites (Stahl, 2018). This differs when we look at portable batteries, as producers are mainly responsible once these batteries become spent, and users need only to drop them at designated collection sites. This distinction can cause issues as industrial batteries tend to be much larger and more dangerous to handle, requiring specific training to remove these batteries from vehicles (Deutz, 2009).

However, current practices involve vehicle manufacturers accepting batteries and undertaking the full responsibilities from collection to recycling, according to the provisions on industrial batteries (Stahl, 2018). The Directive establishes a new relationship between producers and consumers and implements financial liability for producers, as failure to adhere to the rules of the Directive will lead to penalties being levied.

The Directive also includes provisions for design for disassembly. The Directive requires that manufacturers design appliances in a way that allows batteries to be removed. If batteries are incorporated, manufacturers must supply instructions detailing how they can be removed (CEC, 2015).

While this does not go into much depth on how electric vehicles and batteries should be designed, the framework is there to build upon and further legislate design for disassembly. Producer responsibility is also seen through the End-of-Life Vehicle (ELV) Directive 2000/53/EC. The ELV Directive requires auto manufacturers to take responsibility for the collection and management of scrap vehicles and their components. Batteries could be considered components, but this Directive does not currently address issues related to battery management (Gaines et al., 2018).

The Battery Directive requires that each Member State transpose the provisions of the Directive into the laws of that country. The provisions must have come into effect by September 26, 2008. This section will analyze the how some Member States have transposed the Directive. These include Denmark, Germany, the United Kingdom, France. Although not members of the European Union, Finland, Norway, and Sweden are also examined.

5.1.2 Denmark

In Denmark, municipalities are responsible for managing waste batteries. Implementation of the Battery Directive continued this model. Municipalities are responsible for collecting all portable batteries while producers finance the collection through a tax of EUR 370 per tonne (Perchards & SagisEPR, 2017). Producer responsibility can be traced back to the Environmental Protection Act of 1991, which required manufacturers and importers to maximize product life and recyclability, and allowed the Environmental Minister to develop agreements with various industry sectors to implement take-back programs (Perchards & SagisEPR, 2017).

Denmark was a signatory to the Battery Directive in 2006 and thus required to transpose the agreement into law. The Amendment Act 509 of 2008 transposed the Directive by requiring manufacturers and importers of batteries to fund the collection of waste batteries through a tax of EUR 370 per tonne (Perchards & SagisEPR, 2017). This tax was doubled in December 2011 through an amendment to the Environmental Protection Act. The government defended this action as necessary to reflect the actual costs of collection for municipalities, and to recoup the losses caused by an insufficient level of tax in 2009 and 2010. Denmark also implemented requirements in 2015 for producers of electronics and electric equipment to design products in a way that allows for easy removal of waste batteries (Perchards & SagisEPR, 2017).

Since 2009, all producers of batteries in Denmark have been subject to the tax. Producers must also join one of the several waste electronic and electrical equipment organizations that facilitate the take-back of batteries from municipalities. These organizations include Elretur, ERP Denmark, RENE AG, and Recipo. Elretur is the largest of the organizations with nearly 70% market share, with RENE AG being the smallest (Perchards & SagisEPR, 2017).

Batteries for electric vehicles follow the same classification as found in the Battery Directive, thus are categorized as an industrial battery. Therefore, producers are responsible for accepting waste EV batteries and cannot refuse to accept them, as stated in the Directive. However, there is no formal collection or compliance organization in Denmark for industrial batteries, and Denmark does not require producers of these batteries to join one (Madsen, 2012).

5.1.3 Germany

Germany adopted a Batteries Ordinance in April 1998 that transposed the original Battery Directive. This placed responsibility on distributors and producers to finance the take-back of waste batteries and develop a framework for the creation of collection organizations. After the adoption of the Directive in 2006, Germany updated the Battery Ordinance to transpose the new rules and procedures with The German Waste Batteries Act (Batteriegesetz) of June 2009. The Batteries Act maintained the existing take-back structures through a single joint organization while also allowing for individual organizations to be developed (Perchards & SagisEPR, 2017). Industrial batteries (which include EV batteries) are also addressed, with manufacturers responsible for developing “reasonable and free collection point for distributors of spent batteries” (M. Brown et al., 2015).

Two types of compliance organizations exist in Germany. Collective or joint organizations allow all manufacturers to participate. These organizations must be not-for-profit and provide containers for collection points and retailers to facilitate the take-back of portable batteries. The organizations must also be financed by producers depending on their market share in the past two years (Perchards & SagisEPR, 2017). Individual organizations can be developed by one or more producers and must similarly offer take-back of batteries; they must be approved by the German Environmental Agency or the environmental agency of a region. Both types of organizations are subject to the same reporting requirements, with the only difference being that individual organizations are not required to disclose costs of collection, sorting and treatment (M. Brown et al., 2015). The four leading collection organizations that producers must comply with are the GRS – Foundation for the Joint Return Organization for Batteries, CCR Rebat, ERP Germany, and ÖcoReCell.

By transposing the Battery Directive, Germany has continued the use of extended producer responsibility as its method for waste management of batteries. Since EV batteries are subject to the rules and procedures of industrial batteries, producers of EV batteries are responsible for financing the collection, treatment and recycling of waste batteries, which is stated in paragraphs 8 and 9 of the Battery Act (Batteries Act (Batteriegesetz—BattG), 2015).

> (1) The manufacturers of vehicle and industrial batteries ensure the fulfillment of their obligations under § 5 by:
>
> 1. the distributors for the vehicle and industrial waste batteries taken back by them in accordance with section 9 (1) sentence 1 and
>
> 2. the treatment facilities according to § 12 paragraphs 1 and 2 for the used vehicle and industrial batteries
>
> offer a reasonable and free return option and recycle the used batteries in accordance with § 14. There is no obligation on the distributors or treatment facilities to hand over these used batteries to the manufacturers.
>
> (2) For vehicle and **industrial waste batteries**, the respective manufacturers, distributors, treatment facilities in accordance with § 12 paragraph 1 and 2 and end users of paragraph 1 sentence 1 may make different agreements.

(3) As far as used vehicle and industrial batteries are used by distributors, treatment facilities according to § 12 paragraph 1 and 2, public waste disposal companies or commercial waste battery disposal companies according to § 14, the obligation of the manufacturers from § 5 is considered fulfilled. (Batteries Act (Batteriegesetz—BattG), 2015)

Paragraph 9:

(1) Every distributor is obliged to take back end-of-life batteries at or in the immediate vicinity of the trading business free of charge. The obligation to take back according to sentence 1 is limited to used batteries of the type that the distributor carries or has carried as new batteries in its range, as well as to the amount that end users usually dispose of. Sentence 1 does not extend to products with built-in batteries; the Electrical and Electronic Equipment Act and the end-of-life vehicle regulation remain unaffected. In the mail order business, trading business in the sense of sentence 1 is the shipping warehouse.

(2) The distributors under paragraph 1 are obliged to take back used device batteries for collection by the common return system. Notwithstanding sentence 1, the distributor can for a period of at least one calendar year in each case waive the collection of the used device batteries by the common return system and instead hand the device batteries to one or more manufacturer-specific take-back systems. The joint redemption system must be informed of the waiver in writing at least three months before the start of the period.

(3) Insofar as a distributor does not make use of the manufacturer's offer in accordance with Section 8 (1) and recycles used vehicle or industrial batteries himself or leaves it to third parties for recycling, he must ensure that the requirements of Section 14 are met. For vehicle and industrial waste batteries that the distributor leaves to a commercial waste battery disposal company or a public waste disposal company with the aim of recycling, the requirements of Section 14 in favor of the distributor are deemed to have been met.

(4) The costs for taking back, sorting, recycling and disposing of used batteries may not be shown separately to the end user when selling new batteries. (Batteries Act (Batteriegesetz—BattG), 2015)

Producers and distributors work together to manage the recycling of batteries, with distributors being responsible for returning waste batteries to producers. Distributors are allowed to charge costs to producers for facilitating the take-back, and all manufacturers must participate in the market by registering with the Federal Environment Agency (M. Brown et al., 2015). Thus, Germany has developed a comprehensive system to facilitate battery collection and recycling while placing that responsibility on producers.

5.1.4 United Kingdom

The Batteries and Accumulators Regulations (S.I. 2164/2008) transposed the Battery Directive in British law and implemented the various market provisions included in the Directive such as hazardous substance restrictions and labelling (Perchards & SagisEPR, 2017). In April 2009, the Waste Batteries and Accumulators Regulations (S.I. 890/2009) introduced extended producer responsibility for battery collection and recycling. These two legislative documents provide the structure for the British government to enforce producer responsibility and mandate the development of compliance organizations.

In the United Kingdom, producers are classified as either large or small producers. Large producers are those that place greater than 1 tonne of batteries on the market, while small producers are those that place less than 1 tonne. The difference between these two classifications is that small producers are not required to join compliance organizations. However, both types of producers are subject to the same reporting obligations (Perchards & SagisEPR, 2017). There are five leading compliance organizations through which all large producers in the United Kingdom can meet their compliance requirements. These include BatteryBack, Valpak, Budget Pack Ltd., ERP UK, and Repic eBatt. Small producers, while not required to join compliance organizations, are registered and report to the various Environmental Agencies in the region (Perchards & SagisEPR, 2017).

The United Kingdom has also implemented comprehensive regulations regarding the management of waste industrial batteries. Part 5-Regulation 35 of the Waste Batteries and Accumulators Regulations handles the take-back of industrial batteries.

Producers of industrial batteries are responsible for their collection, which must be free of charge to the end-user, and must publish how an end-user can request the take-back of industrial batteries (The Waste Batteries and Accumulators Regulations, 2009). Producer responsibility is the theme in this legislation, as it places the onus on producers to finance the collection and recycling for the waste they place on the market. In addition, producers must ensure that all collected batteries are delivered and accepted by an approved battery treatment operator for treatment and recycling, or an approved battery exporter who will facilitate the export for treatment outside of the United Kingdom (The Waste Batteries and Accumulators Regulations, 2009).

The regulations implemented by the United Kingdom ensure that producers of EV batteries are responsible for managing the end-of-life, and ensuring the recycling of batteries occurs in accordance with the provisions of the Waste Batteries and Accumulators Regulations (Waste batteries: Producer responsibility, 2014). This includes a prohibition on the disposal of waste EV batteries in landfills, as stated in Regulation 56 (The Waste Batteries and Accumulators Regulations, 2009). In addition, the United Kingdom has also implemented reporting requirements for producers. The information must be provided to the Secretary of State on the total amount in tonnes of industrial batteries that are placed on the market (The Waste Batteries and Accumulators Regulations, 2009).

5.1.4 France

Producers in France have been required to take back waste batteries collected by distributors, municipalities and others since January 2001. This was implemented through *Decree 374 of 1999*, also known as the *1999 Batteries Decree*. To transpose the Battery Directive, the French government passed *Decree 1139* in September 2009 (*2009 Batteries Decree*), which aligned French regulations with those of the Directive, and *Decree 829/2005* which focused on waste electrical and electronic equipment (Perchards & SagisEPR, 2017). In July 2015, the French government passed another Decree which developed new requirements for battery compliance organizations. These changes mandated that compliance organizations must:

- charge fees for batteries that are environmentally preferable and are modulated by certain percentages
- allow compliance organizations of other products subject to EPR to collaborate with battery compliance organizations
- include proximity and social indicators to be considered when selected collection and treatment operators
- perform a study on batteries available for collection
- have a not-for-profit objective (Perchards & SagisEPR, 2017)

The regulatory structures managing battery collection and recycling in France have been extensively developed and amended to remedy shortcomings that were previously not addressed through the original Decrees (Perchards & SagisEPR, 2017).

Compliance organizations were originally developed through the 1999 Batteries Decree, which included Screlec in September 2001 and Corepile in July 2003. Corepile was developed from a disagreement among those who formed Screlec. Thus, VARTA, Energizer and Duracell formed their own individual compliance organization. Individual organizations were later developed when various major retailers left Corepile (Perchards & SagisEPR, 2017). After the 2009 Batteries Decree, Screlec, Corepile, and one individual organization by the Mobivia Group were approved to act as the primary compliance organizations in France (Perchards & SagisEPR, 2017).

Producers in France are responsible for funding the collection, treatment and recycling of waste batteries. EV batteries fall under this responsibility due to their classification as an industrial battery as per the Directive. However, an exception to this responsibility does exist in the Directive and French national law. “Professional users of batteries or automotive and industrial batteries” can agree with producers to accept the financial and technical responsibilities for the management of waste batteries (M. Brown et al., 2015). Therefore, users can enter into contracts with producers to take on the responsibility of end-of-life management as per Article R.543-130 of the Environment Code (M. Brown et al., 2015). This does conflict with the producer responsibility guidelines in the Battery Directive, as producers are intended to be the cost-bearers for recycling and collection. This raises questions for EV batteries of what will happen if more users agree to take on the responsibilities meant for producers and if the batteries will be disposed of in ways that comply with the Battery Directive?

5.1.5 Finland

Producer responsibility has been used in Finland since 2004 (Ylä-Mella et al., 2014). After the creation of the Battery Directive, Finland introduced an amendment in 2008 to the Waste Act, which transposed the Directive into Finnish law and subjects batteries to producer responsibility. In addition, an Ordinance on Batteries was adopted to introduce substance restrictions, labelling, registration and reporting requirements (Perchards & SagisEPR, 2017). In May of 2012, a new Waste Act, 646/2011, was put into force, which addressed the ownership of wastes and forbids parties other than producers to manage wastes that were subject to producer responsibility, unless in collaboration with producers (Perchards & SagisEPR, 2017). Finally, a new Decree on

Batteries (520/2014) was adopted in July 2014, which aligned waste batteries legislation with the new Waste Act and WEEE Decree. The Decree sets minimum requirements for battery collection points and registration with compliance organizations (Perchards & SagisEPR, 2017).

In Finland, producers may transfer waste management obligations to a registered collection organization. There are two compliance organizations in Finland, Recser and ERP Finland. Recser is the sole manager of waste battery collection for both organizations (Perchards & SagisEPR, 2017). However, these organizations are focused on portable battery collection and recycling, not industrial batteries, as EV batteries are categorized. While producers and third-party operators are responsible for handling waste industrial batteries, the lack of a producer organization for industrial batteries can be troublesome. This can result in free riding, a lack of complete collection of data, and disposal of EV batteries through methods that are not approved (Perchards & SagisEPR, 2017).

5.1.6 Norway

While Norway is not an EU member state, it is obligated to adopt the Battery Directive as a result of the European Economic Area agreement (Ylä-Mella et al., 2014). Norway adopted the Regulations on Waste Recycling in July 2000, which imposed take-back and reporting requirements for producers on lead-acid, industrial nickel-cadmium and rechargeable batteries. In October 2012, an amendment introduced the producer responsibility requirements and collection targets for portable batteries included in the Battery Directive (Perchards & SagisEPR, 2017).

Only one compliance organization is approved for portable batteries in Norway. This is Rebatt AS, which shares management responsibilities with Batteriretur. Rebatt was established in 1999 by large retailers in response to the first take-back requirements (Perchards & SagisEPR, 2017). There is currently no compliance organization for industrial batteries, which raises questions of potential under-collection of EV batteries. Producers are responsible for financing the take-back of industrial batteries, but without an appropriate organization, there is a potential lack of accountability.

5.1.7 Sweden

Municipalities in Sweden were responsible for waste battery collection after the implementation of the *1997 Batteries Order*. Producers were to be charged with a fee for which the funds would finance these activities under the management of the Swedish Environmental Protection Authority (SNV). *Ordinance 2008:384* (*SFS 2008:384*) transposed the Battery Directive while repealing the Batteries Order, and de factor transferring responsibility for collection to producers starting in January 2009 (Perchards & SagisEPR, 2017). Small producers (those placing less than 50 kg of non-hazardous batteries) are exempt from the take-back obligations. However, they are required to abide by the reporting obligations similar to large producers.

After the passing of the *1997 Batteries Order*, the SNV developed the Batteriinsamlingen (Battery Collection) program in cooperation with the Swedish Association of Local Authorities and Regions (SKL), a waste management association called Avfall Sverige, and the battery producer organization Batteriföreningen (Perchards & SagisEPR, 2017). Producers of hazardous batteries financed these organizations through fees paid to the SNV. After the *2008 Battery Ordinance*, WEEE organization El-Kretsen was assigned the take-back responsibilities for batteries collected by the Batteriinsamlingen program. Over 800 producers comply through El-Kretsen in Sweden (Perchards & SagisEPR, 2017).

Similar to other countries that have transposed the Directive, Sweden has implemented producer responsibility requirements along with the creation of producer organizations for compliance purposes. However, there appears to be no collection organization for EV batteries. This is identical to other countries that have transposed the Battery Directive, as the onus appears to be on producers to finance collection and recycling individually. It should be noted that producers of industrial batteries weighing less than 3 kg must join El-Kretsen, but EV batteries are significantly heavier. This means that producers of EV batteries are not required to join a compliance organization, leading to an unclear situation in Sweden regarding oversight for industrial batteries.

5.1.8. Analysis

Currently, EV batteries are categorized as industrial batteries under the Battery Directive and are subject to specific collection requirements for which producers are responsible. However, there seems to be a greater focus on portable batteries, such as those used in cell phones or laptops. There is a lack of targeted policies that directly relate to EVs. While the End-of-Life Vehicle (ELV) Directive manages how waste vehicles are handled, the Directive only provides generic guidelines for handling traction batteries (Gaines et al., 2018).

The issue of spent LIBs is also not addressed in the ELV Directive, resulting in a gap in current legislation on this issue. This also means that countries that transposed the Battery Directive also have this gap in their legislation. In addition, much of the original battery legislation among countries is from the 1990s, predating the emergence of EVs and advanced storage as it is seen today. It should be noted that both of these Directives were developed during the time where EVs were not as prevalent as they are today, and the EU is currently assessing how to better manage the future uptake in waste EV batteries (European Commission, 2019).

When assessing the Directive and how the EU has structured its policies, the performance and potential impact of legislation must be considered. The Battery Directive's scope can be considered comprehensive in its coverage of waste batteries. Member states and producers are subject to strict collection, disposal and recycling requirements. However, the Directive does not include collection targets specific to industrial batteries. The targets that are included are to be interpreted as total collection targets, but considering the importance placed on portable batteries, it can be assumed that these targets are not intended for EV batteries. Although, the potential impact on waste reduction and prevention of environmental damage can be massive, considering the future uptake of various types of batteries.

As stated in the Battery Directive, Member States are required to encourage producers to research and improve the environmental performance of their batteries throughout their lifecycles (The Battery Directive, 2006). While not explicitly mentioned in the Battery Directive, this could apply to EV batteries as producers are responsible for the financing collection and recycling of industrial batteries, as EV batteries are classified. While EV batteries are not hazardous while in use or if they have been removed, they can become dangerous if their outer casing is damaged, which will lead to contamination. Thus, the Directive can play a crucial role in preventing EV batteries from entering municipal landfills.

Finally, from an accountability and oversight viewpoint, the EU has implemented a compliance system to ensure producers are not free-riding or disposing batteries in unauthorized manners. The use of producer organizations, which producers are mandated to join, is a valuable tool for ensuring compliance. How these organizations are structured is left to the governments of EU Member States to determine, but the use of producer organizations predates the Battery Directive. Thus, the transition was more straightforward for some countries.

The one issue that exists is that some Member States, namely the United Kingdom, do not require industrial battery producers to join producer organizations but are still required to adhere to reporting obligations. While this may allow for smaller producers to avoid the costs that joining a producer organization may bring, the EU should consider including these producers in order to prevent any leakages in battery collection no matter the size. Germany has also not required producers of industrial batteries to join compliance organizations. As seen with several Member States, many of the producer responsibility organizations are solely focused on portable batteries and do not accept industrial batteries.

The Battery Directive allows Member states to develop and levy penalties against parties who infringe on the provisions of a country's national law. However, the Directive does not state what kinds of penalties can be levied or their severity, only that the Member States must ensure that the penalties are "effective, proportionate, and dissuasive" (Directive 2006/66/EC of the European Parliament and of the Council of 6

September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, 2006). Overall, the Battery Directive may provide the necessary structures to manage waste EV batteries, but its application to EV batteries is currently unclear and inconsistent at a Member State level. With an uptake in waste EV batteries on the horizon, more stringent regulations and collection targets should be introduced to prevent unwanted environmental harm.

5.2 United States of America

5.2.1 Policy & Regulatory Structures

The United States lacks a federal policy that promotes the recycling of LIBs, while older battery technologies are managed under the *Mercury-Containing and Rechargeable Battery Management Act [Battery Act] of 1996*. Developed by the administration of then-President Bill Clinton, this legislation categorized mercury, nickel-cadmium and small Pb-acid batteries as hazardous waste under Regulation 40 CFR 273, *Standards for Universal Waste Management* (Gaines et al., 2018). The Battery Act implemented various labelling, disposal/recycling, and collection requirements for batteries.

However, this act does not cover LIBs, which are now rising in popularity as the dominant design for EV battery technology. One reason for this omission is that LIBs are not classified as toxic or hazardous waste and the fact that this technology is relatively new compared to other chemistries. However, components such as metals found in LIBs can still leach into the ground and water bodies if they are not correctly handled. The constituents of batteries are classified as hazardous materials potentially resulting in the application of relevant hazardous waste guidelines, but a lack of clarity exists on whether LIBs should be classified in this manner (Gaines et al., 2018). This is because sealed battery packs do not pose risks to the environment unless the outer casing is damaged, which can result in leakages (Gaines et al., 2018). This lack of clarity in policy direction at the federal level is troublesome considering how mainstream this battery technology has become, and the fact that the Environmental Protection Agency has not introduced recycling regulations for these batteries.

While LIBs are not currently covered by federal legislation, some states have begun to develop legislation to manage these batteries. California, Minnesota and New York are the only states that incorporate LIBs into their waste management and EPR regulations. California introduced the *Rechargeable Battery Recycling Act of 2006*, New York state implemented the *Rechargeable Battery Recycling Act* in 2010, and Minnesota created the *Rechargeable Battery and Products Law of 1994*. These states allow for the free return of batteries and prohibit their disposal in municipal landfills (Gaines et al., 2018; Winslow et al., 2018). Minnesota is the only state that has set collection targets, but these are not mandatory. For EV batteries, Minnesota requires manufacturers of vehicles and batteries to co-manage waste batteries. The laws in California and New York only apply to small consumer batteries (Gaines et al., 2018). As a result, except for Minnesota, there is no policy that is explicitly handling waste EV batteries and the current legislation predates the growth in EVs.

Bill AB-2832 *Recycling and Reuse: Lithium Ion-Batteries* in February 2018 was introduced into the California state legislature. This bill proposes to establish proper mechanisms and structures to handle the disposal of EV batteries, specifically LIBs, with no cost to owners. The bill requires state agencies to collaborate to identify appropriate methods for reuse and recycling of EV batteries (Gaines et al., 2018).

5.2.2 Performance & Impact

Due to the lack of policy at the federal and state level in the United States, it is difficult to assess the impact on reducing waste EV batteries. Current legislation is focused on handling consumer batteries rather than high performance units, but no data exists regarding collection. Only Minnesota explicitly requires producers and manufacturers to be responsible for managing waste EV batteries. California is currently considering a bill that would establish proper mechanisms to handle these batteries, but it remains to be seen whether the legislation will be adopted in New York, California and Minnesota to prohibit the disposal of LIBs in municipal landfills (Winslow et al., 2018),

5.2.3 Accountability & Oversight

After analyzing the three states that have implemented LIB-specific legislation, there is a lack of compliance structures for ensuring that waste batteries are not mishandled. This also applies to potential penalties that can be levied against those who do not comply with regulations. The penalties for non-compliance are either negligible or absent. There are no penalties in California or Minnesota for those who improperly dispose of LIBs. The state of New York will subject violators to civil penalties, but the fines are rarely enforced (Gaines et al., 2018). Thus, violators will not be deterred from continuing harmful practices unless penalties are severe and appropriate.

The United States does not appear to have the necessary policy structures to manage waste EV batteries. While there are some state-level programs in place, they do not compare to the structures that exist in the European Union. However, while the federal government avoids this issue, state-level policy must address it as EVs are rising in popularity due to the reduction of entry costs for consumers.

Problems also exist for battery recyclers. One of the biggest drivers in recycling is cost, with disassembly and transportation of batteries, each occupying 35-45% of the total cost (Westlake et al., 2020). In a worst-case scenario, these drivers can occupy up to 90% of the total cost, and with unstable commodity prices for nickel and cobalt, battery recycling poses many risks for potential investors (Westlake et al., 2020). If the United States continues to avoid this issue, they will be responsible for handling massive amounts of EV batteries that have reached their end-of-life, but with a lack of essential infrastructure to prevent environmental damage.

5.3 Canada

5.3.1 Policy & Regulatory Structures

The Canadian policy and regulatory framework for waste management is structured in a way that all levels of government play a crucial role. Responsibility for managing and reducing waste is shared amongst the federal, provincial, territorial and municipal governments in Canada. Municipal governments are responsible for managing, collecting, and recycling waste, while provincial and territorial governments develop policies and programs aimed at reducing waste and monitoring waste management facilities. The federal government funds infrastructure and other projects focused on reducing waste while collaborating with the other levels of government and Indigenous partners to develop and implement standards on various waste management issues. (Government of Canada, 2018).

The management of used EV batteries is an unaddressed issue in the Canadian law and policy. Though in terms of federal law, there is no policy that directly refers to the management of spent EV batteries. There are general waste management and hazardous material policies that may apply. Examples of federal regulations concerning the movement of EV batteries may include the Import of Hazardous Waste and Hazardous Recyclable Material Regulations, the Interprovincial Movement of Hazardous Waste Regulations, and the Transportation of Dangerous Goods Regulations (CEC, 2015). Canada lacks any form of federal policy that directly addresses EV batteries. EV battery packs are not classified as dangerous goods or hazardous waste and are thus unregulated at the federal level. While the current regulations and legislation on movement of hazardous waste and disposal for battery constituents may apply, a more thorough and focused policy is required to address this issue.

At the provincial level British Columbia, Manitoba, Ontario and Quebec all have a form of battery policy in place that requires manufacturers to have a collection system in place for used batteries (Turner & Nugent, 2016). Each province is following a form of EPR for their waste consumer batteries. Producers are responsible for the battery products they place on the market, but they are differences in how the programs are structured.

In British Columbia, Part 2 of the Recycling Regulations states that producers are responsible for developing extended producer responsibility plans that include duties such as the creation and funding of collection sites for batteries (Environmental Management Act—Recycling Regulation, 2004). Schedule 3 includes batteries under the electronic and electrical product category, resulting in producers being responsible for managing waste batteries in BC. The Rechargeable Battery Recycling Corporation of Canada (RBRCC) through Call2Recycle is the industry steward for the program, with Call2Recycle establishing collection rates for batteries (Morawski, 2012). However, there is no mention of EV batteries in BC's legislation or policies.

In the province of Manitoba, the Waste Reduction and Pollution Prevention (WRAP) Act was enacted in 1990. It regulates waste diversion and product stewardship programs (Giroux, 2014). In 2011, Manitoba introduced the Household Hazardous Material and Prescribed Material Stewardship Regulation, which included rechargeable batteries in the WRAP Act. The RBRCC is the industry steward for the program and Call2Recycle sets collection rates for batteries (Morawski, 2012). EV batteries are not included in the legislation, which means there is no regulatory framework in Manitoba to handle this waste.

The province of Ontario has developed some legislation to manage waste batteries. Ontario's battery recycling program was developed under Ontario's Waste Diversion Act of 2002 (WDA), with a private stewardship organization called Stewardship Ontario responsible for planning, implementing and operating programs for municipal hazardous and special waste (Turner & Nugent, 2016). The WDA was repealed and replaced with the Waste-Free Ontario Act in 2016, which also introduced the Resource Recovery and Circular Economy Act and the Waste Diversion Transition Act.

The Resource Recovery and Circular Economy Act focuses explicitly on batteries, introduces producer responsibility for the development of collection systems, and specifies the requirement of producers to register with a producer responsibility organization (Regulations for Recycling of Electrical and Electronic Equipment and Batteries under the Resource Recovery and Circular Economy Act, 2016). The act also classifies batteries into ‘small’ or ‘large’ categories, for which different collection rules apply. EV batteries are not specifically mentioned in the act. EV batteries may classify as large batteries, but there is no clear statement on the issue.

In addition, a private company named Li-Cycle has been formed to develop a resource recovery method from advanced LIBs. They are located in Mississauga, ON, and are an emerging player in the battery recycling industry (Li-Cycle, 2019). They join Glencore, a battery smelter based out of Sudbury, ON, as the only battery recyclers in the province. Glencore utilizes pyrometallurgy as their method of battery recycling (CEC, 2015). Li-Cycle uses a combination of mechanical processes and hydrometallurgy to extract the valuable components from EV batteries (Li-Cycle, 2019). EV batteries only represent a small portion of Glencore’s processes, and unlike Li-Cycle, Glencore processes a variety of battery chemistries (CEC, 2015). Ontario has thus developed the foundation for further policies and programs targeted towards EV batteries, such as the inclusion of producer responsibility provisions, but has yet to develop any policies specific to EV batteries.

The province of Québec has implemented the Environment Quality Act, which provides the abilities to the government to develop policies and frameworks related to waste management. The overall goal of the province is mentioned in the Residual Materials Management Policy adopted in 2011, which is “to create a zero-waste society that maximizes added value through sound residual materials management" (Giroux, 2014).

EPR occupies a role in Québec's waste management policy, as the province has mandated EPR for batteries, with a Crown Corporation called "Recyc-Québec" responsible for promoting, developing and fostering reduction, re-use, recovery, and recycling of various materials and products (Giroux, 2014). Québec has recently invested in further developing the battery recycling market in the province because of the potential of the future battery market in Canada (Rompre, 2019).

Lithion Recycling is a consortium of various entities, including Call2Recycle, Seneca experts-Conseils, Hydro-Quebec's Center of Excellence in Transportation Electrification and Energy Storage (CEETES), and Centre d'étude des proceeds chimiques du Québec (CÉPROCQ). This consortium is committed to research and development in battery recycling, and to develop a commercial factory to process 2,000 tonnes of battery components yearly (Rompre, 2019). Lithion recycling has developed a patent-pending hydrometallurgical recycling process for lithium-ion batteries. The process claims that 95% of battery components can be recycled or reused for new batteries (Lithion Recycling, 2020). The consortium has also begun the development of a recycling plant in Quebec. These plants will be of smaller capacities, and Lithion Recycling claims that local deployment will minimize the transportation of hazardous waste (Lithion Recycling, 2020).

Quebec has taken important steps to address this issue through the creation of this consortium, and it is a model that encourages businesses to invest and cooperate to handle this waste. As summarized in Figure 8, Quebec has emerged as a leader in

North America on the issue of EV battery recycling by supporting the continued research and development of battery recycling technology. While it remains relatively new, it is the first real action taken by a province to address this issue.

5.3.2 Performance & Impact

Analyzing the policy and regulatory structures in Canada highlighted the gaps in existing legislation. Currently, Quebec is the only province with some policies and programs directly focused on EV batteries. Ontario has implemented some regulations regarding producer responsibility and the classification of batteries that could be applied, but further clarification is needed. Therefore, the current legislation on end-of-life management is not comprehensive. This applies not only to Ontario but to almost every province included in this paper. Current provincial legislation is focused on reducing the impact of consumer batteries. EV batteries are not addressed. Most provinces have outlawed the disposal of batteries in landfills, and this will reduce the probabilities of severe environmental damage, as these rules also apply to EV batteries indirectly. While the lack of focused policy is evident, current legislation on batteries can prevent environmental damage by prohibiting disposal in municipal landfills.

Purchasing or leasing an EV requires entering into a contract that outlines various obligations for the manufacturer and owner. When an EV is leased, the vehicle returns to the manufacturer at the end of the lease term. The manufacturer can then decide on whether to sell the vehicle or utilize the various components for other means.

If an EV is purchased, questions arise on who is responsible for managing the end-of-life for the battery because this transaction is classified under private law (Cara Clairman, personal communication, October 8, 2019). It is unclear whether the producer is obligated to accept responsibility for financing the collection and recycling for EV batteries. This is compounded by the fact that contracts for purchased EVs lack any mentions of producer responsibility. This is a grey area in legal terms, as producers have no obligations to take back spent EV batteries. If left unaddressed, there is a possibility that consumers may be responsible for disposal.

5.3.3 Accountability & Oversight

Compliance mechanisms at the federal level of government appear to be scarce. One reason is the lack of clarification on which level of government is responsible for waste EV batteries. The federal government does have regulations regarding hazardous waste, but the provinces are tasked with ensuring that municipalities are meeting the waste management needs of various regions. While the constituents of batteries are hazardous materials, it is unclear if EV battery packs are classified in this manner since no legislation defines these types of batteries at the federal level. However, the federal government is responsible for the interprovincial movement of hazardous waste along with the import or exports of this material. While the battery packs may not be considered hazardous waste, the components inside could be categorized in this way. However, this is currently a grey area and will continue to be so until the provincial and federal governments take action.

The current state of EV battery management in Canada is unclear from a policy and regulatory framework standpoint. Current practices in Canada involve producers voluntarily accepting spent batteries (Cara Clairman, personal communication, October 8, 2019). There is no control or oversight for Canada on the recycling methods or the fate of the recovered materials. Canada must address this issue soon, as consumers are beginning to shift away from traditional combustion engine vehicles due to the increased accessibility of these alternatives.

As summarized in Figure 8, the United States is in a similar situation, with producers engaged in similar practices for handling waste batteries. The European Union is well-ahead of both parties in all aspects of waste management for batteries and has developed the policy and compliance structures to prevent the disposal of EV batteries in municipal landfills. While areas of improvement exist for the European Union, they appear to be far more prepared than North America on this issue. However, current practices in all jurisdictions appear to favour recycling over second-life applications and reuse of components. As mentioned in Section 4, second-life applications should be pursued, followed by disassembly and then recycling. This will increase the supply of battery packs for non-EV purposes and reduce the need for recycling, which generates unfavourable waste streams.

Figure 8: Overview of Current Policy Structures for End-of-Life EV Batteries

Jurisdiction		Current Policy Structures
European Union	*Overview*	• The Directive stipulates several requirements related to battery recycling including extended producer responsibility and the banning of battery disposal in landfills • All signatories are required to adopt the provisions of the Directive • Much of the original battery legislation in various countries is from the 1990s and pre-dates electric vehicles • Focus is principally on the management of portable batteries • EV batteries are categorized as industrial batteries but lack collection targets and compliance organizations as seen for portable and automotive batteries (CEC, 2015; The Battery Directive, 2006)
	Denmark	• Municipalities are required to collect portable batteries, but producers are responsible for industrial batteries. • All producers are subject to a battery tax that funds the collection of portable batteries (Perchards & SagisEPR, 2017) • No formal collection or compliance organization exists for industrial batteries, and producers are not required to join one. (Madsen, 2012)
	Germany	• Germany has implemented extender producer responsibility which extends to industrial batteries • Requires producers to finance the collection, treatment and recycling of waste batteries (Batteries Act (Batteriegesetz—BattG), 2015)
	UK	• Producers are responsible for the collection of waste batteries of all types • Disposal of waste EV batteries in landfills is prohibited, and recycling must adhere to the provisions of the Waste Batteries and Accumulators Regulations • Producers are also required to report the total amount of batteries placed on the market (The Waste Batteries and Accumulators Regulations, 2009)
	France	• Producers are responsible for funding the collection, treatment and recycling of waste EV batteries • Agreements can be made between producers and professional users of industrial batteries to accept the waste management responsibilities (M. Brown et al., 2015)
	Finland	• Producers are responsible for handling waste industrial batteries • No evidence of a producer organization for EV batteries, as the focus of existing organizations is for portable batteries (Perchards & SagisEPR, 2017)
	Norway	• Producers are responsible for financing the take-back of industrial batteries • No compliance organization exists for industrial batteries, which raises questions of potential under-collection of EV batteries (Perchards & SagisEPR, 2017)
	Sweden	• Producer responsibility exists through the implementation of *Ordinance 2008:384* (*SFS 2008:384*) which transposed the Battery Directive • El-Kretsen is responsible for the take-back of batteries collected under the Batteriinsamlingen program

		• No collection organization for EV batteries and producers are responsible for financing the collection and recycling of battery packs • Producers are not required to join a compliance organization, leading to an unclear situation in Sweden regarding oversight for industrial batteries (Perchards & SagisEPR, 2017)
United States of America		• Lack of a federal policy for EV batteries • California, Minnesota and New York State are the only states with some legislation for LIBs • Existing legislation in New York and California does not apply to EV batteries • Minnesota requires manufacturers of EVs and batteries to co-manage waste batteries • Lack of compliance structures at the federal and state level for end-of-life EV batteries (Gaines et al., 2018; Winslow et al., 2018)
Canada		• Lack of federal policy for managing waste EV batteries; confusion over whether batteries should be classified as hazardous waste (CEC, 2015) • Lack of policy at the provincial level concerning EV batteries – policy is focused on managing waste consumer batteries for various electronics such as computers and smartphones (Turner & Nugent, 2016) • Quebec appears to be the leader on the issue of EV battery recycling through the funding of various battery recycling programs (Giroux, 2014) • Quebec has supported the creation of Lithion Recycling, a consortium of various organizations all tasked towards developing solutions for end-of-life EV batteries (Rompre, 2019) • Questions exist regarding who is legally responsible for end-of-life EV batteries, specifically if they are redeveloped for second-lives

Section 6: Recommendations

The analysis of the European Union, the United States and Canada has yielded significant findings on the state of the policy structures for the management of end-of-life EV batteries. These findings are summarized in Figure 8. Certain things can be taken from the European Union's experiences to improve the policy structures in Canada. One example involves the legal ambiguities that currently exist for EV batteries, and producers and consumers. The current assumption, based on EPR principles, is that producers will take back batteries once they have reached their end-of-lives. However, existing battery EPR programs were developed before the widespread adoption of EVs and did not anticipate the issue of end-of-life EV batteries. Only a few jurisdictions, such as Germany, have amended or developed legislation that focuses on EV batteries. Since the development of EV batteries occurs outside of Canada, this would subject them to federal jurisdiction as they are international and interprovincial commerce. This section will list several recommendations for the Government of Canada and the provincial governments to consider when developing future policies on the issue of end-of-life batteries.

Recommendation 1: Develop a National EPR System for End-of-Life EV Batteries

The Government of Canada should develop and implement, in conjunction with the provinces and territories, a national EPR system for EV batteries that have reached their end-of-lives.

This will ensure that producers are responsible for financing the collection and recycling of EV batteries, and avoid situations of consumers having to dispose of these battery packs. Since these batteries are imported into Canada, the federal government would be responsible for developing standards, similar to emission standards for cars.

One of the significant issues with EV batteries is the design. As mentioned in this paper, EV battery packs are becoming more difficult to disassemble, as producers favour performance over future disassembly. This can damage the prospects of second-lives for EV batteries because of the added difficulty of repair and extracting the valuable components.

Recommendation 2: Mandate Design for Disassembly for EV Batteries

The Government of Canada should develop regulations that require design for disassembly for EV batteries. This would be in conjunction with the national EPR system established through recommendation 1.

EPR can incentivize producers to design for end-of-life disposal of battery packs, and make disassembly a more straightforward process for recyclers in Canada and abroad. This would also help stimulate the second-life application market, as it would be theoretically easier to retrofit EV battery packs for other uses.

As mentioned in the analysis of Canada, there is a lack of a clear understanding regarding which level of government is responsible for policy development and enforcement for end-of-life EV battery rules. The provincial and federal levels of government have not engaged on this issue. Currently, the federal government manages the interprovincial movement of hazardous waste along with imports and exports, while the provincial governments monitor waste management facilities and develop policies to reduce waste.

> ***Recommendation 3: Clarify the Application of Provincial Battery EPR Requirements to EV Batteries***
>
> The provinces should clarify the application of battery EPR programs to EV batteries. Program legislation and regulations should make clear that the original producers/distributors are responsible for the end-of-life management of EV batteries. Producers/distributors must ensure the environmentally sound re-use, dismantling and recycling of batteries and their components.

Addressing the legal questions surrounding the ownership of EV batteries given second-lives is imperative. While EPR is an effective tool for alleviating the burdens of waste management on municipalities and consumers, it is not a perfect tool. It fails to address issues of second-lives for batteries. If the consensus is to exploit EV batteries for second-lives, how would EPR affect the responsibilities of producers? Would producers remain responsible for batteries during their second-lives? Where does responsibility end for producers? For example, if an EV battery is utilized as an advanced energy storage unit for renewable energy generation, would the original producer be responsible for when the battery enters its end-of-life? These questions are yet to be answered, and they form a portion of the concerns of EPR critics.

Recommendation 4: Clarify Ownership and EPR Responsibilities for EV Batteries Given Second-Lives

The Government of Canada and the provincial governments should clarify who is responsible for EV batteries that are given second-lives.

One solution is for producer responsibility to extend beyond the first sale of an EV, as the market for used electric vehicles will continue to grow. Producers would be responsible for batteries throughout their lifecycles in EVs and second-lives. An alternative is to allow producers to enter into agreements with businesses that will retrofit batteries for second-uses and will accept the responsibilities and liabilities normally placed on producers in EPR. Providing this flexibility can allow for growth in second-life markets because producers would no longer be responsible at the end of the second-life or if an accident occurs.

The categorization of end-of-life EV battery packs as hazardous wastes or dangerous goods is another question that remains unanswered. While the internal components of EV batteries can be subject to hazardous waste regulations, there is a lack of clarity on battery packs as a whole. Currently, federal regulations on interprovincial and international transport of hazardous wastes could apply to batteries, but there is no definitive answer (CEC, 2015). A similar situation exists with respect to the intra-provincial movement of end-of-life EV batteries.

Recommendation 5: Clarify the Status of End-of-Life EV Batteries for the Purposes of Federal and Provincial Hazardous Waste, Hazardous Recyclable Materials, and Transportation of Dangerous Goods Regulations

The Government of Canada must determine if EV battery packs should be classified as hazardous waste under the Transboundary Movement of Hazardous Waste and Hazardous Recyclable Materials Regulation or as dangerous goods for the purposes of the Transportation of Dangerous Goods Act. The provinces should make similar determinations under their waste management and transportation of dangerous goods legislation.

Clarifying these issues can help develop policies that appropriately handle the end-of-lives for EV batteries. In addition, some battery packs are sent abroad to receive recycling and disposal treatments from various recyclers in Europe and Asia (CEC, 2015). The federal government should implement policies to ensure, consistent with the provisions of the Basel Convention (Secretariat of the Basel Convention, 2011), that the practices of overseas recyclers ensure the environmentally sound management of end-of-life batteries. This is to safeguard Canada from potential liabilities and establish relationships with partners that prioritize environmental protection.

Finally, the reporting on EV batteries appears to be an issue that is currently affecting the European Union, and one that must be avoided in Canada. For industrial batteries in the European Union, there is no reporting or systematic analysis of data for batteries placed on the market or collected (Stahl, 2018). A lack of reporting data can lead to the disposal of batteries through methods not permitted by the Battery Directive.

One argument against this claim is that because of the inherent value of the battery components, producers will not refuse to accept or dispose of batteries inappropriately. This claim can be dangerous as it relies on the assumption that value will result in demand for these batteries, and producers would have no incentive to refuse the take-back. This may be true in the current environment due to the lack of end-of-life batteries in circulation, but in the future could pose a more significant problem with the rising sales of EVs. It also hinges on the belief that commodity prices for the battery constituents are protected from market fluctuations, which is false (Kurdve et al., 2019).

Recommendation 6: Establish Reporting and Compliance Requirements Regarding the Fate of End-of-Life EV Batteries

The federal government and the Provinces should develop reporting requirements around the fate of end-of-life EV batteries.

EV batteries pose higher risks than consumer batteries because of the chemistries and the original purpose of these products for high-performance use. Effective oversight can be achieved through strict annual reporting and requiring producers and third-party battery collectors to show evidence that the rules are being followed.

While the issue of end-of-life batteries has not become large enough to warrant an immediate policy response, policymakers should practice the precautionary principle. Much can be learned from the European Union on this issue. The recommended approach for Canada is a national, joint federal-provincial EPR program. The federal government should handle the issues relating to the design and import/export, and the interprovincial movement and status issues that currently exist with EV batteries. The provinces will be responsible for addressing the specifics of the EPR requirements in order to develop structures that respond to their needs. Canada must avoid the shortcomings that currently exist with the Battery Directive to ensure sufficient policy structures are developed to manage the end-of-life for EV batteries.

Section 7: Conclusion

EVs represent the future of vehicular transportation around the world. With the pollution that is caused by ICE-powered vehicles and is currently being experienced by countries today, EVs can provide a solution to breaking free of the lock-in that exists with the combustion engine. The end-of-life management of batteries has already begun to be addressed by countries and organizations. This involves the development of recycling processes to extract valuable materials from used batteries, along with developing second-lives to delay recycling.

This paper provided a comparative analysis of the current situation regarding EV batteries in the European Union, the United States, and Canada. These findings are summarized in Figure 8 and demonstrate how the European Union has implemented some policy structures for end-of-life EV batteries, while North America has lagged behind. The overarching issues on this topic are linked with socio-technical transitions and the lack of attention to the downstream effects of transitions. Extended producer responsibility represents the dominant theory for managing waste batteries, which is to hold producers responsible for managing the waste they place on the market.

This paper focused on the question of what are the policies and regulatory structures that handle the post-consumer management of EV batteries, and to determine if they were sufficient for ensuring the safe management of these batteries. While the European Union has developed a basic framework on this issue, the United States and Canada, with the exception of Quebec, are falling behind. However, some issues exist regarding EV batteries legislation in the European Union. Focus has primarily been on consumer batteries, which is also seen in North America. This is important as consumer batteries represent a larger share of the current market. However, greater focus must now be placed on high-performance batteries because of the shift away from non-renewable resources and the increasing demand for advanced energy storage. In addition, much of the original battery legislation dates from the 1990s, predating the emergence of EVs and advanced storage as seen today.

Canada has time to address this issue, as the vehicle market is of a smaller size when compared to the United States or the European Union. However, that does not allow policymakers to delay a policy response, as there has been with various environmental problems in Canada’s past. Addressing this issue now will avoid the need for a swift and reactive policy response when EV batteries are entering waste streams at more substantial quantities. The various levels of government in Canada must collaborate and develop policy structures that avoid future environmental harm from a technology that has the potential to change how our society functions.

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