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Post-Consumer Management of End-of-Life Electric Vehicle Batteries

A Comparative Study of Regulatory Regimes in Canada, the U.S. and European Union

Mark Winfield, Jonathan Myers, and Sumeet Sooch

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About the Sustainable Energy Initiative

The challenges of climate change and the need to support sustainable energy, economies and communities inspired the Faculty of Environmental and Urban Change (EUC) to establish the Sustainable Energy Initiative. SEI builds and strengthens research, education and skills for students and professionals in energy efficiency and conservation, renewable energy sources and community energy planning. SEI seeks collaboration and partnerships to support analysis of technical, economic, social, and political contexts and innovation in sustainable energy and its applications. SEI encourages sustainable, equitable communities in Canada and around the world.

What we do:

- Provide research and analysis to advance policies, projects and practices that encourage and support a transition to a sustainable energy economy and resilient communities;
- Support undergraduate and graduate student teaching and research, including the EUC Certificate in Climate Solutions and Sustainable Energy, to educate and train the new cohort of sustainable energy entrepreneurs, social innovators, policy-makers, and community activists;
- Build and strengthen partnerships among educational institutions, government agencies, business and industry, and non-governmental organizations through research, knowledge mobilization, and field experiences; and
- Provide learning opportunities for professionals to enhance their knowledge of leading-edge research and practice about sustainable energy solutions.

About the Authors

Mark Winfield is a Professor of Environmental and Urban Change at York University. He is also Co-Chair of the Faculty's Sustainable Energy Initiative, and Coordinator of the Joint Master of Environmental Studies (MES)/Juris Doctor (JD) program offered in conjunction with Osgoode Hall Law School. He has published articles, book chapters and reports on a wide range of climate change, environment and energy law and policy topics.

Jonathan Myers completed the MES/JD Program at the Faculty of Environmental and Urban Change and Osgoode Hall Law School in 2023. His graduate-level research examined the circular economy and sustainability and how those concepts interact with energy transitions in response to climate change. Jonathan is currently completing his articling placement, and he hopes to practice litigation related to environmental and natural resources law.

Sumeet Sooch is a graduate of the Master of Environmental Studies (2020) at York University and is a third-year student in the JD program at Osgoode Hall Law School in Toronto, Ontario. His graduate-level research concerned environmental policy and sustainability, with a focus on energy storage and electric vehicle battery recycling. In law school, Sumeet has focused on expanding his knowledge in the practice areas of corporate, securities and tax law.

The authors also thank EUC BES alum **Abdeali Saherwala** (BES Hons, York; MEM, Yale) and MES/JD student **Angela Dittrich** for their contributions to this report.

Executive Summary

The electrification of passenger road transportation through the replacement of internal combustion engine (ICE) vehicles with electric vehicles (EVs) will help to mitigate climate change by reducing transportation-related greenhouse gas (GHG) emissions. However, the electrification of road transportation has the potential to create significant negative risks and impacts related to human health and the environment of its own. In addition to the impacts related to the need for increased electricity generation, which fall beyond the scope of this report, these negative risks primarily occur within two stages of the EV battery life cycle: material supply chains; and end-of-life (EoL). The extraction and processing of materials, particularly those classified as 'critical' minerals for EV battery production, can carry major negative environmental and social consequences. The need for expanded extractive activities should be limited to the greatest extent possible for these reasons. The recovery, reuse, and recycling of materials contained in EoL EV batteries offers the potential to reduce demand for newly extracted materials in this context. However, EoL EV battery recycling processes can themselves be energy-intensive and generate potentially hazardous emissions and waste streams.

The report examines the EoL EV battery management regimes in Ontario, Quebec, British Columbia, California, and the European Union through a sustainability assessment lens. It finds that regulatory frameworks for EoL EV battery management are essentially non-existent in North America, although B.C. and California may be moving in the direction of establishing preliminary regulatory structures, and Quebec launched a voluntary recovery system in June 2023. In contrast, EoL EV batteries have been managed under a European Union (EU) Battery Directive since 2006. The EU adopted an updated regulatory framework in June 2023 that will be binding on all Member States. The EU regime is based on extended producer responsibility (EPR) principles and establishes systems for tracking the fate of EoL EV batteries, including 'battery passports.' The paper recommends the development of a national regime for EoL EV battery management in Canada, following the model of the key elements of the EU regulation. The need for additional measures, particularly transportation demand management strategies, to reduce overall demand for private passenger vehicles, is also highlighted. The need to build and maintain strong regulatory regimes around extractive activities related to EV battery supply chains is emphasized as well.

Preface

This report flows from a number of research projects that the York University Faculty of Environmental and Urban Change Sustainable Energy Initiative (SEI) has participated in or led. The most significant of these was the Natural Sciences and Engineering Research Council (NSERC) Network on Energy Storage Technology (NEST) led through Ryerson University (now Toronto Metropolitan University). SEI led the policy component of the NEST research stream focussed on economics, policy and social acceptance.

The primary focus of the policy dimensions of this work was on grid-based applications of advanced energy storage technologies, particularly as part of what are now referred to as distributed energy resources (DERs). Among other things there was interest in the potential roles of electric vehicle (EV) batteries that had reached the end of their life in vehicle applications, in 'second life' grid uses as parts of DER or microgrid systems.

The NEST research stream led into wider questions about the management and ultimate fate of end-of-life (EoL) EV batteries, especially their status within regulatory regimes for recycling and waste management. These inquiries led to the completion of two major research papers through the Master of Environmental Studies (MES) and Master of Environmental Studies/Juris Doctor (MES/JD) programs at the Faculty of Environmental and Urban Change and Osgoode Hall Law School at York University by the co-authors of this paper, Sumeet Sooch (2020) and Jonathan Myers (2023), respectively. Both papers are available via the SEI website.

The significance of the findings contained in these two papers, particularly the lack of any meaningful regulatory regimes around EoL EV battery management in North America, and the contrast between the situation in Canada and the U.S. and that found in the European Union, was seen to warrant their publication in the stand-alone report presented here as part of the SEI Studies in Energy Policy paper series.

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List of Acronyms

B.C.	British Columbia
BMS	Battery management system
CEPA	*Canadian Environmental Protection Act*
DFE	Design for environment
EMC	Electric Mobility Canada
EoL	End-of-life
EPA	Environmental Protection Agency
EPR	Extended producer responsibility
EU	European Union
EV	Electric vehicle
E-waste	Electronic waste
FNRI	First Nations recycling initiative
GHG	Greenhouse gases
ICE	Internal combustion engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle analysis
MECP	Ministry of Environment, Conservation, and Parks
OEM	Original equipment manufacturer
RPRA	Resource Productivity and Recovery Agency
SOH	State of health
UN SDGs	United Nations Sustainable Development Goals
U.S.	United States
ZEV	Zero-emissions vehicle

1. Introduction: Key Challenges in Decarbonizing Transportation Systems

The scientific community has reached an overwhelming consensus that anthropogenic releases of greenhouse gases (GHGs) have led to increasing concentrations of these gases (principally carbon dioxide and methane) in the upper atmosphere. This has, in turn, enhanced the “greenhouse effect” through which heat is trapped by these gases and re-radiated back towards the Earth’s surface, leading to increases in average global temperatures. The overall effect is producing significant negative changes in the planet’s climate, including incidents of extreme weather, droughts, flooding, sea level rise, and wildfires (Natural Resources Canada, 2016). The United Nations Intergovernmental Panel on Climate Change (IPCC) has consistently recommended reducing GHG emissions as the main strategy for mitigating the effects of climate change (Intergovernmental Panel on Climate Change, 2021). Canada, for its part, has committed to reducing its GHG emissions by 40-45% relative to 2005 levels by 2030, and to achieving net-zero emissions by 2050 (Environment and Climate Change Canada, 2023).

Most anthropogenic greenhouse gas emissions result from fossil fuel combustion and industrial processes (Intergovernmental Panel on Climate Change, 2021, Chapter 1). In order to reduce such emissions, the IPCC and other authorities have strongly supported a transition away from fossil fuels as a primary energy source. The electrification of road transportation, which produces 14% of global GHG emissions (United States Environmental Protection Agency, 2022a), is also widely accepted as an essential component of effective decarbonization plans.

The Canadian federal government, as well as the provincial governments of Ontario and Quebec, have committed billions of dollars to the development of electric-vehicle (EV) battery manufacturing facilities and supply chains (Radwanski & Stone, 2023; The Canadian Press, 2023). Substantial support is also being provided by the federal government and various provincial governments to subsidize EV purchases for Canadians (Transport Canada 2023) and for the development of EV charging infrastructure (Natural Resources Canada, 2023). Regulatory proposals are also under consideration to mandate 100% zero emission vehicle sales for light duty vehicles by 2035 (Environment and Climate Change Canada, 2023).

Electric vehicles outperform conventional internal combustion engine (ICE) vehicles by wide margins in terms of their direct emissions of GHGs and other pollutants, as well as energy use. However, the electrification of transportation through the adoption of EVs does raise a number of wider sustainability issues when viewed on a life cycle basis. Key questions that arise in this context are:

- The need for increased electricity supplies to meet the additional demand flowing from the widespread adoption of EVs;
- The impacts and risks associated with the material and supply chains needed for EV manufacturing, particularly the mining of "critical" minerals (Natural Resources Canada, 2022) for EV battery production; and
- The management and disposal of end-of-life (EoL) EV batteries. EV batteries are complex manufactured products that may contain, among other things, materials that are classified as "toxic" for the purposes of the *Canadian Environmental Protection Act* (CEPA) and other legislation.

The question of managing increased electricity demand due to the electrification of transportation is beyond the scope of this report. The issue is being examined through a number of other studies being undertaken by governments, utilities, non-governmental organizations, and the academic community (Lusney, 2022; Green & Thomas, 2022; Independent Electricity System Operator, 2022; Canadian Energy Regulator, 2023).

This report is focussed on the second and third key issues in a sustainability context: the development of supply chains for EV batteries, including mineral resources, and the management of EoL EV batteries. The Canadian federal government, and various provincial governments, are aggressively supporting the development of Canada's "critical" mineral resources for EV battery manufacturing (Natural Resources Canada, 2022; Government of Ontario, 2022), but there has been little action or discussion so far regarding what will happen when EV batteries reach their end-of-life. This is despite the potential connections between the two issues. In addition to the need to prevent harm to the environment or human health from EoL EV battery disposal, materials recovered from EoL batteries could reduce the need for the mining of new critical materials, and the negative environmental, health and social impacts associated with those extractive activities.

In that context, this report specifically examines the state of the development of policy and regulatory regimes for the post-consumer management of EoL EV batteries in Canada, the United States, and the European Union. Based on a comparative analysis of the approaches being taken in selected jurisdictions, the report makes recommendations for a Canadian policy and regulatory regime for EoL EV batteries. Beyond this introduction, the second section of the report provides a background discussion of sustainability issues in EV material supply chains. Section 3 focuses on the development of a framework for evaluating EoL EV battery management regimes, grounded in the United Nation Sustainable Development Goals (SDGs), the literature on sustainability assessment, and extended producer responsibility (EPR) principles. This is followed by five case studies examining the policy and regulatory regimes for EoL EV batteries in Ontario, Quebec, British Columbia, California, and the European Union. The existing and emerging regimes are assessed relative to the framework developed in Section 3. The final section draws conclusions and makes recommendations for an EoL EV battery regime for Canada.

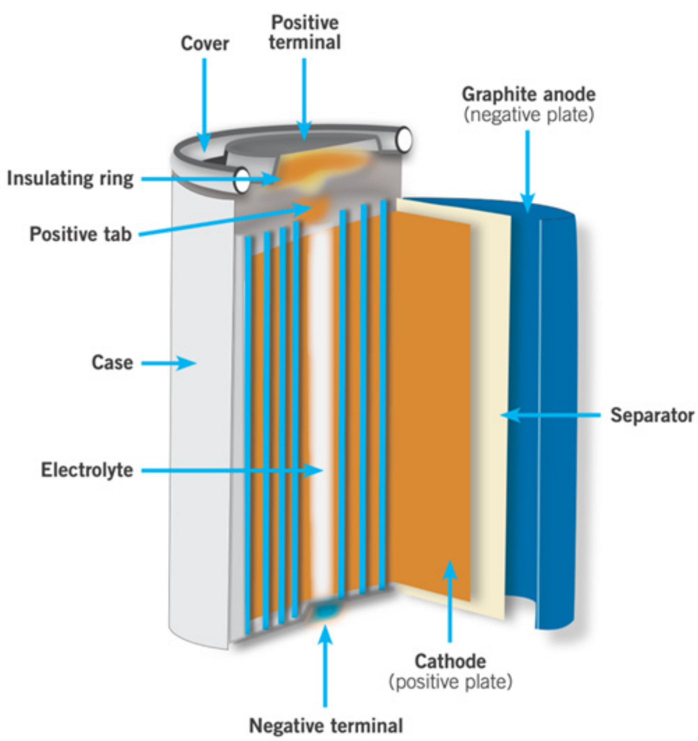
2. Sustainability in EV Battery Material Supply Chains

It is widely accepted that the electrification of road transportation will be a crucial step towards the decarbonization of the transportation sector. The transition would mean that cars and trucks, which have traditionally been powered by internal combustion engines (ICE) that have run on either fossil fuels (e.g., gasoline and diesel) or biofuels, would largely need to be replaced by battery-powered electric vehicles. Other technologies, like hydrogen-based fuel cells, may also play roles in the transition. However, as noted in the introduction, there may be significant negative environment, social, and health impacts associated with the electrification of transportation, stemming primarily from the supply chains for the materials used in the manufacturing of EV batteries, and their ultimate disposal.

Electric Vehicles and Batteries

There are three major types of EVs: hybrid electric vehicles (HEVs); plug-in hybrid electric vehicles; and battery electric vehicles (Kelleher, 2020). Common battery chemistries for some HEVs were nickel-metal hydride, but most EV batteries are now lithium-ion (Kelleher, 2020) as shown in **Figure 1**.   The lithium-ion category can be broken down into more specific battery chemistries, with the two most popular being lithium nickel manganese cobalt and lithium nickel cobalt aluminum (Kelleher, 2020).

Figure 1: Components of a Lithium-Ion Battery (Castro Diaz, 2015)



EV batteries are complex manufactured products, involving substantial investments of energy, labour and materials. Some of the materials used in their construction may be classified as "toxic" or hazardous. This implies that the recycling of EoL EV batteries containing these materials can involve significant environmental and health risks of its own. If EV batteries are sealed, they are seen to pose minimal risks to the environment and human health. However, if the constituents are released during disassembly or due to a broken seal, there is a greater risk of adverse environmental impacts due to the leakage of the hazardous materials (Casto Diaz, 2015).

The materials used in EV battery manufacturing include steel, zinc, manganese, nickel, cobalt, and other metals, as well as water, and other non-metal materials. The specific components present vary with battery design (Casto Diaz, 2015). Nickel, which is widely used in EV battery manufacturing is, for example, 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 (Casto Diaz, 2015).

Manganese is a significant compound in nickel-metal hydride (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 (Casto Diaz 2015).

Lithium-ion batteries (LIBs) are 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 cause severe burns if combined with water (Casto Diaz, 2015). Another common compound within LIBs is cobalt, which is also categorized as a toxic substance under CEPA (Casto Diaz, 2015).

EV Battery Life Cycles, Risks, and Impacts

The production, use, recycling and final disposal of EV batteries may negatively impact human health and the natural environment in many ways. The nature of these impacts can be best understood through a life cycle analysis (LCA) of the production, use and ultimate fates of EV batteries.

An LCA takes a product's full life cycle into account starting from resource extraction, on to production and use, and concluding with EoL management (which includes recycling and disposal of any remaining materials). A 2020 study by Temporelli, Carvalho, & Girardi compared seventeen LCAs of electric-vehicle batteries and identified the phases of the EV battery life as: 1) raw materials extraction and processing; 2) battery production; 3) transportation; 4) use phase; and 5) EoL with material recycling and disposal. For the purposes of this study, EoL is considered the point at which a battery is no longer desirable for use in any energy-related applications and would require some form of end-of-life management, specifically some form of recycling and/or disposal. **Table 1** breaks

Table 1: Life Cycle Stages of EV Batteries and their Environmental, Social and Health Risks and Impacts

Life Cycle Stage	Activities at this Stage	Negative Impacts and Risks
Raw Materials Extraction and Manufacturing	Mining metals like lithium and cobalt because there is not an adequate supply in the market (Church & Wuennenberg, 2019).	Land disruptions -- Estimates show that in order to produce the metal for one billion EVs, 156,000 sq km of land will be disrupted (The Metals Company, 2020).
	Most cobalt is mined in the Democratic Republic of the Congo (DRC) (United Nations Conference on Trade and Development, 2020).	Cobalt mines contain sulphur minerals that can create sulfuric acid when encountering air or water, contaminating water sources and affecting aquatic life for hundreds of years (United Nations Conference on Trade and Development, 2020).
	Cobalt mining has been linked to human toxicity concerns, classifying the possible health effects as either cancer or non-cancer. Blasting and refining processes release particles from these ores into the air, which can then be ingested by people living near mines and refineries and by the miners, who particularly inhale large quantities of particles that are in the air (Farjana, Huda, & Mahmud, 2019).	Cobalt and cadmium are responsible for cancer effects (Farjana, Huda, & Mahmud, 2019).
	There are significant lithium deposits in South America, between Bolivia, Argentina, and Chile (Campbell, 2022).	Lithium extraction leads to biodiversity loss, water contamination, and water shortages, which are especially problematic in arid areas where water is scarce (Campbell, 2022). Soil contamination along with water loss and other forms of environmental damage have forced some South American communities to leave ancestral settlements (United Nations Conference on Trade and Development, 2020).
	Conditions in many of the mines are poor and dangerous. Workers earn wages of $3.50 USD per day, with pay being deducted for sick days (Pattison, 2021). Increased pressures for new mine development to supply critical minerals in Canada.	In the DRC, there have been concerns about environmental and health impacts of mining as well as human rights violations for the treatment of miners (Pattison, 2021). High risk of serious negative environmental and climate impacts, particularly in the boreal region and potential negative effects on Indigenous communities on whose treaty or traditional territories critical minerals may be found. Potential negative impacts on reconciliation with Indigenous peoples.
Battery Production	There is currently specific data available on the environmental and health impacts of EV battery. However, these complex processes that may involve materials classified as "toxic" for the purposes of CEPA and other legislation.	One can reasonably conclude that the dangers are similar to the dangers present at EoL, which are risks of exposure to toxic materials, the risk of combustion and fire, and the risk of electrocution since the batteries carry an electric charge.
Transportation	Once the batteries are manufactured, they must be transported to the original equipment manufacturer (OEM) where they will be inserted into electric vehicles. It is important that new batteries are packaged properly to protect against potential physical damage.	The unsafe transportation of EV batteries can potentially lead to contamination for individuals transporting batteries or in the case of an accident could cause a fire and the release of toxic, corrosive, or flammable gases that could contaminate air, ground, and water sources (Ottaviani, 2022).

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Life Cycle Stage	Activities at this Stage	Negative Impacts and Risks
Use Phase	EV batteries are generally regarded as safe when inside vehicles unless they become damaged through an accident.	If a battery were damaged during use, the same hazards would likely be present such as those at battery production and at EoL, which are risks of exposure to toxic materials, the risk of combustion and fire, and the risk of electrocution since the batteries carry an electric charge.
EoL including material recovery and recycling, and final disposal	Batteries that can no longer be repaired, repurposed in a vehicle, or repurposed in a second-life application, such as stationary energy storage, will have reached EoL. These batteries must first be safely removed from vehicles before they can be transported to recycling facilities.	Disassembly requires high levels of expertise and exposes dismantlers to the electric charge and hazardous chemicals within EV batteries.
	After removal, batteries will be sent to a recycler where they will be recycled in one of three processes: dismantling or disassembly and reuse and/or recycling of components, pyrometallurgical recycling, and hydrometallurgical recycling.	Disassembly or dismantling involves removing and utilizing working components of a battery. There are few environmental risks associated with dismantling or disassembly beside those that generally accompany battery removal (Baltac & Slater, 2019). Pyrometallurgy involves the use of high temperatures that cause smelting, thereby separating materials that are recovered as alloys. The by-product of this process is known as furnace slag, which must be treated as hazardous waste due to its potential for environmental damage. There is also the potential for hazardous emissions (Baltac & Slater, 2019). Hydrometallurgy uses acids to dissolve the metals in EV batteries in a process called leaching. The process utilizes dangerous chemicals such as sulfuric acid that can be harmful to human health and the environment. The acidic liquid leftover after leaching the metals is again hazardous waste that must be treated and properly disposed of (Baltac & Slater, 2019).
	Second-life facility, household and electricity grid level uses for EV batteries are emerging. These applications will extend the useful life of EV batteries, although they will ultimately require some form of EoL management.	

down the stages of the EV battery life cycle according to the steps outlined by Temporelli, Carvalho, & Girardi (2020) and summarizes the activities and key environmental, health, and social risks and impacts resulting from each stage.

Table 1 reveals that the most significant environmental, social, and health risks and impacts of EV battery life cycles occur during the raw materials extraction and processing phases of battery production and at EoL.

Publicly available information on the actual fate of EoL EV batteries in North America is extremely limited. It has been argued that the value of EoL EV batteries to recyclers and manufacturers is high enough to prevent them ending up in landfills or long-term storage. (Interview B, 2022). However, in the absence of any transparency requirements around recovery rates and the tracking of the fate of EoL batteries, it is difficult to substantiate these claims.

With respect to raw materials extraction and processing, the availability of what are being termed “critical” minerals has been identified as a key component of EV battery manufacturing supply chains by the Canadian federal government and many provinces (Natural Resources Canada, 2022; Government of Ontario, 2022). The development of new critical mineral resources (i.e., mines) is being aggressively pursued in Canada and internationally as a result. Minerals identified as critical for EV battery production typically include nickel, lithium, cobalt, manganese, nickel, and graphite (Carreon, 2023). There are growing concerns about the serious negative environmental, economic, social, and cultural impacts that may arise from these developments (Kramarz, Park, & Johnson, 2021).

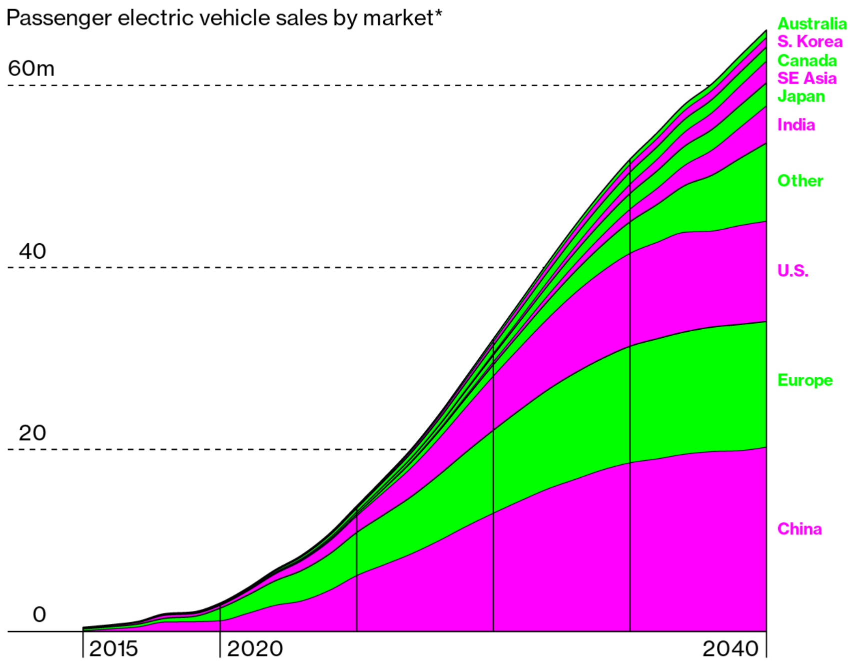
Analyses of the likely scale and character of material supply chains for EV batteries are only beginning to emerge. Initial analyses by the International Energy Agency (IEA), for example, envision potential growth in battery-related mineral demand of between nine and thirty times from 2020 to 2040 (International Energy Agency, 2022). Analyses of the potential environmental and social consequences of meeting such a dramatic growth in minerals demand through new or expanded extractive activities are also only at a preliminary stage (Watari et al. 2019). However, it is important to consider that serious questions have already been raised around the sustainability of existing levels of mineral extraction given its impacts on landscapes, biodiversity, water resources, energy use, and waste generation (Young, 1991; von Weizsäcker, Lovins, & Lovins, 1997; Winfield et al., 2002; Sonter et al., 2020; Council of Canadian Academies, 2021; Cole, 2022; Cundiff et al., 2023), suggesting the need for significant reductions in the materials intensity of economic activities and the rate of primary extraction. The climate impacts of proposed mining development in the Canadian boreal region, itself a major global carbon sink and storage site, has drawn increasing attention (Cimellaro, 2021), as have concerns regarding the impact of critical minerals extraction in the Canada’s territorial North (Struzik, 2023). Proposals for deep ocean mining of critical minerals have also been a source of growing concern due to their impacts on the ocean floor and ecosystems (International Union for the Conservation of Nature, 2022).

The questions of how to manage EoL EV batteries and how to develop material supply chains needed to support EV battery manufacturing can be linked in important ways. A key question will be to what extent the reuse and recycling of EoL EV batteries can offset the need to extract new materials. Research surrounding these questions is at an early stage. Existing research does suggest that effective EoL management regimes could have significant effects on the need for newly extracted materials. For example, a 2020 white paper suggested that EV battery recycling could reduce the need for mining new materials by 20% before 2040, and by 40% before 2050 (Slowik, Lutsey, & Hsu, 2020). Other analysis suggest even higher recovery and substitution rates for materials may be possible under policy regimes emphasizing the circularity of material supply chains (Victor & Chapariha, 2021).

Current Approaches to EoL EV Battery Management

Current estimates suggest that global capacity for recycling EoL EV batteries is 180,000 metric tons per year (International Energy Agency, 2023). Given the rates of projected growth in EV fleets, with 10 million vehicles purchased in 2022 and sales expected to continue to accelerate (International Energy Agency, 2023), supplies of EoL EV batteries may be as high as eight million metric tons per year by 2040 (Stone, 2021). **Figure 2** below summarizes current projections for the growth in EV fleets, with the implication that each vehicle will eventually result in an EoL battery.

Figure 2: Projected Growth in Passenger Sales to 2040 by Market (Bloomberg 2021)



*Battery-electric and plug-in hybrid vehicles.
Source: BloombergNEF Economic Transition Scenario, which assumes no new clean energy policy initiatives are introduced and costs, supply, and demand are controlled by market dynamics. It does not take into account the White House's recently announced goal for half of all vehicles sold in the U.S. to be battery-electric, plug-in hybrid, or fuel-cell-powered by 2030.

Bloomberg

EV batteries can be considered to have reached EoL for a number of reasons. They may fail outright and be unable to be repaired. In other cases, their performance may degrade over time to a point where it is unacceptable from the perspective of vehicle performance, typically in the range of 80% of original capacity (Ramoni & Zhang, 2013). Estimates of the point at which EV batteries will reach EoL in these terms vary. Early projections suggested 7-10 years of regular use (Ramoni & Zhang, 2013). More recent assessments suggest that much longer battery lifetimes in vehicle applications are likely (Dahn, 2021).

Once batteries reach EoL in a vehicle application there are three major options available for their management:

1. Direct disposal via landfill, storage, or incineration;
2. Application in a "second-life" use, such as supporting electricity grid management in a distributed energy system, or to provide building or facility level back-up energy supplies; or
3. Recycling to recover useable materials and components, and then final disposal of the remaining materials.

Direct Disposal

There have been concerns regarding the potential disposal of EoL EV batteries in conventional municipal waste landfills, where there could be risks of hazardous components entering groundwater through leaching, particularly if the battery casing is damaged and materials contained within the battery cathode are exposed. Disposal through incineration or waste-to-energy facilities could also lead to the release of toxic materials into the atmosphere through stack emissions or their presence in bottom or fly ash (Winslow et al., 2018). As noted earlier, it is generally thought that EoL EV batteries in North America are not ending up in landfills or going to other forms of disposal, but there is no publicly available information on their actual fate.

Second-Life Applications

A second-life application is the reuse of a battery pack for a different purpose once the battery can no longer fulfill its original intention (Ramoni & Zhang, 2013). Repurposing batteries increases their total service life, which potentially slows the required rate of resource extraction for new production, and disposal requirements (Jiao & Evans, 2016). Second-life applications for EV batteries also align with the concept of a circular economy, which emphasizes re-using products to reduce the amount of waste generated through the creation of new products with the overarching goal of eliminating waste (Olsson et al., 2018).

The potential for second-life EV batteries to be used for grid energy storage is an area of growing interest. EV batteries could be used in grid applications to provide energy storage capacity in support of intermittent renewable power sources, such as wind and solar energy. Batteries could also be used to provide backup power in the event of a blackout for residential or commercial purposes, to power server farms intended for a variety of electronic services, or support the time-shifting of energy use (Castro Diaz, 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).

While second-life applications are promising, there are some barriers, including the potentially high costs associated with battery refurbishment, the uncertainty of long-term degradation rates, and the consumer perceptions of used batteries (Casto Diaz, 2015). In addition, in Canada there is a lack of market structures and economic models in electricity systems for the types of distributed energy resources (DERs) that second-life EV batteries might provide (Winfield & Gelfant, 2020; Dunsky and Power Advisory, 2022). It is also important to recall that second-life applications do not solve the ultimate problem of end-of-life management, as batteries will still require recycling and disposal once they are completely degraded.

EoL EV Battery Recycling and Disposal

There are three main recycling methods for EoL EV batteries to recover useable components and materials. These are: 1) physical dismantling/disassembly and component reuse and/or recycling; 2) pyrometallurgical recycling; and 3) hydrometallurgical recycling.

Physical Dismantling/Disassembly and Component Reuse and/or Recycling

Dismantling or disassembly of EV batteries can consist of manual and/or automated processes, with valuable components being retrieved in their original state (Baltac & Slater, 2019). These processes allow for some components (e.g., electrodes, wiring, casing) to be reused in new batteries, and others can be recycled using pyro- or hydrometallurgical techniques (see below). The benefit of this method is the absence of intensive chemical or energy usage found in other recycling processes, and the potential for the components to be recovered in useable condition, conserving the original energy and materials embodied in their manufacturing (Watari et al., 2019). A further advantage of a disassembly approach is that the volumes of extraneous materials that ultimately need to be fed into pyro- or hydrometallurgical processes, such as casings, can be greatly reduced, as only components with high concentrations of recoverable materials need to be processed. This reduces the energy and other inputs required for these processes and reduces the volume of final waste produced (Baltac & Slater, 2019).

At the same time, high levels of technical expertise are required for large-scale EV battery disassembly. Disassembly of batteries in laboratory experiments is, for example, sometimes performed in argon gas-filled gloveboxes (Ramoni & Zhang, 2013). Other potential drawbacks include the considerations that the performance of recovered components in new applications may not be 100%, and there is a risk of some components becoming obsolete in the future (Baltac & Slater, 2019).

Pyrometallurgical Processes

Pyrometallurgical recycling, also known as pyrometallurgy, involves the use of heat to recover metallic battery components (Baltac & Slater, 2019). Within these processes, batteries are typically shredded, and useable components may be recovered. They are then placed in high-temperature furnaces (i.e., smelters). These burn away materials like graphite anodes, aluminum wires, paper, and plastic casings. Other components, particularly metals such as copper, cobalt, nickel, and iron, can then be recovered (Baltac & Slater, 2019).

Pyrometallurgy is an energy-intensive process that can produce significant negative environmental impacts. The process can generate high levels of emissions of conventional (e.g., smog and acid rain precursors) and hazardous (e.g. heavy metals) air pollutants. As renewable energy sources cannot generate the energy required for hydrometallurgical processes, they are typically powered by coal or natural gas, resulting in substantial GHG emissions of their own (Baltac & Slater, 2019).

Pyrometallurgical processes also produce significant amounts of slag, potentially containing lithium, aluminum, silicon, calcium, and some iron compounds. Recovering useful materials from the slag is generally not economically feasible. Some recyclers do sell or reuse the slag in other products, such as cement additives, but in general it requires disposal, sometimes, depending on its contents, as a hazardous waste (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). Claimed recovery rates from pyrometallurgy for raw materials to be used for making new products are up to 85% (Canadian Vehicle Manufacturers' Association, 2021a).

Hydrometallurgical Processes

Hydrometallurgical recycling, also known as hydrometallurgy, is a process that utilizes acids to dissolve and extract the metal components of the battery through 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 partially separates metals from paper, plastics and other materials prior to acidification. Once the materials are dissolved into an acid solution, the solutions are put through solvent extraction, chemical precipitation, or electrolysis processes to separate the desired metals (Baltac & Slater, 2019). In theory, the recovery rate for components can be high due to the nature of the process that separates individual elements as inorganic salts (Baltac & Slater, 2019).

An advantage of hydrometallurgy is that it can be customized to each battery type. This can also be a disadvantage in that multiple battery chemistries cannot be recycled at once. The composition of batteries must be known beforehand so that they can be sorted by their chemistry (Kushnir, 2015). Recycling sequences must be optimized for each battery chemistry to ensure high recovery rates and favourable economics (Baltac & Slater, 2019).

Although less energy-intensive than pyrometallurgy, hydrometallurgy creates more difficult to manage waste streams. The by-products of hydrometallurgical processes can include acidic liquid wastes containing hazardous materials that typically need to be managed as hazardous wastes. Organic acids such as citric or malic acids have been proposed as more environmentally friendly alternatives but have yet to be widely adopted (Winslow et al., 2018). Claimed recovery rates from hydrometallurgy for raw materials to be used for making new products are up to 95% (Canadian Vehicle Manufacturers' Association, 2021a).

Among the three main recycling processes for EoL EV batteries, approaches rooted in maximizing the potential for physical dismantling first are generally preferred from a sustainability perspective (Ramoni & Zhang, 2013; Baltac & Slater, 2019). They allow for the recovery of complete and potentially reuseable components, conserving the material and energy embedded through their original production. Dismantling also offers the potential to minimize the amounts of material ultimately handled through hydro- and pyrometallurgical processes, reducing the required inputs of energy and chemicals, and outputs of wastes associated with these processes. Design for disassembly may also facilitate repairs to extend battery life and refurbishments for second-life uses. Unfortunately, as will become apparent in the following sections, EV manufacturers are moving in the opposite direction in terms of battery design, favouring the use of stronger adhesives and welding to bond components, which makes disassembly more difficult.

3. Designing an EoL EV Battery Management Framework

Research Approach

This study assesses the current state of regulatory regimes around EoL EV batteries in Canada, the United States and the European Union. It utilizes both interviews with stakeholders and literature reviews to inform its conclusions and recommendations. The goal of the interviews was to have stakeholders provide updates on management regimes for EoL EV batteries across jurisdictions in Canada, the U.S., and the EU. Managing EoL EV batteries is a novel, dynamic field. Stakeholders were able to provide more up-to-date pictures of current practices than the formal peer-reviewed literature. To protect the anonymity of interviewees, each interviewee is identified by a letter (e.g., Interview A, 2022) where references are made to information gathered through interviews. A list of the interviews referenced in the paper with dates and geographic locations of interviewees is provided at the end of the bibliography.

Case Study Selection

The literature reviews provided the bulk of the background information for the analysis. Five jurisdictions were chosen as case studies for this report: Ontario; Quebec; British Columbia; California (U.S.); and the EU. The Canadian federal government has made no significant statements to date regarding the establishment of a policy or regulatory regime for EoL EV batteries and therefore was excluded from the detailed analysis.

Among the provinces, Ontario is the home jurisdiction of the authors and has aggressively positioned itself as a leader in EV battery manufacturing and as a supplier of critical minerals for that purpose (Government of Ontario, 2023). Quebec and British Columbia are unique among the other provinces in having made formal policy announcements regarding EoL EV battery management regimes. Quebec stated its intention to set minimum recovery rates for EV battery producers in 2021, along with regulations for smaller and lead-acid batteries (Dentons, 2022). British Columbia has released an Extended Producer Responsibility Five-Year Action Plan ("the Five-Year Action Plan") that includes plans to expand the province's battery regulation to include EV and HEV batteries (Ministry of Environment and Climate Change, 2021). Implementation would not take place until 2024 at the earliest.

The U.S. federal government has provided substantial new subsidy programs around EV battery recycling through the 2021 *Jobs and Investment Act* and 2022 *Inflation Reduction Act* (Carreon, 2023). However, it has been silent on the question of regulatory requirements around EoL EV battery management. It was excluded from the analysis for this reason. Among the U.S.

states, California has emerged as a leader. The work of the Advisory Group on Lithium-ion Car Battery Recycling, established under California Assembly Bill AB-2832, represents the most extensive investigation in the U.S. of potential EoL EV battery regimes to date. The Advisory Group's report (Kendall, Slattery & Dunn, 2022) and discussions provided important insights into the thinking of key actors, including the original equipment manufacturers (OEMs), on EoL management of EV batteries.

The European Union presents the most robust EoL EV battery management regime developed so far. The EU's approach has been grounded in a 2006 Directive on batteries and accumulators (2006/66/CE), which explicitly included EV batteries, and a 2000 Directive on end-of-life vehicles (2000/53/CE). The EU has recently adopted a Regulation Concerning Batteries and Waste Batteries, repealing the 2006 Directive and amending Regulation (EU) No 2019/1020 (Council of the EU, 2023).

It is important to note that EoL EV batteries are not categorized as hazardous wastes or hazardous recyclable materials for the purposes of Basel Convention on the Transboundary Movement of Hazardous Wastes and Hazardous Recyclable Materials, and therefore fall outside of its regime for tracking the movements of these materials and obtaining prior informed consent from the counties of import. E-wastes and lead-acid batteries are covered by the Convention. The status of EoL EV batteries for the purposes of domestic hazardous waste and transportation of dangerous goods regimes was found to be indeterminate in Canada, the United States and EU.

Developing a Framework for an EoL EV Battery Management Regime

Sustainability Considerations

The United Nations (UN) Brundtland Commission (a.k.a. the World Commission on Environment and Development) first defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" in 1987 (World Commission for Environment and Development, 1987). The United Nations has since outlined 17 Sustainable Development Goals (the UN SDGs). These aim to support the 2030 Agenda for Sustainable Development, which has been adopted by all UN Member States (United Nations Department of Economic and Social Affairs, 2022). The 17 UN SDGs are as follows: 1) No poverty; 2) Zero hunger; 3) Good health and well-being; 4) Quality education; 5) Gender equality; 6) Clean water and sanitation; 7) Affordable and clean energy; 8) Decent work and economic growth; 9) Industry, innovation, and infrastructure; 10) Reduced inequalities; 11) Sustainable cities and communities; 12) Responsible consumption and production; 13) Climate Action; 14) Life below water; 15) Life on land; 16) Peace, justice, and strong institutions; 17) Partnerships for the goals (United Nations Department of Economic and Social Affairs, 2022). Each of the goals contains their own targets and actions toward achieving those targets (United Nations Department of Economic and Social Affairs, 2022).

The Brundtland sustainable development principles and the SDGs served as a framework to guide the development of an EoL EV battery regime in this report. Within the contexts of sustainability and waste management, as in the case with EoL EV batteries, a hierarchy of waste reduction and reuse, followed by recycling, is widely accepted (Macdonald, 2020).

The framework used in this study is also informed by Robert B. Gibson's work on sustainability assessment, particularly the importance of identifying potential trade-offs among sustainability goals and adopting pathways that avoid or minimize these trade-offs to the greatest extent possible (Gibson 2006; 2016). This rule provides important guidance in approaching the design of an EoL EV battery management regime. Electrification of road transportation through the adoption of EVs offers significant potential to reduce transportation-related GHG emissions. At the same time, policymakers and stakeholders need to ensure that the potential trade-offs created though the electrification of road transportation do not compromise the overall net sustainability gains sought by transitioning away from internal combustion engine (ICE) vehicles.

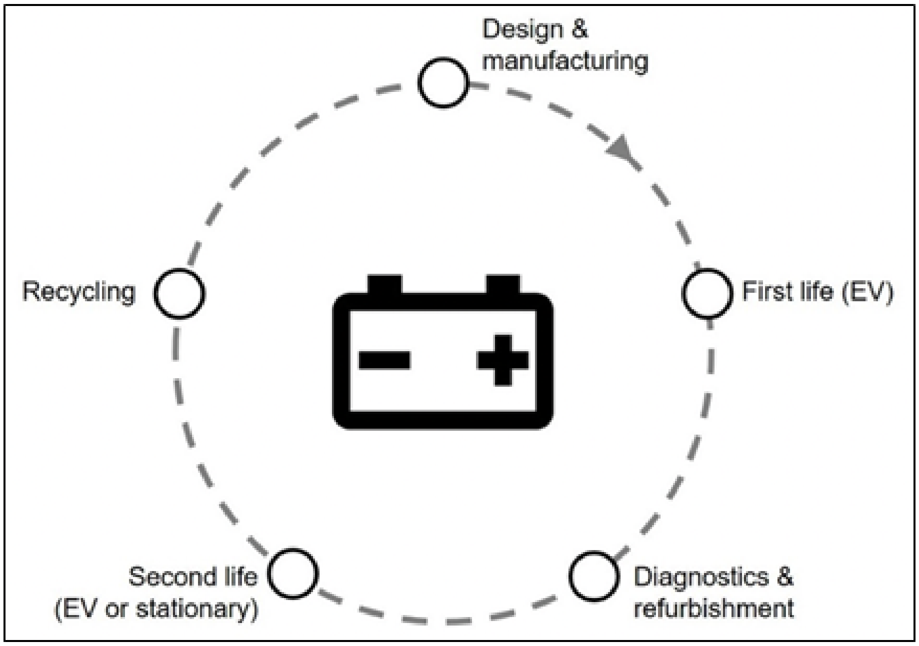
Extended Producer Responsibility

Extended Producer Responsibility (EPR) is a policy approach where a producer's responsibility, both financially and in some cases, functionally, is extended to the post-consumer stage of its products (Environment and Natural Resources Canada, 2017). EPR systems are usually linked to requirements that producers not simply provide for the disposal of end-of-life products, but also that producers ensure that their products or their components are reused or recycled. In principle, EPR systems aim to motivate producers to facilitate the reuse and recycling of their products by making them responsible for their products' post-consumer management costs. The transfer of post-consumer management costs back to the producers is intended to provide them with incentives to establish efficient collection and recovery systems. As producers also control product design and manufacturing, EPR systems are intended to provide incentives for them to reconsider product design in favour of efficient disassembly, reuse of components, and recycling as well. These considerations are often referred to as "design for the environment" or "design for disassembly" (Organization for Economic Cooperation and Development, 2016; McKerlie et al., 2006). EPR regimes are usually implemented through legislation, although voluntary EPR systems also exist.

An early example of EPR-based design for disassembly legislation was the European Directive for End-of-Life Vehicles, which stipulated 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" (European Parliament and Council Directive 2000/53/EC 2000).

Figure 3 represents the value chain or life cycle for EV batteries. The Design & Manufacturing stage is crucial for considering the potential for efficient and low impact materials recovery and recycling, as it is where design for disassembly can be implemented. The EU's EPR regime for EoL vehicles has incentivized producers to design vehicles for disassembly (Mayers, 2008). Similar results could be envisioned through the application of an EPR regime for EoL EV batteries, as discussed in Section 2, disassembly and component reuse and recycling are considered the most efficient approaches with the least negative impacts to materials recovery from EoL EV batteries.

Figure 3: The Circular EV Battery Value Chain (Olsson et al., 2018)



A Framework for Evaluating EoL EV Battery Management Regimes

For the purposes of this study a six-principle framework for an EoL EV battery management regime was developed using the Brundtland sustainable development principle, UN SDGs, sustainability assessment literature, and EPR principles. The six principles are:

1. Promote design for the environment and disassembly;
2. Advance a circular economy;
3. Encourage second-life uses of EV batteries;
4. Address environmental justice concerns;
5. Support innovation; and
6. Ensure transparency, accountability and oversight.

Table 2 provides definitions for each principle. More detailed discussions of the principles and their relationship to the UN SDGs are provided in **Appendix 1**.

Table 2: Principles for the Design of an EoL EV Battery Management Regime

Principle	**Key Features**
Design for the Environment	Includes concepts such as design for disassembly and remanufacture, design for recyclability and environmentally friendly disposal, design for energy and emission efficiency, and design for reduced packaging (Industry, Science and Economic Development Canada, 2011).
Advancing a Circular Economy	Products and their packaging are designed to have the least possible environmental impact, meaning both products and packaging can easily be recovered, reused, and when necessary, recycled (Resource Productivity & Recovery Authority, 2022).
Encourage Second Lives for EV Batteries	Includes resale as is, remanufacturing, and repurposing ("What Happens at the End of the Electric Vehicle Battery's Journey?" n.d.). • <u>Resale as is -</u>- A buyer purchases a battery to be used in an EV, likely the same model. • <u>Remanufacture –</u> The battery recovered and faulty parts replaced or repaired. <u>Repurposing -</u>- The battery is used outside of a vehicle as stationary energy storage or electricity grid backup.
Address Environmental Justice	Defined as: "The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (United States Environmental Protection Agency, 2023).
Support Innovation	Pursuit of new battery chemistries that are more energy efficient and do not rely on critical minerals that are potentially toxic such as cobalt, nickel, lead, mercury, and cadmium (Man, 2023).
Transparency, Accountability, and Oversight	Oversight mechanisms that require producers to be transparent about the amount of product they introduce to the market and about recovery rates. Accountability measures must be enforceable, and punishments should be significant enough to act as deterrents for non-compliance.

4. The Jurisdictional Case Studies

As noted in Section 3, this report is focussed on five jurisdictional case studies: Ontario, Quebec, British Columbia, California, and the EU.

Case Study 1: Ontario

In 2016, Ontario introduced Bill 151 (*Waste-Free Ontario Act 2016)* to enact the *Waste Diversion Transition Act* (2016) and the *Resource Recovery and Circular Economy Act* (2016). The *Resource Recovery and Circular Economy Act, 2016* (RRCEA) created the Resource Productivity & Recovery Authority (RPRA) as a delegated administrative authority and regulator, to support Ontario's transition to a circular economy by overseeing the transition of existing programs to individual producer responsibility-based programs (i.e., Ontario's version of EPR) (*Resource Recovery and Circular Economy Act,* 2016). The RRCEA has several regulations that align with the programs being transitioned by RPRA. These include: hazardous and special products; blue box materials; electrical and electronic equipment; batteries; and tires. EV batteries are not listed under any of the regulations, including the one for batteries, which led the research team to contact RPRA and the Ontario Ministry of Environment Conservation and Parks (MECP).

RPRA confirmed via an October 3, 2022 e-mail that at that time there was no EV battery regulation in Ontario (RPRA, 2022). The MECP similarly replied to an e-mail on October 26, 2022, stating that Ontario has not included EV batteries under its extended producer responsibility framework for batteries. The e-mail went on to expand on the situation, stating that original equipment manufacturers (OEMs) in the vehicle industry indicated that batteries have value and are being properly managed, so at this point no regulation is necessary (MECP, 2022). It appears that Ontario is relying on the assurances of the OEMs as opposed to conducting its own research regarding recovery practices and recovery rates for EoL EV batteries.

Case Study 2: Quebec

Until June 2022, Quebec seemed poised to establish a regulatory framework for EoL EV batteries. The Quebec government released a draft regulation under the *Environment Quality Act* in October 2021. The draft called for producers to recover EoL EV batteries after 10 years (*Gazette Officielle Du Québec,* 2021). Article 8.1 of the draft regulation would also have prohibited parallel recovery activities such as the resale of EV batteries for reuse, converting EV batteries for other uses, and reconditioning batteries to extend their lives. The draft regulation additionally called for the identification and traceability of EV batteries and indicated the possibility of setting up a non-profit organization to manage EV batteries at EoL (*Gazette Officielle Du Québec,* 2021).

Not-for-profit organizations, such as Electric Mobility Canada (EMC) and other stakeholders in the EV battery community, expressed concerns over the draft regulation. (Breton, 2021). By mandating a 10-year collection time through Article 33, the Quebec government appeared to set an arbitrary target that was in no way related to the actual lifespans of EV batteries. Dr. Jeffrey Dahn of Dalhousie University, a leading expert in EV battery technology, strongly opposed the 10-year collection time stating that it would stifle innovation and encourage OEMs to use inferior batteries that would last no longer than 10 years (Dahn, 2021).

Article 8.1, which would have prohibited the use of parallel recovery activities. also caused concern, as reuse in vehicles or in second-life uses could help offset the environmental impact of manufacturing EV batteries by extending their lifespan (Breton, 2021). Critics also opposed the integration of EoL EV batteries into regulations for waste management, arguing that EV batteries are products that maintain a higher value compared to the smaller batteries found in portable electronics and therefore should be treated differently (Breton, 2021). The value attached to EV batteries was also seen to suggest a need to regulate the second-life EV battery market. Stakeholders hoped that their comments and recommendations would push Quebec's government toward a more sustainable policy. However, the government went in the opposite direction, and announced that its EoL EV battery management regime would be voluntary (Interview B, 2022).

Quebec's emerging voluntary policy became operational at the end of June 2023, and therefore fell outside of the scope of analysis for this paper. The details of the system are still emerging. The system is reported as being a voluntary take-back system available for free to vehicle dismantlers, recyclers and shredders, car dealers, independent auto repair shops, fleet operators and even individual vehicle owners. It includes commitments that all batteries collected will either be remanufactured for reuse in vehicles, repurposed for alternate use, recycled back to original metals for use in new products, or sent to vehicle manufacturer research and development centres for analysis (Rivard, 2023; Yakubin, 2023). The voluntary policy will likely push back any chance at a regulation for five years, which has been seen as a blow to supporters of a sustainable EV battery life cycle in Quebec (Interview B, 2022).

Case Study 3: British Columbia

British Columbia (B.C.) appears to be the first Canadian province or territory with a firm plan to institute an EoL EV battery management regime. The B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026 states that EV batteries will be included in the EPR programs covered by the Recycling Regulation of the B.C. *Environmental Management Act* (2003). The EPR program supports reuse and highlights B.C. as the Canadian leader in battery recovery and EoL EV battery management (Ministry of Environment and Climate Change, 2021). However, the Recycling Regulation does not specifically mention EV batteries. Rather, it only briefly states that EV batteries will be phased into B.C.'s EPR regime in 2024 without any additional details.

The EPR framework would operate under the Recycling Regulation (2004) of the *Environmental Management Act*. Section 4 of B.C.'s Recycling Regulation requires producers to submit an EPR plan for products listed within the product category of the regulation. Under Section 5(1)(a)(i), either a 75% recovery rate or another rate established by a director designated by the B.C. Ministry of Environment and Climate Change Strategy would be required. Section 5(1)(C)(i) requires that: "the plan adequately provides for (i) the producer collecting and paying the costs of collecting and managing products within the product category covered by the plan, whether the products are currently or previously used in a commercial enterprise, sold, offered for sale or distributed in British Columbia." The implication is that that producers would be fully responsible for funding the collection of their products.

Case Study 4: California, U.S.

California has emerged as the leader among U.S. states in the formulation of policy around EoL EV batteries. In 2018, California Assembly Bill AB-2832 required the establishment of a Lithium-ion Car Battery Recycling Advisory Group to provide policy recommendations to the legislature to ensure that close to 100% of lithium-ion car batteries are reused or recycled when they reach EoL (Kendall, Slattery, & Dunn, 2022). There were 19 voting members on the committee, including original equipment manufacturers (OEMs), non-governmental organizations, governmental departments and organizations, and battery recycling and other related industry organizations. Committee members voted on 27 policy proposals. The Advisory Group released its Final Report in 2022. The report identified the two policies receiving the most support as a core exchange and vehicle backstop policy (93% support) and the producer take-back (i.e., EPR) policy (67% support).

The outcome of the voting was not binding, as the mandate of the Advisory Group was to develop policy recommendations for the Legislature. No actual legislation has come forward so far, so it is unclear what policy will be adopted and how it would be funded.

The core exchange and vehicle backstop policy considered by the advisory committee had three options detailed in **Table 3**.

A producer take-back policy received the second-highest level of support. Under this policy, an OEM would take possession of a battery from a vehicle owner once the battery is no longer desirable and has not been acquired by a separate party, such as a refurbisher or repurposer (Kendall, Slattery, & Dunn, 2022). The OEM would be responsible for recovering the battery as soon as they are notified by the original battery owner that the battery had reached EoL. The OEM would then be responsible for properly reusing, repurposing, or recycling the battery in a licensed facility at no cost to the consumer (Kendall, Slattery, & Dunn, 2022). OEMs would provide literature to consumers and other stakeholders in both print and digital form regarding the battery return process.

Key advantages of a producer take-back policy were seen to include clearly defined transfer of responsibility for managing EV batteries at EoL when acquired by a refurbisher or repurposer and the ability for batteries to be sold to third parties for second-life uses. A major disadvantage of the policy was seen to

Table 3: California Core Exchange and Vehicle Backstop Policy Options

Option	Description
(a) EVs still in service	• Core exchange program will be detailed by the battery supplier. The party removing the battery will be responsible for ensuring the used battery component (module, cell, or complete battery) is reused, repurposed or recycled. • The party selling the battery will track the used battery to ensure it is properly managed.
(b) EV reaches EoL and goes to a licensed dismantler	• A dismantler who takes ownership of an EoL vehicle is responsible for ensuring that a battery is properly reused, refurbished, or recycled. • If a battery is reused in another vehicle with no changes, option (a) EVs still in service applies. • The responsibility transfers to a repurposer or refurbisher when a battery is repurposed or refurbished
(c) EV reaches EoL and goes to an unlicensed dismantler	• The OEM is responsible for ensuring that the vehicle is properly dismantled and the battery is either reused, repurposed, or recycled.

be that OEMs may incur higher costs, as they would likely only be called upon to manage EV batteries with no value in the second-life market (Kendall, Slattery, & Dunn, 2022).

Case Study 5: The European Union

The EU provides the most robust framework for EoL EV battery management. The EU had adopted Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators ("the 2006 Battery Directive") in September 2006 (Directive 2006/66/EC).

The 2006 Battery Directive replaced the previous Battery Directive, which had been in effect since March 1991 because of its failure to achieve its original objectives (Stahl, 2018). The main objective of the 2006 Battery Directive was to reduce the negative impacts of waste batteries and accumulators on the environment (Casto Diaz, 2015, p. 59).

The 2006 Battery Directive set requirements related to battery recycling. All collected batteries had to be recycled, and certain components, such as mercury, could not be used in further battery production. In addition, batteries were not permitted to be disposed of in landfills, and battery producers or third parties acting on their behalf could not refuse to take back waste batteries (Casto Diaz, 2015). In order to facilitate the take-back of batteries, the 2006 Battery Directive mandated various collection and recycling schemes along with targets. The Member States were required to develop collection schemes for the take-back of batteries that are separate from mixed municipal waste systems, and those collection schemes had to allow end users to dispose of their waste batteries conveniently and free of charge (Stahl, 2018).

Under the 2006 Battery Directive, batteries were categorized into three distinct groups: portable batteries; automotive batteries; and industrial batteries. Portable batteries were those used in consumer electronics such as laptops and cellphones, while also including traditional AA and AAA batteries. Automotive batteries were those used for igniting a vehicle's engine or lighting system (e.g., lead-acid batteries). Finally, industrial batteries were high-performance batteries such as those used for grid energy storage purposes. Batteries for electric-drive vehicles fell into this category and were subject to its requirements as per paragraph 9 of the Directive:

> "Industrial batteries and accumulators also include batteries and accumulators used in electrical vehicles, such as **ELECTRIC CARS** (emphasis added by authors), 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" (Directive 2006/66/EC).

The central theme of the 2006 Battery Directive was the concept of EPR. The Directive emphasized the reduction of responsibility on the part of consumers to handle waste batteries and the transfer those responsibilities back to the producers. The Directive also included provisions for design for disassembly. Manufacturers were, for example, required to design appliances in ways that allowed batteries to be removed if they were embedded in a device. If batteries were embedded, manufacturers had to supply instructions detailing how they could be removed (Casto Diaz, 2015). The 2006 Battery Directive also required that each Member State transpose the provisions of the Directive into the laws of their countries by September 2008.

A 2019 report ("the Report") on the implementation and impact on the environment and the functioning of the 2006 Directive revealed numerous weaknesses. These findings partly contributed to the EU's decision to pursue a different legal instrument through a Proposal for a Regulation (European Commission, 2019). **Table 4** outlines the main shortcomings of the 2006 Directive mentioned in the 2019 report.

Table 4: Shortcomings of the 2006 EU Battery Directive

Shortcoming	Details
Dangerous substances	• The Directive encouraged the use of smaller quantities of dangerous chemicals without specifying criteria for identifying what qualifies as dangerous and without offering management suggestions.
Collection targets	• Most Member States met the 2012 collection target of 25%, yet only 14 Member States met the 2016 collection target of 45%.
Material recovery	• The Directive failed in its objective to recover high levels of materials, and the targeted materials for recovery were limited to lead and cadmium, which does not consider cobalt or lithium. This indicates a directive made for lead-acid batteries as opposed to lithium-ion batteries.
Incorporating new technology	• Lithium-ion batteries are not mentioned as a specific category, and it is not possible to add new battery chemistries to the Directive.
Second life	• The Directive makes no mention of giving batteries a second life.
Alignment with policy	• The Directive does not align with climate change or circular economy policy.

The 2019 report, along with public comments, led to the conclusion that a regulation would provide a more effective framework for EoL EV battery management for the entire EU (European Commission, 2020). Under a regulation, all EU Member States would have the same product requirements for batteries, and producers would be obligated to provide the same level of waste management services across all Member States. The Proposal for a Regulation additionally aimed to support a healthy secondary market for raw materials, promote a circular economy, and decrease the environmental damage from the production and use of batteries.

The Proposal for a Regulation was based on an impact assessment that included 13 measures. The measures aimed to address the following problems: "(i) the lack of framework conditions to provide incentives for investments in production capacity for sustainable batteries; (ii) the sub-optimal functioning of recycling markets; and (iii) the social and environmental risks that are currently not covered by the EU's environmental acquis" (European Commission, 2020 "Impact assessment"). Each measure contained sub-measures, grouped under four main options:

1. Business-as-usual, which would continue to rely on the 2006 Directive;
2. A medium level of ambition, which gradually strengthens the requirements of the 2006 Directive;
3. A high level of ambition, which strengthens the requirements a bit faster within the limits of what can be achieved technically; and
4. A very high level of ambition, which could greatly strengthen the current regulatory framework, and potentially exceed existing business and technological capacities.

Table 5 below outlines the 13 measures grouped into the three policy options that differ from business as usual:

Table 5: Key Features of Proposed EU Regulation

Measures	Option 2 - medium level of ambition	Option 3 - high level of ambition	Option 4 – very high level of ambition
1. Classification and definition	New category for EV batteries Weight limit of 5 kg to differentiate portable from industrial batteries	New calculation methodology for collection rates of portable batteries based on batteries available for collection	/
2. Second life of industrial batteries	At the end of the first life, used batteries are considered waste (except for reuse). Repurposing is considered a waste treatment operation. Repurposed (second-life) batteries are considered as new products that have to comply with the product requirements when they are placed on the market	At the end of the first life, used batteries are not waste. Repurposed (second-life) batteries are considered as new products that have to comply with the product requirements when they are placed on the market.	Mandatory second-life readiness
3. Collection rate for portable batteries	65% collection target in 2025	70% collection target in 2030	75% collection target in 2025

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Measures	Option 2 - medium level of ambition	Option 3 - high level of ambition	Option 4 – very high level of ambition
4. Collection rate for automotive and industrial batteries	New reporting system for automotive, EV and industrial batteries	Collection target for batteries powering light transport vehicles	Explicit collection target for industrial, EV and automotive batteries
5. Recycling efficiencies and recovery of materials	Lithium-ion batteries and Co, Ni, Li, Cu: Recycling efficiency lithium-ion batteries: 65% by 2025 Material recovery rates for Co, Ni, Li, Cu: respectively 90%, 90%, 35% and 90% in 2025 Lead-acid batteries and lead: Recycling efficiency lead-acid batteries: 75% by 2025 Material recovery for lead: 90% in 2025	Lithium-ion batteries and Co, Ni, Li, Cu: Recycling efficiency lithium-ion batteries: 70% by 2030 Material recovery rates for Co, Ni, Li, Cu: respectively 95%, 95%, 70% and 95% in 2030 Lead-acid batteries and lead: Recycling efficiency lead-acid batteries: 80% by 2030 Material recovery for lead: 95% by 2030	/
6. Carbon footprint for industrial and EV batteries	Mandatory carbon footprint declaration	Carbon footprint performance classes and maximum carbon thresholds for batteries as a condition for placement on the market	/
7. Performance and durability of rechargeable industrial and EV batteries	Information requirements on performance and durability	Minimum performance and durability requirements for industrial batteries as a condition for placement on the market	/
8. Non-rechargeable portable batteries	Technical parameters for performance and durability of portable primary batteries	Phase out of portable primary batteries of general use	Total phase out of primary batteries
9. Recycled content in industrial, EV and automotive batteries	Mandatory declaration of levels of recycled content in 2025	Mandatory levels of recycled content in 2030 and 2035	/
10. Extended producer responsibility	Clear specifications for extended producer responsibility obligations for industrial batteries Minimum standards for PROs	/	/
11. Design requirements for portable batteries	Strengthened obligation on removability	New obligation on replaceability	Requirement on interoperability
12. Provision of information	Provision of basic information (as labels, technical documentation or online) Provision of more specific information to end users and economic operators (with selective access)	Setting up an electronic information exchange system for batteries and a "battery passport" scheme (for industrial and electric-vehicle batteries only)	/
13. Supply chain due diligence for raw materials in industrial and EV batteries	Voluntary supply chain due diligence	Mandatory supply chain due diligence	/

The commission largely recommended measures in categories two and three.

A key element of the EU's proposals was the concept of a "battery passport." A battery passport is a "digital twin" of the physical battery, which contains information on the sources of the materials used in its production, its chemical makeup, manufacturing, ownership and use history, and its sustainability performance (GBA, 2020).

An EU regulation concerning batteries and waste batteries was adopted by the European Council in June 2023 (Council of the EU, 2023; EU REGULATION (EU) 2023/...). The purpose of the regulation is stated to be to "prevent and reduce the adverse impacts of the generation and management of waste batteries on human health and the environment and... aim to reduce the use of resources and favour the practical application of the waste hierarchy" (Para 12). Key elements of the regulation include the following:

- The creation of a new category of battery for electric-vehicle batteries (Para 15);
- An emphasis on ethical sourcing of materials, due diligence around supply chains and security of supply to facilitate reuse, purposing and recycling of batteries (Para 9 and Chapter VII);
- The establishment of EPR requirement for the management of EoL batteries, including the costs of collection, and recycling batteries, reporting on battery fates (Para 101, Art. 56);
- The establishment of a digital battery passport system for EoL EV batteries (Para 123 and Chapter IX);
- Requirements for the provision of information on EV battery carbon footprints (Chapter 2, Article 7);
- Prohibitions on the disposal of EoL batteries or their use in energy recovery (i.e., incineration) operations (Art 70);
- The establishment of targets for recycling efficiency, starting in 2025 (65% for lithium- based batteries; rising to 70% by 2030); recovery targets of 90% cobalt, copper, lead and nickel and 50% for lithium by 2027, with special storage requirements for lithium-based batteries (Annex XII);
- The establishment of recycled content requirements for cobalt, lead, lithium and nickel, although not starting until eight years after regulation coming into force (Chapter 2, Art. 8). Batteries will have to hold recycled content documentation;
- The provision of restrictions on presence of mercury, cadmium and lead in certain types of batteries (EV batteries are exempted for cadmium) (Para 22);
- Requirements for access to vehicle repair and maintenance information on a non-discriminatory basis (para 42);
- Registration and reporting requirements for manufacturers, importers, collection and recycling facilities; and

- Labelling and information requirements, among other things, on the battery's components and recycled content, the electronic battery passport and a QR code. In order to give Member States and economic actors on the market enough time to prepare, labelling requirements will apply by 2026 and the QR code by 2027.

A full evaluation of the effectiveness of Proposal for a Regulation compared to its predecessor, the Directive, will not be possible for several years.

5. Evaluation and Discussion

The following analysis applies the six EoL EV battery regime design principles developed in Section 3 of this report to systems emerging the case study jurisdictions. Ontario and Quebec have been omitted from the analysis because Quebec's voluntary take-back program for EV batteries has only just been launched, and Ontario currently has no EoL EV battery management regime at all. The detailed evaluations for each jurisdiction against the criteria are provided in **Appendix 2**.

The Proposal for a Regulation by the EU presented the most robust framework across the six principles. The EU has a history of addressing the issue of EoL batteries, dating back to the 2006 Battery Directive on Waste Batteries and Accumulators. A new EU Regulation Concerning Batteries and Waste Batteries, based on the Proposal for a Regulation, was adopted in June 2023 (Council of the EU, 2023). In contrast, to date there has been no bill put forward in California based on the Advisory Group's Final Report. Details about B.C.'s Five-Year Action Plan remain largely abstract, and its measures related to EV batteries are not scheduled to begin until 2024. The assessments of the B.C., California and EU regimes against the six design principles are as follows.

Principle 1: Design for the Environment

Under the Design for Environment principle, the EU Proposal stood out. The EU proposal emphasized the importance of the availability of safe disassembly instructions to licensed dismantlers and repurposers, indicating that batteries should be designed for disassembly. The limiting of disassembly to licensed parties may suggest an attempt to control resource flows, but the push in the direction of disassembly, is clearer than the approaches being considered in B.C. or California. These seem to stress design for reuse and recycling over design for disassembly.

B.C.'s Five-Year Action Plan and Recycling Regulation mentions design for recyclability but omits mention of design for disassembly or design for remanufacture. The discussions with the California Advisory Group also focussed design for recycling over design for disassembly. The use of fasteners in EV battery assembly, as opposed to welding parts together was not something that OEMs supported. It was also noted that recyclers were adapting their technologies around battery design, as opposed to manufacturers designing batteries that were easier to recycle or disassemble (Kendall, Slattery & Dunn, 2022).

Principle 2: Supporting a Circular Economy

The EU has developed a Circular Economy Action Plan, a strategy that sets it apart from B.C. and California. The circular economy plan would work in conjunction with the Proposal for a Regulation. The EU's plan appears all-inclusive, but until it is implemented its usefulness as a tool for controlling the supply of "critical" materials for EV batteries and keeping them within the EV battery supply chain remains uncertain. B.C.'s Five-Year Action Plan states that the Plan and the province's EPR policy support a circular economy, but the plan does not define the concept of a circular economy beyond the level of general statements.

The California Advisory Group's Final Report states that the state should strive to create a circular economy for waste EV batteries, similar to what it has done for lead-acid batteries. However, the only proposed measures related to a circular economy that received majority support were an economic incentive package for lithium-ion battery recyclers within California (73% support) and expanding eligibility for relevant incentive programs to include reused and repurposed batteries (67% support). Other measures, such as setting minimum recovery rates (47% support), design for reuse, repurposing, and recycling (33% support), and the development of a reporting system for lithium-ion battery recycling recovery rates (33% support) received less than majority support. These voting trends indicate a preference for financial incentives for recycling while not setting or tracking recovery rates for battery materials (Kendall, Slattery, & Dunn, 2022).

Principle 3: Environmental Justice

Environmental justice concerns were the least addressed principle in all three jurisdictions. The term "environmental justice" is mentioned twice in the California Advisory Group's Final Report. The EU did not use the term but the Proposal for a Regulation encourages due diligence schemes to track where materials originate to encourage ethical sourcing under measure 13 of the Proposal for a Regulation. The due diligence policies are meant to address both the social impacts of material sourcing, which include impacts on social structures, human rights, human health and safety, and labour rights as well as negative environmental impacts on water, soil, air, and biodiversity. The Proposal notes that the same impacts must be avoided when repurposing batteries.

The EU's new Circular Economy Action Plan also discusses the ethical sourcing of materials, particularly in relation to mining and those who work and live around the mines, indicating a degree of consistency across the two EU policy measures. At the same time, the Proposal for a Regulation and Regulation did not incorporate an outright ban on sending waste EV batteries outside of the EU for processing. It is similarly silent on the potential harm to humans and the environment surrounding battery recycling facilities.

B.C.'s Five-Year Action Plan mentions the First Nations Recycling Initiative, but it is unclear if this initiative will have any effect on Indigenous groups in the province or if it will cover EoL EV batteries. The California Advisory Group's Final Report notes that waste EV batteries could create environmental justice concerns if mismanaged, yet the report does not specifically address the question of protecting vulnerable communities. Although the Report details many of the concerns related to the mining and ethical sourcing of EV battery materials, none of the voting measures covered such upstream dimensions of the battery life cycle. The Report also makes no reference to batteries having to be processed in North America, leaving open the possibility that EoL EV batteries could be sent to the global south. It has been observed that policies to mandate recycling in the U.S., even if recycling is not profitable, may be necessary to ensure that waste EV batteries are not sent abroad (Interview C, 2022).

Principle 4: Encouraging Second-Life Uses

With respect to second-life uses, the EU's Proposal for a Regulation surpassed B.C.'s Five-Year Action Plan and the California Advisory Group's Final Report by referencing specific second-life uses for EV batteries. These include stationary energy supplies and integration into electricity grids for energy backup. The Proposal also discusses the second-life market less as a possibility and more as an inevitability, citing the need to create a regulatory and policy framework for the second-life market.

B.C.'s Five-Year Action Plan supports the reuse of batteries. This aligns with two sections in the Recycling Regulation under the *Environmental Management Act* that reference reuse as a goal of provincial EPR frameworks. However, neither the plan nor the *Act* go into any further details about what EoL EV battery reuse will entail, such as reuse only in vehicles or broader uses for energy storage and other applications. In response to B.C.'s Plan, Electric Mobility Canada (EMC) recommended the addition of provisions to the Recycling Regulation to encourage the reuse, remanufacture, and repurposing of batteries (Electric Mobility Canada, 2022).

The California Advisory Group's Final Report referenced second-life uses in vehicles and identified stationary energy storage as a potential second-life application. However, the voting measures focussed solely on reuse in vehicles. Nearly all the voting members supported reuse in vehicles, but the report did not explain how repurposing or refurbishing for use in a vehicle would specifically work. The report noted the need for a battery state of health (SOH) measure to properly assess if a battery can be reused in a vehicle. While nearly all voting members favoured an SOH measure for batteries within vehicles, only 53% supported the institution of a universal diagnostic system for battery health for removed batteries. The OEMs exhibited significant opposition to the measure. Without a universal diagnostic system, it will be difficult and expensive to assess the health of batteries, creating a barrier to reusing EV batteries that reach EoL.

Principle 5: Supporting Innovation

With respect to innovation, the EU listed innovation as one of its specific objectives under the Proposal for a Regulation. The EU has devoted over €500 million to research projects on topics that cover the entire EV battery value chain. B.C.'s Five-Year Action Plan and the Recycling Regulation minimally mention innovation but relate it more to innovation in the recycling system and collection practices as opposed to the battery technology. The California Advisory Group's Final Report states that limiting product design and diagnostic tools could stifle innovation. While there is strong interest in the use of more abundant materials in battery chemistries, it has been observed that batteries using more common materials may be less profitable to recycle and might necessitate policies to ensure that they are recycled. Neither the California nor the B.C. measures discussed the need to research novel battery chemistries that may be more sustainable, or mentioned solid-state or sodium-ion batteries as potential alternative technologies.

Principle 6: Transparency, Accountability, and Oversight

The EU already has experience with transparency, accountability, and oversight concerns, as one of the key critiques of the regime under the Battery Directive was the lack of a unified regime to provide accountability among Member States. The Proposal for a Regulation called for all Member States to manage waste batteries in the same way, with oversight by the European Commission. The EU is also the only jurisdiction that is committed to the use of a battery passport, which will allow for secure data sharing and transparency related to the carbon footprint and material makeup of individual batteries.

That said, one of the major problems identified by the Proposal for a Regulation was the lack of transparency around the sourcing of raw materials. Measure 13 addresses this problem directly by promoting due diligence in the battery supply chain. The European Commission must approve individual Member States' rules and penalties related to enforcement and is to provide oversight.

B.C.'s Recycling Regulation requires producers to create an Extended Producer Responsibility Plan and report annually on actions and recovery rates. However, the Regulation says nothing about targets and does not provide any specific measures that address the unique challenges created by waste EV batteries.

While B.C.'s proposed EPR program indicates progress toward establishing policy frameworks for managing EoL EV batteries in Canada, EMC proposed changes to the Recycling Regulation of the *Environmental Management Act* where they believe it could be improved for better accountability and oversight. Specifically, EMC recommended adding a large battery category, for batteries weighing over 10 kg or with a rating of more than 1,000-watt hours to the regulation (Electric Mobility Canada, 2022). EMC's recommendation reflected the considerations that HEV and EV batteries are larger, more complex, and carry significantly more value compared to smaller lithium-ion batteries, meaning they should be managed differently. These batteries will likely require unique collection schemes and processes that may need to be regulated differently than schemes for other products. EMC also recommended specifying who would be considered an EV battery producer under the recycling regulation. The addition of a battery registry and notification system, which would assist the B.C. regulator in tracking the level of producer compliance with collection mandates for EoL EV batteries, was recommended as well (Electric Mobility Canada, 2022).

The Advisory Group Final Report from California indicated that voting members overwhelmingly supported physical labelling of batteries, an SOH measure for batteries while inside a vehicle, and the provision of training materials for safe handling, storage, and shipping of EV batteries. However, the voting members provided less than majority support for two critical reporting measures: EVs retired from use and lithium-ion battery recovery rates, each receiving only 33%. The group did not vote on a tracking and reporting system like the EU battery passport. This would imply a significant deficiency in reporting the handling and fate of EoL EV batteries.

6. Conclusions and Recommendations

The analysis in this study was limited to five jurisdictions, with a deeper analysis of only three jurisdictions (B.C., California and the EU). The North American cases represented the locations of the most advanced discussions of the management of EoL EV batteries that could be identified, or in the case of Ontario, where aggressive commitments were being made to the development of EV battery manufacturing activities and supply chains. Future comparative studies could incorporate policy measures from Asia in jurisdictions such as Japan, China, and the Republic of Korea.

It is also important to note that of the three regulatory and policy regimes featured in the analysis only the EU's regulatory framework has reached the point of implementation. B.C.'s plan is backed by the Recycling Regulation under the *Environmental Management Act,* but a plan for EV batteries will not be articulated until 2024. Details on its contents and direction remain scarce. In California, there has yet to be any legislation resulting from the conclusions of the Advisory Group's final report.

A major research constraint was the limited information regarding the actual fate of EoL EV batteries in North America. Interviews suggested that batteries are not being discarded in landfills or abandoned. However, there is virtually no information available related to the location of EoL EV batteries that have been removed from vehicles or recovery and recycling rates.

Pathways Forward for EoL EV Battery Management in Canada

The Canadian federal government and the provinces of Ontario and Quebec have committed billions of dollars to the development of EV battery manufacturing facilities and supply chains (Radwanski & Stone, 2023; Karim, 2023) A further $3-4 billion has been committed by the federal government in its 2023-24 Budget to the development of "critical" mineral supply chains. However, within Canada, only the governments of Quebec and B.C. have given any formal consideration to question EoL EV battery management, and neither province has implemented any substantive regulatory measures to date. Within the United States, policy development initiatives have been focussed in the State of California, but it has yet to implement any substantive measures as of the time of publication.

The situation in North America is in sharp contrast to that within the EU. The European Commission has built on its original 2006 Battery Directive and adopted a comprehensive EU regulation on post-consumer management of batteries, including EV batteries. The lack of action from North American governments is surprising given the environmental and health risks associated with EoL EV battery handling, recycling and disposal, as well as the potential for battery recovery and recycling operations to be significant sources of supply for materials in EV battery manufacturing supply chains. The absence of federal leadership is particularly notable and creates risks of different regimes emerging at the provincial and state levels. The EU's experience with the original Battery Directive provides an example of what can happen when Member States are given too much flexibility to institute their own policies, as the failure of the Battery Directive led directly to the Proposal for a Regulation, which will be binding on all EU Member States.

Recommendation 1

The Government of Canada should lead, in conjunction with the provinces and territories, the development of a national EoL EV battery management regime for Canada.

Recommendation 2

The regime should be built on the principle of extended producer responsibility for EV batteries. OEMs should be required to develop and implement extended producer responsibility plans for EV batteries and provide annual reports on the implementation of their plans.

Design for the Environment

The current primary recycling techniques for EoL EV batteries involve either burning away unwanted components at high temperatures (pyrometallurgy) or leaching recoverable materials using acidic compounds (hydrometallurgy). Both involve significant environmental and health risks and impacts. Design for disassembly offers the advantages of facilitating the repair or repurposing of EoL EV batteries and allows for the removal of extraneous materials (e.g., casings) prior to final recycling, reducing the required inputs of energy and chemicals, and the resulting waste streams. However, the California case study suggests that OEMs will be strongly opposed to design for disassembly requirements, as they do not want their proprietary technology leaving their supervision. A potential compromise could be what was proposed within the EU, where disassembly instructions would only be provided to licensed dismantlers, refurbishers, and remanufacturers. Such provisions, combined with a battery tracking system might respond to the concerns of the OEMs, as they would know where batteries are and who is taking them apart.

Recommendation 3

Canada's national EoL EV battery management regime should include provisions for design for disassembly and recycling, similar to those in the EU Regulation on Batteries and Waste Batteries.

Advancing a Circular Economy

Design for reuse, disassembly, and recycling is an important first step towards the development of a circular economy around EV batteries. An effective EoL EV battery management regime should build on these measures to create a circular economy for EV battery materials. These materials should be collected, reused, recycled, and remanufactured into new batteries, remaining within the battery supply chain and reducing demand for newly extracted materials. The EU has made explicit linkages between its regulation on batteries and its wider Circular Economy Action Plan. An effective regime should set minimum recovery rates and recycled content requirements, measured by a reporting system for recovery and verified by a third party.

Recommendation 4

Canada's national EoL EV battery management regime should seek a recovery rate of 100% of batteries that are no longer desirable to their users. Recycled content requirements should be established in EV battery manufacturing, and reporting systems on recovery rates should be established.

Environmental Justice

A policy regime for EoL EV battery management must address environmental justice concerns and commit to protecting vulnerable communities from the negative effects of improperly managing EV batteries. Management regimes need to avoid what has happened with e-waste, which has historically been sent to global south, exposing vulnerable populations to the hazardous materials within electronics (Heacock et al., 2016). An effective EoL EV battery management regime will need to mandate recovery and recycling to prevent EoL EV batteries being sent abroad or illegally dumped in vulnerable communities.

As noted earlier, the Basel Convention provides an international instrument that regulates the transboundary movement of hazardous wastes and recyclable materials. However, EoL EV batteries are currently not categorized under the Basel Convention as hazardous wastes or hazardous recyclable materials (United Nations Environment Programme, 2020) and therefore fall outside of its regime for tracking the movements of these materials and obtaining prior informed consent from countries of import. The status of EoL EV batteries for the purposes of domestic hazardous waste and transportation of dangerous goods regimes was found to be indeterminate in Canada and the United States.

Recommendation 5

Canada should work with the United States, EU and other countries to clarify the status of EoL EV batteries as hazardous wastes or hazardous recyclable materials under the Basel Convention, as well as their status for the purposes of domestic hazardous waste management and dangerous goods transportation requirements.

Supporting Second-Life Uses

The repurposing of EoL EV batteries for second-life uses as stationary energy storage or grid assets will likely become more common. Second-life uses extend the useful lives of batteries and the materials invested in them, and delays the need for EoL management. The second-life EV battery market is unregulated at this point, and energy markets are poorly configured to incorporate distributed resources of this type.

Recommendation 6

A national EoL EV battery management regime should include provisions to facilitate second uses of EoL EV batteries, including clarifications of responsibility for final recycling.

Recommendation 7

The design of electricity systems and markets should be modernized to facilitate the development of distributed energy resources (DERs), including grid applications of stationary EV batteries in primary or secondary life.

The ability to assess battery health will be essential to the development of second-life markets for EoL EV batteries (Börner et al., 2022). However, OEMs appear to be opposed to a universal diagnostic system for EV batteries.

Recommendation 8

A national EoL EV battery regime should mandate that OEMs provide a battery state of health (SOH) based on their own battery management system (BMS) for a battery to facilitate repurposing for a second-life uses.

Facilitating Innovation

Battery technologies are evolving rapidly. In addition to improving battery efficiency and safety, research into new battery chemistries could have an indirect effect by reducing mining impacts using more readily available and abundant materials in battery construction. Additional research into recycling technologies, particularly design for disassembly and component reuse and recycling is required.

Recommendation 9

A national EoL EV battery management regime should incorporate a substantial research and development program, financed through a small surcharge of EV purchases and leases, focussed on improved battery chemistries, recycling technologies, and second-life uses.

Transparency, Accountability, and Oversight

As noted in the introduction to this section, there is a near total lack of information regarding the actual fate of EoL EV batteries in North America. Battery passports, as included in the EU Regulation, could be an important tool in tracking battery origins and fates. Battery passports could also provide information on the carbon footprints of battery manufacturing, the origins of battery materials, battery composition, including hazardous materials, repair and repurposing instructions, and recycling and recovery processes when batteries reach EoL.

Recommendation 10

A national EoL EV battery management regime should incorporate requirements for battery passports to facilitate the tracking of the fate of batteries and facilitate their reuse and recycling, including a battery registry and notification system.

Recommendation 11

EV battery producers should be required to report annually on recovery rates of their products and the fates of recovered batteries. Noncompliance with collection targets, reporting, and other outlined obligations should lead to enforceable penalties that carry enough weight to deter noncompliance.

Concluding Observations

The focus of the policies in the five case studies presented in this report has been on the reuse and recycling of EoL EV batteries. Largely overlooked in these strategies is the first "R" in the sustainable materials management hierarchy, namely reduction (MacDonald, 2020). Although the recycling and reuse of EoL EV batteries and the materials they contain will reduce extractive pressures in EV battery supply chains, the direct replacement of ICE vehicle fleets with EVs to mitigate the effects of transportation-related emissions on climate change would raise serious sustainability issues of its own. The numbers of batteries and volumes of battery materials needed, particularly if vehicle fleets continue to expand, may exceed the capacity of the planet to provide sustainably, particularly given the scale of the impacts of existing extractive activities.

The implication is that electrification of existing road transportation systems will need to be accompanied by strategies for Transportation Demand Management (TDM) to reduce the number and use of personal vehicles for transportation (Axsen, Plotz, & Wolinetz, 2020). TDM strategies will be needed to encourage and facilitate modal shifts in the direction of public transportation, and create more accessible and sustainable communities, where walking, cycling and other forms of active transportation are feasible and encouraged.

The actual material recovery rates that can realistically be achieved through an EoL EV battery management regime remain uncertain. Primary extraction of EV battery materials seems likely to remain a significant source of EV battery materials for the foreseeable future. These considerations reinforce the need to incorporate ethical material sourcing requirements into EV battery management regimes, and to establish and maintain high regulatory standards around mine development, operation, and closure.

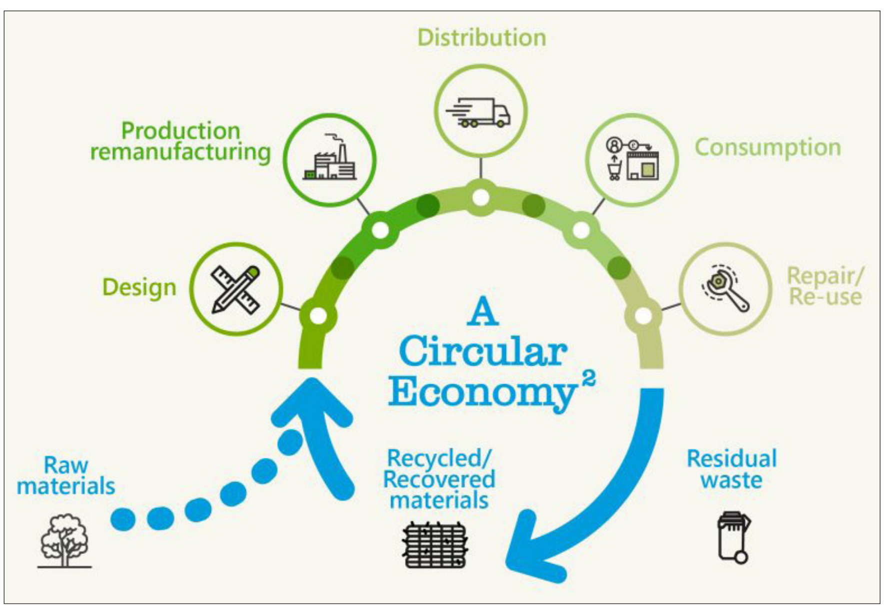
Appendix 1: Principles for Design of EoL EV Battery Management Regime

Principle 1: Support Design for the Environment

Description
• Includes all upstream processes for producing and sourcing raw materials, components, and energy necessary for the creation of a product as well as the downstream processes that allow for distribution, use, and disposal (Deathe, MacDonald, & Amos, 2008). • Includes concepts such as design for disassembly and remanufacture, design for recyclability and environmentally friendly disposal, design for energy and emission efficiency, and design for reduced packaging (Industry, Science and Economic Development Canada, 2011).   • Design for disassembly with EV batteries can refer to the use of fasteners as opposed to strong adhesives or welding parts together, which would make it easier to separate parts (Interview C, 2022). • Contrasts with the concept of "planned obsolescence" where products are only designed to last for a short period of time before being replaced by newer technology (Deathe, MacDonald, & Amos, 2008). • Parts should also be made from durable materials and should be by easily separated from other parts (Deathe, MacDonald, & Amos, 2008). • Producers should consider human health and safety and environmental effects when designing products, meaning they should limit if not eliminate the use of toxic substances (Deathe, MacDonald, & Amos, 2008).
Applicable UN SDGs
• 3) Good health and well-being- Electronics, and specifically EV batteries contain toxic substances, as cobalt and nickel are listed as toxic substances under the Schedule 1 of CEPA. Eliminating toxic substances from batteries or limiting the danger that they pose during resource extraction and disposal would better protect the health and well-being of those who work closely with batteries or in resource extraction. • 12) Responsible consumption and production- Batteries should be produced responsibly, meaning that they align with DFE by being designed for disassembly and remanufacture, designed for maximum emissions efficiency, and designed to use as little packaging as possible.

Principle 2: Advancing the Circular Economy

Figure 4: Circular Economy (TEI Experts, 2014)



Description
• Runs in contrast to the linear economy where resources are extracted and used to manufacture products, and those products are then used and discarded when no longer desirable (Resource Productivity & Recovery Authority, 2022). • Products and their packaging are designed to have the least possible environmental impact, meaning both products and packaging can easily be recovered, reused, and when necessary, recycled (Resource Productivity & Recovery Authority, 2022). • Waste is viewed as a resource. • Materials are meant to be reused in their jurisdiction and within the same industry (i.e., EoL batteries in Ontario are recycled in Ontario and raw materials are reused to manufacture new EV batteries in Ontario).
Applicable UN SDGs
• 6) Clean water and sanitation- Increasing resource recovery means that there will be less waste in general, meaning less waste to contaminate water sources. • 7) Affordable and clean energy- Supports the transition to cleaner energy by not relying on fossil fuels to power vehicles while potentially reducing the cost of EVs by reducing the reliance on mining. • 8) Decent work and economic growth- A circular economy would also lead to economic growth as new jobs would be created for people to recover, repair and remanufacture, and recycle the material from EV batteries. • 12) Responsible consumption and production- Producers would be creating products while considering resource recovery from the beginning, and consumers would ideally have simple ways to dispose of undesirable batteries. • 15) Life on land- a circular economy for resources would likely reduce the EV battery industry's reliance on mining, meaning less land, plant life, and wildlife would be disturbed in a circular economy (Schroeder, Anggraeni, & Weber, 2019).

Principle 3: Encourage Second-Life Uses of EoL EV Batteries

Description
• Once a battery is no longer desirable by its original owner there are several possible second uses, resale as is, remanufacturing, and repurposing (Canadian Vehicle Manufacturers' Association, 2021a). • Resale as is- A buyer purchases a battery to be used in an EV, likely the same model because a battery must align with the battery management system (BMS). • Remanufacture- An OEM recovers a battery and replaces or repairs faulty parts such as battery cells or modules (multiple cells) so the battery could be returned to like-new condition for use in another vehicle as a service or replacement battery (Canadian Vehicle Manufacturers' Association, 2021a). • Repurposing- The battery is used outside of a vehicle as stationary energy storage or electricity grid backup. This is the most common application when stakeholders refer to a "second life" for EV batteries. • Reusing batteries in a second life can offset the energy and emissions used to create the battery by extending its lifespan (Breton, 2022).
Applicable UN SDGs
• 7) Affordable and clean energy- One of the significant drawbacks with renewable energy that second-life EV batteries could solve is that most grid systems currently cannot store electricity from renewable sources such as wind and solar for future use (Deb, 2016). Stored electricity would also decrease the need to fire fossil fuel-based plants to meet demand allowing for an increase in the use of clean electricity. • 9) Industry innovation and infrastructure- Presents an opportunity for significant innovation in the energy sector that has to date struggled to find solutions for storing energy generated by wind, solar, and other renewable sources. • 11) Sustainable cities and communities- Storage for the electricity grid as well as smaller storage projects for homes and businesses helps to create an infrastructure built to store energy generated by renewable sources, pushing communities and cities to be more sustainable as they reduce their reliance on burning fossil fuels for energy. • 12) Responsible consumption and production- The reduced reliance on burning fossil fuels supports responsible production and consumption of electricity. • 13) Climate action- As energy storage from renewable sources becomes more possible, producers will be able to rely less on burning fossil fuels, likely meaning less GHG emissions, which translates to mitigating the effects of climate change.

Principle 4: Address Environmental Justice

Description
• The U.S. EPA defines environmental justice as: "The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." (United States Environmental Protection Agency, 2023) • Throughout history, already marginalized communities often made up of people of colour, Indigenous groups, and impoverished communities, have suffered disproportionate environmental and health effects. • Environmental justice concerns first began to arise in the 1960s during the Civil Rights Movement in the U.S. (Canadian Vehicle Manufacturers' Association, 2021). • Environmental justice intersects with waste products when such products are sent to remote areas or developing countries, overburdening already vulnerable populations. An example of such an occurrence is electronic waste (e-waste) being sent to developing countries or remote areas inhabited by Indigenous peoples (Heacock et al., 2016).
Applicable UN SDGs
• <u>3) Good health & well-being</u>- Exposure to toxic substances threatens the health and well-being of those who encounter such substances, who in the life0cycle of EV batteries would be those who work in sourcing critical minerals through mining or at EoL. • <u>8) Decent work and economic growth-</u> In the DRC, where most of the world's cobalt is mined, many miners, including children, are subject to harsh work conditions, contravening Goal 8, which promotes decent work and condemns child labour (United Nations Department of Economic and Social Affairs, 2022). • <u>10) Reduced inequalities</u>- People living in developing countries, remote areas, and Indigenous communities may already face substantial inequalities in the form of their standard of living and the available social services, so exposure to toxic substances only increases existing inequalities. • <u>12) Responsible production and consumption</u>- Producing and using EV batteries in a way that management at EoL results in batteries being sent to vulnerable communities can hardly be categorized as responsible consumption and production. • <u>15) Life on land</u>- If batteries are not safely processed at established facilities there is a good chance that toxic substances can enter the environment, threatening life on land. • <u>16) Peace, justice, and strong institutions</u>- This goal calls for access to justice for all and for building effective, accountable, and inclusive institutions. If people in developing countries receive hazardous waste from abroad, it would likely be difficult for them to seek justice due to jurisdictional issues and potentially a lack of resources and access to an international court.

Principle 5: Support Innovation

Description

• Many of the discussions around innovation relate to the pursuit of new battery chemistries that are more energy efficient and do not rely on critical minerals that are potentially toxic such as cobalt, nickel, lead, mercury, and cadmium (Man, 2023).
    • Battery manufacturers such as Panasonic, Samsung, and LG are constantly developing batteries that are lighter, safer, more energy dense, and more sustainable (Man, 2023).
    • Sodium-ion batteries present a safer and cheaper alternative to lithium-ion batteries because sodium is cheap, abundant, and non-flammable (Lewis, 2022).
    • Solid-state batteries are nearly the same as lithium-ion batteries except the core electrolyte is solid as opposed to the liquid core found in presently used lithium-ion batteries. The solid core provides many advantages such as being lighter, safer (no flammable liquid), possessing more range, faster recharge times, and a longer lifespan (Braga, 2021).
• More innovation related to data sharing of battery performance and battery tracking could both speed technological innovation and measure the performance of collection schemes and recycling systems. The battery passport has been touted as one potential solution for tracking and measuring performance (Global Battery Alliance, 2020).
• Recycling technology is another stage in the battery life cycle where innovation could lead to higher recovery rates and less harmful environmental impacts from the recycling process.

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Applicable UN SDGs
• 7) Affordable and clean energy- One of the significant reasons why EV adoption has not taken off is the higher price tag of a new EV compared to a new ICE vehicle (Trop, 2022). An EV battery stores the energy used to power EVs, and the cost of that battery makes EVs $10,000 more expensive (on average) than their ICE counterparts (Tchir, 2020). • 9) Industry innovation and infrastructure- Directly aligns with the sustainability criteria of innovation. • 12) Responsible production and consumption- Producers who want to act responsibly should strive to produce the most sustainable batteries they can. By constantly innovating and advancing technology they can achieve such a goal by constantly creating batteries that last longer, are less harmful, and are more easily reused or recycled. • 15) Life on land- less mining for new minerals and more reuse of existing resources, or utilizing “urban mines” means less disruption of land. Mining can have a profound effect on plant and animal life, so battery innovation that reduces a reliance on mining by utilizing more readily available material protects such life forms.

Principle 6: Transparency, Accountability, and Oversight

Description
• Few regulations or oversight mechanisms ensure that entities who purchase used EV batteries are safely handling and storing them in a way that prevents decay and corrosion that could release toxic substances into the environment.   • A major concern associated with lithium-ion EV batteries is the hazard created if these batteries encounter fire. Lithium-ion battery fires are difficult to extinguish, and they release toxic substances such as fluorine gas (Carleton & Gordon, 2021). • The first step is tracking, to make sure battery locations are known, which will allow regulators to evaluate if batteries have been removed and stored and will enable regulators to calculate the true recovery rates for EoL EV batteries. Tracking could potentially be achieved using a battery passport, a tool that has received support in the EU (Global Battery Alliance, 2020). • An effective EoL EV battery management policy should include oversight mechanisms that require producers to be transparent about the amount of product they introduce to the market and about recovery rates. • Accountability measures must be enforceable, and punishments should be significant enough to act as deterrents for non-compliance.
Applicable UN SDGs
• 12) Responsible production and consumption- EV battery producers are almost certainly aware that their batteries contain toxic substances. This places a responsibility on them to track their products and ensure that they are being properly used, repaired, dismantled, and transported, so those toxic substances are not released into the environment. Producers may additionally be responsible for providing professional training for those tasked with handling EV batteries. • 16) Peace, justice, and strong institutions- Calls for accountable institutions at all levels, meaning the EoL EV battery management policy should have the ability to hold producers accountable for not meeting set performance and reporting targets. Further, such policy should be empowered under the law through government institutions who can punish entities that contravene set policies.

Appendix 2: Evaluation of the B.C., California and EU Regimes Against Program Design Principles

British Columbia

Table 6: Sustainability Assessment of B.C.'s Proposed Regime

Sustainability Criteria	Future B.C. EPR Battery Framework based on the Five-Year Action Plan and the Recycling Regulation under the *Environmental Management Act*
Design for Environment (DFE)	• Section 5(3)(a) of the Recycling Regulation in the *Environmental Management Act* calls for reducing the environmental impact of a product by limiting toxic components, which in the case of EV batteries could be materials such as cobalt and nickel, which are listed as toxic under *CEPA*. • Section 5(3)(b) of the Recycling Regulation in the *Environmental Management Act*, which is the section that focusses on the approval of an extended producer responsibility plan, states that products should be redesigned to improve reusability and recyclability in order to prevent pollution (*Environmental Management Act- Recycling Regulation*, 2004). • The Five-Year Action Plan states that B.C.'s EPR policy approach supports the design of more easily recyclable products (BC Ministry of Environment and Climate Change, 2021). • No mention of design for disassembly.
Circular Economy	• The Five-Year Action Plan argues that reuse, recycling, and remanufacturing of products supports the circular economy, and that adding more product categories under EPR promotes a growing circular economy (BC Ministry of Environment and Climate Change, 2021).
Minimizes Environmental Justice Concerns	• The First Nations recycling initiative (FNRI), aims to promote recycling and community collections events for Indigenous and remote communities in B.C. • The initiative currently focusses on packaging materials such as paper, plastic, aluminum, and glass. • There is the potential to incorporate EV battery collection for these communities in the future. • It will be important to have a proper infrastructure for managing EoL EV batteries in place, so they are not dumped illegally in remote, Indigenous communities. (BC Ministry of Environment and Climate Change, 2021).

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Sustainability Criteria	Future B.C. EPR Battery Framework based on the Five-Year Action Plan and the Recycling Regulation under the *Environmental Management Act*
Promotes Second-Life Uses	• The Five-Year Action Plan mentions that B.C. will support the reuse of batteries, citing other EPR initiatives that promote reuse such as gently used mattresses. • Specific plans for reuse and second-life uses for EV batteries are not outlined in the Five-Year Action Plan or in the Recycling Regulation (BC Ministry of Environment and Climate Change, 2021). • The Recycling Regulation in the *Environmental Management Act* addresses second-life uses and reuse under two sections: • **Section 5-Approval of Extended Producer Responsibility Plan** ... • (3) For the purposes of subsection (1) (c) (viii), the pollution prevention hierarchy is as follows in descending order of preference, such that pollution prevention is not undertaken at one level unless or until all feasible opportunities for pollution prevention at a higher level have been taken ... • (b) redesign the product to improve reusability or recyclability ... • (d) reuse the product **Section 13-Management of Collected Products** A producer must manage all products collected at a collection facility provided by that producer in adherence to the following descending order of preference, such that pollution prevention is not undertaken at one level unless or until all feasible opportunities for pollution prevention at a higher level have been taken: (a)reuse the product
Innovation	• The Five-Year Action Plan states that producers have the flexibility to develop innovative ways to meet regulated outcomes, which includes more accessible recycling via province-wide collection, improving recycling practices, and supporting reuse and the recovery of resources (BC Ministry of Environment and Climate Change, 2021).
Transparency, Accountability, and Oversight	• The Recycling Regulation in the *Environmental Management Act* addresses accountability and oversight in sections 4, 5, and 6, which require producers to develop and submit an extended producer responsibility plan to a director designated by the B.C. Ministry of Environment and Climate Change Strategy and to update that plan every five years (Recycling Regulation, 2004). • Section 8 of the Recycling Regulation requires producers to submit an annual report to the director and to publicize the annual report on the internet: • The report should include: s.8(2)(b)) the location of collection facilities; s.8(2)(c) efforts taken by the producer to reduce the environmental impact of their products, s.8(2)(d) a description of how the product was managed relative to the pollution prevention hierarchy; s.8(2)(e)) the total amount of product collected and recovery rate if available; s. 8(2)(f) independently audited financial statement; and s. 8(2)(g) a comparison of the year's performance relative to the performance measures and requirements outline by s. 5(1)(a) of the Recycling Regulation. • Section 16 of the Recycling Regulation titled "Offences" states that anyone who contravenes the sections requiring producers to establish an extended producer responsibility plan, amend that plan every five years, and to submit annual reports is liable for a fine not exceeding $200,000 (Recycling Regulation, 2004).

California

Table 7: Sustainability Assessment of California's Proposed Regime

Sustainability Criteria	California's Proposed Policy based on the Lithium-Ion Car Battery Recycling Advisory Group Final Report
Design for Environment (DFE)	• Only 33% of members voted for a policy requiring design for reuse, repurposing, and recycling, meaning it was not ultimately recommended to the legislature (Kendall, Slattery, & Dunn, 2022). • DFE was opposed by OEM representatives on the grounds that it might interfere with safety, cost, or performance (Interview C, 2022). • Focus on design for recycling over design for disassembly (Interview C, 2022). • The proposed producer take-back policy might encourage DFE if producers are responsible for the cost of repurposing and recycling (Kendall, Slattery, & Dunn, 2022).

Circular Economy	• The Advisory Group recommended that EV batteries reaching EoL should be reused, repurposed, and recycled to create a more circular economy and that policy leaders create a circular economy for EV batteries in California similar to what has already been achieved for lead-acid batteries.
	• Section 7.2.2 of the Report is titled Circular Economy and Quality Recycling. These following policies in s. 7.2.2 did not receive majority support in the vote:
	• <u>Recycled content standards</u>- Mandatory use of XX% of recycled content in batteries.
	  • <u>Minimum material recovery rates:</u> Rates proposed by the EU to ensure critical materials are recovered.
	  • <u>Third party verification:</u> Batteries should be disassembled, processed, and recycled in facilities verified by a third party to ensure environmental protection and worker safety.
	  • <u>Require design for reuse and recycling:</u> Addressed above in the DFE section.
	  • <u>Develop a reporting system for EV batteries retired from use:</u> Creating an online database to track the final recipients of batteries to see how many batteries stay in California and to identify potential issues with the battery recycling system.
	  • <u>Develop a reporting system for lithium-ion battery recycling and recovery rates:</u> Recycling companies need to report their total recovery rates for cobalt, lithium, manganese, and nickel.
	• The Advisory Group recommended further research into the recycled content standards and recycling performance targets in Section 8 (Areas of Future Research).
	(Kendall, Slattery, & Dunn, 2022).

Minimizes Environmental Justice Concerns	• The Report mentions that exporting EoL lithium-ion batteries could create environmental justice concerns if batteries are managed or processed using unsafe practices (Kendall, Slattery, & Dunn, 2022). • The Report was not specific enough to discuss protecting vulnerable populations and communities (Interview C, 2022). • EoL EV batteries are supposed to go to a licensed and verified facility where emissions and environmental impacts will be calculated (Interview C, 2022). • There is no requirement in the Report that batteries must be recycled in North America (Interview C, 2022).

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Sustainability Criteria	California's Proposed Policy based on the Lithium-Ion Car Battery Recycling Advisory Group Final Report
Promotes Second-Life Uses	• Nearly everyone is in favour of reuse in a vehicle. There was more debate on the benefits of repurposing vs. recycling, at least in the short term (Interview C, 2022). • Once a battery is refurbished or repurposed the refurbisher or repurposer becomes the producer, making them responsible for properly managing the battery at EoL (Interview C, 2022). • The Report discusses the information needed by different actors to facilitate reuse and repurposing and proposes requiring a label and an electronic information exchange, which includes open access to information, a QR code, and disassembly instructions. These measures were both supported, with the labelling requirement receiving 93% approval and the digital identifier 87% approval (Kendall, Slattery, & Dunn, 2022). • Nearly everyone supported a state of health measurement while the battery is in the vehicle; the issue is accessing the data once the pack has been removed (Interview C, 2022).
Innovation	• The Report focusses on innovations in battery recycling technology (Kendall, Slattery, & Dunn, 2022). • The Report recommends supporting further research and demonstration of repurposing technologies, as well as strategies to reduce the cost of transportation. • The Report claims that increased EV battery recycling will lead to innovation in the space (Kendall, Slattery, & Dunn, 2022). • Several members opposed policies such as a universal diagnostic tool or strict limitations on product design on the basis that they could limit innovation (Kendall, Slattery, & Dunn, 2022). • The U.S. has no prescriptive policies for innovation, so those who wish to research seek funding, creating lots of room for innovation. Policies will therefore likely not affect innovation (Interview C, 2022) • The Advisory Group did not examine emerging technologies such as solid-state and sodium-ion batteries (Interview C, 2022).
Transparency, Accountability, and Oversight	• Physical labelling requirement with the "manufacturer name, cathode modules or cells are separated chemistry, voltage, performance/capacity, product alert statements/hazards, composition/process related information, and electronic information exchange/ digital identifier" received 93% support (Kendall, Slattery & Dunn, 2022). • Transparency for vehicle owners about battery health addressed with an SOH while the battery is in the vehicle, gained close to full support (Kendall, Slattery & Dunn, 2022). • A measure to develop a reporting system for EVs retired from use, increasing transparency across the EV value chain, received only 33% support (Kendall, Slattery & Dunn, 2022). • A measure to develop a reporting system for lithium-ion battery recycling recovery rates received only 33% support indicating a need for more transparency on recovery rates (Kendall, Slattery & Dunn, 2022). • A measure to support enforcement of unlicensed dismantling laws received 87% support indicating major support for accountability for safe dismantling (Kendall, Slattery & Dunn, 2022). • A measure to develop training materials received 93% support and indicates accountability by producers to show the public how to properly handle, store, and ship EoL EV batteries (Kendall, Slattery, & Dunn, 2022). • The Advisory Group did not recommend a tracking and reporting system like the battery passport that is mentioned in the EU's Proposal for a Regulation (Interview C, 2022). • It will be extremely important to evaluate the success of the core exchange and take-back policies; need to know that dismantlers can send batteries on for recycling (Interview C, 2022).

European Union

Table 8: Sustainability Assessment of EU's Proposed Battery Regulation

Sustainability Criteria	Proposal for a European Battery Regulation
Design for Environment (DFE)	• Measure 11 in *Table 4*- Design requirements for portable batteries- encourages battery strengthening and battery removability, which is followed by the more ambitious goal of battery replaceability (and the highest level of ambition requires battery interoperability). • Par. 13- "Batteries should be designed and manufactured so as to optimise their performance, durability and safety and to minimise their environmental footprint." The Proposal states that disassembly requirements will only be made accessible to the European Commission and accredited remanufacturers, second-life operators, and recyclers. One can interpret this measure to indicate a desire to create a regulated recycling, remanufacturing, and second-life market and to protect individuals from the health and safety consequences of dismantling EV batteries in an unsafe manner, while also maintaining control over the supply of resources. • Par. 15- The use of hazardous substances should be limited to protect human health, yet it only mentions mercury and cadmium specifically. One critique here is that the restriction on hazardous substances is limited and does not include cobalt, nickel, and other potentially hazardous substances. (European Commission, 2020)
Circular Economy	• On 11 March 2020, the European Commission released the new Circular Economy Action Plan. The Plan states that the new Proposal for waste batteries will weigh measures regarding recycled content and improving collection methods and recycling rates in order to keep materials from EV batteries within the battery supply chain. Such measures would ensure the recovery of valuable resources, provide guidance to consumers, and would consider the possible elimination of non-rechargeable batteries. The new Circular Economy Action Plan further emphasizes a focus on sustainability and transparency by evaluating the carbon footprint of battery manufacturing, the ethical mining and sourcing of raw materials, and "the security of supply in order to facilitate reuse, repurposing, and recycling of batteries" (European Commission, 2020b). • The Proposal for a Regulation has three main objectives: 1) strengthening the functioning of the internal market (including products, processes, waste batteries and recyclates), by ensuring a level playing field through a common set of rules; 2) **promoting a circular economy;** and 3) reducing environmental and social impacts throughout all stages of the battery life cycle. The focus on a circular economy shows how the new Circular Economy Action Plan and the Proposal for a Regulation are closely interlinked (European Commission, 2020). • Representatives from civil society expressed concerns about sustainable sourcing of materials and applying the principles of a circular economy to the battery value chain during public comment periods (European Commission, 2020).

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Sustainability Criteria	Proposal for a European Battery Regulation

Minimizes Environmental Justice Concerns	• The following sections in the Proposal for a Regulation addresses topics related to environmental justice concerns:
	  • Par. 66- Supply chain due diligence policies should be incorporated to address, at least, the most significant social and environmental risk categories. This should cover the likely impacts on social structures, human rights, human health and safety, and labour rights. In addition, such policies should protect the environment, in particular water, soil, air, and biodiversity from different sources of pollution.
	  • Article 59- Remanufacturers must ensure that remanufactured batteries comply with human health and environmental protections laid out by the Proposal. Repurposers and remanufacturers must additionally protect the environment by safely transporting, loading, unloading, and packaging second-life and waste batteries (European Commission, 2020).
	• The new Circular Economy Action Plan discusses the ethical sourcing of materials, related to mining and those who work and live around the mines (European Commission, 2020b).
	• The Proposal for a Regulation does not contain an outright ban on sending waste batteries to other countries for processing. EU may want to keep battery recycling in the continent. The EU does not want to get cobalt from mines where children and pregnant women are working under inhumane conditions (Interview D, 2022).

Promotes Second-Life Uses	• Second life of industrial batteries is the second measure listed under the 13 broad policy measures of the impact assessment that shapes the Proposal. Options two or three differ on the conclusion that second-life batteries are waste, yet both state that batteries must comply with product requirements when they enter the market, showing that the EU anticipates a second-life battery market. • Some of the anticipated second-life applications for EV batteries are stationary energy storage systems and integration into electricity grids as energy resources. • Par. 88- Acknowledges that a second-life market is emerging meaning there must be rules to regulate the market and guidelines related to battery health assessments for when batteries can be used in second-life applications. (European Commission, 2020)
Innovation	• Article 79- The section titled "Specific Objectives" states the following sub-objective under the specific objective of Strengthening Sustainability: "Promote **innovation** and the development and implementation of EU technological expertise." • The European Commission allocated over $500 million Euros in funding for 100 projects under the Horizon 2020 (H2020) Programme. These projects cover the entire value chain of several types of batteries focussing on improving the materials used in batteries and limiting their environmental impact, improving battery recycling technology to create more efficient resource recovery in Europe, and to research new battery systems and alternatives to existing batteries (European Commission, 2020). • Some of the studies under Horizon 2020 are researching solid-state and sodium-ion batteries (Interview D, 2022).

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Sustainability Criteria	Proposal for a European Battery Regulation
Transparency, Accountability, and Oversight	• Measure 12, Provision of information, proposes an online labelling system for batteries in option 2, and a battery passport supported by the Global Batteries Alliance in option 3. The purpose of these new technologies will be to facilitate secure data sharing, provide information about the carbon footprint of the battery manufacturing process, track the origin of materials used in batteries, label batteries to show their composition including hazardous chemicals, outline possibilities for repair and repurposing, provide dismantling instructions to licensed dismantlers and repurposers, track large batteries throughout their life cycle, and to communicate recycling and recovery processes for batteries that reach EoL. • Proper labelling of batteries with capacity, hazardous materials, and main characteristics via a QR code • The Proposal for a Regulation states that one problem in a group of problems related to social and environmental risks not currently covered by EU laws is the lack of transparency on the sourcing of raw materials. • Article 39 section 2(d)- Calls for transparency within the supply line with traceability to upstream actors in the supply chain. • Measure 13 calls for due diligence of the battery supply chain, option 2 is voluntary and option 3 is mandatory. Member States that develop supply chain due diligence schemes can apply to the European Commission to have those schemes recognized. • Oversight appears to be the task of the European Commission. • Article 76- Enforcement via penalties appears to be the responsibility of Member States, who will submit their rules and penalties to the Commission for approval, as well as any subsequent amendments to such rules or penalties. (European Commission, 2020).

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