An Evaluation of the Environmental Trade-offs of Electric Vehicles: A Comparative Analysis of Potential Management Regimes for End-of-life Electric Vehicle Batteries

By Jonathan Myers

Supervised by Professor Mark Winfield

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Abstract

The electrification of road transportation has been touted as the way to limit the greenhouse gas emissions resulting from road transportation thereby mitigating some of the potentially disastrous effects of climate change. The process involves switching from vehicles with an internal combustion engine to electric vehicles (EVs) powered by a battery. This solution comes with significant trade-offs related to the environment and human health which can be identified by conducting a life cycle analysis. Such an analysis reveals that most of these trade-offs occur at either the raw materials extraction and manufacturing phase or at end-of-life (EoL). Policy measures however typically target batteries when they reach EoL, potentially ignoring the trade-offs that occur in the upstream portion of the battery life cycle. In order to assess the effectiveness of such policy measures, this paper conducts a sustainability assessment based on the model established by Robert B. Gibson. The researcher applied the sustainability assessment to proposed regimes for managing EoL EV batteries in British Columbia (B.C.), California, and the European Union (EU). Other than the EU's Proposal for a Regulation, the results revealed significant shortcomings in the proposed regimes in B.C. and California. The paper concludes with three recommendations from the researcher based on the results of the sustainability assessment: 1) Establish a national framework for managing EoL EV batteries similar to the Proposal for a Regulation in the European Union; 2) limit the power of original equipment manufacturers (EV and EV battery manufacturers) to influence battery management policy; 3) consider more comprehensive policies for sustainable road transportation.

Foreword

This section describes how this major research paper fulfills the requirements of the Master of Environmental Studies/Juris Doctor Degrees. The research paper critiques the design and implementation of policy regimes thereby directly engaging with the statutes enacted by state/provincial and national legislatures. A significant part of my research involved statutory interpretation and analysis to identify both the meaning and the ambiguity within different statutes.

My area of concentration focuses on the concepts of the circular economy and sustainability and how these concepts can aid in the global transition away from burning fossil fuels to produce energy in order to mitigate the effects of climate change. I am interested to see how these concepts can be implemented in a specific industry through policy measures. My major research paper reflects this area of concentration as the paper compares the effectiveness of three end-of-life (EoL) electric vehicle (EV) battery management regimes by conducting a sustainability analysis. The results of the sustainability analysis provide the basis for the recommendations laid out in this paper for improving EoL EV battery management regimes moving forward.

My plan of study consists of three learning components: 1) Circular economy and sustainability; 2) Climate change and energy transitions; and 3) Environmental justice. Both my major research paper and my coursework have fulfilled all three components.

My major research paper satisfied my first component, as the tool I have chosen to assess the effectiveness of the comparison regimes is a sustainability assessment. This required me to develop a deep understanding of the concept of sustainability and to develop context-specific criteria that effectively evaluate the sustainability of a regime. The circular economy plays a significant role in the sustainability assessment as it is one of the six criteria.

The second component, climate change and energy transitions, plays a foundational role in my paper as the transition from vehicles using internal combustion engine that burns fossil fuels to EVs represents an energy transition that is directly in response to climate change. By eliminating the need to burn fossil fuels that release greenhouse gas emissions, electrification aims to mitigate the effects of climate change that result from the road transportation industry.

Environmental justice is also one of the six criteria used in the sustainability assessment and serves as an important measure for the effectiveness of EoL EV battery management regimes. Many of the trade-offs related to electrification relate to environmental damage and human health risks tied to the sourcing, production, and disposal of EV batteries, which can occur in the developing world.

Acknowledgements

I would like to thank my family for their support during the completion of my MES/JD degree and the writing of this major paper. I would also like to thank two faculty members who helped me tremendously in both the writing of this paper and the completion of the MES/JD degree. Professor Dayna Scott provided significant guidance and assistance both before entering the program and during the degree. Professor Scott offered clarity and answered important questions on numerous occasions, especially during my MES II-III exam, which helped me sharpen my plan of study and major research paper. Professor Mark Winfield, who is both my faculty advisor and my supervisor for this major paper, has been instrumental in helping me create my plan of study and in refining my major research paper. Professor Winfield consistently provided detailed guidance and feedback throughout the MES/JD and has encouraged and challenged me to refine and share my paper, highlighting to the importance of my research.

Table of Contents

List of Tables & Illustrations

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	The 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

Ch. 1. Introduction: Trade-offs Resulting from the Energy Transition to Electrification

The scientific community has provided definitive proof that the release of greenhouse gasses (GHGs) traps heat in the atmosphere, which causes global temperatures to rise, leading to climate change (Natural Resources Canada (NRCan) 2016). The Intergovernmental Panel on Climate Change (IPCC) has consistently recommended reducing greenhouse gas emissions as one of the main strategies for mitigating the effects of climate change such as increased droughts, hurricanes, floods, and rising sea levels ("Working Group III Sixth Assessment Report" 2021).

Most greenhouse gas emissions result from fossil fuel combustion and industrial processes ("Working Group III Sixth Assessment Report Chapter 01" 2021). In order to reduce such emissions, the IPCC and other leading experts on climate change have supported a transition away from burning fossil fuels to electrification, where energy would be generated (hopefully from clean and renewable sources) and stored, often within batteries for later uses. One sector that is already transitioning away from burning fossil fuels to electrification is transportation, which produces 14% of global GHG emissions (United States Environmental Protection Agency (EPA) 2022). According to the IPCC, road transportation accounts for 70% of global direct transportation emissions, and the road transportation industry has in recent years made significant strides towards electrifying cars, busses, and trucks.

This transition however has brought with it significant environmental trade-offs unrelated to climate change due to the electric vehicle (EV) battery life cycle. This research paper aims to evaluate the sustainability of policy measures, with an emphasis on Canadian jurisdictions as the researcher is located in Canada, that address the cumulative environmental effects of the EV battery life cycle including non-climate change related trade-offs.

Chapter 2 frames the problem explaining the different stages of the battery life cycle from material sourcing and extraction to end-of-life (EoL) and will introduce the concept of extended producer responsibility. Chapter 3 explains the research methods, a literature review supplemented by interviews, and the approach, a comparative study of potential management regimes for EoL EV batteries. Chapter 4 presents the goals of an optimal EoL EV battery management policy offered as criteria for a sustainability assessment based on the model by Robert B. Gibson and framed by the United Nations Sustainable Development Goals. Chapter 5 presents the case studies for this research paper which are Ontario, Quebec, British Columbia, California, and the European Union. Chapter 6 analyzes the case studies using a sustainability assessment, based on the criteria outlined in Chapter 4, and provides preliminary conclusions about the sustainability of the policy regimes. Chapter 7 outlines limitations of the study and makes policy recommendations based on the analysis in Chapter 6. Chapter 8 concludes the research paper and is followed by the bibliography.

Ch. 2. Framing the Problem

Life-Cycle Analysis for Transition to Electrification

Many tout the electrification of the road transportation industry as an emission-reducing and thereby more environmentally friendly way forward, yet there could be significant trade-offs associated with the electrification of transportation. This transition would mean that cars and trucks, which have traditionally been powered by an internal combustion engine (ICE) that runs on either petrol-based fuels such as gasoline and diesel, or on biofuels, would need to be replaced by electric vehicles that are powered by a battery.

The three types of EVs are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles, and battery electric vehicles (Kelleher 2020). Common battery chemistries for some HEVs (mostly Toyota) are nickel-metal hydride, yet most EV batteries are lithium-ion (Kelleher 2020). Lithium-ion itself 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). Producing these batteries using such minerals makes the EV battery industry reliant on mining or sourcing through energy intensive and environmentally damage activities (“Understanding EV Batteries” n.d.). Material sourcing along with other stages in the EV battery life cycle may create trade-offs unrelated to climate change that negatively impact human health and the natural environmental. These trade- offs could be revealed by conducting a life cycle analysis (LCA) of EV batteries.

An LCA (also referred to as a life cycle assessment) take a product’s full life cycle into account starting from resource extraction, continuing on to production and use, and concluding with EoL management (which includes recycling and disposal of any excess waste). A 2020 study compared seventeen LCAs of electric vehicle (EV) batteries and identified the phases of the EV battery as "raw materials extraction and manufacturing, battery production, transportation, use phase, and EoL with material recycling (Andrea Temporelli, Maria Leonor Carvalho, and P. Girardi 2020)." For the purposes of this paper, EoL is considered the point at which a battery is no longer desirable by a consumer for a first or second life application and would likely be sent to a recycling facility. The following table breaks down the stages of the EV battery life cycle according to the steps outlined by Temporelli et al. and outlines the activities and non-climate-change environmental trade-offs resulting from each stage.

Life Cycle Stage	**Activities at this stage**	**Trade-offs (unrelated to climate change)**
Raw Materials Extraction and Manufacturing	Mining metals like lithium and cobalt because there is not an adequate supply in the market (Clare Church and Laurin 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 ("EV Batteries Made from Deep-Sea Rocks Dramatically Reduce Carbon" 2020).
	Most cobalt is mined in the Democratic Republic of the Congo (DRC) ("Developing Countries Pay Environmental Cost of Electric Car Batteries" 22 July 2020).	Cobalt mines contain sulphur minerals which can create sulfuric acid when encountering air or water, contaminating water sources and affecting aquatic life for hundreds of years ("Developing Countries Pay Environmental Cost of Electric Car Batteries" 22 July 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,	Cobalt and cadmium are responsible for cancer effects (Shahjadi Hisan Farjana, Nazmul Huda, and M.A. Parvez Mahmud 2019).

	who particularly inhale large quantities of particles that are in the air (Shahjadi Hisan Farjana, Nazmul Huda, and M.A. Parvez Mahmud 2019).	
	There are significant lithium deposits is in South America, between Bolivia, Argentina, and Chile (Maeve Campbell 2022).	Lithium extraction leads to biodiversity loss, water contamination, and water shortages, which are especially problematic in arid areas where water is scarce (Maeve Campbell 2022). Soil contamination along with water loss and other forms of environmental damage have forced some South American communities to leave ancestral settlements ("Developing Countries Pay Environmental Cost of Electric Car Batteries" 22 July 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)	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).
Battery Production	There is currently little data about the dangers associated the construction or assembly of EV batteries.	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	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,

	batteries are packaged properly to protect against potential physical damage.	corrosive, or flammable gases that could contaminate air, ground, and water sources (Dr. Marco Ottaviani 2022).
Use Phase	Jean-Christophe Lambert of Lithion, a major lithium-ion battery recycler, revealed that EV batteries are generally safe when inside vehicles unless they become damaged through an accident where the battery if hit (Personal Communication, Lambert 2022).	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 with material recycling	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, and will thereby be a waste product that must be managed. 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: direct recycling, pyrometallurgical recycling, and hydrometallurgical recycling.	Direct recycling involves removing and utilizing working components of a battery. There are few environmental risks associated with direct recycling beside those that generally accompany battery

		removal (Silvian Baltac and Shane Slater 2019). Pyrometallurgy involves the use of high temperatures that cause smelting, thereby separating materials which 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 (Silvian Baltac and Shane Slater 2019). Recovery rates from pyrometallurgy for raw materials to be used for making new products are up to 85% (“What Happens at the End of the Electric Vehicle Battery’s Journey?” n.d.). Hydrometallurgy uses several 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 (Silvian Baltac and Shane Slater 2019). Recovery rates from hydrometallurgy for raw materials to be used for making new products are up to 95% (“What Happens at the End of the Electric Vehicle Battery’s Journey?” n.d.).

		Battery recycling is still in its infancy, as much of the material being recycled is scrap from manufacturing, so it is difficult to accurately quantify any negative health and environmental effects of the recycling process at this point (Personal Communication, Louise Levesque 2022).

Table 1: Life Cycle Analysis

The above table reveals that the most significant trade-offs occur during the raw materials extraction and manufacturing phase and at EoL. One important finding from the initial research is that while many fear that EoL EV batteries are ending up in landfills, this is simply not the case, as these batteries are too valuable to recyclers and OEMs to be discarded (Personal Communication, Louise Levesque 2022). The lack of transparent recovery rates and tracking makes it difficult to back up these claims with data, leading some to question where EV batteries actually end up when they reach EoL. EV batteries are almost certainly not in landfills or municipal recycling centres; however, they can be purchased on the open market, packaged, and stored in unsafe ways due to a lack of transparency, regulation, and oversight.

While EoL EV battery management regimes appear to currently be handling the volume of batteries that reach EoL, the proliferation of electrification means that many more batteries will soon reach EoL, with a recycling industry that may not be equipped to handle the demand. The International Energy Agency (IEA) estimates that the world can currently recycle 180,000 metric tons of EoL EV batteries per year (Madeline Stone 2021). There could be as much as 8 million metric tons of EoL EV batteries that need to be recycled by 2040, according to IEA calculations using a Tesla Model 3 battery weighing just over 1,000 pounds as the baseline (Madeline Stone 2021). These numbers indicate there could be a significant shortfall between recycling capacity and demand in the coming decades if EoL EV battery management regimes are not properly constructed and executed.

The researcher argues that policies (and proposed policies) related to EV battery management to date in the European Union (EU), the United States (U.S.) (there is currently no U.S. recycling law or collection infrastructure in place for lithium-ion batteries like those in place for lead-acid batteries (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022)), and Canada to manage their EV batteries typically concerns EV batteries that reach EoL ("European Union a Step Closer to Adopting Expansive New Rules Covering Lifecycle of Electric Vehicle Batteries" 2022; "Waste Not, Want Lots" 2022). The emphasis on EoL appears to indicate that EV battery management regimes attempt to handle both the up-stream and downstream challenges created by EV batteries by recovering and reusing as many battery materials as possible at EoL thereby reducing if not eliminating the need to mine virgin material.

The conclusion that recovering and reusing EoL batteries significantly reduces the reliance on mining has been challenged by researchers who in a 2020 white paper revealed that EV battery recycling will reduce the need for mining new material by 20% by 2040 and 40% by 2050 (Peter Slowik, Nic Lutsey, and Chih-Wei Hsu 2020). This logic also relies on such EoL EV battery management regimes setting recovery rates that align with the market demand for new EV batteries and meeting those rates with efficient collection schemes. Reporting on recovery rates must therefore be possible via transparent reporting methods, to see if regimes are meeting their targets, resulting in a reduced need to source new material. These regimes often utilize some form of extended producer responsibility (EPR) to accomplish recovery goals.

Extended Producer Responsibility (EPR)

EPR is a policy approach where a producer's responsibility, often financial yet sometimes procedural, is extended to the post-consumer stage for the treatment or disposal of products ("Introduction to Extended Producer Responsibility" 2017). In principle, EPR aims to motivate producers to design their products for the environment and support recycling and resource recovery goals and infrastructure ("Extended Producer Responsibility," n.d.). The logic is that producers will be motivated to create more efficient recycling processes and products that can be disassembled, so parts and resources can be recovered and reused, creating a massive financial incentive.

Ch. 3. Research Methods and Approach

Methods and Approach

This research paper evaluates how effectively certain policy measures address the environmental trade-offs unrelated to climate change that are created by the electrification of the road transportation industry by a comparative study of potential management regimes for EoL EV batteries. The research utilizes both interviews with stakeholders and a literature review. The goal of the interviews is to have stakeholders provide current updates on management regimes for EoL EV batteries across jurisdictions in Canada, the U.S., and the EU. The interviews will be important because managing EoL EV batteries is a novel, dynamic field, so stakeholders would likely provide a more accurate picture of current realities compared to peer-reviewed literature that may be outdated.

The researcher interviewed four people and received important information from others via e-mail communication. The interviews took place over the Zoom video conferencing software, and the researcher recorded the minutes and responses to questions during the interview with hand-typed notes. Questions related to the subjects' knowledge of the EV battery life cycle, an EoL EV battery management regime, similarity to other EoL EV battery management regimes, and responses to common critiques.

The first interviewee is Jean-Christophe Lambert, a business development manager at Lithion, a lithium-ion battery recycler. Jean-Christophe provided valuable insight about the battery recycling process, battery safety, and predictions for the amount recoverable material from EoL batteries that could be utilized in the near future. The second interviewee is Louise Levesque, the Policy Director at Electric Mobility Canada (EMC), a not-for-profit organization devoted exclusively to advancing electronic mobility. Louise has significant expertise on the electrification of road transportation, and the researcher specifically chose to interview Louise to learn more about the regimes for managing EoL batteries in Quebec and British Columbia (B.C.). The third interviewee is Margaret Slattery, one of the co-authors of the Lithium-ion Car Battery Recycling Advisory Group Final Report. California Assembly Bill 2832 (AB2832) mandated the formation of the Advisory Group to submit policy recommendations to the state legislature that would outline a pathway to reaching as close as possible to 100% reuse or recovery of EoL lithium-ion EV batteries. The fourth interviewee is Karim Zaghib, a Professor of Chemical and Materials Engineering at Concordia University with 36 years of experience working on batteries. Professor Zaghib provided general information about EV battery technology and clarification about the EU's EoL EV battery management regime.

The literature review aims to provide the bulk of the background information necessary for the analysis by describing EoL EV battery management regimes in the five select jurisdictions: Ontario, Quebec, B.C., California (U.S.), and the EU. Ontario, to date, has no policy in place for managing EoL EV batteries, yet it has been selected because it is the home jurisdiction of the research, and Ontario highlights some of the barriers in place for instituting EoL EV battery regimes. In 2021, Quebec announced its intention to create minimum recovery rates for EV battery producers, which it included in regulations for smaller batteries and lead-acid batteries ("Waste Not, Want Lots" 2022). Since then, Quebec has changed course, removing EV batteries from the regulation and setting up a voluntary takeback program that will begin in the spring of 2023 (Office of the Minister of the Environment and the Fight Against Climate Change 2022). British Columbia released an Extended Producer Responsibility Five-Year Action Plan ("the Five-Year Action Plan") that began in 2021 and includes plans to expand the province's battery regulation to include provisions for EV and HEV batteries ("Advancing

Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 2021). The Advisory Group Final Report on Lithium-ion Car Battery Recycling ("The Advisory Group Final Report") from California could shape the first EoL EV battery management regime in the U.S. (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). The European Union presents arguably the most robust EoL EV battery management regime, formerly with the Directive on batteries and accumulators (2006/66/CE) and the Directive on end-of-life vehicles (2000/53/CE) ("Study of Extended Producer Responsibility for Electric Vehicle Lithium-Ion Batteries in Quebec" 2020). As of 2020, the EU chose a new policy approach with the Proposal for a Regulation concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020.

The first step in the comparative study of EoL EV battery management regimes will be to describe the different regimes as case studies. The framework for describing the regimes will be similar to the framework utilized by Winfield and Benevides in *Drinking Water Protection in Ontario: A Comparison of Direct and Alternative Delivery Models*. Winfield and Benevides described the alternative regimes in the following sections: Definition, example of the policy, functions, funding, and notes (Winfield and Benevides 2001). These sections could be applied to the current research with some adjustments. Definition remains the same, but there is no need for an example of the policy since the comparison regimes will be an example of a policy. Functions remains the same and funding will discuss the percentage of the program that is currently being paid for by producers, since the regimes are based on EPR, meaning producers should be covering the costs. The notes section provides relevant additional information such as if the policy is active or still in development and any major exclusions. The researcher will then evaluate the effectiveness of the regimes by conducting a sustainability assessment.

Sustainability Assessment with Context-Specific Criteria

The criteria for the sustainability assessment will be based on the model outlined by Robert B. Gibson's *Sustainability Assessment*: *Basic Components of a Practical Approach* (Robert. B. Gibson 2006). The model provides the flexibility to create context-specific criteria, which the researcher has done by considering criteria that are both relevant to the electrification of road transportation and the United Nations Sustainable Development Goals. The context-specific criteria that have been applied to the five selected EoL EV battery management regimes are: the extent to which the policy encourages design for environment, promotes a circular economy, minimizes environmental justice concerns, reduces consumption, mandates second-life uses, demands innovation, and provides transparency, accountability, and oversight.

Following the evaluation, the researcher makes recommendations that go beyond what exists in the comparison regimes. These recommendations aim to provide research-based improvements to existing or planned EoL EV battery management policy to advance sustainability and create a circular economy for electric vehicle battery materials.

Ch. 4. Goals of a Sustainable EoL EV Battery Management Policy

The researcher outlined the below goals of a sustainable EoL EV battery management regime to serve as the criteria for the sustainability assessment. The United Nations (UN) Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" in 1987 ("Sustainability" n.d.). The United Nations has since outlined 17 Sustainable Development Goals (UN SDGs) that aim to support the 2030 Agenda for Sustainable Development, which has been adopted by all UN member states ("The 17 Goals" 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 ("The 17 Goals" 2022). Each of the goals contains their own targets and thousands of actions toward achieving those targets ("The 17 Goals" 2022). The goals served as a guiding tool for creating the criteria for the sustainability assessment. When discussing sustainability and waste specifically, such as EoL EV batteries, the hierarchy for sustainably managing waste is reduce, reuse, recycle, in that order (Emma Macdonald 2020). While the criteria for the sustainability assessment do not specifically address reduction, the recommendations section will address potential ways of reducing the number of batteries and vehicles on the road through policy.

Robert B. Gibson Gibson's article provides instructions for how to design a practical sustainability assessment regime (Robert. B. Gibson 2006). Gibson begins by stating that the idea of sustainability results from two key problems: the growing gap between the rich and poor and the increasing destruction of the biosphere (Robert. B. Gibson 2006). He then goes on to establish that a core idea underlying sustainability is that current human actions and trends appear to be not viable in the long term. Gibson argues that sustainability presents a problem that is just as much social economic as it is biophysical, as humans cannot live without favourable biophysical conditions (Robert. B. Gibson 2006). Sustainability assessments differ from conventional decision-making as they directly and jointly address all trade-offs between ecological or biophysical and social or economic factors as opposed to addressing trade-offs separately and outside of a common framework (Robert. B. Gibson 2006). Gibson outlines two interdependent ways for dealing with trade-offs, rules and processes. While the applicable rules may vary depending on the context of an assessment, the fundamental rule is that "trade-off decisions must not compromise the fundamental objective of a net sustainability gain (Robert. B. Gibson 2006). This rule represents the appropriateness of a sustainability assessment for EoL EV battery management policy based on EPR that arises from the electrification of road transportation. Electrification is considered a more sustainable method of road transportation because of its potential to reduce GHG emissions, yet policymakers and stakeholders must ensure that the trade-offs created by electrification do not compromise the net sustainability gain of transitioning away from ICE vehicles.

Gibson goes on to state that general rules must be complemented by case and context specific clarifications, which in this case would be context-specific criteria that outline a sustainable EoL EV battery management regime. One of the key challenges of the sustainability assessment is identifying context-specific criteria, as criteria are often established by experts or stakeholders in the study area. The researcher in this case developed criteria based on preliminary research and discussions with experts on EPR, sustainability, and EV batteries. While the UN SDGs did not exist at that time of Gibson's publication, one can reasonably assume that Gibson would have either incorporated or would be open to incorporating the UN SDGs in some way into as sustainability assessment. The researcher made that leap in this case by aligning each case-specific criterion to one or more of the UN SDGs to ensure that the assessment measures sustainability. The six sustainability criteria measure the extent to which an EoL EV battery management policy: 1) Promotes design for the environment; 2) promotes a circular economy; 3) encourages second life uses; 4) minimizes environmental justice concerns; 5) encourages innovation; and 6) creates transparency, accountability and oversight. The following section expands upon the above criteria and identifies the UN SDGs that align with each individual criterion.

<u>Design for Environment (DFE)</u>

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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, and 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 ("Design for Environment" 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 (Personal Communication, Margaret Slattery 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, and Amos 2008).
Parts should also be made from durable materials and should be by easily separated from other parts (Deathe, MacDonald, and Amos 2008).

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• 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, and 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 the *Canadian Environmental Protection Act (CEPA), 1999* (*Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33)* 1999). 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.

Table 2: Design for Environment (DFE)

Circular Economy

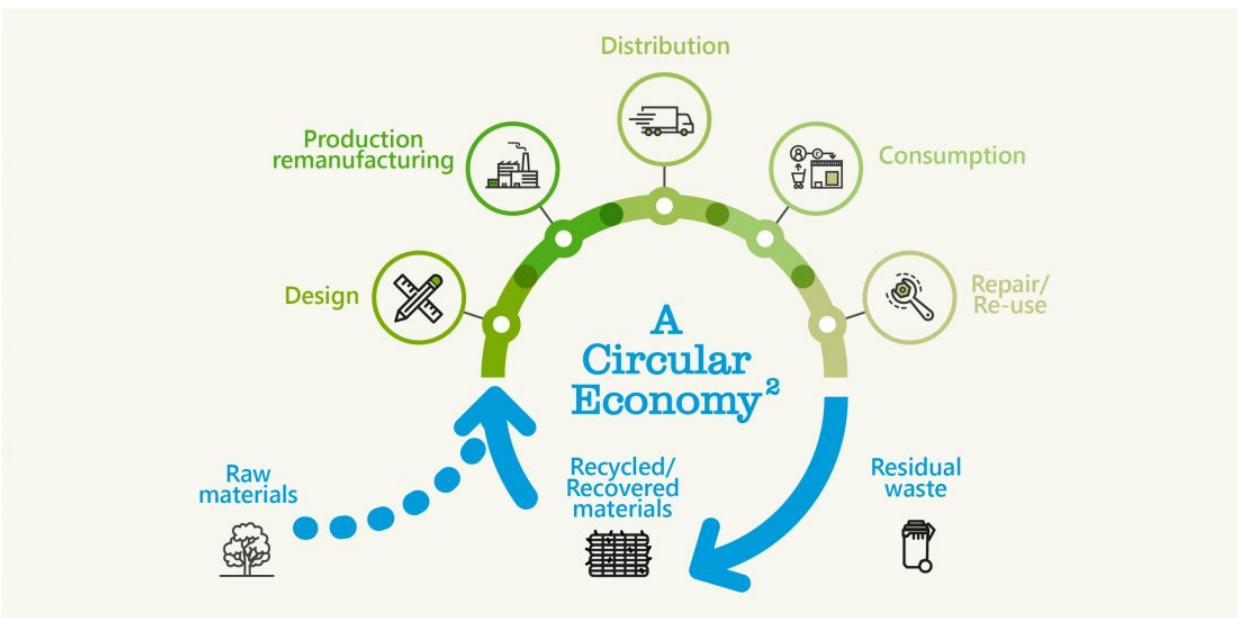

Illustration 1: Circular Economy (Circular Economy Image 2014)

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 ("The Circular Economy" n.d.). • 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 ("The Circular Economy" n.d.). • 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. (Patrick Schroeder, Kartikka Anggraeni, and Uwe Weber 2019)

Table 3: Circular Economy

Second Life Uses

Description
• Once a battery is no longer desirable by its original owner there are several possible second uses, resale as is, remanufacturing, and repurposing ("What Happens at the End of the Electric Vehicle Battery's Journey?" n.d.).   o 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).

o 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 ("What Happens at the End of the Electric Vehicle Battery's Journey?" n.d.). o 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 life span (Daniel 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 use future use (Anrica 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.

Table 4: Second Life Uses

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 (EPA) n.d.)."

• 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. (United States Environmental Protection Agency (EPA) n.d.). • 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
• 3) Good health & Well-being- Exposure to toxic substances threatens the health and well-being of those who encounter such substances, who in the life cycle of EV batteries would be those who work in sourcing critical minerals through mining or at EoL. • 8) Decent work and economic growth- 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 ("The 17 Goals" 2022). • 10) Reduced inequalities- 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. • 12) Responsible production and consumption- 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. • 15) Life on land- 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. • 16) Peace, justice, and strong institutions- 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.

Table 5: Environmental Justice

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 (Henry Man 2022).
  o Battery manufacturers such as Panasonic, Samsung, and LG are constantly developing batteries that are lighter, safer, more energy dense, and more sustainable (Henry Man 2022).
  o Sodium-ion batteries present a safer and cheaper alternative to lithium-ion batteries because sodium is cheap, abundant, and non-flammable (Michelle Lewis 2022).
  o 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 (Beverly Braga 2021).
• More innovation related to data sharing of battery performance and battery track 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 ("The Global Battery Alliance Battery Passport: Giving an Identity to the EV's Most Important Component" 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.

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 (Jaclyn 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 (Jason 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.

Table 6: Innovation

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.   o 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 (Audrey Carleton and Aaron 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 ("The Global Battery Alliance Battery Passport: Giving an Identity to the EV's Most Important Component" 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 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.

Table 7: Transparency, Accountability, and Oversight

Ch. 5. Case Studies

The following chapter describes the five selected case studies- Ontario, Quebec, B.C., California, and the EU- using a framework similar to that of Winfield and Benevides in *Drinking Water Protection in Ontario: A Comparison of Direct and Alternative Delivery Models*. The first jurisdiction of focus is Ontario, which to date has no policy for managing EoL EV batteries.

<u>Ontario</u>

Definition	• Ontario currently has no policy for managing EoL EV batteries (Anonymous- MECP 2022) (Anonymous- RPRA 2022).
Function	• None.
Funding	• No EoL EV battery management policy in Ontario, based on EPR or otherwise, producers are not responsible for funding EoL EV battery management • Ontario is supporting billions of dollars in investments from large OEMs such as Ford and Honda to build hybrid and electric vehicles. • Ontario is additionally supporting investments for a local EV battery factory (Anonymous- MECP 2022).

Table 8: Ontario- Definition, function, and funding

Notes

In 2016, Ontario introduced the *Waste-Free Ontario Act, 2016* to enact the *Waste Diversion Transition Act, 2016* and the *Resource Recovery and Circular Economy Act, 2016* (*Waste-Free Ontario Act, 2016, S.O. 2016, c. 12 - Bill 151* 2016). The *Resource Recovery and Circular Economy Act, 2016* utilizes 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 (Ontario's version of EPR) (*Resource Recovery and Circular Economy Act, 2016, S.O. 2016, c. 12, Sched. 1* 2016). The *Act* has several regulations that align with the programs being transitioned by RPRA: hazardous and special products, blue box, electrical and electronic equipment, batteries, and tires. EV batteries are not listed under any of the regulations, including one for batteries, which led the researcher to contact RPRA and the Ontario Ministry of Environment Conservation and Parks (MECP).

An employee at RPRA confirmed via an October 3, 2022, e-mail that at that time there was no EV battery regulation in Ontario (Anonymous- RPRA 2022). The MECP similarly replied to an e-mail on October 26, 2022, stating that Ontario has not included EV batteries under its producer responsibility framework for batteries. The e-mail went on to expand on the situation, stating that OEMs in the vehicle industry indicated that batteries have value and are being properly managed, so at this point no regulation is necessary (Anonymous- MECP 2022). It appears at 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.

Louise Levesque explained that OEMs in Ontario have significant lobbying power, which could explain why the province has yet to establish an EPR policy for EV batteries (Personal Communication, Louise Levesque 2022). EPR means more costs and responsibility for OEMs as they would need to support recovery and management of EV batteries at EoL, so it makes sense that they would be opposed to such a policy. The power of OEMs in the formation of policy will be revisited in the recommendations section of this paper.

The second jurisdiction of focus is Quebec, which like Ontario, has no plans for a mandatory EoL EV battery management regime in place; however, Quebec is developing a voluntary EV battery take-back program.

<u>Quebec</u>

Definition	• Currently developing a voluntary battery take-back program with OEMs that should be released in the Spring of 2023 (Office of the Minister of the Environment and the Fight Against Climate Change 2022).
Functions	• Unknown to date.
Funding	• Unknown to date.

Table 9: Quebec-Definitions, function, and funding

Notes

Until June of 2022, Quebec seemed poised to create regulations for managing waste EV batteries. The Quebec government released draft legislation for the *Environment Quality Act* in October of 2021, which called for producers to recover waste EV batteries after 10 years in Article 33 of the *Act* (*Gazette Officielle Du Québec* 2021). Article 8.1 of the draft legislation also 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 (Daniel Breton 2022). The draft legislation additionally called for the identification and traceability of EV batteries under Article 5-4 and for the possibility of setting up a non-profit organization to manage EV batteries at EoL under Article 6 (*Gazette Officielle Du Québec* 2021).

Not-for-profit organizations, such as EMC, and other stakeholders in the EV battery space showed concern for the draft legislation particular with Articles 8.1 and 33 (Daniel Breton 2022). By mandating a 10-year collection time (Article 33) the Quebec government appeared to set an arbitrary target that in no way related to the actual life span of EV batteries, which could be 25 years, but in reality, nobody knows for how long EV batteries will last. 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 (Dr. Jeff Dahn 2021).

Article 8.1, which prohibited the use of parallel recovery activities also caused concern, as reuse in vehicles or in second life uses offsets the environmental impact of manufacturing EV batteries by extending their lifespan (Daniel Breton 2022). One can argue that the Quebec draft legislation skipped the reduce and reuse steps of the sustainability hierarchy by jumping straight to the third “R”, recycling, which according to the hierarchy should be the last resort (Emma Macdonald 2020). Critics of the lack of support for second life uses also oppose the integration of EV batteries into regulations for waste management because of the distinct nature of EV batteries as products that maintain a higher value compared to smaller batteries that are found in portable electronics (Daniel Breton 2022). The value attached to EV batteries also indicates 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 when it announced that the battery takeback policy would be voluntary.

Few details have emerged to date about Quebec’s voluntary policy, and the government has been developing the policy mostly with international OEMs (Honda, Ford, GM, Toyota) while excluding not-for-profit organizations and all but one local OEM from the process (Personal Communication, Louise Levesque 2022). A voluntary policy would likely push back any chance at a regulation for five years, which presents a big blow to supporters of a sustainable EV battery life cycle in Quebec (Personal Communication, Louise Levesque 2022).

B.C. appears to be the first Canadian province or territory to institute an EoL EV battery management regime as part of the B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026, which states that EV batteries will be included into the EPR programs covered by the Recycling Regulation of the B.C. *Environmental Management Act*.

British Columbia (B.C.)

Definition	• The B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026 builds on the province's rich history of EPR and will develop a system to safely repurpose and recycle HEV and EV batteries • Will develop a system to safely repurpose and recycle HEV and EV batteries. • EPR program aims to additionally support reuse and will highlight B.C. as the Canadian leader in battery recovery and EoL management. ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 2021).
Functions	• EPR framework operates under the Recycling Regulation (B.C. Reg. 449/2004, O.C. 995/2004) of the *Environmental Management Act*. • The Five-Year Action Plan states that HEV and EV batteries will be added to the recycling regulation in a phased in approach beginning in 2024, with full integration of the EPR program by 2026. • Section 4 of B.C.'s Recycling Regulation requires producers to submit an extended producer responsibility plan for products listed within the product category of the regulation. • <u>Recovery rate</u>: Recycling Regulation 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 (*Environmental Management Act-Recycling Regulation* 2004).
Funding	• Recycling Regulation Section 5(1)(C)(i): "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." • One can then conclude that producers would be fully responsible for funding the collection of the products. (*Environmental Management Act-Recycling Regulation* 2004).

Table 10: B.C.- Definition, function, funding

Notes

The Recycling Regulation does not specifically mention electric vehicle batteries and the Five-Year Action Plan briefly mentions that EV batteries will be phased into B.C.'s EPR regime in 2024 without providing additional details.

While California does not yet have an EoL EV battery management regime, the Lithium-ion Car Battery Recycling Advisory Group completed its Final Report in March 2022, which provides policy recommendations for a potential regime in California. The Report does not provide details about how the voting members were chosen, and the researcher cannot conclude if the Report's findings are binding on the state legislature.

[1]California (U.S.)

Definition	• In 2018, California Assembly Bill AB-2832 required the construction of the Lithium-ion Car Battery Recycling Advisory Group to provide policy recommendations to the legislature that ensure close to 100% of lithium-ion car batteries are reused or recycled when they reach EoL (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022).
Functions	• In 2022, the Advisory Group released its Final Report which proposed two policies to assign responsibility for EoL Management: a core exchange and vehicle backstop policy (93% support) and the producer takeback policy (67% support). • There were 19 voting members (including OEMS, non-governmental organizations, governmental departments and organizations, and battery recycling and other related industry organizations) voting on 27 policy proposals, which included measures to address more specific barriers in addition to the vehicle backstop and producer takeback policy. • The outcome of the voting was not binding, as the mandate of the Advisory Group was to develop policy recommendations for the legislature. (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022).
Funding	• A bill had not yet been put forward in the California state legislature for a policy, so it is unclear both what policy will be put forward and how funding for that policy will operate.

Table 11: California- Definition, function, and funding

Notes

1

The core exchange and vehicle backstop policy has three options detailed in the below table (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022):

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.

Table 12: Core Exchange and Vehicle Backstop Policy

The producer take-back policy is the policy that 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 reached EoL. The OEM is then responsible for properly reusing, repurposing, or recycling the battery in a licensed facility at no cost to the consumer (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). OEMs will provide literature to consumers and other stakeholders in both print and digital form regarding the battery return process.

Some advantages of the producer take-back policy are the 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 a third party for second life uses. A major disadvantage of the policy is that OEMs may incur higher costs, as they will likely only be called upon to manage EV batteries with no value in the second life market (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). While the Advisory Group made its recommendations, it remains unclear if and when an EPR policy for EoL EV batteries will be created in California.

The EU is the final jurisdiction evaluated in this paper and arguably provides the most robust framework that is closest to becoming an enforceable regulation.

<u>European Union (EU)</u>

Definition	• Introduced Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators ("the Directive") in September 2006 (*Directive 2006/66/Ec of the European Parliament and of the Council of 6 September 2006 on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC* 2006). • For the reasons described below, namely due to the flexibility of implementation from state to state and the legal uncertainty of each EU member state's implementation, the EU decided to propose a regulation ("the Proposal for a Regulation") concerning batteries and waste batteries, repealing Directive 2006/66/EC) ("Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020). • On December 9th, 2022, the European Parliament & Council reached a provisional political agreement to adopt the Regulation, bringing the Regulation one step close to being signed into law.
Functions	• Protect the European environment by prohibiting hazardous substances from being used in batteries and for mandating the collection, treatment, recycling, and disposal of all waste batteries regardless of their size or category. • The functions of the Directive and the Proposal for a Regulation that follow are elaborated upon below in Table 14.
Funding	• Paragraph 76 of the introduction of the Proposal for a Regulation recommends that producers should be fully responsible for funding the

	EU's EPR program for EoL EV battery recovery. ("Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020).

Table 13: EU- Definition, function, funding

Notes

The following section describes the function of both the Directive and the Proposal for a Regulation that will replace it. Several of the important articles in the Directive are stated in the below table:

Article	Function
4	• Prohibition on the amount of mercury and cadmium allowed in batteries.
5	• Promotes research into batteries with better environmental performance.
8	• Mandates that each EU member state must set up their own collection scheme that is convenient and takes back all batteries at no charge to consumers.
10	• Collection targets for batteries, 25% by 2012, 45% by 2016.
13	• Promotes the development of new recycling technology.
16	• Producers will fully finance battery collection schemes with no extra costs advertised to consumers.
17	• Mandates that all battery producers are registered within member states.
21	• Requires that batteries be labeled as containing toxic substances.
25	• Requires member states to develop penalties for non-compliance and to ensure that penalties are implemented.
26	• Transposition allows member states to develop their own laws to aid in the transition to the new battery management scheme under the Directive.

Table 14: Select Articles, European Union Battery Directive

A report on the on the implementation and the impact on the environment and the functioning of the internal market of Directive 2006/66/EC ("the Report") revealed numerous weaknesses, which partly contributed to the EU's decision to pursue a different legal instrument with the Proposal for a Regulation (European Commission 2019). The below table outlines the main shortcomings of the Directive mentioned in the Report:

Shortcoming of the Directive based on the Report

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.

Table 15: Shortcomings, European Union Battery Directive

The Report, along with other evaluative measures of the Directive such as public comments, led to the conclusion that a regulation would better achieve harmonization of an EoL battery management regime for the entire EU ("Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020). Under a regulation, all 27 EU member states would have the same obligations for product requirements for batteries and producers would be obligated to provide the same level of waste management services same way and at the same time across all member states. The Proposal for a Regulation additionally aims to support a healthy secondary market for raw materials, promoting a circular economy, and decreasing the environmental damage from the production and use of batteries.

The Proposal for a Regulation is based on an impact assessment which includes 13 measures. The measures aim 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." Studies on the effectiveness of the Directive, consultations with the public, additional supporting reports, and political commitments to the environment, climate change, and the circular economy such as the European Green Deal all contributed to the construction of the 13 measures. Each of these measures also contain sub-measures, which are collected into four main policy options: business-as-usual, which would continue utilizing the Directive; a medium level of ambition that gradually strengthens the regulations in the Directive; a high level of ambition which strengthens a bit faster but still within the limits of what can technically be achieved; and a very high level of ambition, which could greatly exceed both the current regulatory framework, and business and technological limitations. The following table in the Proposal for a Regulation outlines the 13 measures grouped into the three policy options that differ from business as usual:

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 which 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 which 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
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: resp. 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: resp. 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 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	/

Table 16: 13 Measures from Sustainability Assessment

The commission recommended solutions in the realm of options two and three.

The Proposal for a new law has not yet entered into force, and the requirements for a more robust EPR framework will be applied starting in mid- 2025 (Adalbert Jahnz et al. 2022). This means that a true evaluation of the effectiveness of Proposal for a Regulation compared to its predecessor, the Directive, will not be possible for several years.

Ch. 6. Analysis

The following analysis applied the six sustainability criteria to the jurisdictions outlined in the above case studies. The jurisdictions of Ontario and Quebec have been omitted from the analysis because Quebec will have a voluntary, opt-in takeback program for EV batteries and Ontario currently has no EoL EV battery management regime. The below tables outline how the remaining three jurisdictions, B.C., California, and the EU and their EPR regimes for managing EoL EV batteries performed under the sustainability criteria. The section following the tables then compares the performance of B.C., California, and the EU.

<u>B.C.</u>

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 state's the B.C.'s EPR policy approach supports the design of more easily recyclable products ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 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 ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 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. ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 2021).
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 ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 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 ("Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026" 2021).
Transparency, Accountability, 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 (*Environmental Management Act- 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: o 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 (*Environmental Management Act- Recycling Regulation* 2004).

Table 17: Sustainability Assessment of B.C.'s Proposed Regime

California

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 (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). • DFE was opposed by OEM representatives on the grounds that it might interfere with safety, cost, or performance (Personal Communication, Margaret Slattery 2022). • Focus on design for recycling over design for disassembly (Personal Communication, Margaret Slattery 2022). • The proposed producer takeback policy might encourage DFE if producers are responsible for the cost of repurposing and recycling (Alissa Kendall, Margaret Slattery, and Jessica 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: o <u>Recycled content standards</u>- Mandatory use of XX % of recycled content in batteries. o <u>Minimum material recovery rates:</u> Rates proposed by the EU to ensure critical materials are recovered. o <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. o Require design for reuse and recycling: Addressed above in the DFE section. o Develop a reporting system for EV batteries retired from use: 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. o Develop a reporting system for lithium-ion battery recycling and recovery rates: 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). (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). • The report was not specific enough to discuss protecting vulnerable populations and communities (Personal Communication, Margaret Slattery 2022). • EoL EV batteries are supposed go to a licensed and verified facility where emissions and environmental impacts will be calculated to avoid placing a burden on surrounding communities (Personal Communication, Margaret Slattery 2022). • There is no requirement in the report that batteries must be recycled in North America (Personal Communication, Margaret Slattery 2022).
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 (Personal Communication, Margaret Slattery 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 (Personal Communication, Margaret Slattery 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 labeling requirement receiving 93% approval and the digital identifier 87% approval (Alissa Kendall, Margaret Slattery, and Jessica 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 (Personal Communication, Margaret Slattery 2022).
Innovation	• The Report focusses on innovations in battery recycling technology (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). • The report recommends supporting further research and demonstration of repurposing technologies, as well as strategies to reduce the cost of transportation. • Claims that increased EV battery recycling will lead to innovation in the space (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 (Personal Communication, Margaret Slattery 2022). • The Advisory Group did not examine emerging technologies such as solid state and sodium-ion batteries (Personal Communication, Margaret Slattery 2022).
Transparency, Accountability, Oversight	• Physical labeling 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). • A measure to support enforcement of unlicensed dismantling laws received 87% support indicating major support for accountability for safe dismantling (Alissa Kendall, Margaret Slattery, and Jessica 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 (Alissa Kendall, Margaret Slattery, and Jessica 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 (Personal Communication, Margaret Slattery 2022). • Extremely important to evaluate the success of the core exchange and takeback policies; need to know that dismantlers can send batteries on for recycling (Personal Communication, Margaret Slattery 2022).

Table 18: Sustainability Assessment of California's Proposed Regime

EU

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 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. ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020)
Circular Economy	• On 11 March 2020, the European Commission released the new Circular Economy Action Plan, which states that the new Proposal for a Regulation 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" ("A New Circular Economy Action Plan for a Cleaner and More Competitive Europe" 2020). • 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 ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 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 ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020).

Minimizes Environmental Justice Concerns	• The following sections in the Proposal for a Regulation addresses topics related to environmental justice concerns: o 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, labour rights. In addition, such policies should protect the environment, in particular water, soil, air, and biodiversity from different sources of pollution. o 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 ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 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 ("A New Circular Economy Action Plan for a Cleaner and More Competitive Europe" 2020). • The Proposal for a Regulation does not contain an outright ban on sending waste batteries to other countries for processing. That being said, Professor Karim Zaghib believes that the EU wants 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 (Personal Communication, Karim Zaghib 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. ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 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 ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020). o Professor Zaghib says that some of the studies under Horizon 2020 are researching solid state and sodium-ion batteries (Personal Communication, Karim Zaghib 2022).
Transparency, Accountability, 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 labeling 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. ("Proposal for a Regulation of The European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020" 2020).

Table 19: Sustainability Assessment of the EU's Proposed Regime

Comparison of Policies in B.C., California, and the EU

The Proposal for a Regulation by the EU presents the most robust framework across the six sustainability criteria. This makes sense when considering the EU's history of addressing the issue of waste batteries, which dates back to 2006 with the Directive on Waste Batteries and Accumulators. In addition to being the most robust of the three policy measures, the Proposal for a Regulation is arguably the closest measure to becoming a law, as the European Parliament and the Council of Ministers reached a preliminary agreement on December 9th, 2022, after the European Commission adopted the proposal for new rules on batteries on the same day ("Timeline" 2022). Further, to date there has been no bill put forward in California based on the

Advisory Group's Final Report and details about B.C.'s Five-Year action plan remain mostly abstract with measures related to EV batteries not scheduled to begin until 2024.

Under the DFE criteria, the EU stood out as it cited the availability of safe disassembly instructions to licensed dismantlers and repurposes, indicating that batteries should be designed for disassembly. Limiting disassembly to licensed parties may reveal the EU's attempt to control resources, yet the push toward disassembly is arguably more sustainable compared to policies put forth by B.C. and California, which stressed design for reuse and design for recycling over design for disassembly. One major critique of the European policy is that the measures against using hazardous materials only outline prohibited quantities of mercury and cadmium, where other critical minerals used in batteries such as cobalt and nickel can be harmful to the environment and human health if not properly handled (Shahjadi Hisan Farjana, Nazmul Huda, and M.A. Parvez Mahmud 2019). While *CEPA* lists cobalt and nickel under Schedule 1- List of Toxic Substances, most jurisdictions in Canada still lack a potential framework for managing EoL EV batteries (*Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33)* 1999). In the U.S. the *Toxic Substances Control Act (TSCA)* of 1976 to regulate chemical substances and mixtures listed under the *Act*, excluding food, drugs, cosmetics and pesticides ("Summary of the Toxic Substances Control Act" 2022). While the *Act* does lists both mercury and lead as toxic substances, neither cobalt nor nickel are listed, creating a potential hurdle for developing an EoL EV battery management regime in the U.S. and showing a lack of uniformity across the three jurisdictions regarding is considered toxic (*Toxic Substances Control Act of 1976*).

B.C.'s Five-Year Action Plan and Recycling Regulation mention design for recyclability while omitting mention of design for disassembly or design for remanufacture. Discussions during the composition of the Advisory Group's Final Report from California also focussed design for recycling over design for disassembly. Margaret Slattery stated that in discussions with OEMs, the use of fasteners to hold parts together in EV batteries as opposed to welding parts together were strongly resisted (Personal Communication, Margaret Slattery 2022). Slattery went on to mention that recyclers are often adapting their technology around batteries as opposed to manufacturers designing batteries that are easier to recycle or disassemble (Personal Communication, Margaret Slattery 2022).

The EU developed its new Circular Economy Action, another comprehensive policy measure that sets it apart from B.C. and California, that works in conjunction with the Proposal for a Regulation. The EU's plan appears all-inclusive, yet until it is put into action it remains a theoretical tool for controlling the supply of critical materials for EV batteries and keeping them within the EV battery supply chain. B.C.'s Five-Year Action Plan states that the Plan and the province's EPR policy support a circular economy, yet the Plan does not expand on the concept of a circular economy beyond the general statement. In comments and recommendations to B.C.'s proposed regulation, EMC proposes an alternative recovery measure to further promote a circular economy that stands out from the 75% target in s. 5 of the Recycling Regulation. EMC believes that B.C. should recover 100% of EV and HEV batteries that are available for collection upon notice from the vehicle owner that the battery is no longer desirable. ("Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.)").

While the Advisory Group's Final Report states that California should strive to create a circular economy for waste EV batteries similar to what it has done for lead acid batteries, the only voting measures related to a circular economy that received major support were, an a economic incentive package provided to lithium-ion battery recyclers within California (73%

support) and expanding eligibility for relevant incentive programs to include reused and repurposed batteries (67% support) (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). 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 appear to indicate a preference to provide financial incentives for recycling while not setting or tracking recovery rates for battery materials, which would make it difficult to assess California's progress toward a circular economy for EV battery materials.

Environmental justice concerns were the least addressed criterion that was least all three policy measures, with the term "environmental justice" only twice mentioned in the California Advisory Group's Final Report. Although the EU did not use the term outright, the Proposal for a Regulation encourages due diligence schemes for the battery supply chain to track where materials originate in order to encourage ethical sourcing under measure 13 of the Proposal for a Regulation with mandatory due diligence listed as option 3, the high level of ambition. These 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, labour rights as well as negative environmental impacts on water, soil, air, and biodiversity. The proposal echoes that the same impacts must be avoided when repurposing batteries. The EU's new Circular Economy Action Plan similarly discusses the ethical sourcing of materials, related to mining and those who work and live around the mines, indicating consistency across the two EU policy measures. The Proposal for a Regulation falls short on environmental justice because it lacks an outright ban on sending waste EV batteries outside of the EU for processing and remains silent on the potential harm to humans and the environment surrounding battery recycling facilities. Professor Karim

Zaghib however believes that the EU wants to keep battery recycling in the continent, which could indicate an unwritten emphasis on environmental justice.

B.C.'s Five-Year Action Plan mentions the FNRI, yet it is unclear if this initiative will have any effect on Indigenous groups in the province or if it will cover waste EV batteries. The California Advisory Group's Final Report mentions that waste EV batteries could create an environmental justice concern if mismanaged, yet the report does not specifically address protecting vulnerable communities. Although the Report details many of the concerns related to mining and ethical sourcing, none of the voting measures covered such upstream actions in the battery life cycle. The Report also makes no mention that batteries must be processed in North America, leaving open the possibility that EoL EV batteries could be sent to the developing world. While not part of the report, Margaret Slattery mentioned 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 (Personal Communication, Margaret Slattery 2022).

The EU's Proposal for a Regulation again surpasses B.C.'s Five-Year Plan and the California Advisory Group's Final Report by citing specific second life uses for EV batteries such as stationary energy and integration into electricity grids for energy backup. The Proposal also discusses the second life market less as a possibility but more as an inevitability, citing the need to create additional regulations for the second life market.

The Five-Year Action Plan mentions that B.C. will support the reuse of batteries which aligns with two sections in the Recycling Regulation in the *Environmental Management Act* that also cite reuse as a goal of provincial EPR frameworks. Neither the plan nor the *Act* go into further details about what reuse will entail, whether that means reuse in vehicles only or broad reuse for energy storage and other applications. In response to B.C.'s Plan, EMC proposed to add provisions to the Recycling Regulation that encourage reuse, remanufacture, and repurposing of batteries (“Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.)”).

The California Advisory Group’s Final Report addresses second life uses in vehicles and identified stationary energy storage as a potential second life application; however, there was only one policy recommendation that was specifically intended to support repurposing (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). Nearly all the voting members supported reuse in a vehicle, yet the Report fell short of detailing how repurposing or refurbishing for use in a vehicle would specifically work. The Report also cited the need for an SOH measure to properly assess if batteries 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, with OEMs exhibiting significant opposition to the measure. Without a universal diagnostic system or access to a specific OEM’s BMS, it would be both difficult and expensive to assess the health of batteries, creating a barrier to reusing EV batteries that reach EoL.

The EU lists innovation as one of its specific objectives under the Proposal for a Regulation and has devoted over $500 million Euros 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 mentions innovation and relates it more to innovating 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 industry stakeholders have lobbied for the use of more abundant materials to be used in new battery chemistries, Margaret Slattery stated that cheaper batteries may be less profitable to recyclers and would necessitate policy to ensure they are recycled. Slattery also commented that policies will likely not affect innovation since researchers in the U.S. seek funding as opposed to following prescriptive policies for innovation (Personal Communication, Margaret Slattery 2022). 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 alternatives.

The EU already has experience with transparency, accountability, and oversight, as one of the key critiques of the previous regime under the Battery Directive was the lack of a unified regime affecting the accountability and oversight of different member states. The Proposal for a Regulation calls 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. One of the major problems identified by the Proposal for a Regulation is the lack of transparency around the sourcing of raw materials, and Measure 13 addresses this problem directly by promoting due diligence of the battery supply chain. While some may criticize that enforcement will be the responsibility of member states, echoing the failures of the Battery Directive, the European Commission must approve rules and penalties related to enforcement and will provide oversight.

B.C.'s Recycling Regulation dictates the requirements of producers to create an Extended Producer Responsibility Plan along with the annual reporting of 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. The penalties for contravening the Regulation are fines "not exceeding $200,000," which creates ambiguity about the true amount of fines and if those amounts are significant enough to encourage producers to adhere to the provisions of the states.

While B.C.'s proposed EPR program indicates progress toward establishing policy frameworks for managing EoL EV batteries in Canada, Louise Levesque and EMC proposed changes to the Recycling Regulation of the *Environmental Management Act* where they believe it could be improved for better accountability and oversight. EMC would first like to add Schedule 6, a large battery category, for batteries weighing over 10kg or with a rating of more than 1,000-watt hours ("Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.) Ministry of Environment and Climate Change Strategy" 2022). Large 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. This means that batteries will likely have unique collection schemes and processes that may need to be regulated differently than schemes for other products. The proposed amendments additionally specify who an EV battery producer would be under the recycling regulation. EMC also proposed the addition of a battery registry and notification system to the Recycling Regulation, which would assist the B.C. regulator to track the level of producer compliance with collection mandates for EoL EV batteries ("Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.).

The Advisory Group Final Report from California indicates that voting members overwhelmingly supported physical labeling of a battery, an SOH measure for batteries while inside a vehicle, and providing training materials for safe handing, storage, and shipping of EV batteries. The voting members however provided less than majority support for two critical reporting measures, one for EVs retired for use and one for lithium-ion battery recovery rates (each receiving only 33%). The Group did not vote on a tracking and reporting system like the Battery Passport, indicating a significant deficiency in reporting the progress related to an EPR regime, whether it be the core exchange or takeback policy that received the most support by the advisory group.

Ch. 7. Limitations & Recommendations

Limitations

This research study was limited in its methodology as the researcher utilized a literature review that was complimented by interviews with industry experts. The lack of quantitative analysis and any double-blind scientific experts featuring a control and experimental group may limit the applicability of the researcher's conclusions. The study also only examined five jurisdictions with a deep analysis on three of those five. Future comparative studies could incorporate policy measures from Asia in jurisdictions such as Japan, China, and the Republic of Korea (ROK). The researcher's sustainability assessment could also be criticized for developing context specific criteria that have not been recognized by other researchers as effective evaluative measures for the sustainability of the EV battery life cycle.

All three of the policy measures featured in the analysis- B.C.'s Five-Year Action Plan in conjunction with the Recycling Regulation, the Lithium-ion Car Battery Recycling Advisory Group Final Report, and the EU's Proposal for a Regulation Concerning Batteries and Waste Batteries- are to some degree still theoretical. While B.C.'s Plan is backed by law- the Recycling Regulation under the *Environmental Management Act*- the Plan as it relates to EV batteries will not be integrated until 2024, and details on the management of EV batteries remain scarce. In California, there has not to date been any bill put forward based on the conclusions of the Advisory Group Final Report. Europe appears closest to implementing its Regulation, yet until the Regulation is implemented and evaluated for a significant period of time, it will be difficult to definitively conclude if the measures are being followed and if the Regulation is in fact sustainable.

The study also did not evaluate all policy measures related to the electrification of road transportation such as a zero-emissions vehicle (ZEV) mandate. Louise Levesque of EMC mentioned the need for a national ZEV mandate several times during her interview, which would ensure a greater EV supply to meet the consumer demand (Personal Communication, Louise Levesque 2022). The researcher chose to exclude the ZEV mandate in order limit the scope of the research.

A major limitation to this research and related research in the field is the dearth of information related to the true fate of EoL EV batteries. Interviews with experts revealed that the batteries are not being discarded in landfills or abandoned; however, there is a significant lack of information related to the location of EoL EV batteries that have been removed from vehicles, recovery rates, recycling rates, and the true environmental and human health impacts resulting from recycling processes. The researcher also did not evaluate the financial costs of implementing an EoL EV battery management regime and how government subsidies may have to fund some aspects of an effective regime.

Finally, the first recommendation proposes a National EoL EV battery management regime without attempting to navigate the conflict over if such a regime would fall under provincial/state or federal jurisdiction. While *CEPA* and the *TSCA* provide federal regulations in Canada and the United States respectively for toxic substances, regulating EoL EV battery management goes beyond toxic substances into subjects such as waste management, trade and commerce, and the transboundary movement of hazardous substances to name a few. Analyzing all these challenges would likely expand the scope of this research paper beyond its current purposes and would therefore be best left for a future research study.

Recommendations

Recommendation 1: National EoL EV Battery Management Policy

The three case studies represent the need for a national EoL EV battery management policy. The EU provides a prime example of what happens when member states are given the 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. One can arguably see the same failure occurring in Canada, as B.C. is incorporating EoL EV batteries into its EPR while Quebec and Ontario have regimes that are voluntary or non-existent respectively. California also appears to be pushing toward an EoL EV battery management policy while the federal government and most other states have no such policies. While the EU's Proposal for a Regulation provides a sufficient starting point for a national EoL Battery Management Policy, the policy itself could still be made more sustainable with following recommendations based on sustainability criteria utilized in this paper.

Recommendation 1(a) DFE

One can argue that batteries are not being designed for the environment when the two primary recycling techniques involve either burning away components at high temperatures (pyrometallurgy) or leaching components using acidic compounds (hydrometallurgy). The better way forward appears to be design for disassembly, yet the idea of creating batteries that could be easily disassembled continues to encounter opposition from OEMs who do not want their proprietary technology leaving their supervision. A potential compromise could be what the EU proposes, which is disassembly instructions being provided only to licensed dismantlers, refurbishes, and remanufacturers. Such a measure combined with battery tracking could satisfy OEMs, as they would know where batteries are and who is taking them apart.

The use of hazardous materials in battery construction must also be limited and when necessary, banned. The problem; however, is a lack of uniformity regarding what EV battery components are considered toxic. *CEPA* lists cobalt and nickel, primary materials used in EV batteries, in addition to lead, mercury, and cadmium, which are used in lead-acid batteries, as toxic substances. The *TSCA* and the Proposal for a Regulation do not list cobalt or nickel as toxic, presenting a problem on an international scale for regulating EV batteries that can arguably be classified as toxic. In order to improve the level of DFE in EV battery technology there will likely need to be international harmonization of the classification of toxic substances.

Recommendation 1(b) Circular Economy

An effective EoL EV battery management regime should attempt to create a circular economy for EV battery materials, so those materials can be collected, reused or recycled, and remanufactured into new batteries, thereby remaining within the battery supply chain. The EU has already done this by creating its Circular Economy Action Plan, and other jurisdictions that wish to create an effective EoL EV battery management regime should institute a similar measure. Supporting a circular economy should begin by designing batteries for reuse and recycling. An effective regime should then set recycled content standards and minimal recovery rates that are measured by a reporting system for recovery and verified by a third party. These measures come directly from the Advisory Group Final Report in California, where they did not receive majority support (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022). The recovery rate endorsed by EMC of 100% of batteries that are no longer desirable to a consumer should be adopted by all EoL EV battery management regimes ("Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.). Adopting such a recovery rate would promote a circular economy for battery materials and reduce the EV battery industry's reliance on mining.

Recommendation 1(c) Environmental Justice

Any policy regime that addresses EoL EV battery management must address environmental justice outright and commit to protecting vulnerable communities from the negative effects of improperly managing EV batteries. While there is currently enough recycling infrastructure to handle the number of EoL EV batteries, this could change in the future when millions of EVs reach EoL. Management regimes must strive to avoid what has happened with e-waste, which has historically been sent to developing countries exposing vulnerable populations to the hazardous materials within electronics (Heacock et al. 2016). A current problem that can foreshadow what could happen to EoL EV batteries without a comprehensive management regime is the illegally dumping and landfilling of solar photovoltaic cells in California due to no strict policy or enforcement mechanisms for proper EoL management (Millette and Kelleher 2020). An effective EoL EV battery management regime will need to mandate recycling, regardless of profitability, otherwise the risk of EoL EV batteries being sent abroad or illegally dumped in areas that affect vulnerable communities is possible (Personal Communication, Margaret Slattery 2022).

While the Basel Convention provides an international instrument that bans the transboundary movement of hazardous wastes and their disposal, EV batteries are currently not included under the Basel Convention as a category of hazardous waste ("Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal" 2020). The Convention should be updated to include EV batteries, as it covers e-waste and lead-acid batteries. EoL battery management regimes could then become parties to the Convention, showing an international commitment to not send EoL EV batteries abroad, thereby supporting environmental justice.

Recommendation 1(d) Second Life Uses

Whether or not producers want batteries to be repurposed for a second life as either stationary energy storage or grid backup, second life uses for EV batteries are already happening and will likely become more common. The second life EV battery market however is largely unregulated to date, so a comprehensive EoL battery management regime must also create companion regulation for the second life EV battery market (Personal Communication, Louise Levesque 2022). Another major challenge in the second life market is the difficulty in assessing battery health because every battery producer uses their own BMS (Martin F.Börner et al. 2022). While OEMs appear to be opposed to a universal diagnostic system, policy measures should mandate that OEMs provide an SOH based on their own BMS for a battery before that battery is repurposed for a second life.

Recommendation 1(e) Innovation

EoL EV battery management policy should support innovation by allocating funding for innovation similar to what is happening in the EU with Horizon 2020. Such innovation should look at all stages of the battery life cycle. This means there should be research into safer and less energy intensive mining and ethical sourcing, novel battery chemistries that are safer and more efficient, and more research into recycling technologies such as direct recycling, which is mostly still in the research and development stage (Alissa Kendall, Margaret Slattery, and Jessica Dunn

2022). Research into new battery chemistries could also have an indirect effect by reducing mining due to the use of more readily available and abundant materials in EV battery construction.

Recommendation 1(f) Transparency, Accountability, Oversight

Nearly all of the EPR-based policy for managing EV batteries focusses on EoL management, largely ignoring the upstream processes such as material sourcing and extraction. Unless policy starts to address the ethical material sourcing, that part of the life cycle will continue producing negative trade-offs. The EU's focus on the transparency of the battery supply chain should be incorporated by an EV battery management policy as an initial towards more ethical material sourcing and eventually to a reduced reliance on mining and resource extraction.

Another element of transparency that should be part of an EoL EV battery management regime is the labelling of batteries to show figures such as the carbon footprint of battery manufacturing, origin of battery materials, battery composition including hazardous materials, repair and repurposing instructions, and recycling and recovery processes when batteries reach EoL. This measure received support in both California and the EU, with the main difference being repair, repurposing, and disassembly instructions. Utilizing a Battery Passport, as the EU has, would be an excellent initial step in an EoL EV battery management regime to increase the level of transparent data sharing.

Regarding the downstream functions of the EV battery life cycle, it will be important for producers to establish collection targets that align with sustainability goals and are approved by governing bodies. Producers should then be able responsible for reporting on those targets with oversight completed by a third party that is not affiliated with producers. Noncompliance with collection targets, reporting, and other outlined obligations should lead to enforceable penalties that carry enough weight to deter noncompliance. B.C. has such measures in place with its requirements for producers to submit an extended producer responsibility plan and annual reports on the level of compliance with the plan. The EU also has strong oversight via the European Commission, which along with B.C. provides a blueprint for accountability and oversight mechanisms with a government regulator that could be incorporated to another jurisdiction seeking to establish an EoL EV battery management regime.

Recommendation 2- Limit the Power of OEMs in Policy

One consistent theme throughout the research has been the power of OEMs in establishing and shaping EoL EV battery management policy. OEMs have significant lobbying power and are likely the reason why there is no policy in Ontario and a voluntary policy in Quebec (Personal Communication, Louise Levesque 2022). The power of OEMs also emerged in the Advisory Group Final Report in California, where OEMs mostly opposed several critical measures such as design for repurposing, reuse and recycling, the use of a universal diagnostic system, a reporting system for EV batteries retired from use, and a reporting system for lithium-ion battery recycling recovery rates (Alissa Kendall, Margaret Slattery, and Jessica Dunn 2022).

It appears that OEMs want to both protect their proprietary battery technology, the battery and BMS, and they want to control the supply of battery materials in the market. This often means that OEMs want their batteries back at EoL, which leads to a consumer protection issue, as consumers who fully pay for the EVs should have a right to resell, repurpose, or recycle their battery when they determine it has reached EoL. EVs on average cost $10,000 more than their ICE counterparts, and it appears that OEMs want EV batteries back, but they are not always willing to compensate consumers accordingly (Jason Tchir 2020). Margaret Slattery stated that

OEMs focussed more on the fact that they were saving consumers the cost of managing their EoL EV batteries and did not address the possibility of compensating consumers for EoL EV batteries (Personal Communication, Margaret Slattery 2022).

While it will be nearly impossible to remove OEMs from discussions related to EoL EV battery management, especially since they have valuable industry expertise, their lobbying power must be limited. This paper cannot present a solution for limiting such power, yet it is important to point out that such a power exists and has to date limited or stopped EoL EV battery management regimes from operating. The power dynamic also calls into question if EPR is the right framework to incorporate outside of the EU, as the producers, in this case OEMs, appear to be dictating the direction of EoL EV battery management regimes without focussing on sustainability.

If a compromise will be struck with OEMs, it will likely involve them maintaining control over the battery materials, protecting their proprietary technology, and continuing to increase profits as these seem to be the chief concern of OEMs. Regimes should attempt to balance the values of OEMs with consumer rights and sustainability objectives while constructing and amending policy for managing EoL EV batteries.

Recommendation 3- Consider More Comprehensive Road Transportation Policies

It is likely not difficult to argue that replacing every ICE vehicle with an EV is not a sustainable solution to mitigate the effects of transportation-related emissions on climate change. The sheer number of batteries and battery materials needed would be staggering and would potentially create environmental trade-offs that exceed the current environmental effects of ICE vehicles. Much of the research in this paper pointed to policies in the five case studies related to reuse and recycling, which largely ignores the first “R” in the sustainability hierarchy, reduce

(Emma MacDonald 2020). The number of vehicles on the road will likely need to be reduced, meaning effective EoL EV battery management regimes should work together with policies promoting the increased use of public transportation, and the creation of more accessible and sustainable communities where walking and cycling are both possible and encouraged.

Another aspect of the current EoL EV battery management regimes that may need to be rethought is the idea that by increasing recovery rates and levels of recycling, there will be enough battery materials available to offset the need to mine virgin material. Jean-Christophe Lambert of Lithion stated that recycled materials make up less than 10% of EV batteries, and mining will be the major source of battery materials for the next 10-15 years (Personal Communication, Lambert 2022). Those estimates may be conservative as a 2020 white paper revealed that EV battery recycling will reduce the need for mining new material by 20% by 2040 and 40% by 2050 (Peter Slowik, Nic Lutsey, and Chih-Wei Hsu 2020). The fact that mining will still be the primary source of supplying new EV battery materials in nearly 30 years reinforces the need to incorporate ethical material sourcing guidelines into EoL EV battery management regimes. These figures also further support the need to approach the electrification of transportation in a more comprehensive way with the primary goal being to reduce the number of vehicles used in road transportation.

Ch. 8. Conclusion

The electrification of road transportation will almost certainly help to mitigate climate change by reducing the amount of GHG emissions produced by the transportation sector, yet electrification creates trade-offs related to human health and the environment. The trade-offs typically occur at two stages of the EV battery life cycle, material sourcing and EoL. Regimes for managing EV batteries to date are based on EPR and have typically focussed on EoL, establishing collection protocols with batteries being sent to licensed recyclers who then recover critical battery materials through energy-intensive and potentially hazardous processes. These regimes largely ignore the trade-offs that occur at the upstream, material sourcing stage, which typically involves mining.

This paper identifies five jurisdictions spanning Canada, the United States, and the EU and conducts a sustainability assessment of the regimes put forth in the three jurisdictions that are closest to enacting a policy. While California has yet to put forth a bill based on the Advisory Group Final Report and B.C. has yet to provide details about how its existing legislation will specifically manage EV batteries, both plans provide sufficient details to conduct an analysis and identify weaknesses within the proposed regimes. The EU is closest to having its regime enacted into binding legislation and provides the most detailed and comprehensive regime of the three.

The sustainability assessment measured the different regimes' potential effectiveness based on six, context-specific sustainability criteria, which identified strengths and weaknesses of each regime. Takeaways from the assessment provide the basis for recommendations that could be incorporated to improve future EoL EV battery management regimes. Most notably, this paper recommends that states implement EoL EV battery management regimes on a national scale, that policy makers and regulators limit the power of OEMs to dictate the direction of EoL EV battery management regimes, and that policymakers take a more comprehensive approach to transitioning road transportation to a more sustainable future. Future policy could be improved based on recommendations laid out on this paper and beyond that, to consider the full battery life cycle and address all environmental trade-offs related to the transition away from ICE vehicles to the electrification of road transportation.

Bibliography

"A New Circular Economy Action Plan for a Cleaner and More Competitive Europe." 2020. The Commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN.

"Advancing Recycling in B.C. Extended Producer Responsibility Five-Year Action Plan 2021-2026." 2021. British Columbia Ministry of Environment and Climate Change Strategy. https://www2.gov.bc.ca/assets/gov/environment/waste-management/recycling/recycle/extended_producer_five_year_action_plan.pdf.

Anonymous- MECP. 2022. "Response from Ministry of the Environment, Conservation and Parks (Ref. No. 246-2022-1610)," October 26, 2022.

Anonymous- RPRA. 2022. "Graduate Student Conducting Research," October 3, 2022.

Silvian Baltac and Shane Slater. 2019. "Batteries on Wheels: The Role of Battery Electric Cars in the EU Power System and Beyond." The United Kingdom: Element Energy. https://www.transportenvironment.org/wp-content/uploads/2021/07/2019_06_Element_Energy_Batteries_on_wheels_Public_report.pdf.

"Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal." 2020. United Nations Environment Programme. http://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx.

Martin F. Börner, Moritz H.Frieges, Benedikt Späth, Kathrin Spütz, Heiner H. Heimes, Dirk Uwe Sauer, and Weihan Li. 2022. "Challenges of Second-Life Concepts for Retired Electric Vehicle Batteries." *Cell Reports Physical Science* 3 (10). https://doi.org/10.1016/j.xcrp.2022.101095.

Daniel Breton. Recommendations. 2022. "Extended Producer Responsibility (EPR) Draft Regulation Recommendations from Electric Mobility Canada," March 2022. https://emc-mec.ca/wp-content/uploads/Mars-2022-Recommandations-M%C3%89C-sur-la-R%C3%89P-batteries-ENG-1.pdf.

Maeve Campbell. 2022. "In Pictures: South America's 'lithium Fields' Reveal the Dark Side of Our Electric Future." *Euronews.Green*, September 12, 2022, sec. Nature. https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future?utm_source=newsletter&utm_medium=green_newsletter&_ope=eyJndWlkIjoiYmZkN2YzMDE0NjZkZDg1MTE2YTIzMjJlNzZkNDA5NTUifQ%3D%3D.

Audrey Carleton and Aaron Gordon. 2021. "Everyone Thought the Warehouse Was Abandoned. Then It Caught Fire." *Vice*, November 1, 2021. https://www.vice.com/en/article/m7vj73/everyone-thought-the-warehouse-was-abandoned-then-it-caught-fire.

Clare Church and Laurin Wuennenberg. 2019. “Sustainability and Second Life: The Case for Cobalt and Lithium Recycling.” Industry Report. Winnipeg, MB: International Institute For Sustainable Development. https://www.iisd.org/publications/report/sustainability-and-second-life-case-cobalt-and-lithium-recycling.

Circular Economy Image. 2014. Digital image. https://www.triumvirate.com/blog/do-you-know-about-the-circular-economy.

Dr. Jeff Dahn. 2021. “Quebec Risks a Critical Circular Economy Misstep with Proposed EV Battery Recycling Plan.” Independent News Platform. *Electric Autonomy Canada* (blog). October 29, 2021. https://electricautonomy.ca/2021/10/29/jeff-dahn-quebec-ev-battery-recycling/.

Deathe, Ashley L.B., Elaine MacDonald, and William Amos. 2008. “E-Waste Management Programmes and the Promotion of Design for the Environment: Assessing Canada’s Contributions.” *Review of European Community & International Environmental Law* 17 (3): 321–36. https://doi.org/10.1111/j.1467-9388.2008.00610.x.

Anrica Deb. 2016. “Why Electric Cars Are Only as Clean as Their Power Supply.” *The Guardian*, December 8, 2016, sec. Climate Crisis. https://www.theguardian.com/environment/2016/dec/08/electric-car-emissions-climate-change.

“Design for Environment.” 2011. Government of Canada. *Specialized Design Services* (Government wesbite). October 4, 2011. https://ised-isde.canada.ca/site/specialized-design-services/en/statistics-analysis-and-industry-profiles/design-environment.

“Developing Countries Pay Environmental Cost of Electric Car Batteries.” 22 July 20202. Global Trade and Development News. *United Nationals Conference on Trade and Development* (blog). 22 July 20202. https://unctad.org/news/developing-countries-pay-environmental-cost-electric-car-batteries.

Directive 2006/66/EC Of The European Parliament and of The Council of 6 September 2006 on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC. 2006. *OJ L*. Vol. 266. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006L0066-20131230&rid=1.

Environmental Management Act Recycling Regulation. 2004. *B.C. Reg. 449/2004 O.C. 995/2004*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/449_2004.

European Commission. 2019. “Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Implementation and the Impact on the Environment and the Functioning of the Internal Market of Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC.” COM (2019) 166. Brussels, Belgium. https://circabc.europa.eu/ui/group/636f928d-2669-41d3-83db-093e90ca93a2/library/35a10862-2dd9-49af-b391-53d75eb361c5/details?download=true.

“European Union a Step Closer to Adopting Expansive New Rules Covering Lifecycle of Electric Vehicle Batteries.” 2022. Law Firm Blog. *Sidley Austin LLP- Insights* (blog). August 24, 2022. https://www.sidley.com/en/insights/newsupdates/2022/08/eu-a-step-closer-to-adopting-expansive-new-rules-covering-lifecycle-of-electric-vehicle-batteries.

“EV Batteries Made from Deep-Sea Rocks Dramatically Reduce Carbon.” 2020. Metal production company wesbite. *The Metals Company* (blog). September 2020. https://metals.co/ev-batteries-made-from-deep-sea-rocks-dramatically-reduce-carbon-3/#:~:text=Producing%20metals%20for%20one%20billion,of%20land%20during%20metallurgical%20processing.

“Extended Producer Responsibility.” n.d. International Organization. *OECD- Environmental Policy Tools and Evaluation* (website). https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm.

Shahjadi Hisan Farjana, Nazmul Huda, and M.A. Parvez Mahmud. 2019. “Life Cycle Assessment of Cobalt Extraction Process.” *Journal of Sustainable Mining* 18 (3): 150–61. https://doi.org/10.1016/j.jsm.2019.03.002.

Gazette Officielle Du Québec. 2021. “Draft Regulation: Environmental Quality Act- Recovery and Reclamation of Products- Amendment,” October 13, 2021, Vol. 153 No. 41 edition, sec. Part 2 Section 29-34.

Robert. B. Gibson. 2006. “Sustainability Assessment: Basic Components of a Practical Approach.” *Impact Assessment and Project Appraisal* 24 (3): 170–82. https://doi-org.ezproxy.library.yorku.ca/10.3152/147154606781765147.

Heacock, Michelle, Carol Bain Kelly, Ansong Asante Kwadwo, Lisa S. Birnbaum, Ake Lennart Bergman, Marie-Noel Brune, Irina Buka, et al. 2016. “E-Waste and Harm to Vulnerable Populations: A Growing Global Problem.” *Environmental Health Perspectives* 124 (5): 550–55. https://doi.org/10.1289/ehp.1509699.

“Implementation of the B.C. Extended Producer Responsibility (EPR) Five-Year Action Plan 2021-2023: Comments and Recommendations on EV Battery EPR Regulation Submitted to British Columbia (B.C.) Ministry of Environment and Climate Change Strategy.” 2022. Electric Mobility Canada.

"Introduction to Extended Producer Responsibility." 2017. Government of Canada. *Environment and Natural Resources Canada* (website). August 11, 2017. https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/overview-extended-producer-responsibility/introduction.html.

Adalbert Jahnz, Sonya Gospodinova, Daniela Stoycheva, and Federica Miccoli. 2022. "Green Deal: EU Agrees New Law on More Sustainable and Circular Batteries to Support EU's Energy Transition and Competitive Industry (Press Release)." European Commission. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_7588.

Kelleher, Maria. 2020. "Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries." Kelleher Environmental. https://www.api.org/-/media/Files/Oil-and-Natural-Gas/Fuels/EV%20Battery%20Reuse%20Recyc%20API%20Summary%20Report%2024Nov2020.pdf.

Alissa Kendall, Margaret Slattery, and Jessica Dunn. 2022. "Lithium-Ion Car Battery Recycling Advisory Group Final Report." Advisory Report. California, USA: California Environmental Protection Agency. https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

Lambert, Jean-Christophe. 2022. Personal Communication, Interview with Jean-Christophe Lambert Re. EV Batteries at EoL. Zoom Video Communications.

Louise Levesque. 2022. Personal Communication, Interview with Louise Levesque, Policy Director at Electric Mobility Canada Zoom Video Communications.

Michelle Lewis. 2022. "A New Sodium-Ion Battery Breakthrough Means They May One Day Power EVs." Electrification of Transportation News. *Electek Blog* (blog). July 14, 2022. https://electrek.co/2022/07/14/sodium-ion-battery-breakthrough/.

Emma Macdonald. 2020. "The Three Rs: Order Is Important." University Website. *UCONN Institute of the Environment- Office of Sustainability* (university website). April 7, 2020. https://sustainability.uconn.edu/2020/04/07/the-three-rs-order-is-important/.

Henry Man. 2022. "What Are LFP, NMC, NCA Batteries in Electric Cars?" Electric Vehicle Buying Guide. *Zecar- Guides* (blog). July 18, 2022. https://zecar.com/resources/what-are-lfp-nmc-nca-batteries-in-electric-cars.

Millette, Samantha, and Maria Kelleher. 2020. "Electric Vehicle (EV) Batteries- What Municipal Staff Need to Know." Municipal Waste Association's 4 R Information Newsletter. https://www.linkedin.com/pulse/electric-vehicle-batteries-what-municipal-staff-need-know-millette/.

Natural Resources Canada (NRCan). 2016. "Links between Fuel Consumption, Climate Change, Our Environment and Health." Government of Canada. *Transportation Initiatives* (website). September 20, 2016. https://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4419.

Office of the Minister of the Environment and the Fight Against Climate Change. 2022. "Quebec Promotes the Circular Economy by Making New Products Subject to Extended Producer Responsibility (EPR)." Newswire. *Cision* (blog). June 21, 2022. https://www-newswire-ca.translate.goog/fr/news-releases/quebec-favorise-l-economie-circulaire-en-assujettissant-de-nouveaux-produits-a-la-responsabilite-elargie-des-producteurs-rep--832681343.html?_x_tr_sl=auto&_x_tr_tl=fr&_x_tr_hl=fr&_x_tr_pto=wapp.

Dr. Marco Ottaviani. 2022. "EV Battery Transportation – a Guide." News and Information for the vehicle recycling industry. *Auto Recycling World* (blog). January 28, 2022. https://autorecyclingworld.com/ev-battery-transportation-a-guide/#:~:text=Furthermore%2C%20under%20normal%20conditions%20of,or%20flammable%20gases%20or%20vapors.

Pete Pattison. 2021. "'Like Slave and Master': DRC Miners Toil for 30p an Hour to Fuel Electric Cars." *The Guardian*, November 8, 2021. https://www.theguardian.com/global-development/2021/nov/08/cobalt-drc-miners-toil-for-30p-an-hour-to-fuel-electric-cars.

"Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020." 2020. European Commission. https://eur-lex.europa.eu/resource.html?uri=cellar:4b5d88a6-3ad8-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF.

Resource Recovery and Circular Economy Act, 2016, S.O. 2016, c. 12, Sched. 1. 2016. https://www.ontario.ca/laws/statute/16r12.

Patrick Schroeder, Kartikka Anggraeni, and Uwe Weber. 2019. "The Relevance of Circular Economy Practices to the Sustainable Development Goals." *Journal of Industrial Ecology* 23 (1): 77–95. https://doi.org/10.1111/jiec.12732.

Margaret Slattery. 2022. Personal Communication, Interview with Margaret Slattery, PhD student and co-author of the Lithium-ion Car Battery Recycling Advisory Group Final Report. Zoom Video Communications.

Peter Slowik, Nic Lutsey, and Chih-Wei Hsu. 2020. "How Technology, Recycling, and Policy Can Mitigate Supply Risks to the Long-Term Transition to Zero-Emission Vehicles." The International Council on Clean Transportation. https://www.zevalliance.org/wp-content/uploads/2020/12/zev-supply-risks-dec2020.pdf.

Madeline Stone. 2021. “As Electric Vehicles Take off, We’ll Need to Recycle Their Batteries.” *National Geographic*, Mat 2021. https://www.nationalgeographic.com/environment/article/electric-vehicles-take-off-recycling-ev-batteries.

“Study of Extended Producer Responsibility for Electric Vehicle Lithium-Ion Batteries in Quebec.” 2020. Quebec: Propulsion Quebec. https://propulsionquebec.com/wp-content/uploads/2020/11/ETUDE-REP-EN-FINAL-WEB.pdf?download=1.

“Summary of the Toxic Substances Control Act.” 2022. U.S. Government Agency. *United States Environmental Protection Agency- Laws and Regulations* (blog). October 4, 2022. https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

“Sustainability.” n.d. The United Nations. *Academic Impact* (Organization Website). Accessed November 23, 2022. https://www.un.org/en/academic-impact/sustainability.

Jason Tchir. 2020. “Without Incentives, Will People Buy EVs? Maybe Not.” *The Globe and Mail*, February 20, 2020. https://www.theglobeandmail.com/drive/mobility/article-without-incentives-will-people-buy-evs-maybe-not/.

Andrea Temporelli, Maria Leonor Carvalho, and P. Girardi. 2020. “Life Cycle Assessment of Electric Vehicle Batteries: An Overview of Recent Literature.” *Energies* 13 (11): 1–14. https://doi.org/10.3390/en13112864.

“The 17 Goals.” 2022. The United Nations Department of Economic and Social Affairs- Sustainable Development. https://sdgs.un.org/goals#history.

“The Circular Economy.” n.d. Government Regulator Website. *Resource Productivity and Recovery Authority* (Organization website). Accessed April 25, 2022. https://rpra.ca/about-us/the-circular-economy/.

“The Global Battery Alliance Battery Passport: Giving an Identity to the EV’s Most Important Component.” 2020. Global Battery Alliance. https://www.globalbattery.org/media/publications/wef-gba-battery-passport-overview-2021.pdf.

“Timeline.” 2022. European Commission. *Batteries* (website). December 9, 2022. https://environment.ec.europa.eu/topics/waste-and-recycling/batteries_en#timeline.

Toxic Substances Control Act of 1976. 1976. *15 U.S.C. §2601 et Seq. (1976)*. https://uscode.house.gov/view.xhtml?path=/prelim@title15/chapter53&edition=prelim.

Jaclyn Trop. 2022. “28% of Americans Still Won’t Consider Buying an EV.” Tehcnology News. *TechCrunch- Transportation* (blog). July 7, 2022. https://techcrunch.com/2022/07/06/28-of-americans-still-wont-consider-buying-an-ev/#:~:text=Price%2C%20range%20and%20access%20to,electric%20cars%2C%20trucks%20and%20SUVs.

"Understanding EV Batteries." n.d. Canadian Vehicle Manufacturers' Association. Accessed April 25, 2022. http://www.cvma.ca/wp-content/uploads/2021/06/Understanding-EV-Batteries.pdf.

United States Environmental Protection Agency (EPA). n.d. "Environmental Justice." U.S. Government Agency. *Environmental Topics* (website). Accessed November 30, 2022. https://www.epa.gov/environmentaljustice.

United States Environmental Protection Agency (EPA). 2022. "Global Greenhouse Gas Emissions Data." U.S. Government Agency. *Greenhouse Gas Emissions* (website). February 25, 2022. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

Waste-Free Ontario Act, 2016, S.O. 2016, c. 12 - Bill 151. 2016. https://www.ontario.ca/laws/statute/s16012.

"Waste Not, Want Lots." 2022. Independent News Platform. *Electric Autonomy Canada* (newsire). March 1, 2022. https://electricautonomy.ca/2022/03/01/dentons-epr-ev-battery-recycling/.

"What Happens at the End of the Electric Vehicle Battery's Journey?" n.d. Canadian Vehicle Manufacturers' Association. Accessed April 25, 2022.

Winfield, Mark S., and Hugh J. Benevides. 2001. "Drinking Water Protection in Ontario: A Comparison of Direct and Alternative Delivery Models." Issue Paper Part II. Walkerton Inquiry. Ottawa, ON: Pembina Institute. https://www.pembina.org/reports/DrinkingWater.pdf.

"Working Group III Sixth Assessment Report." 2021. Assessment Report IPCC-57. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/.

Karim Zaghib. 2022. Personal Communication, Interview with Professor Karim Zaghib of Concordia University. Zoom Video Communications.