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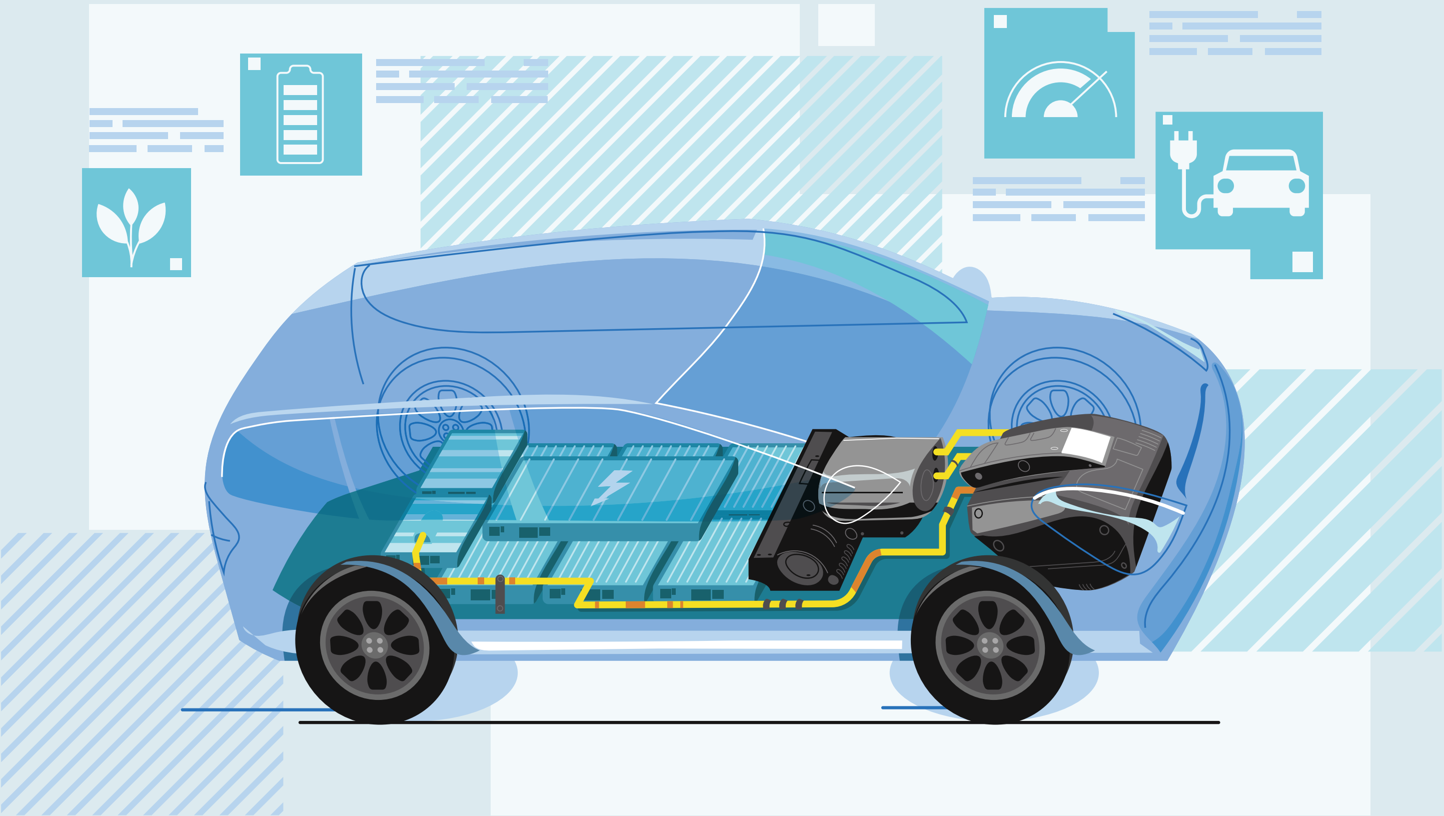

Electric Vehicle Battery Management at End-of-Vehicle Life

A Primer for Canada


SUNSHINE
Jeep
Jeep
RUBICON

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Please direct enquiries about the Primer to CVMA (projectevbattery@cvma.ca) or Call2Recycle (ev@call2recycle.ca or ve@appelarecycler.ca). The Primer is available for downloading at www.cvma.ca/news/publications, www.call2recycle.ca/EV.

Executive Summary

There is tremendous interest and attention being paid to electric vehicles (EVs) and EV batteries in Canada (and across North America). Canadian consumer adoption of EVs – hybrid, plug-in hybrid, full electric, and fuel cell – reached 10% of new vehicle sales in 2021, up from 6.2% in 2020 and 0.7% in 2011[1] as vehicle manufacturers increased available models, government's provided consumers with purchase incentives, and charging infrastructure became increasingly available.

The Canadian federal government is, as are many other jurisdictions, promoting greater EV adoption to support and accelerate greenhouse gas (GHG) reductions to help fight climate change.

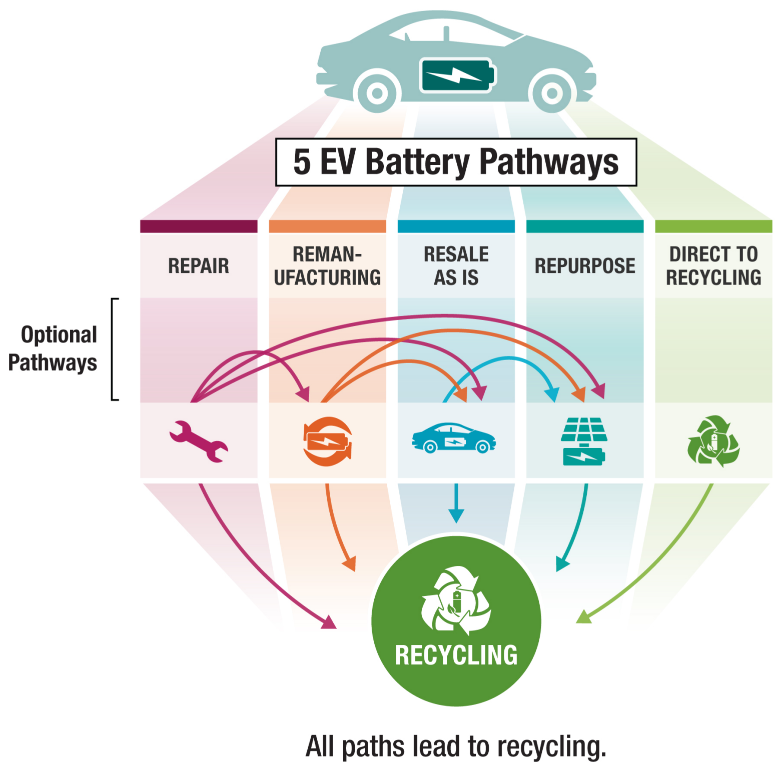
As EV adoption rises, questions are being asked about EV batteries at their end-of-vehicle life. Members of the Canadian Vehicle Manufacturers' Association (CVMA) and Call2Recycle have researched and prepared this EV battery management at end-of-vehicle life Primer as a foundational document articulating the evolving EV battery management ecosystem and how it is forming its own circular economy. The Primer includes recommendations on how to help facilitate the EV battery management ecosystem.

Fundamental to understanding EV batteries and their end-of-life is the fact that most EV batteries weigh hundreds of kilograms, require specialized tools and training to be removed from a vehicle, and are prohibited from being disposed of in landfills under existing federal and provincial regulations. EV batteries are not like other consumer batteries or electronics and require different policies and programs to manage them.

It is also important to recognize that EV batteries are lasting in vehicles between 15 and 18 years[3] and when repurposed for secondary non-automotive uses may last up to a decade longer before being directed to recycling. As a result, there are different management options for EV batteries than the traditional hierarchy of reduce, reuse, and recycle. A more comprehensive 5R model is developing, reflective of how an EV battery's available pathways include repair, remanufacturing, resale as is, repurposing, and recycling.

The journey for each individual battery can be quite different as the pathways are not necessarily sequential. Some pathways can be repeated while others skipped entirely. Importantly, these pathways are already developing, driven by for-profit market forces and various vehicle manufacturer's sustainability goals.

The 5Rs Pathways for EV Batteries

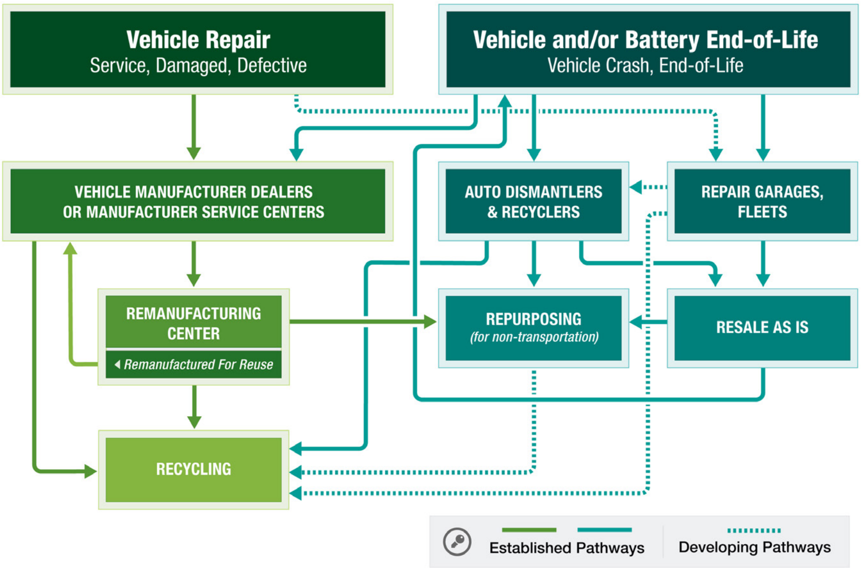


Source: Call2Recycle®

No matter the journey an EV battery takes during its useful life, all pathways lead to recycling with significant environmental benefits. Materials recovered from recycled batteries including lithium, nickel, cobalt, manganese, graphite, copper, and aluminum, are used to manufacture new products, and soon will be used to make new batteries, reducing demand for newly mined metals.

Knowing the potential management options for each battery provides insight into the evolving ecosystem for EV batteries and the flow of batteries today depending on where and when they are removed from the vehicle. Some pathways are quite developed already, while others are in their infancy, with all pathways leading to recycling.

EV Battery Journey Along the 5Rs Pathways

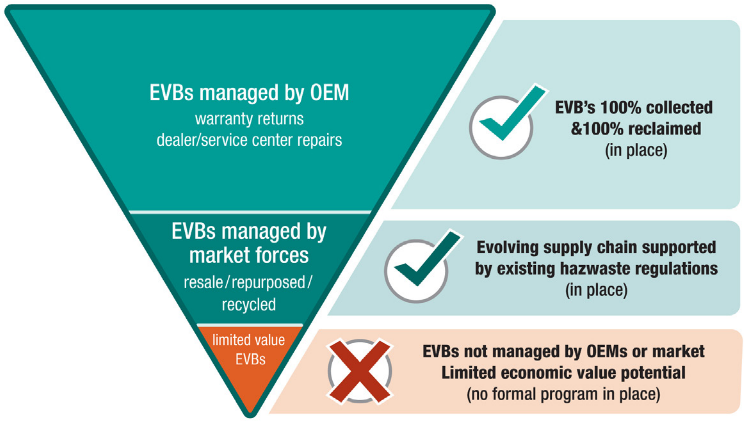


Source: Call2Recycle®

The established and developing pathways interconnect the companies servicing the EV battery management ecosystem and ensure batteries returned through the dealer network are managed by the vehicle manufacturer. Many of the batteries that reach end-of-vehicle life in the initial EV application, are being appropriately managed by market forces as depicted in this next graphic.

This leaves a small number of EV batteries that may be at risk of falling outside of the current collection and management system. These batteries, depending on proximity to a recycler, market price for metals contained within, and other factors including not having the skills and/or resources on-hand, can be a net cost to collect, transport, and process, resulting in them being held in storage by their owner waiting for conditions to change.

Current Management Programs for EV Batteries



Source: Call2Recycle®

Collecting, transporting, temporarily storing, importing, exporting, and processing of EV batteries along all these pathways is directed by a set of regulations established by both the federal and provincial governments.

These requirements were largely enacted prior to the rapidly evolving EV battery ecosystem taking shape, and as a result, can create obstacles to the efficient and environmentally sound management of EV batteries.

In addition, there are several initiatives, tools, and efforts under development that will help inform and facilitate decision making along the 5 pathways. These include EV battery diagnostics, methods of tracking or tracing batteries, labeling and information sharing, and standards.

The costs and revenues associated with managing EV batteries between the various pathways vary significantly. Freight usually is the single largest expense averaging 60% of all expenditures due in part to long distances to the processing facilities. Recycling costs/revenues vary by battery size, condition, and chemistry (therefore commodity value), whereas reselling an EV battery 'as is' or repurposing generates significant revenue depending on age, condition, and demand for the specific EV battery.

The following recommendations are outlined to support development of a robust and environmentally sustainable circular economy for EV batteries.

Recommendations

1. **Develop one national EV battery end-of-vehicle life management policy** to be adopted across all Canadian jurisdictions and aligned where possible on a continental basis.
2. **Ensure all policies impacting EV batteries support their entire useful life.**
3. **Review and amend current regulations**, **including the applicable transportation and waste management regulations, to remove barriers and facilitate EV battery movement** across provinces/territories, states and within North America.
4. **Review and assess storage requirements to support EV battery management** while minimizing risk to human health, the environment, and property.
5. **Assess and support information sharing between EV battery stakeholders** working within the EV battery management ecosystem, that will support effective and environmentally sound management of the batteries along the 5 pathways.
6. **Support initiatives under development by OEMs and their industry partners** that address batteries at risk of falling outside of the developing collection and management pathways, thus ensuring they are appropriately handled at end-of-vehicle life.
7. **Develop training standards and/or safety requirements** for those along the EV battery management ecosystem that cover proper handling, storage, transportation, and emergency response related to EV batteries.
8. **Adopt the 5Rs Pathways presented in this Primer** as the foundation for business decision making and adoption of policy.

Acknowledgements

The CVMA and Call2Recycle thank the many subject matter experts who shared their time, experience, and expertise throughout the development of this Primer. Discussing EV battery management at end-of-vehicle life, dispelling myths, and clarifying facts help provide for a common understanding about EV batteries, while assisting the evolution of the most efficient and sustainable collection and management system for EV batteries.

Introduction

Electric Vehicle Battery Management at End-of-Vehicle Life. A Primer for Canada

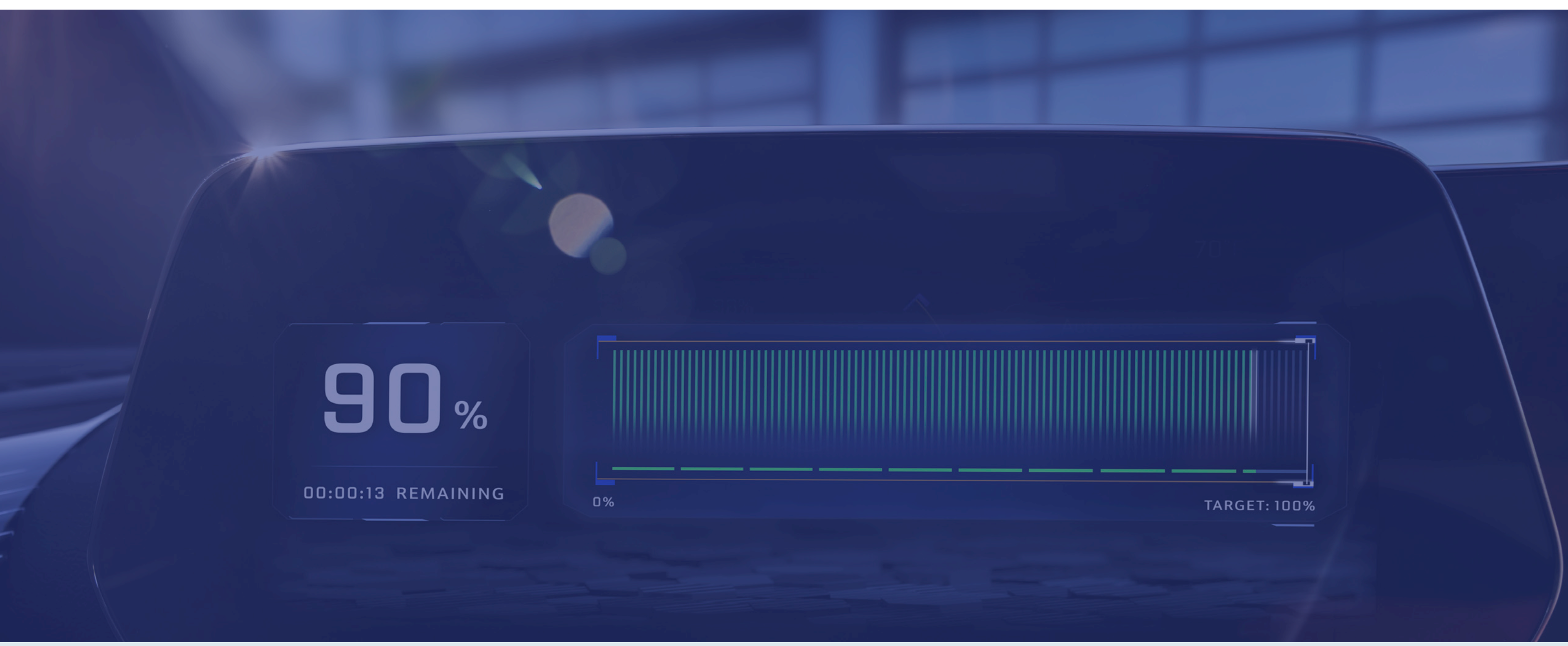
Interest in EVs and how to manage their batteries is growing in Canada as EV sales increase and the fleet size grows. Sales of hybrid, plug-in hybrid, full electric, and fuel cell vehicles reached 10% of new vehicle sales in 2021, up from 6.2% in 2020 and 0.7% in 2011[1].

Sales are expected to continue to increase thanks to billions of dollars in investment into electrification by automakers and manufacturers, as the auto industry goes through an unprecedented transformation. As of May 2022, announced new investments in Canada total $13.7 billion[2].

The purpose of the Primer is to define the ecosystem for EV battery management at end-of-vehicle life and how a circular economy is forming within this ecosystem. The Primer evolved from the need to have one foundational document that provides a Canadian context for EV battery management at end-of-vehicle life (which may differ from a battery's actual end-of-life).

Fundamental to any discussion of the Canadian auto industry is recognition that it operates within an integrated North American supply chain. As a result, the movement of EV batteries – both interprovincially and between the United States and Canada - must be facilitated to support important investment and economic opportunities. This integration underpins the policy recommendations in the Primer.

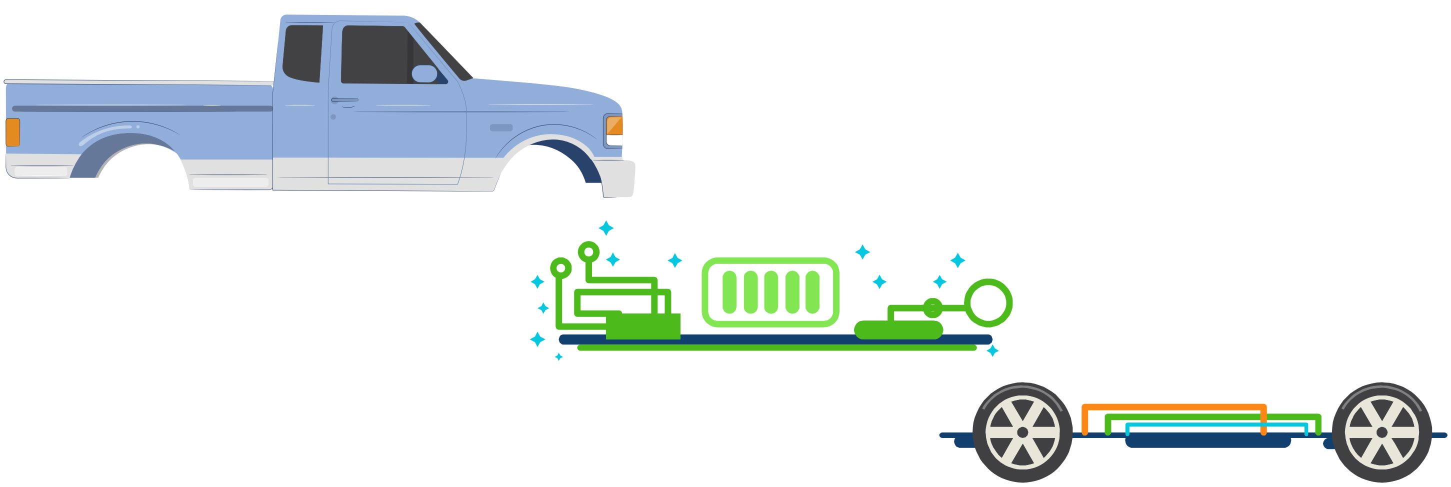
The Primer has been authored by members of the automotive manufacturing and battery recycling industries. The information presented reflects first-hand experience managing EV batteries, as well as interviews with industry participants and experts. The recommendations in the Primer are designed to help support the development of a robust, efficient, and environmentally sustainable circular economy for EV batteries, address misconceptions and close the knowledge gap that still exists with respect to the collection and management of EV batteries at end-of-vehicle life.



There are several myths and misconceptions related to EV battery management. These are important to address before proceeding into the Primer:

Myth	Reality
There is limited ability to recycle EV batteries in Canada	Canada has two commercially active recycling processors, and two additional demonstration plants are operational. By 2024 it is expected that at least 4 recycling processors will be commercially operational.
There is not enough recycling capacity in North America to handle today's recycling demand	The number of EV battery recycling processors has more than doubled in the past 5 years according to a market review by Call2Recycle. There is enough capacity to manage today's demand for EV battery recycling and there is no anticipated shortfall for the future due to recent announced investments in this area.
EV batteries last between 8 and 10 years and then need to be recycled	EV batteries last on average between 15 and 18 years and in some instances are reaching 21 years before being removed from automotive use.[3]
EV batteries are going to landfills	Existing regulations prevent the disposal of large EV batteries in landfills. Due to their size, weight, and characteristics, they cannot accidentally be placed in traditional waste streams and must be sent for appropriate processing.
There is limited circularity in the EV battery industry	A full circular economy is evolving rapidly, aided by economic drivers that are directing EV batteries towards a closed looped system. EV batteries travel along a mix of five potential management pathways, all eventually leading to recycling. Recycled materials are then sold for use in the manufacturing of a variety of products.
There are limited standards in place to help manage EV batteries at end-of-vehicle life	There are a number of standards in place that help govern aspects of EV battery management including those for labelling, transportation, packaging, and processes.

This Primer contains information that addresses many of the misconceptions about EV batteries at end-of-vehicle life. It will also address the various pathways that EV batteries are likely to follow, from use in a vehicle through to end-of-vehicle life and eventual battery end-of-life. The Primer includes reviews of ancillary, supporting and secondary issues such as battery diagnostics, regulatory requirements, and management as these issues impact the evolving circular economy of EV batteries, as well as recommendations to support EV battery management at end-of-vehicle life.

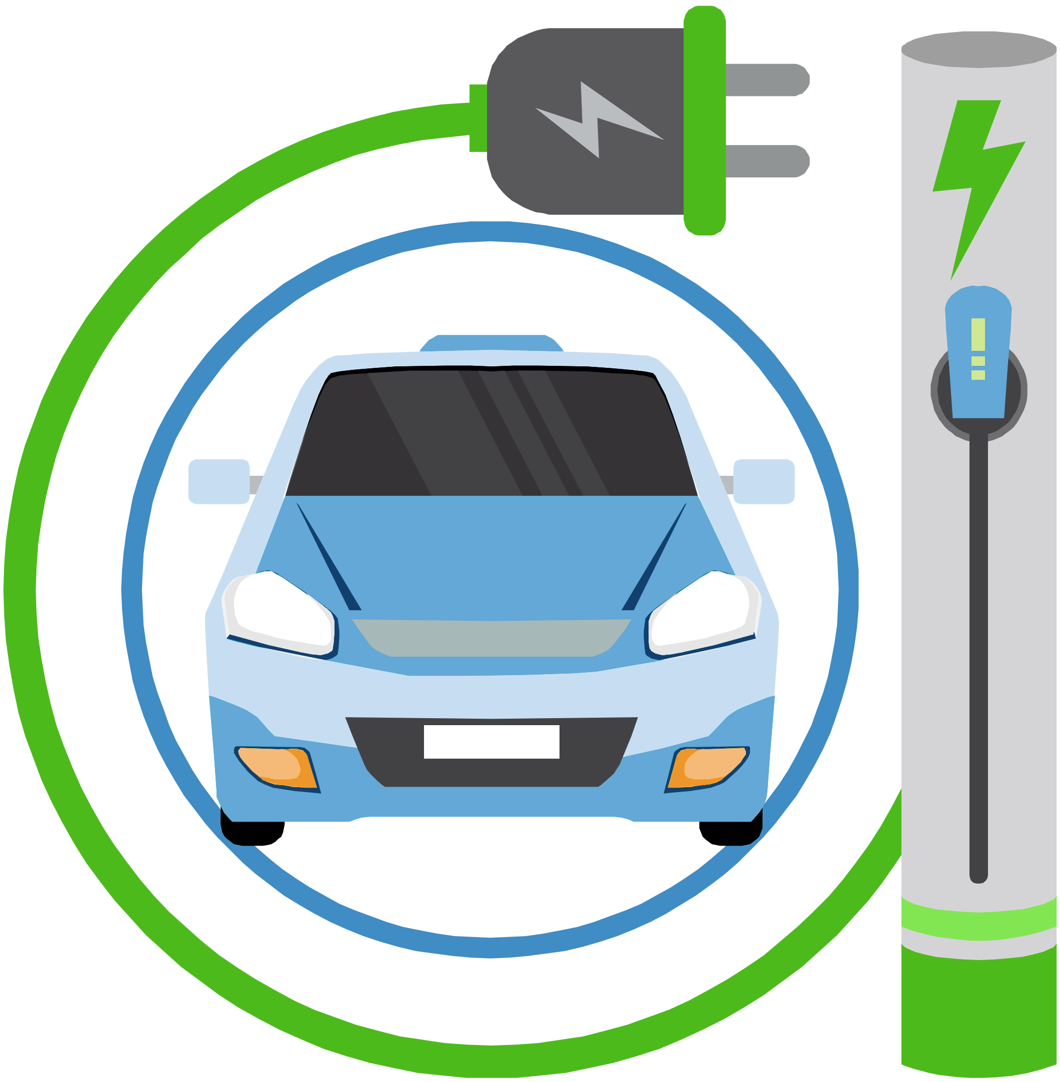


Abbreviations and Definitions

Abbreviation/Term	Full Name	Definition
5Rs or 5Rs Pathways	Repair, Remanufacturing, Resale as is, Repurposing, and Recycling	The five pathways available for EV batteries to travel on their journey
Ahr	Ampere-hours	Measure of battery capacity
BEV	Battery electric vehicle	A vehicle propelled solely by electricity stored in the batteries
BIN(s)	Battery identification number(s)	A vehicle manufacturer's coding system that identifies EV batteries by a number
Black mass	Battery materials	The output material from the first stage of processing batteries at a battery recycling facility
CGSB	Canadian General Standards Board	A Canadian federal government organization that offers client-centred, standards development and conformity assessment services
CSA	Canadian Standards Association	A not-for-profit membership-based association organization that develops and maintains consensus standards
CVMA	Canadian Vehicle Manufacturers' Association	The National Canadian trade association representing Ford, General Motors, and Stellantis (FCA Canada)
DD or DDR	Damaged-defective or damaged-defective-recalled	A battery pack that has been damaged or is defective. Sometimes 'recalled' is also referenced in this abbreviation. These batteries are to be handled differently per regulations due to a higher level of safety risk
EC	Equivalency Certificate	A certificate issued by Transport Canada permitting the use of a non-standardized means of containment to transport EV battery packs
ECCC	Environment and Climate Change Canada	The Canadian regulatory department responsible for environmental matters, including establishing and maintaining the Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations
EOL	End-of-life	Refers to a battery pack whose entire useful life has come to an end and is ready for recycling
EOVL	End-of-vehicle life	Refers to a battery pack whose life within a vehicle has come to an end and is ready for its journey along one of the pathways

Abbreviation/Term	Full Name	Definition
EPR	Extended producer responsibility	A waste management policy that requires a manufacturer or importer to manage a product through its end-of-life including final disposition
EV(s)	Electric vehicle(s)	A vehicle powered by either 100% electricity or a combination of electricity and fossil fuel. Includes hybrid, plug-in hybrid, battery electric, and fuel cell vehicles
EVB(s)	Electric vehicle battery(ies)	The large battery that stores energy that is used to then propel the vehicle (EV batteries is generally used throughout the document to refer to the entire battery known as the battery pack)
EV battery management	Electric vehicle battery management	The process of making decisions and handling of EV battery pack/model/cells through the 5Rs Pathways
FCEV	Fuel cell electric vehicle	A vehicle that is powered by electricity that is generated by a source of hydrogen
GHG	Greenhouse Gas	Greenhouse gases as listed by Canadian Government: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3)
HEV	Hybrid electric vehicle	A vehicle that is powered by both electricity and fossil fuel, where the electricity generated comes from the motion of the vehicle itself
ICE vehicle	Internal Combustion Engine vehicle	A vehicle propelled solely by fossil fuels (e.g. gasoline, diesel, etc.)
kWh	Kilowatt hours	Measure of battery capacity
LFP	Lithium iron phosphate	A type of lithium-based EV battery chemistry
Li or Li-ion	Lithium or lithium-ion	A battery chemistry
LTL	Less-than-truckload	Industry term referring to a shipment of goods by truck that uses less than a full trailer worth of space
NCA	Nickel, cobalt, aluminum	A type of lithium-based EV battery chemistry
NiMH	Nickel Metal Hydride	A battery chemistry
NMC	Nickel, manganese, cobalt	A type of lithium-based EV battery chemistry

Abbreviation/Term	Full Name	Definition
OEM	Original equipment manufacturer	A term referring to the first manufacturer and/or brand owner of the product being placed on the market, herein this document implying vehicle manufacturers
PHEV	Plug in hybrid electric vehicle	A vehicle that is powered by both electricity and fossil fuel, where the battery can be recharged from an external source
R&D	Research & development	A set of innovative activities undertaken in developing new products or services, and improving existing ones
SAE	SAE International, formerly Society of Automotive Engineers	A global professional association and standards developing organization for industry
TC	Transport Canada	The Canadian regulatory department that established and maintains the Transportation of Dangerous Goods Act and its regulations
TDG or TDGR	Transportation of Dangerous Goods Regulations	The Canadian regulations governing the transportation of dangerous goods
TL	Truckload	Industry term referring to a shipment of goods by truck that uses the entire space in the trailer
UN	United Nations	The letters UN followed by a series of numbers used to reference a global standard being followed, often seen in classification or packaging identification
USDOT	United States Department of Transportation	The United States regulatory agency established by the Department of Transportation Act that regulates, among other items, the transportation of dangerous goods through the Pipeline and Hazardous Materials Safety Administration (PHMSA)
Wh	Watt hours	Measure of battery capacity
XBR	Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations	The Canadian regulations pertaining to Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material established and maintained by Environment and Climate Change Canada
ZEV	Zero emission vehicle	A vehicle that can operate with no tailpipe emissions, including plug in hybrid vehicles, battery electric vehicles, and fuel cell electric vehicles



Section 1

Understanding EV Batteries

Electric vehicles (EVs) are entering the market as alternatives to traditional internal combustion engine (ICE) vehicles. Burning gasoline or diesel (fossil fuel) in passenger cars and trucks results in greenhouse gas (GHG) emissions and transitioning to EVs is a complementary and effective way to support GHG reductions.

Governments across Canada are looking for ways to increase the adoption of EVs through point-of-sale purchase incentives, ownership incentives (such as free parking, free tolls, use of high occupancy vehicle lanes), education regarding ownership benefits (such as reduced maintenance and fueling cost), regulations, and infrastructure development. As the number of EVs on the road continues to increase, questions have been raised about the potential impact of end-of-vehicle life EV batteries on the environment, and the infrastructure needed to remanufacture, repurpose, and recycle in a way that creates a circular economy.

What are Electric Vehicles and are they all the same?

Hybrid electric vehicle (HEV):
Hybrid electric vehicles are vehicles with an internal combustion engine and an electric motor/battery pack. The battery pack is not charged by an external source but rather through regenerative braking, which captures energy that would otherwise be lost. HEVs produce zero tailpipe emissions when running on electric power. They contain a relatively small battery (~27-120 kg) and the battery chemistry has traditionally been nickel-metal hydride (NiMH).

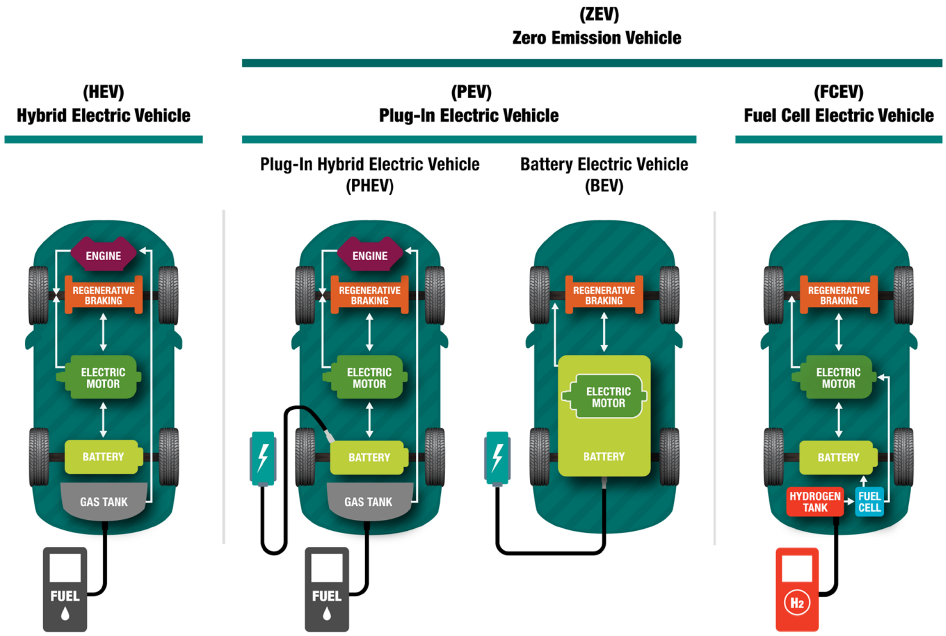
Plug-in hybrid electric vehicle (PHEV):
Plug-in hybrid electric vehicles are vehicles with an internal combustion engine and an electric motor along with a battery pack that can be recharged from an external source as well as from regenerative braking. They typically run solely on electric power until the battery is drained and then the internal combustion engine takes over for propulsion. PHEVs produce zero tailpipe emissions when running on electric power. Common battery range (available distance for travel) of these vehicles is 40-60 km or higher. The battery is typically slightly larger than those found in a HEV and the chemistry is either lithium or NiMH based.

Battery electric vehicle (BEV):
Battery electric vehicles are powered solely by an electric motor with a battery pack that is recharged from an external source as well as from regenerative braking. BEVs produce zero emissions. They typically have a range greater than 200 km. As a result, the battery packs are much larger weighing between 200-1,200 kg. The chemistry of these batteries in North America are lithium-based.

Fuel cell electric vehicles (FCEV):
Fuel cell electric vehicles are also powered solely by an electric motor like a BEV but instead of recharging the battery from an external source, they generate their own electricity. FCEVs store hydrogen gas in an onboard tank that the fuel cell combines with oxygen from the air to produce electricity. The electricity from the fuel cell then powers an electric motor, which propels the vehicle just like a BEV. Also, like BEVs, they produce zero emissions. Unlike BEVs or PHEVs, however, there is no need to plug-in FCEVs, since their fuel tanks are filled at a hydrogen station. The batteries in these vehicles support regenerative braking, receive some charging from the fuel cell, are similar in size to HEVs and PHEVs and tend to be lithium-based.

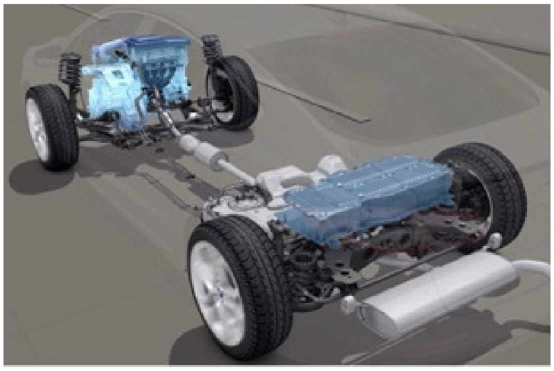
Although HEV, PHEV, BEV and FCEV are often grouped together as electric vehicles, HEVs or hybrids that cannot be recharged from an external source are generally not considered zero-emission vehicles (ZEVs). In addition, PHEV, BEV, and FCEV use predominantly lithium battery chemistries whereas HEV typically use nickel metal hydride technology, making the opportunity for reuse and the technology used for recycling different.

FIGURE 1: Visual Comparison of EV Configurations



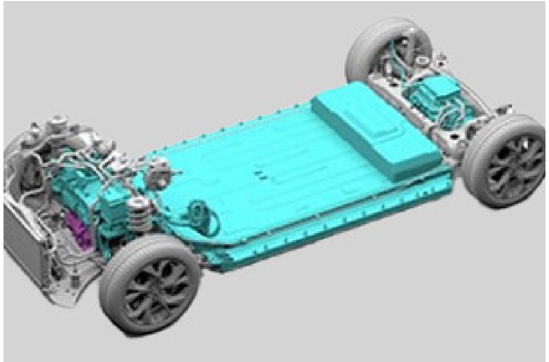
Source: Call2Recycle®

Pictures of different EV batteries

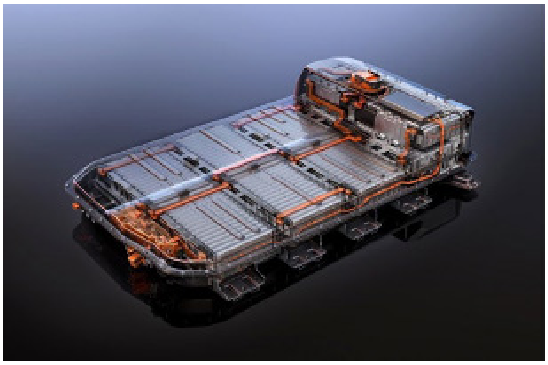


2020 Ford Fusion HEV
Source: www.ford.ca

PHEV 2021 Jeep® Wrangler 4xe
Jeep is a registered trademark of FCA US LLC.



BEV 2021 Ford Mach-E Extended Range
Source: www.ford.ca

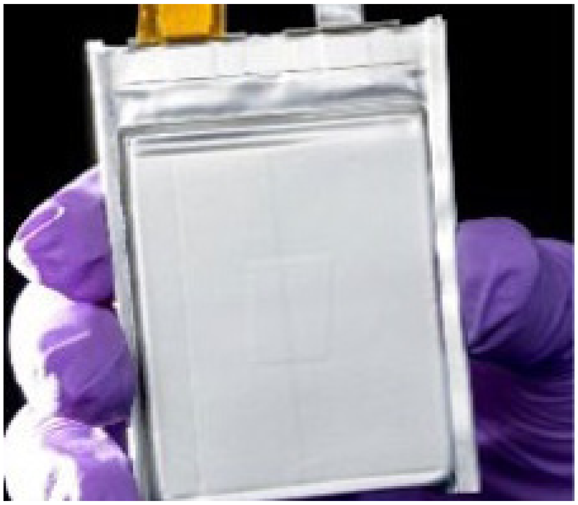


BEV 2017 Chevrolet Bolt
Source: https://media.gm.com

Understanding EV Battery Terminology

A battery cell is one single rechargeable pouch, cylinder, or unit within a battery module. A battery module is a group of cells fitted together as a unit, wired and ready for connection into a larger configuration. A battery pack is a set of modules wired together and performing as one large entity via battery management software. Battery packs are comprised of many modules (typically 3-16), weigh hundreds of kilograms, and occupy a significant space in the vehicle. Throughout this Primer, the term EV battery means a battery pack.

Different configurations of cells, modules, and battery packs allow automotive manufacturers to create unique vehicle designs that address differences in size and weight, provide additional power, or extend vehicle range. Although battery pack configurations may vary between vehicles, this does not create barriers to recycling. All battery recyclers that specialize in recycling lithium batteries can accept and process all the batteries found in EVs, just as they can process different consumer-based lithium batteries found in cell phones or computers.



Lithium-ion cell

Module

Pack

Source: https://media.gm.com

Vehicle Sales and the Popularity of Electric Vehicles

Figure 2 shows all new vehicle registrations by vehicle type over the last 11 years. Electric vehicle registrations have grown significantly over the last decade since sales began and now represent 10% of total new vehicle sales in 2021.[4/5] If only zero-emission vehicle sales are considered (this excludes hybrid vehicles by definition), that number is 5.2%.[4/5] Over 120 models are expected by 2023 and there are currently 75 models available in Canada.[6]

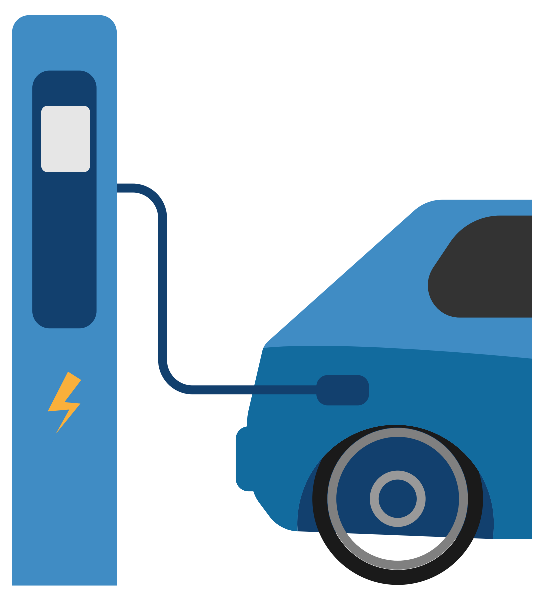
Some vehicle manufacturers have committed to convert their entire light-duty product offering to EVs by 2035 or having an EV available in every product category before that. This does not mean that all vehicles on the road in 2035 will be EVs, but that all new light duty vehicle sales by these manufacturers is projected to be electrified.

FIGURE 2: New Motor Vehicle Registrations in Canada Over Past 11 Years by Type[1]

Statistics Canada New Motor Vehicle Registrations Data

Fuel Type	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
BEV	215	646	1,602	2,839	4,151	4,990	8,921	22,544	35,523	39,036	58,726
PHEV	303	1,343	1,548	2,533	2,737	7,019	11,405	21,111	20,642	15,317	27,306
HEV	10,106	20,938	20,695	19,791	17,309	21,722	22,832	25,355	38,390	41,435	79,330
FCEV*						4	0	4	85	24	126
Gasoline	1,548,815	1,582,476	1,662,103	1,723,164	1,776,345	1,815,693	1,925,026	1,838,445	1,776,571	1,384,928	1,415,361
Diesel	63,849	68,902	74,342	88,204	85,635	71,217	65,406	70,855	59,089	64,769	65,881
Other fuels*						2	7	238	145	34	12
All vehicles	1,623,288	1,674,305	1,760,290	1,836,531	1,886,177	1,920,647	2,003,597	1,978,562	1,930,445	1,545,561	1,646,742
EV % of Registrations	0.7%	1.4%	1.4%	1.4%	1.3%	1.8%	2.1%	3.5%	4.9%	6.2%	10.0%

Source: Statistics Canada[1]
Source: *FCEV* - IHS Markit



Section 2

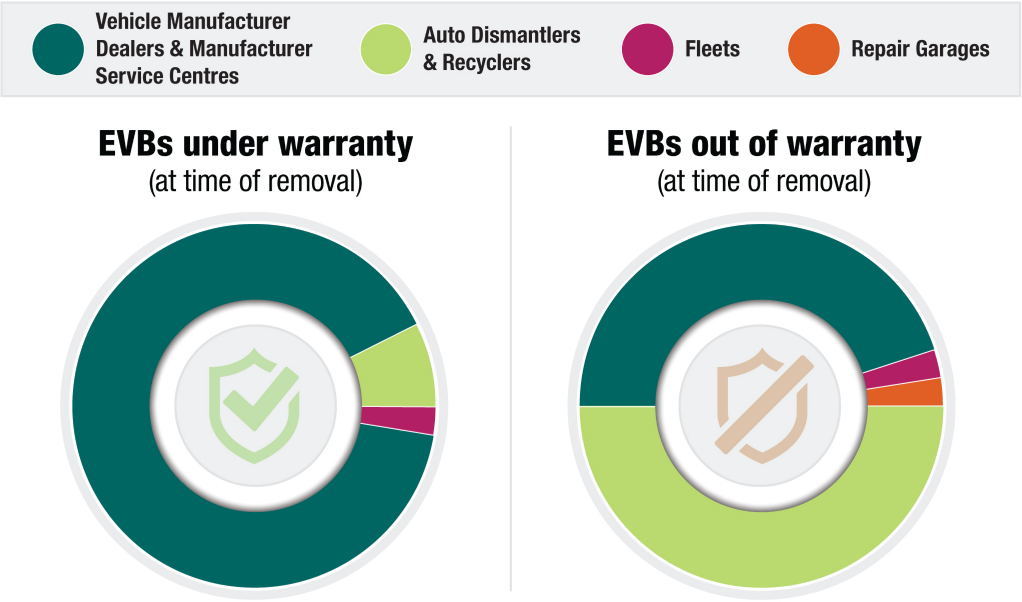
Journey of an Electric Vehicle Battery

With a common understanding of what an EV battery is, one may wonder where electric vehicle batteries can be found after they are removed from the vehicle.

When considering how any or all batteries at end-of-vehicle life are managed, it is easy to assume a potential risk to the environment exists. For example, small consumer batteries may be removed from the device they are powering, left behind in a drawer, or thrown out as household waste that may or may not make it to landfill. However, this is not the case for EV batteries.

They are simply too big to misplace, transport, or appear at landfills without notice. Hybrid vehicle battery packs weigh 27 - 120 kg, while plug-in EV battery electric packs weigh 200 - 1,200 kg. The trend is towards larger and heavier battery packs to support longer driving ranges and larger vehicle models while addressing increasing consumer demands and preferences. As a result, most EV batteries today are removed from a vehicle by trained professionals at a vehicle manufacturer dealer, through a manufacturer service centre, or at an auto dismantler & recycler at end-of-vehicle life. These batteries will either be remanufactured or made available for resale, repurposed, or sent for recycling.

FIGURE 3: Where EV Battery Removal Happens



Source: Call2Recycle®
Illustrations represent estimated proportions for comparison.

Most EV batteries under warranty are removed from the vehicle by the vehicle manufacturer dealer or through the manufacturer service centre. Comparatively fewer are removed by auto dismantlers & recyclers when a vehicle is no longer road worthy prior to the expiration of the battery warranty (e.g., vehicles involved in crashes).

A vehicle manufacturer dealer is an independent business or dealership associated with a particular manufacturer where vehicles are sold and serviced. A manufacturer service centre is an alternative mobile or designated location that services vehicles on behalf of the manufacturer.

It is unlikely that a repair garage that is not associated with the vehicle manufacturer would replace an EV battery that is still under warranty. New replacement EV batteries are generally available only through the vehicle manufacturer dealer network, and to be covered under warranty, the work must be completed by an approved dealer with the required tools, knowledge, and training.

When EV batteries are beyond the warranty period, they are generally serviced and replaced by vehicle manufacturer dealers or manufacturer service centres (due to the present limited supply of replacement EV batteries) or removed by auto dismantlers & recyclers when the vehicle reaches end-of-life.

Auto dismantlers & recyclers are businesses that specialize in the management of end-of-life vehicles. In many provinces these businesses are also subject to regulations that require the depolluting of vehicles prior to crushing or shredding.

This includes the removal of batteries. When an EV is received by an auto dismantler & recycler, various parts including the EV battery, are removed and assessed for revenue potential through resale, repurposing, or they are sent for recycling. EV batteries are not to be sent to landfill due to existing provincial waste regulations that protect the environment.

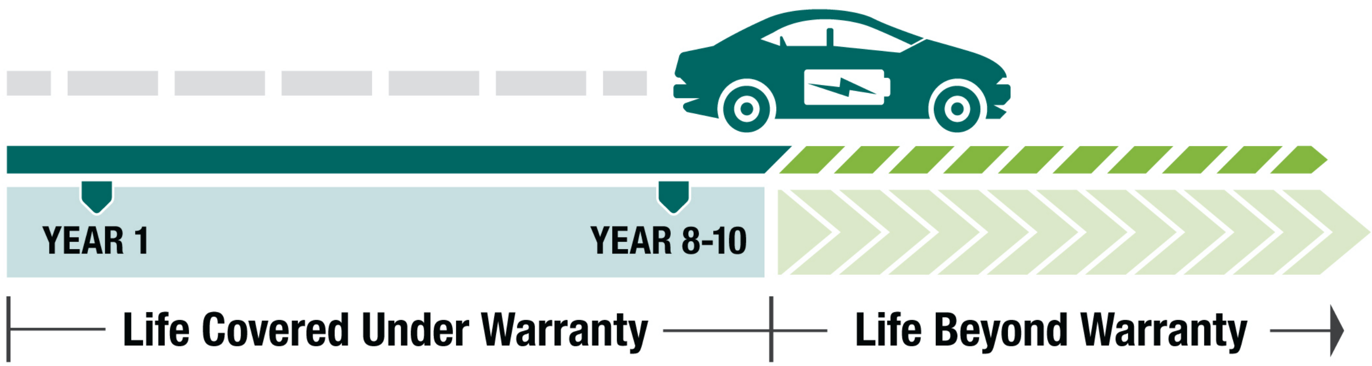
Other than vehicle manufacturer dealers, manufacturer service centres, and auto dismantlers & recyclers, locations of additional EV batteries that require end-of-vehicle life management are limited across Canada at this time. There are some independent repair garages servicing electric vehicles that generate a battery for end-of-vehicle life management. There are also organizations that manage a large fleet of vehicles with access to their own service garage and trained technicians that will do EV battery maintenance or battery exchange themselves.

What is the typical lifespan of an EV Battery?

There is a lot of dialogue and speculation about the lifespan of a typical EV battery. Many people mistakenly assume EV batteries last 8 – 10 years because this is generally the length of warranties.

The full useful life of an EV battery is expected to be quite long. During a presentation at the Canadian EV/Hybrid Auto Recycling webinar in Canada (November 4, 2021), Hans Eric Melin of Circular Energy Storage presented information on how EV batteries are lasting much longer than previously predicted. His company's review of real-world global EV battery data indicates that EV batteries last on average 15-18 years before vehicle end-of-life, with many batteries lasting up to 21 years[7]. Therefore, it's possible that an EV battery may potentially last as long or longer than the electric vehicle which it was initially a part of.

In situations where EV batteries are removed from EVs and replaced, it is usually done to address concerns that the vehicle is no longer performing to a customer's satisfaction, or when the vehicle is damaged such that it is best addressed via replacement. In either circumstance, the removed battery may still have a significant portion of its charging capacity available when it is no longer suitable for use in the vehicle. This has generated great interest and innovation to identify and redeploy EV batteries for secondary life applications such as standby energy storage where they would remain in use for many years before they would need to be recycled.

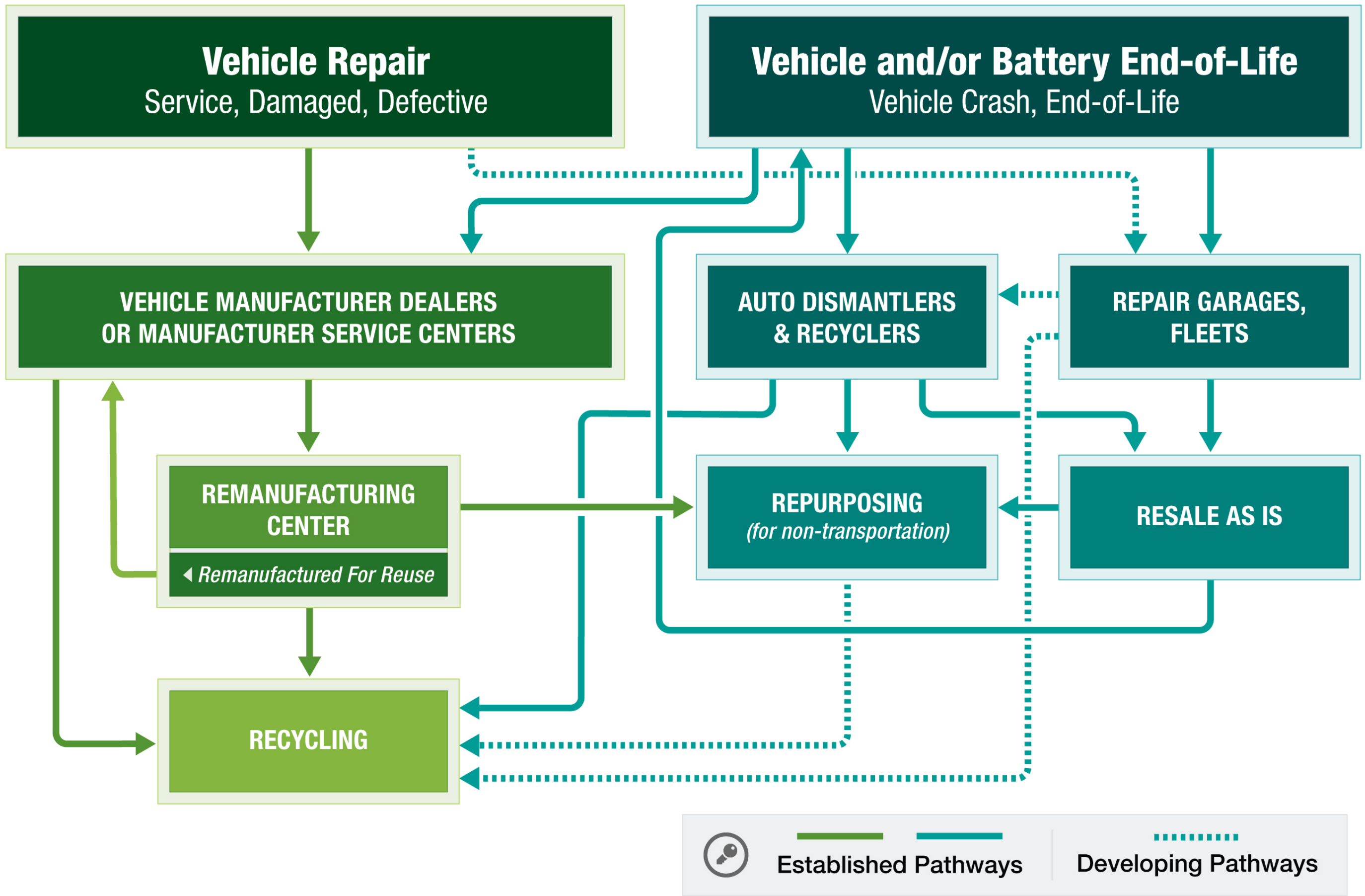


What is the Warranty for EV Batteries?

Standard EV battery warranties are typically 8 – 10 years / 160,000 kilometres; however, there are some vehicle manufacturers offering extended warranties of up to 12 years with varying kilometres.

See individual manufacturer's website for details.

FIGURE 4: EV Battery Journey Along the 5Rs Pathways



Source: Call2Recycle®

What Happens at Vehicle Manufacturer Dealers and Manufacturer Service Centres with EV batteries?

Vehicle manufacturer dealers and manufacturer service centres diagnose EV battery issues and replace batteries needing more in-depth service with new or remanufactured batteries. Batteries requiring additional diagnostics or repair are typically shipped to a location for consolidation and remanufacturing. These remanufacturing centres provide life cycle management of EV batteries including repair, remanufacturing, refurbishment, repurpose and if necessary, shipping for recycling.

What are Remanufacturing Centres?

Remanufacturing centres are independent businesses that provide vehicle manufacturers life cycle management of used EV batteries using a combination of reused, repaired, and new components or modules. Currently, there are at least three independent companies working with the various vehicle manufacturers offering these services today in North America. Remanufactured batteries are sent back to vehicle manufacturers for distribution as service replacement parts, while non-useable battery packs and/or modules are either repurposed in a second life application or sent for recycling.

What Happens to EV Batteries at Auto Dismantlers & Recyclers?

Auto dismantlers & recyclers are businesses that specialize in vehicle recycling. Their primary goal is to maximize the value of the entire end-of-life vehicle in an environmentally responsible manner, irrespective of the type of vehicle. An EV is similar to a traditional internal combustion engine vehicle in that it is made up of parts that can be removed and sold as used parts, sold for a secondary use, or sent for recycling.

Auto dismantlers & recyclers assess how best to realize a return on an EV battery by either selling the battery “as is” for use in another electric vehicle, to a third party for use in a secondary application such as power for stationary energy storage units or sending it to a battery recycling processor. Auto dismantlers & recyclers may inventory EV batteries, as they do with other vehicle components, if there is no immediate demand.

What do Independent Repair Garages do with EV batteries?

A small number of independent repair garages may remove an EV battery from a client’s vehicle and replace it with a used or remanufactured battery purchased on the open market. The battery once removed may similarly be resold “as is” for reuse in an EV, for secondary use, sent to an auto dismantler & recycler, or sent to a battery recycler for processing.

Section 3

The 5Rs: Repair, Remanufacture, Resale as is, Repurpose, and Recycle

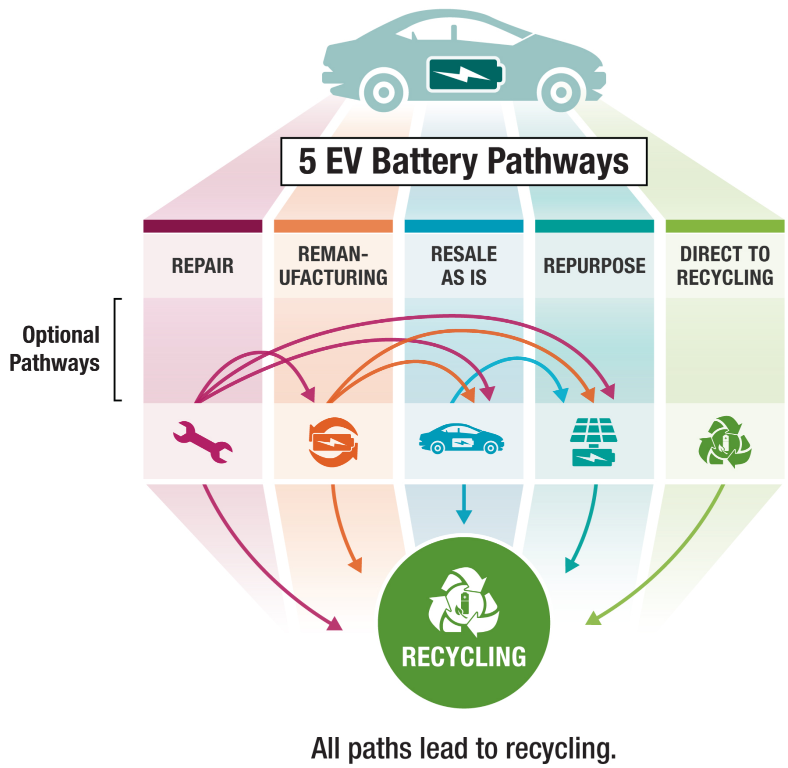
There are multiple pathways available for EV batteries to travel at the end of their vehicle life. This section will explore what the authors are calling the 5Rs Pathways.

Reduce, Reuse, Recycle: How does this apply to EV Batteries?

In the automotive world of EV batteries, the typical environmental management hierarchy of 'reduce, reuse, recycle' becomes a little more complex.

As depicted below, an EV battery may be directed to any of the possible pathways depending on the EV battery owner's business model, processes, and the overall health of the battery. The overarching goals are typically to prioritize extending the life of the EV battery through either repair, remanufacturing, reselling as is, or repurposing; and then recycling the battery when its entire working life is complete.

FIGURE 5: The 5Rs Pathways for EV Batteries



Source: Call2Recycle®

It is important to know all paths lead to recycling of the EV batteries; this has environmental benefits. Recycled battery metals – lithium, nickel, cobalt, manganese, graphite, copper, and aluminum – are used to manufacture new products, and soon will be used to make new batteries (reducing demand for newly-mined metals). Plastic is either removed from the battery packs before processing and then recycled, or the entire battery is shredded with plastics being recovered through a float-sink process, and then recycled.

Introducing the 5Rs Pathways

Repair, Remanufacturing, Resale as is, Repurpose, and Recycling

Repair – Performing minor repairs to an EV battery to allow for ongoing use in an EV.

Remanufacturing – The ability to extend a battery's life by assessing a damaged, defective, or poorly performing battery pack and subsequently replacing only faulty cells/modules/components. The battery is remanufactured (or rebuilt) to a like-new condition suitable for redeploying in a vehicle, thus extending its life.

Resale as is – Resale can refer to the owner of the battery reselling it as is. Buyers are often sourcing the battery as a used replacement part for their EV. An EV owner may select a previously used EV battery rather than purchasing a new replacement EV battery if it is less expensive and meets their range needs.

Repurpose – Commonly referred to as preparing a battery for a "secondary life". An EV battery that no longer meets performance requirements for use in a vehicle is repurposed by identifying useful components, assessing their suitability for alternative use, and if appropriate the battery is reconfigured for use in alternative, non-automotive applications such as propulsion, energy storage, or backup power for residential/commercial/industrial uses.

Recycling – Returning a battery to either its original metals to be sold into the market for use in new non-battery products or using advanced processes to extract materials at a quality sufficient to be re-incorporated into new EV battery components.

Let us review remanufacturing, repurposing, and recycling in more detail.

Remanufacturing

Remanufacturing automotive components is not a new concept. The remanufacturing of engines, catalytic converters, transmissions, and other valuable automotive components has been a common practice for decades. Therefore, it is not surprising that many OEMs have incorporated remanufacturing of EV batteries into their current business practice such that when they are removed at a dealer or automotive service centre they are automatically sent to a remanufacturer. Remanufactured EV batteries meet the same high standards as the original EV battery and can be used as service and replacement batteries. EV battery cells/modules that are removed and cannot be remanufactured are either repurposed for a second life application or sent for recycling.

Remanufacturing is highly valuable as it keeps useable cells and modules in service, supports a circular economy and reduces the need for new battery production (minimizing the need for mining virgin materials). The process requires customized software, specialized equipment, and skilled labour. Today there are only a few companies offering EV battery remanufacturing services to automotive manufacturers in North America (Figure 6). Remanufacturing requires a reliable and steady supply of EV batteries to be efficient and effective. As the number of EV batteries in the market is still low, remanufacturing sites sometimes consolidate batteries from a large geographic area.

Repurposing

Research suggests that EV batteries will have more than half of their useful capacity left when removed from a vehicle. Batteries may be removed due to reduced charging capacity, collision, software issues, battery pack upgrades, and other causes. It may be more appropriate to repurpose these batteries in a non-vehicle "second life" setting rather than sending them for remanufacturing or recycling.

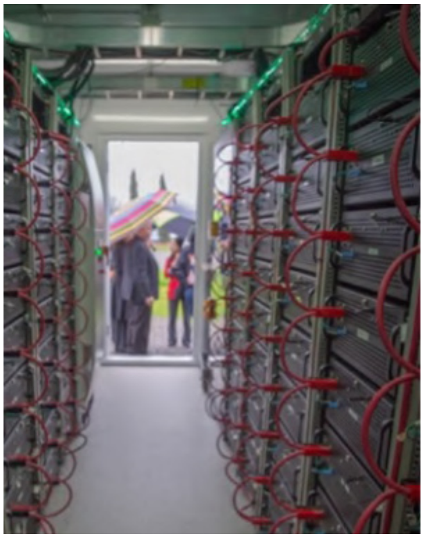
Used Chevrolet Volt batteries are helping keep the lights on at the new General Motors Enterprise Data Center at its Milford Proving Ground in Milford, Michigan. Five Volt batteries work with an adjacent solar array and two wind turbines to help supply power to the data centre's administrative offices.

Photo by John F. Martin for General Motors

Commercial-scale second-life battery system at the Robert Mondavi Institute For Wine and Food Science, a combined winery, brewery, and food processing complex located in Davis, California. This 300-kWh energy storage system is paired with 200 kW of solar PV for peak demand reduction of 20% and at times more. Batteries sourced from retired electric vehicles.

The energy storage unit is built into the shipping container

Photos courtesy of RePurpose Energy



View from inside energy storage unit

Photos courtesy of RePurpose Energy

A battery pack or module is repurposed when it is disassembled and its components are assessed, with those meeting a certain performance standard being assembled with new software or controls into a new finished product, not intended for vehicle use. In certain cases, entire battery packs are repurposed without disassembly. If the repurposed batteries are redirected for use as a new energy storage product, then they are paired and calibrated to an energy source such as solar panels, a wind generator, or an electrical grid. Several larger repurposers have been identified in North America at the time of publishing (Figure 6). (The total number of repurposers active in the market is difficult to ascertain as this business activity is relatively new).

New products produced using repurposed cells, modules, or packs are targeted for use in the residential, commercial, and municipal sectors for:

- Alternative energy sources to provide power (commercial applications)
- Emergency back-up power (all sectors)
- Off-grid power sources (remote areas)
- Managing peak power demand (all sectors)
- Auxiliary power (within recreational vehicles or maritime vessels)
- Off-road vehicles (golf carts being one example)

Recycling

Recycling of EV batteries has been undergoing significant innovation and financial investment over the last 10 years. Until recently there were only a handful of recyclers in North America that accepted and processed EV batteries. Some of these initial recyclers use pyrometallurgical recycling to recover the valuable metals in the batteries. In North America, there are several new recycling facilities that use more advanced hydrometallurgical processes, and there are at least another half dozen sites that have been announced or are currently under construction.

Pyrometallurgical Recycling[8]

Pyrometallurgical recycling uses high temperatures to essentially melt and separate base metals such as cobalt, manganese, and nickel. This method can be used to recycle both lithium-ion batteries and nickel-metal hydride batteries (NiMH). According to Call2Recycle, recovery rates are typically up to 85% for the base metal battery components which can be sold as raw materials for the production of new products but are not suitable to be directly reused in EV battery manufacturing without additional processing.

Hydrometallurgical Recycling[8]

Hydrometallurgical treatments involve the use of aqueous solutions to leach the desired materials contained in the battery with a stated recovery rate of 95% or higher for battery components. Some of these facilities have developed, or are in process of developing, proprietary technology to recover the base metals of nickel, cobalt, manganese, and lithium used in cathodes. These in turn are used in the manufacturing of new battery cells. Hydrometallurgical processes have also been refined to recover additional materials such as copper, aluminum, and other battery materials which increases the overall battery recycling efficiency. At the time of writing, up to four of the hydrometallurgical processors in North America are at various stages of developing the capability to manufacture the cathode precursors which in turn will be used to directly produce new EV battery components. Many of the other recyclers have indicated their intent to build new facilities or modify their processes to follow suit over the coming years.

Figure 6: Current Recycling Facilities Across North America

Presented in alphabetical order

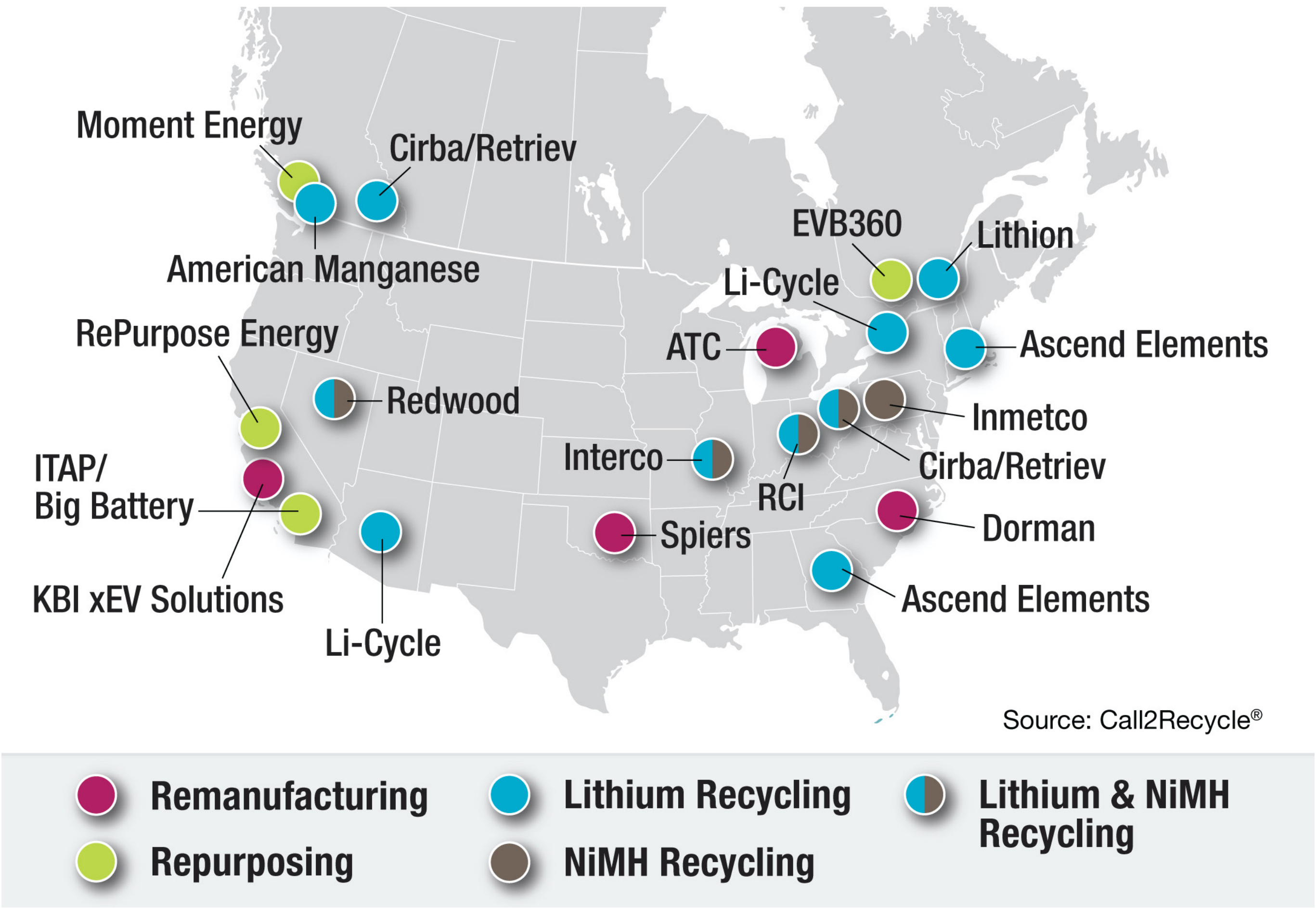
Canada	Plant	Chemistry	Process
American Manganese	Demonstration Plant	Lithium	Hydrometallurgical
Li-Cycle	Commercial Scale	Lithium	Hydrometallurgical
Lithion	Demonstration Plant	Lithium	Hydrometallurgical
Cirba (formerly Retriev)	Commercial Scale	Lithium	Hydrometallurgical
United States	**Plant**	**Chemistry**	**Process**
Ascend Elements	Commercial Scale	Lithium	Hydrometallurgical
Inmetco	Commercial Scale	Lithium	Pyrometallurgical
Interco	Commercial Scale	Lithium	Pyrometallurgical
Li-Cycle	Commercial Scale	Lithium	Hydrometallurgical
Recycling Coordinators	Commercial Scale	Lithium	Pyrometallurgical
Redwood	Commercial Scale	Lithium	Hydrometallurgical
Cirba (formerly Retriev)	Commercial Scale	Lithium	Hydrometallurgical

Lithion Recycling
Demonstration Plant (hydro)
Source: Lithion

Cirba (formerly Retriev Technologies)
Lancaster Commercial Scale Plant (hydro)
Source: Cirba

Li-Cycle Commercial Scale Plant (hydro)
Source: Li-Cycle

FIGURE 7: North American EVB Battery Management Sites



Facility list compiled by Call2Recycle based on publicly available information June 10, 2022.

To Repair, Remanufacture, Resale as is, Repurpose, or Recycle?

Choosing between repair, remanufacturing, resale as is, repurposing, or recycling for each EV battery requires the owner of the EV battery to consider several criteria. Owners will consider the overall capacity/health of their battery, access or proximity for shipping to the nearest processing facility, the market price for batteries versus base metals, and the overall cost/value proposition.

There is no single pathway that is superior and therefore should be prioritized. All paths have environmental and financial considerations, and as the EV battery ecosystem develops and innovates, market forces may pull or push batteries towards any of these options or completely different ones as they become available.

Section 4

Rules and Requirements Governing the Management of EV Batteries in Canada

There are multiple regulators at both the Federal and Provincial levels who set and enforce rules and requirements for the management of EV batteries.

At the federal level, EV batteries are governed by Transport Canada through the Transportation of Dangerous Goods Act, 1992 (TDG Act) and the Transportation of Dangerous Goods Regulations, and by Environment and Climate Change Canada through the Canadian Environmental Protection Act, 1999 and the Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations (SOR/2021-25).

Canadian Provinces and Territories have their own separate and distinct statutes and regulations dealing with the management of EV Batteries and other hazardous wastes and recyclables.

As a result, providing a simple and concise summary describing how to move EV batteries throughout their journey is a challenge. Figure 8 provides an overview of the various federal and provincial/territorial regulatory requirements.

FIGURE 8: Defining an EV Battery per Regulations in Canada

Regulatory Body	Transport Canada	Environment and Climate Change Canada	Provincial Ministries of Enviornment
Regulation	Transportation of Dangerous Goods Regulations	Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations	Waste regulations; recycling regulations
Battery Classification	Class 9	Haz8	Varies
Battery Defined As...	Dangerous Goods	Hazardous Recyclable Material	Hazardous Waste, Hazardous Recyclable Material or none

The following section outlines the regulatory requirements in Canada as it relates to EV batteries. The information in the Primer is provided as a guide however it is not to be interpreted as a replacement for understanding and complying with the applicable laws themselves. It is the responsibility of the handlers of EV batteries to know the laws and how they apply to the unique business situation. Obtaining legal assistance may be beneficial for due diligence purposes.

Transportation of Dangerous Goods Regulations

Both new and used EV batteries are considered dangerous goods while being transported. The Transportation of Dangerous Goods Regulations ("TDG Regulations") and standards require the following:

- Proper Classification;
- Documentation;
- Dangerous Goods Safety Marks;
- Containment;
- Training;
- Emergency Response Assistance Plan (if required);
- Reporting Requirements;
- Mode of Travel Instructions;
- Protective Direction; and
- Permit of Equivalent Level of Safety (also known as Equivalency Certificate) *

**Transport Canada updated the naming of 'Permit of Equivalent Level of Safety' to 'Equivalency Certificate', however did not change the section title in the regulations*

Classification of Dangerous Goods

Proper classification of an EV battery is imperative to understanding the TDG regulatory requirements for transporting each type of EV battery defined by its chemistry. Most EV batteries can be classified as either:

a. NiMH batteries
UN 3496, Class 9, NICKEL METAL HYDRIDE (NiMH) BATTERIES

OR

b. Lithium-ion batteries
UN3480, Class 9, LITHIUM-ION (Li-Ion) BATTERIES (including lithium-ion polymer batteries)

The classification of a battery helps in understanding the TDG regulatory requirements for transporting, inclusive of the packaging, or in TDG terminology the "means of containment", that must be used for transport. Requirements are based on the volume of the goods being transported, either small or large.

Small Means of Containment

Transport Canada classifies 'small means of containment' as being a volume of less than 450 litres. These types of containers would include drums, barrels, boxes, and crates. Many HEV and PHEV batteries could be shipped using a small means of containment. Further, if a larger EV battery is disassembled to modules and the modules ship in 205 litre drums, this type of shipment may also fall into the definition of small means of containment.

Section 5.12 of the TDG Regulations indicates that when NiMH and Li-ion EV batteries (Class 9) are transported in small means of containment, it must be done in compliance with Packing Instruction 801 of Transport Canada Standard TP14850E.

The packing instruction states that[9]:

- Batteries may be handled, offered for transport, or transported in a non-UN standardized container if they are placed in a rigid container, in a wooden slatted crate or on a pallet
- Batteries must be protected against short circuits
- Stacked batteries must be adequately secured in tiers separated by a layer of non-conductive material
- Battery terminals must not support the weight of other superimposed elements
- Batteries must be packaged or secured to prevent inadvertent movement.

Large Means of Containment

Most EV batteries from full battery electric vehicles require a large means of containment (defined as having a volume greater than 450 litres), but the identification of a specific container is not as straightforward as with small means of containment. TDG Regulation Section 5.14 directs shippers to follow standards CGSB-43.146 (Canadian General Standards Board) and CSA B621 (Canadian Standards Association).

However, means of containment built to these two standards are often not suitable for EV batteries. Therefore, to transport EV batteries in Canada, a company may need to apply to Transport Canada for an Equivalency Certificate (EC) to permit the use of a non-standardized means of containment such as those depicted below.

Multiple reuse UN-rated container for use with end-of-vehicle life, full end-of-life or damaged-defective-recalled NiMH or Li-ion batteries.

Multiple reuse UN-rated container engineered to contain large scale EV battery, for use with damaged-defective-recalled Li-ion batteries with built-in fire containment material.

Equivalency Certificates

Section 31 of the Transportation of Dangerous Goods Act authorizes the Minister to issue an Equivalency Certificate (also previously known as ELSP or Equivalent Level of Safety Permit) for most activities that do not comply with the Act or Regulations but are demonstrated to the Minister to have an equivalent level of safety as would be achieved by compliance with the Act and/or Regulations. Equivalency Certificates will contain relevant terms and conditions and are often valid for durations of three to five years. An Equivalency Certificate issued by Transport Canada is recognized and valid for purposes of compliance with provincial and territory transportation of dangerous goods requirements.

An Equivalency Certificate can be issued to cover both the applicant and transporters or other parties acting on behalf of the applicant. The transportation of end-of-life, or damaged-defective-recalled (DDR) EV batteries is subject to the terms and conditions set forth by the specific Equivalency Certificate that a company receives.

Information on obtaining an equivalency certificate can be found on the Transport Canada website. (Equivalency certificate applications – and access can be made using the following web portal Approvals - Login (tc.gc.ca) or via email at tdgpermits-permistmd@tc.gc.ca)

Depending on the size of an EV battery it may require using a small means of containment or applying for a non-standard means of containment via an Equivalency Certificate. This can be confusing and may result in smaller hybrid vehicle batteries being transported in different types of shipping containers than larger hybrid and full electric vehicle batteries. It would be beneficial to establish a separate EV battery means of containment use guideline that will simplify containment selection.

It is also important to highlight a difference between Transport Canada's and the United States Department of Transportation's requirements for use of means of containment for end-of-life EV batteries.

End-of-life EV batteries with a hard outer shell do not need additional means of containment when being transported in the United States, whereas in Canada they may require it depending on the type of Equivalency Certificate issued. This difference in regulations adds to logistics complexity when shipping batteries between the two countries.

Training

Part 6 of the TDG Regulations requires that a person who handles, offers for transport, or transports dangerous goods, be adequately trained and hold a valid training certificate. A person who does not have proper training and/or a valid training certificate may perform these activities in the presence and under direct supervision of a properly trained person who holds a valid training certificate. In addition, specific training requirements or exemptions are set forth and may be specified in an Equivalency Certificate.

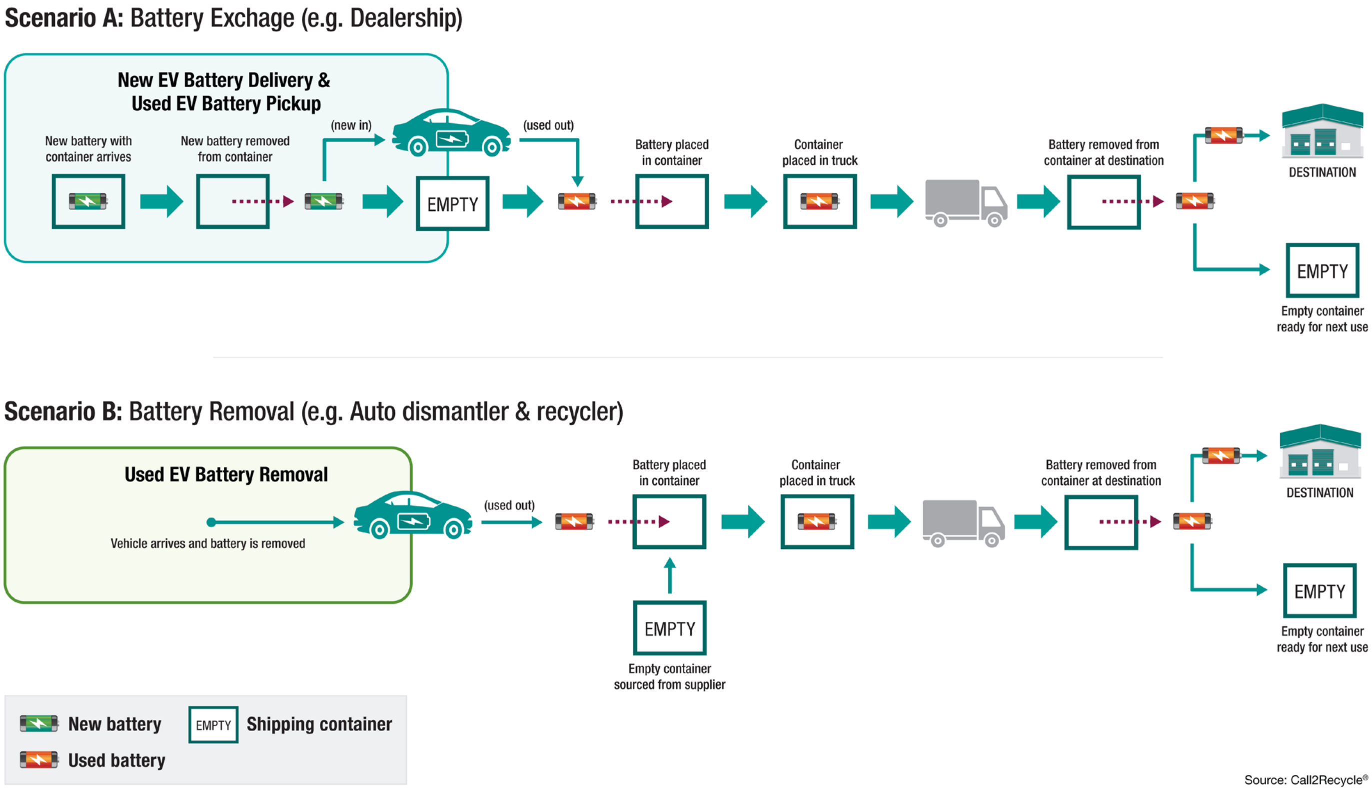
A person is considered to be properly trained if they have sound knowledge of all the topics listed in sections (a) to (m) of Part 6.2 Adequate Training of the regulations, particularly as it relates to that individual's duties and to the dangerous goods they are handling and/or offering for transport.

An employer may issue a signed certificate to the employee if they have reasonable grounds to believe that employee is adequately trained (per section 6.3 of TDG regulations). An employer may also require the employee to take hazmat shipper certification training from an independent third-party company. These can be found on the internet by searching 'hazmat shipper certification Canada'.

The Logistics for EV Batteries and EV Battery Containers

When batteries are being removed from a vehicle and there is no incoming replacement container to leverage for purposes of transporting the recently removed battery, an appropriate means of containment must be procured. In these instances, TDG regulations dictate the type of packaging required to safely transport an EV battery.

FIGURE 9: The Logistics of EV Battery Shipping Containers



Once the packaging or means of containment have been identified, a properly trained individual will prepare the EV battery for shipment by completing the necessary documentation, arranging a qualified carrier, ensuring the proper markings are affixed and keeping the appropriate records as required.

Authorized (Qualified) Carriers

Selecting the appropriate carrier to handle an EV battery is important. Some criteria a carrier may be required to meet includes:

1. Licensed or permitted to move dangerous goods
2. Licensed or permitted to move hazardous recyclable/waste material
3. Appropriate permits to move hazardous waste interprovincially and/or internationally
4. TDG approved shipping containers for containing the EV batteries
5. Appropriate Equivalency Certificates for movement of large EV batteries
6. Safety standards that meet and/or exceed those set forth in regulations
7. Drivers that are hazmat shipper certified

Environment and Climate Change Canada

In addition to the federal TDG requirements administered by Transport Canada, there are federal requirements administered by Environment and Climate Change Canada (ECCC) that pertain to the interprovincial and/or international movement of Lithium-ion and NiMH batteries.

Under the Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations (also known by its acronym XBR, which came into force on October 31, 2021), all interprovincial movements must be undertaken by an authorized carrier and accompanied by a movement document (also known as hazardous waste manifest) as per the definitions and requirements set in the Regulation. EV batteries intended to be recycled meet the current definition of HAZ8 as detailed on Schedule 6 of the Regulation and that of 'hazardous recyclable material' per R4, R5, and RC2 recycling codes column 2 of Part 2 of Schedule 1 Recycling Operations table.

All international movements to or from Canada must be covered by an export permit or import permit issued by ECCC. Export and import permits are normally issued for a twelve month term and specify the type of hazardous material being moved, the maximum number of shipments per year, the maximum cumulative quantity of hazardous recyclable materials, the specific chemical and other characteristics of each distinct form of waste stream, the identity of the authorized carriers, the identity of the exporter and receiving facility and a list of the specific ports of entry or exit to or from Canada being used.

XBR regulation is divided into 3 PARTS and 12 SCHEDULES:

PART 1 – Defines the import, export, and transit of batteries between Canada and any other country, and through Canada. In PART 1, DIVISION 1, section 8.2.d describes the need for permits to import batteries from one origin site to one destination site. Likewise in PART 1, DIVISION 2, section 20.2.d describes the need for permits to export batteries from one origin site to one destination site.

PART 2 – Defines the various conditions, documents, and record retention for the movement of EV batteries within Canada between provinces and territories.

PART 3 – Addresses various transitional provisions from the previous regulations as well as when the regulation came into force.

PELES Permits

Similar to Transport Canada and Equivalency Certificates, Environment and Climate Change Canada has the authority, under s.190 of the Canadian Environmental Protection Act, to issue a PELES (Permit of Equivalent Level of Environmental Safety) where it is not possible or practical to fully comply with the Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations (division 8, part 7).

PELES permits have been issued to provide relief from the use of movement documents (hazardous waste manifests) as well as other requirements under the regulation, if the applicant can demonstrate that its proposed alternative measures provide an equivalent level of environmental safety. The duration of a PELES is normally limited to about three years.

Provincial Regulations

Batteries deemed end-of-life, damaged, or defective are all provincially regulated as hazardous recyclable materials. Individual Provinces and Territories have different rules on how to handle the batteries, generally following federal guidelines.

If the battery has not reached its natural end-of-life, and is not damaged, defective, or been recalled, and has the potential for reuse as a part, it may be classified as a dangerous good and not a hazardous waste depending on the jurisdiction.

An EV battery removed from a vehicle and temporarily stored may be considered a hazardous material (a part for reuse) or a hazardous waste. The transition from material to waste occurs when the battery has been damaged, is defective, has been recalled, or reaches natural end of useful life.

The generation, storage, recycling and disposal of hazardous recyclables and hazardous wastes, such as end-of-life or defective EV Batteries is governed provincially. The quantity allowed to be stored on a given site is dependent on the requirements of the particular jurisdiction. These requirements may be found in environmental hazardous waste regulations and or in fire codes. Requirements may vary based on business location, size of facility, storage method, and if the hazardous item is a material or a waste. Often, any facility that accepts, stores, sorts, processes, recycles and/or disposes of hazardous waste, requires a Certificate of Approval, or other provincial government authorization.

Other Safety Considerations

EV batteries are designed to be safe during normal use, storage, and transportation. Best practices have EV batteries stored with other batteries of similar chemistries. This means that EV batteries from different vehicle manufacturers or different models with similar chemistries are all stored together, whereas EV batteries with different chemistries are grouped and stored separately. Further, EV batteries should be stored indoors and ideally in a temperature-controlled environment. The benefit of temperature-controlled environment at or around 21.5 degrees Celsius is a reduced degradation of the battery over time.

EV battery safety concerns typically arise when dealing with an EV battery that is damaged or when the battery's condition is not expressly known. Minimum safety standards are set forth in sections 4, 5, 6, and 7 of Transport Canada's transportation of dangerous goods regulations. Provincial and municipal regulations, including the fire code, may provide further guidelines.

Additional safety measures could be considered based on the specific circumstances such as:

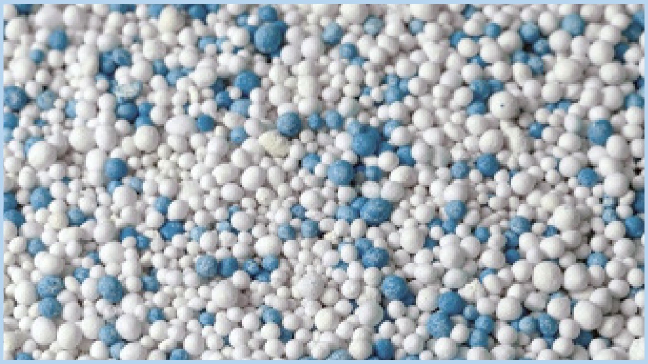
- Addition of fire-retardant materials within the EV battery shipping container
- Maintaining a 15-foot perimeter around EV battery storage areas
- Availability of vehicle fire blankets and battery fire blankets at commercial operations handling electric vehicles and/or EV batteries
- Storing away from combustible items; storing out of direct sunlight to avoid degradation of plastics and batteries
- Training of personnel on how to identify a thermal runaway for batteries in storage, being transported, or still in a vehicle
- Technology such as sensors to identify thermal events through electronic monitoring

Examples of fire-retardant materials available for use with EV vehicles and batteries

Vermiculite is commonly used in its expanded form. It is lightweight, absorbent, non-combustible, and is seen as an effective insulator; useful in many environmental and public safety applications including fire protection and packaging aid for the safe transport of various materials.

Source: Vermiculate.org

Emerging prevention and firefighting safety materials for lithium-ion batteries created from lightweight non-crystalline glass granulates, such as those being pioneered by CellBlock, potentially offer an environmentally friendly, mineral-based thermal runaway extinguishing agent. The heat melts the granulates, encapsulating the fire, smoke, and gas.



Source: Cellblockfcs.com

Summary

The handling, transportation, storage, processing, recycling, and disposal of EV batteries is governed by multiple federal and provincial government agencies, who, together, regulate how EV batteries are to be packaged, transported, and stored.

The current patchwork of requirements can lead to confusion, delays, and additional cost when it comes to managing and moving EV batteries. A harmonized North American approach needs to be considered that modernizes and streamlines the process and does not require out of process exemptions to transport these materials.

Each company handling EV batteries should review the regulations and determine their obligations based on the business activity conducted by the company and ensure that relevant personnel are trained and qualified to carry out their respective tasks and duties.

Section 5

Battery Diagnostics: Understanding Performance of an EV Battery

An EV battery pack is comprised of a grouping of modules and these modules consist of a grouping of individual cells. Combined, this forms the electrical power source for a new electric vehicle. However, over many years individual cells within modules will degrade gradually to a point where it may no longer meet the performance requirements of the vehicle owner.

Battery capacity degradation is impacted by several factors including usage patterns, environmental conditions, and charging cycles. To help assess the health of an EV battery, new testing methods and metrics are being developed. The diagnostic information generated by the tests can be used to inform which pathway is best suited to either extend the battery's life or to maximize its value once removed from the vehicle.

EV battery diagnostics is a relatively new field under rapid development. On-board or in-vehicle diagnostics is the most advanced form of this technology and is integrated into most EVs to provide data during vehicle servicing. More recently on-board diagnostics is being made visible to vehicle owners through their dashboard displays. Post-vehicle diagnostics at the module and cell level are under development or in the early stages of commercialization.

Battery Diagnostics

Diagnosing a battery's overall performance (sometimes referred to as a battery's health score) has several benefits:

- Informing decisions regarding continued use of the battery or re-directing it along the 5Rs Pathways
- Assessing the relative health of one battery compared to another
- Assisting vehicle and battery manufacturers' research and development efforts to improve the battery pack's durability or life expectancy
- Supporting fleet operators in scheduling or routing decisions based on each vehicle's battery status

Assessing batteries can happen in one of four ways, each for a different purpose:

1. Battery Pack - Analytics: data can be collected and analyzed across a large population of EV batteries to assess average performance or provide meaningful data for research and development
2. Battery Pack – Battery Management System (BMS): using either on-board or in-vehicle diagnostic software or by connecting the battery to a stand-alone diagnostic tool, the overall condition of the entire battery pack can be assessed
3. Module: individual modules can be assessed using ultrasound or other proprietary techniques under development
4. Cell: individual cells can be assessed after the battery pack and modules have been disassembled

FIGURE 10: Four Emerging Methods of Battery Diagnostics (view A)

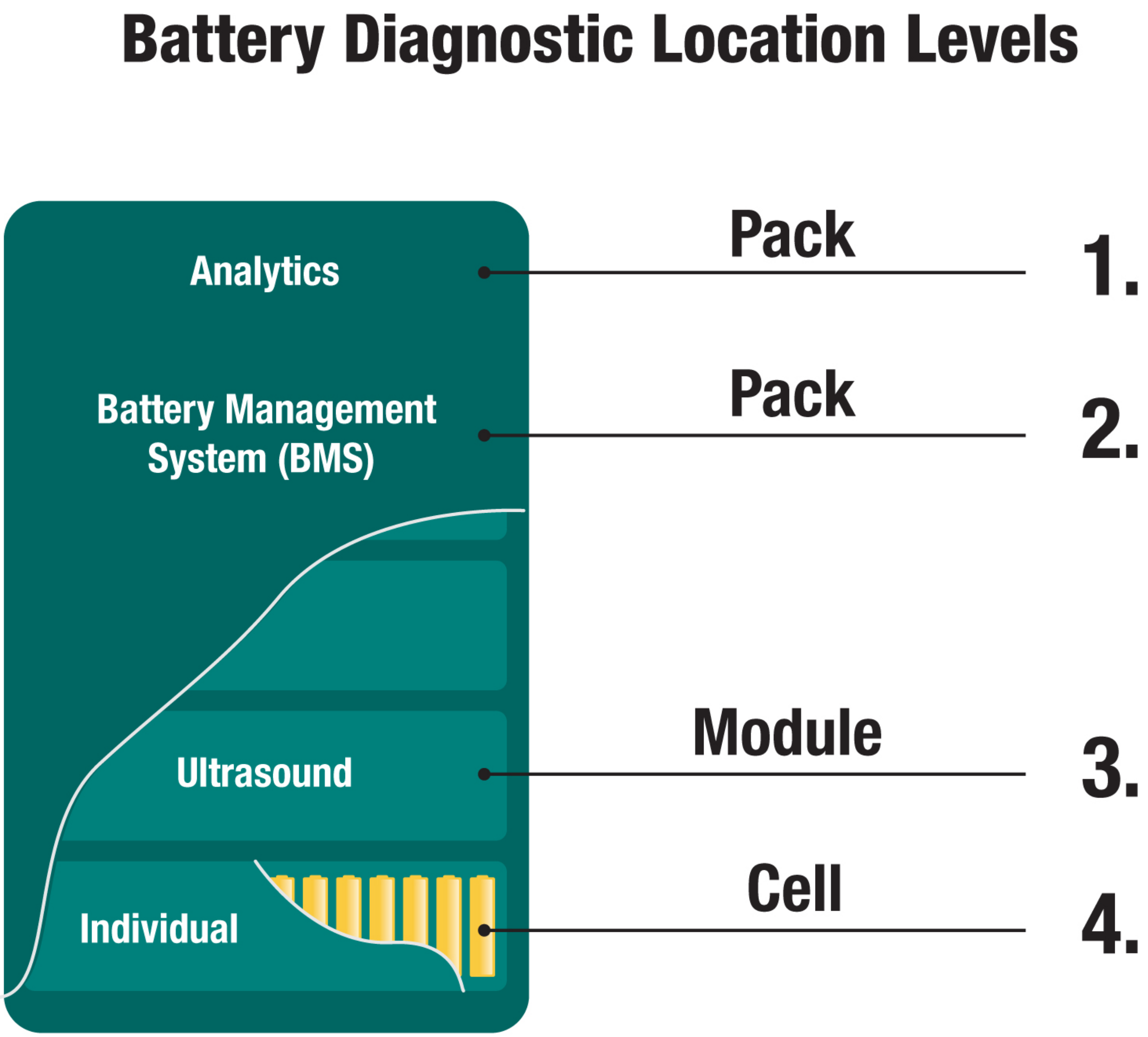


Image source: Call2Recycle®

Battery Assessment Characteristics

EV batteries start their life with 100% capacity and over time they degrade. For example, a 60-kWh battery that has 90% capacity would effectively act like a 54-kWh battery. There are several characteristics that can be assessed depending on the methods and tools available for the diagnostic evaluation that help explain the battery's state of health.

Geotab, a company specializing in vehicle data collection and analysis, analyzed the battery health of 6,300 fleet and consumer EVs, representing 1.8 million days of data for 21 distinct electric vehicle models. They found EV batteries are exhibiting high levels of sustained health and, based on the observed average annual degradation rate of 2.3%, most batteries will outlast the usable life of the vehicle[10].

This information may be beneficial to a variety of stakeholders and may include:

Battery capacity – Measured in either watt-hours (Wh), kilowatt-hours (kWh), or ampere-hours (Ahr) with higher capacity generally meaning better performance (e.g. longer driving range).

Charge cycles incurred – Measure of the charging history of the battery. Charging behaviour including frequency of charging, charge method, and maximum and minimum charge are all correlated to changing battery capacity. Repeated direct current (DC) fast charge may be more degrading than level 1 or 2 charging.[10]

Climate conditions – Environmental conditions such as ambient temperatures can impact a battery's state of health. There is a correlation between vehicles operating in sustained higher ambient temperatures greater than 27 degrees Celsius experiencing slightly higher rates of degradation. Sustained colder ambient temperatures below 0 degrees Celsius do not appear to contribute to an increase in battery degradation, however it does result in temporary lower battery efficiency, mainly due to energy being used for the battery thermal management system and for heating the cabin. The ideal operating and storage temperature for an EV battery based on maximum capacity is 21.5 degrees Celsius.[11]

Degradation rate – Calculated as the percentage of a battery's capacity loss year over year from all contributing factors, with that figure for North America being on average 2.3%.[10]

Time in use – A measure of the years the vehicle has been in operation and a contributing factor to battery degradation.[10]

Usage – Measure of the distance travelled or hours in use or energy cycles used. High vehicle and cycle use does not necessarily equal higher degradation.[10]

Battery Diagnostic Audience

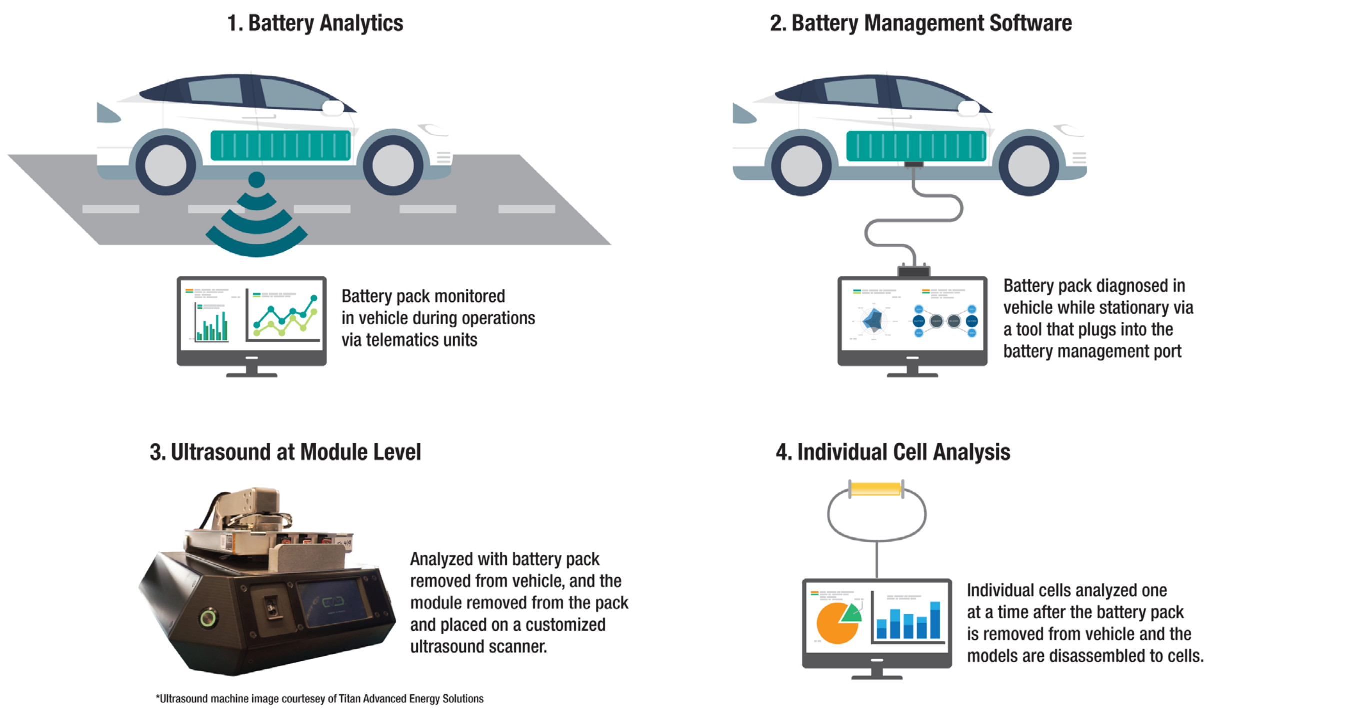
There are a variety of stakeholders within the EV battery ecosystem that use or may benefit from EV battery diagnostic tools. These include:

- **Automotive Auctions** – To identify for potential buyers the health of the battery within the vehicle as it comes to auction, allowing that vehicle to sell for maximum value
- **Automotive Dismantlers & Recyclers** – To identify EV batteries best suited for resale versus those that should be repurposed or recycled
- **Independent Garages & Fleet Centres** – To differentiate between battery pack performance and to direct them along the appropriate EV battery pathway
- **Manufacturer Dealers and/or Service Centres** – For the purpose of repair, to determine if battery should be replaced, and the appropriate EV battery pathway
- **Remanufacturers** – To assess remanufacturing potential and to segregate components that cannot be remanufactured and should be redirected
- **Repurposers** – To identify appropriate modules/cells needed for the manufacture of new products versus those that should be repaired or recycled
- **Vehicle Owner/Manufacturer** – To provide information for the owner regarding the ongoing condition of the battery, and to provide vehicle manufacturers with information to support research and development

Four emerging methods for diagnosing batteries:

1. **On-Board analytics (#1 on Figure 10 & 11) (pack level)**: On-board in-vehicle analytic software collects data in real-time related to how the battery pack is performing (e.g. capacity, charge cycles, mileage, climate, power output, degradation rate). Similar to other on-board diagnostics, this is valuable for research and development, and for managing a fleet of vehicles. Some of the information is also available to the customer through vehicle display settings.
2. **Battery management system (BMS) (#2 on Figure 10 & 11) (pack level)**: The performance of the battery is assessed while in the vehicle by connecting a standalone software tool to the vehicle software port (technically referred to as the OBD-II port). The benefit of diagnosing through the BMS are speed and ease of assessment.
3. **Ultrasound at a moment-in-time (#3 on Figure 10 & 11) (module level):** This diagnostic method is in pilot stage and expected to be commercially available in late 2022 or 2023. It requires the battery pack to be disassembled to the module level, then uses an ultrasound signal that applies pulses through the module to assess its state of health. This technology may be useful for larger auto dismantlers & recyclers, repair garages, or consolidation points that may have many EV batteries to assess. This diagnostic method will facilitate decisions between sending batteries for repair, replacing the module, determining if the module is suitable for repurposing, or designating it for recycling. The equipment and software are designed to produce a unique battery performance analysis which can be provided during the transfer of the battery from one owner to the next. This analysis is managed as a digital certificate that can optionally be integrated into a battery passport (see section #6).
4. **Individual cell analysis (#4 on Figure 10 & 11) (cell level)**: The target audience for this method are remanufacturers and repurposers who need to identify appropriate cells for their manufacturing process. The method requires disassembling down to the cell level, followed by testing each cell individually based on the battery capacity that is important to that company's work. One industry participant shared that while this process is more time consuming, it does allow for a high recovery rate (roughly 70%) of cells for use in remanufacturing modules or used within a new second life application.

FIGURE 11: Four Emerging Methods of Battery Diagnostics (view B)



Source: Call2Recycle®

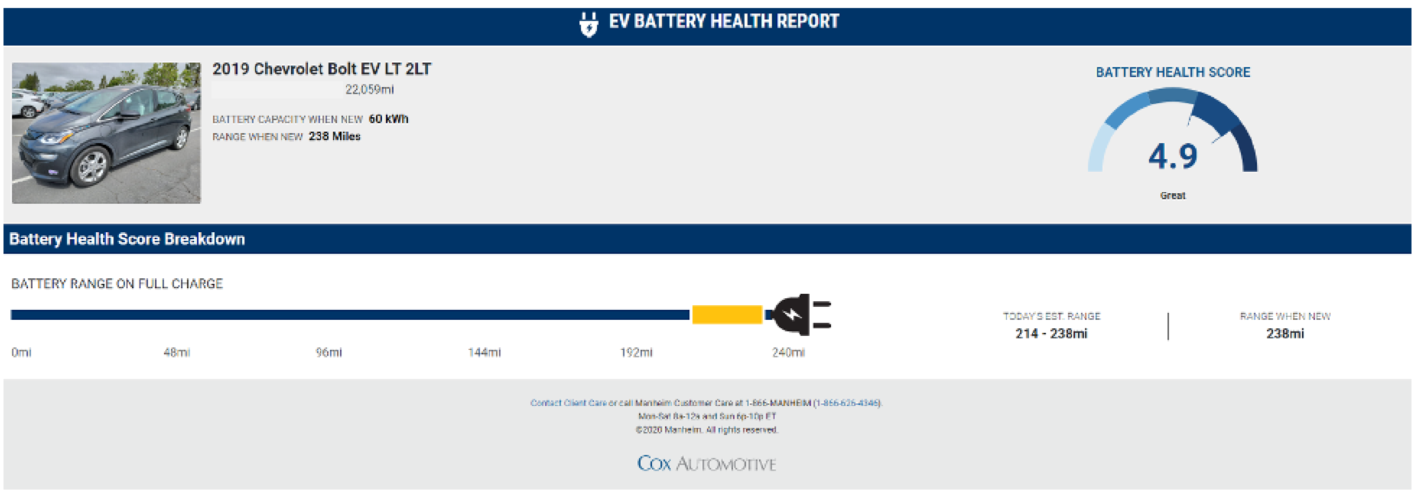
Battery Health Scores

Once an EV battery has undergone some type of diagnostic test, that information needs to be retained, distilled to a form that is easily understood and then shared among relevant stakeholders in the EV battery ecosystem. One such method that has emerged is a battery health score.

Battery health scores are a new tool being piloted at select vehicle auction business locations and provides valuable information to support the purchasing process and is having a positive impact on the transactional value of the vehicle/battery in a wholesale setting. Unlike a CARFAX report that captures the repair and ownership history of a vehicle, a battery health or performance score will identify the battery's performance relative to specific metrics such as battery degradation or total capacity at the time the test was taken.

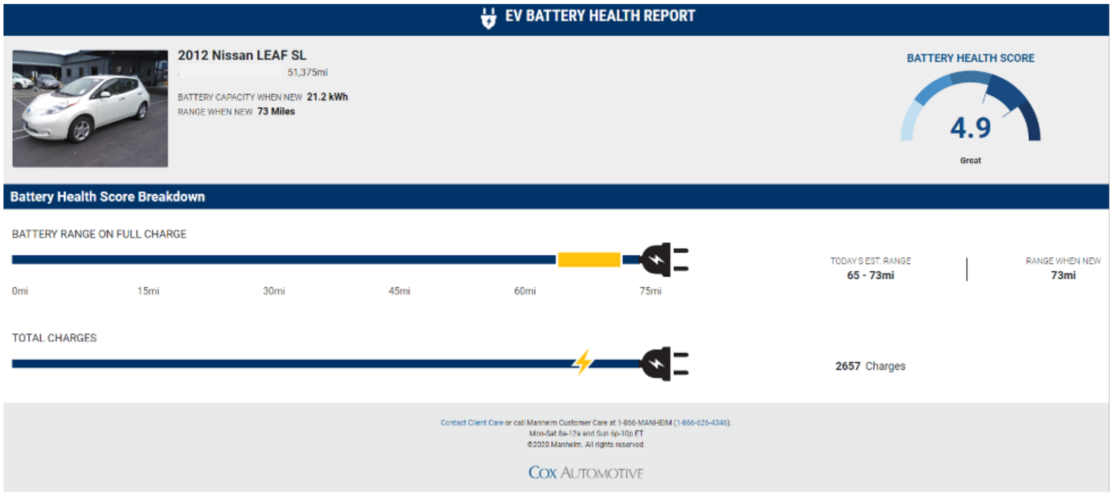
The score is determined from information obtained via the vehicle's electronic control unit (ECU) both directly and indirectly tied to the battery. This information is aggregated and put through a series of patented algorithms to create a summary of battery health. The battery health scores presently exist for select vehicle models in Manheim Condition Reports at pilot vehicle auction locations.

FIGURE 12: Excerpt from Manheim Condition Report summarizing battery health for a 2019 Chevrolet Bolt EV



Source: Cox Automotive, owner of Manheim

FIGURE 13: Excerpt from Manheim Condition Report summarizing battery health for a 2012 Nissan Leaf EV



Source: Cox Automotive, owner of Manheim

A second example of a battery health score is being piloted at select auto dismantlers & recyclers for the purpose of informing the EV battery holder as to whether the battery's individual modules should be replaced, sent for repurposing, or directed to recycling.

FIGURE 14: Excerpt from Titan Advanced Energy Solutions digital diagnostic certificate summarizing one particular 2011-2012 model year Nissan Leaf's EV battery module

Source: Titan Advanced Energy Solutions

FIGURE 15: Label applied to EV battery following diagnostic analysis using Titan Advanced Energy Solutions ultrasound method

Source: Titan Advanced Energy Solutions

Some stakeholders are encouraging the adoption of battery health scores to help support used electric vehicle evaluations. According to Cox Automotive, used EVs are discounted by up to 15% when compared to their internal combustion engine counterparts when buyers do not know the performance capacity of the battery pack.

Transparency provided by battery health scores provides buyers and sellers alike a simplified way for those not familiar with battery degradation, condition, or chemistry, comfort in the transactional process.

Similarly, a battery health score at the pack or module level will likely be useful in making decisions on where the battery pack or module should be directed along the 5Rs Pathways.

Summary

Battery diagnostics, although relatively new, are undergoing significant innovation and change. The importance of battery diagnostics or consumer battery information is even being contemplated in proposed state level regulations in the United States. At this time there is no single preferred method amongst those described in this section. Diagnostics are important to inform the direction EV batteries and/or their modules should take along their journey; however, to be truly valuable, education about key performance characteristics of EV batteries (battery capacity, degradation rate, usage, power output, etc.) will be needed to help all stakeholders understand how to assess and make decisions with the available information.


Ford

Section 6

Information Sharing: Battery Identification, Tracking, and Tracing

Businesses along the 5Rs Pathways are realizing the importance of shared battery information, as well as the potential benefit of tracking batteries to support various business practices.

This section provides information on where to find key EV battery information, as well as exploring the concepts of EV battery tracking and tracing. It also addresses the interconnectedness of these issues.

Battery Identification

EV batteries come in many shapes, sizes, and chemistries, influencing how these batteries are handled and where they are directed. Some EV batteries may use nickel metal hydride (NiMH) as the base chemistry, while others use lithium-ion base chemistry. This in turn impacts how to pack, transport, and temporarily store batteries, as well as who in the EV battery ecosystem can remanufacture, repurpose, or recycle the EV batteries after they are received.

Simply differentiating between NiMH and Lithium based batteries may be insufficient to truly maximize the value and opportunities for EV batteries along their journey. For instance, there are lithium-ion based EV batteries that use a nickel, manganese, and cobalt (NMC) sub-chemistry, others use a nickel, cobalt, aluminum (NCA) sub-chemistry, and still others use lithium iron phosphate (LFP), while new solid state lithium batteries are also under development. Although all these lithium batteries can be stored together and recycled at the same facilities, their value to a recycler or even to a repurposer may vary. As a result, battery identification is becoming more and more important to assist with maximizing safety and help assess which pathway is the most suitable for an EV battery along its entire life journey.

Today EV batteries have a label that identifies its base chemistry (either NiMH or Li-ion) and conveys that the battery cannot be placed in the garbage (i.e., must be recycled). These labels may use words, pictograms, or colours to convey the information, and should be readily apparent when handling the battery. In addition, many vehicle manufacturers provide more detailed information on a label that conforms to standard SAE J2984 published by SAE International (formerly Society of Automotive Engineers; access behind SAE International paywall).

This label's background colour quickly identifies the base chemistry of the battery and a code provides information to identify details about the cathode and anode materials used, the date of manufacture, and the vehicle or battery manufacturer. Some vehicle manufacturers provide similar information on their website or use a combination of labels, website, and other communication tools.

As awareness of labeling standards such as SAE J2984 increases, it is likely that more vehicle and battery manufacturers will consider adoption of such standard(s) or provide equivalent levels of information to interested parties, and that this will simplify battery identification throughout the management ecosystem.

Another method of battery identification being discussed by industry is the use of unique Battery Identification Numbers (BINs), bar codes, or QR codes combined with readers or databases that provide information similar to that provided on a label.

Battery and vehicle manufacturers provide battery information; however, it is not necessarily in a consistent format, manner, and location. Manufacturers are aware of this challenge and are looking at ways to provide standardized information as more and more EVs are introduced. Efforts are underway by several groups to provide guidance on how and where to access this information and facilitate data retrieval. The good news is that there is a trend towards newer batteries offering a greater amount of information.

Additional Battery Information

Other types of battery information are available to the service industry and interested stakeholders including battery weight, product safety information, safe removal instructions and disclosure of hazardous materials. Many vehicle manufacturers provide this information through their websites or make it available upon request through their customer information centres.

Most vehicle manufacturers provide information on how to safely remove batteries from each different make and model of vehicle produced with an EV battery in North America through their company websites including:

Ford: www.fleet.ford.com/showroom/resources/

General Motors: www.recyclemybattery.com

Stellantis: www.techauthority.com

In addition, other organizations have resources and training material available to support the safe and responsible management of EV batteries.
Some examples include:

- National Fire Protection Association publishes Emergency Response Guides for the safe handling of the electrical power systems of most EVs at https://www.nfpa.org/Training-and-Events/By-topic/Alternative-Fuel-Vehicle-Safety-Training/Emergency-Response-Guides
- Ontario Automotive Recycling Association (OARA) EV/HYBRID VEHICLE DISMANTLING RESOURCES at https://oara.com/resources/ev-hybrid-vehicle-dismantling-resources/
- Supplier Partnership for the Environment (SP) EV Battery Recycling Resources for Recyclers and Dismantlers at https://www.supplierspartnership.org/evb-recycling/

Tracking and Tracing

Tracking and tracing are elements that can support an EV battery's journey.

Tracking a battery means the ability to know where a specific battery is located within a given network. Tracking can start when the battery enters the network (usually when collected, purchased, or inventoried) and ends when it leaves the specified network or the network operator's sphere of control.

A network is typically created at a company level to manage battery movements and this network may be separate from other networks at other companies. Limitations may occur when a battery is transferred out of one network and into another.

The benefits of tracking batteries include:

- owner identification (where privacy laws allow; differentiated between consumer and commercial ownership where the latter may be desired)
- location identification, both when stationary and in transit (where privacy laws allow; differentiated between consumer and commercial ownership where the latter may be desired)
- inventory management
- resource management
- battery history of movement

Some stakeholders believe OEMs have the ability to track EV batteries in real time throughout their EV battery journey, however the reality is that privacy legislation, as well as the open and free market available to consumers as it relates to the ongoing servicing of the EV or EV battery, prevents vehicle manufacturers from having this level of transparency. Many OEMs can and do track batteries at specific times such as when they come out of a vehicle at one of their dealer or service locations, and along a designated EV battery pathway up to and including possible installation as an EV replacement part or being sold for repurposing.

If a battery is removed from a vehicle outside of the vehicle manufacturer dealer or service network, the vehicle manufacturer management system would have no information or knowledge of this occurrence. There are no requirements for third parties who resell an EV battery, export an EV outside Canada, or ship an EV battery to a recycler to provide or maintain tracking information. These third parties may have records or tracking information of their own (such as sales records and shipping documents), but this information is separate and distinct from the vehicle manufacturer tracking system.

Tracing refers to the concept that some stakeholders – including some customers, financial investors, and regulators – would like better awareness regarding where the materials in a battery have been sourced from mining through to their incorporation into a final product and continuing eventually to recycling. This is sometimes referred to as "minerals tracing" and is of interest when some minerals (such as cobalt or nickel) come from regions with questionable human rights records or environmental safeguards. The ability to trace a battery's minerals from end-to-end, in this case from mining of the minerals to the recycling of battery modules and/or packs, is valuable in creating a more sustainable EV battery.

Tracing is a complex activity due to the global nature of the battery supply chain. Each material in the battery can be extracted and procured from different locations in the world but can also be refined or incorporated into various components throughout the world. To accurately trace each metal, mineral, or component would require clear definitions and consistent guidance at a global level.

The Global Battery Alliance – a partnership of 96+ businesses, governments, academics, industry groups, and non-governmental organizations including Natural Resources Canada, Propulsion Quebec, and Government of British Columbia – is exploring tracing at a global level. Their proposed Battery Passport is a means to achieve full value chain transparency. The Battery Passport is intended to provide trusted information on indicators related to responsible and sustainable practices, resulting in a 'quality seal' capturing authenticated records of the responsible sourcing, management, recycling, and use of a battery across its full lifecycle.[12]

Tracking vs. Tracing

Vehicle manufacturers will likely utilize different approaches when it comes to tracking and tracing.

The goal of tracking is the ability to identify a battery in the network at a given moment in time, while the goal of tracing is to encourage sustainable sourcing of the materials used in manufacturing a battery. The latter can also be achieved through the procurement process and governance employed by the battery and vehicle manufacturers, similar to conflict mineral tracing that already occurs in accordance with the United States Frank Dodd Act (United States Securities and Exchange Commission) for the ores that produce tantalum, tin, gold, or tungsten.

The value and need of tracking and tracing vary among different stakeholders. At this time each business along the EV battery ecosystem determines the level of tracking and tracing that may be needed for its business practices and network. Both methods are expected to be in place and co-exist in the market.

Summary

Identification, tracking, and tracing are about information sharing that supports a safe and efficient circular economy for EV batteries. Providing the necessary information as an EV battery travels along different pathways is critical to ensuring as many EV battery pathways are developed as economically and environmentally viable. With appropriate information, options are available, and the decision can be made to support the development of an EV battery circular economy.

Section 7

Defining EV Battery Life Stages: 1st Life vs. 2nd Life

The life or journey of an EV battery begins when a new battery is first placed in an electric vehicle at the factory. Some individuals refer to this as the start of the 1st life of the battery. Understanding when an EV battery's life ends is more difficult and can be the subject of great discussion. Does it end when the EV battery is removed from the vehicle? What if it is remanufactured and placed in another vehicle? Does it end if the battery is repurposed in a non-transportation product and is this the start of a new life or a 2nd life? Or does it end when the battery is ultimately recycled?

The answers have important consequences when engaging in a discussion about producer responsibility and end-of-life management. Input on the topic can be derived from other global regions.

European Battery Directive as Reference

The European Union is undertaking a review of their Battery Directive to more fully incorporate EV batteries. Proposed amendments to the current (2006) European battery directive were published on December 10, 2020. The proposal defines the use of products or components for a different purpose/application/function/context than originally intended, as 2nd life.

Further, the proposal outlined two different approaches on the classification of EV batteries when transitioning between 1st and 2nd life. These are direct statements from the proposed directive:

1. *At the end of the first life, used batteries are considered waste (except for reuse[1])* [footnote is included in excerpt from European Directive and not referenced here]. Repurposing is considered a waste treatment operation. Repurposed (second life) batteries are considered as new products which must comply with the product requirements when they are placed on the market; or
2. *At the end of the first life, used batteries are not waste*. Repurposed (second life) batteries are considered as new products which must comply with the product requirements when they are placed on the market.

At the time of writing, the EU has not yet finalized the revised Battery Directive. However, it does illustrate how a jurisdiction like Europe recognizes a clear separation between 1st life and 2nd life, with 2nd life responsibility falling to the producer of the 2nd life product, an approach that may be worth considering in the EV battery management ecosystem in North America.

1st Life vs. 2nd Life in Canada (and United States): A perspective for consideration

In considering differences between 1st and 2nd life, it is important to think of how EV batteries transact and are modified in the various steps along their journey before recycling. In most cases a transaction – even a 'no charge transaction' – of the EV battery from one owner to another, accompanied by some type of modification of the EV battery or use in a non-designed manner, signals a change between 1st life and 2nd life.

Repairs to the battery pack by independent automotive garages, or more in-depth remanufacturing by 3rd parties with intended re-use in the same or equivalent vehicle could be considered 1st life. However, if the battery pack is remanufactured for use in a vehicle other than the model(s) of intended use or for use other than in a vehicle, this will be considered 2nd life. For example, consider a battery pack from vehicle A is modified and placed in a different vehicle model to electrify its drivetrain. This was not the original intended use of vehicle A's battery pack; therefore, this battery has been repurposed and has started a "2nd life".

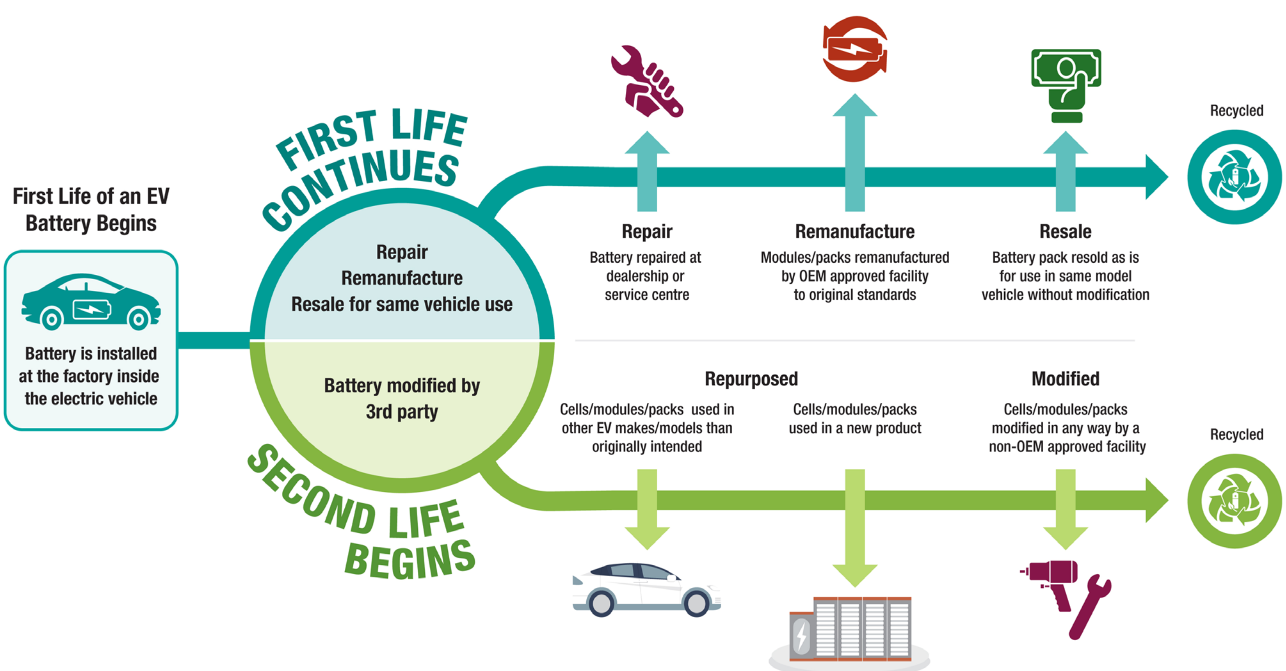
Any modification, attempted change, or application of the EV battery for a new purpose would constitute a 2nd life product. The entity undertaking the development, engineering, modifications, marketing, or sale of the 2nd life product is creating a new product with all the associated responsibilities and obligations as the manufacturer of the original EV battery.

Examples of modifications to an EV battery:

- A battery pack or module is opened by anyone other than the vehicle OEM or their designated agent to look inside and then reseal
- A battery pack or module is purchased and then installed in a different vehicle model than designed by the manufacturer
- An independent repair facility remanufactures a battery to their own specifications to market and sell
- A battery module is disassembled to cells and the cells are rebuilt into a new module and installed in or reconfigured as a new product, such as off-grid energy storage or a similar application

The vehicle manufacturer's responsibility typically ends when both a transaction and modification occur to the battery pack. The cells, modules, or packs begin life as a new product under ownership and responsibility of the 2nd producer. And if these battery cells, modules, or packs have acceptable performance after a 2nd life, it may be suitable for a 3rd producer to assume ownership and responsibility at some point in the future. A quick reference back to Section 5 on Diagnostics: a battery's full life is a result of how and in what conditions the battery is used, and not just a function of time. Figure 16 shows the difference between 1st and 2nd life of an EV battery.

FIGURE 16: 1st Life and 2nd Life of an EV Battery



Source: Call2Recycle®

Having a common set of criteria or a type of "test" that denotes the end of the 1st life of an EV battery, and where a 2nd life or new product begins may be beneficial in determining a new producer's responsibility.

FIGURE 17: Potential 1st and 2nd Life Scenarios

Activity	First Life Producer	Second Life Producer
Repair of battery by an OEM approved facility	✓	
Resale of an original OEM EV battery for use in same vehicle model(s)	✓	
Repair or remanufacturing of battery for use in same vehicle model by OEM approved service providers	✓	
Repair or remanufacturing of battery by a non-OEM approved facility for use in a different vehicle model		✓
Alteration of the battery in any form – software or hardware – for non-vehicle use		✓
Battery pack, module or cells are repurposed in a non-vehicle application		✓

If a non-OEM approved service centre works on an EV battery in a manner that alters its intended primary use in a vehicle (how it is used in the vehicle, a change to the original software, or a change to the battery cell and/or module configuration), then this goes beyond the vehicle manufacturer's intended use and can be considered a new product or 2nd life.

When the battery is used in a non-vehicle application, this too goes beyond the vehicle manufacturer's intended use and can be considered the start of new 2nd life product.

Therefore, who has responsibility for the EV battery is directly linked to 1st life and 2nd life definitions. Hence, the importance to having alignment and clear understanding of 1st and 2nd battery life, and who has responsibility in each battery life stage.

Waste vs. Resource

In considering 1st life and 2nd life of an EV battery, the issue of when an EV's battery is or becomes waste needs to be addressed. Typically, the end of a product's lifecycle means a product has become waste and generally any type of "processing" is considered a waste management method. But as outlined in section 4, designating a product as a hazardous waste can impact the ease of movement as well as the end destination. So, the question should be if a product like an EV battery has a viable 2nd life, does it become a waste during the transition, at the end of its second life, or ever, if it continues to have value?

Are used EV batteries a waste or a resource? The discussion needs to start with better understanding what those terms mean. Across Canada, waste or hazardous waste definitions vary by province, but at a high level there is some convergence.

Waste is typically defined in Canada as an unwanted material, destined for landfill or hazardous treatment facility, with little or no value, and is not a feedstock to another facility or process. In general, provinces want to encourage remanufacturing/repurposing/recycling; therefore, material may be exempted from the definition of waste if destined for those types of processing.

Resources are not strictly defined in regulation but for the purposes of this discussion, the authors are suggesting they are materials or substances that have value (either economic or as a feedstock to another process), can be used or re-used for the original intended purpose, can be repurposed to provide additional value, or can be repaired.

An item that is waste is therefore better defined as a product that no longer serves a specific purpose and should be directed towards landfill or hazardous treatment facility. A used EV battery may follow many pathways but when it is no longer capable of functioning as a battery, even after 2nd life, it remains a resource that contains materials that the recycling industry is able to extract for use in new products.

Summary

The policy discussion on how to define 1st life versus 2nd life, or waste versus resource, will profoundly impact the development of a circular economy for EV batteries in Canada and North America. They will also impact the identification of an appropriate responsible party or "producer" and influence the development of an effective management scheme for EV batteries.

For most consumer products, producer responsibility is the concept whereby the initial entity that placed a product into the market maintains responsibility for that product through to its end-of-life. There is only one primary use for many of these products and the lifecycle moves directly from use to disposal or recycling. Products like EV batteries that have a very long life, combined with opportunities for that life to be further extended multiple times, meet a variety of environmental and social goals. Clarifying 1st life and 2nd life and the responsible producers will become important for the proper functioning of the EV battery management ecosystem.

Section 8

Standards

The Standards Council of Canada defines a standard as a document that provides a set of agreed-upon rules, guidelines or characteristics for activities or their results. Standards establish accepted practices, technical requirements, and terminologies for diverse fields. They can be mandatory or voluntary and are distinct from Acts, regulations, and codes, although standards can be referenced in those legal instruments.

Formal industry standards are often integral to business. They can provide a common level of understanding around a particular aspect or performance requirement of a product or service. The key is to ensure standards are developed at the right time to address specific stakeholder needs such that they don't hinder innovation, add unnecessary cost, or impact business competition.

The risk of setting a particular standard too soon is that it can have the unintended consequence of slowing or pausing innovation. Conversely, setting a standard too late could result in consumers or stakeholders not having a positive experience with the product or service. As EV offerings continue to expand and improve, significant variability in EV battery configurations, chemistries, power, durability, and other characteristics are likely.

This is an example of innovation at work for the benefit of the user, as EV batteries are developed to suit a variety of different needs. Hence, setting a standard at the right time – not too early and not too late – becomes important.

Standards generally follow a similar approach from initiation through adoption:

1. A standards body (examples provided below) consults with stakeholders and experts to identify a need, and then collaborates with industry to develop the standard.
2. Stakeholders evaluate and adopt the standard(s) as needed. This is typically referred to as voluntary standard adoption. Depending on the cost and complexity to conform, as well as the perceived need of stakeholders to address a problem, there are varying levels of adoption.
3. Complete standard adoption tends to occur when governments incorporate standards into law. This is done if a standard meets their policy objectives (e.g. packaging standard sets clear requirements for moving hazardous materials within a jurisdiction and the standards keep requirements aligned nationally or internationally). This is also done if there's a need to create a level playing field across all industry players.

Example organizations involved in standards development include:

CGSB – Canadian General Standards Board

CSA – Canadian Standards Association

ISO – International Organization for Standardization

SAE – SAE International, formerly Society of Automotive Engineers

TC – Transport Canada

UL – Underwriters Laboratories

UN – United Nations

USDOT – United States Department of Transportation

Applicable standards associated with EV battery management

When it comes to EV battery end-of-vehicle life management, there are some distinct areas where standards are currently in use or under development:

Labelling – (e.g. SAE J2984) This document standardizes the information to be depicted on EV battery labels including battery chemistry, cathode material, anode material, manufacturer, and date.

Transport – (e.g. TP 14850) This Transport Canada standard provides requirements about small containers used for the transport of dangerous goods, including Class 9 products like EV batteries (section 4 of this Primer discusses EV battery classification). Other TC standards provide information relating to the safe handling, packing, and movement of EV batteries.

Packaging – United Nations (UN) tables were issued for referencing battery material types, classifications, special provisions, and packing instructions. Lithium-ion batteries are classified as UN3480; NiMH batteries are UN3496. The UN also provides standards for types of containers used for transportation of dangerous goods including battery packs, modules, and cells.

Training – (e.g. CGSB 192.3 – click 'Continue to publication' on landing page) A standard for the transportation of dangerous goods training, assessment, and competency. The standard sets requirements for both general awareness training as well as function-specific training.

Product Performance – (e.g. UN – Global Technical Regulation #21) A United Nations Global Technical Regulation on the determination of system power of hybrid electric vehicles and of pure electric vehicles having more than one electric machine for propulsion – Determination of Electrified Vehicle Power (DEVP). A power rating for electrified vehicles should be qualitatively and quantitatively comparable with the traditional engine-based power ratings of conventional vehicles.

Management – (e.g. ISO 14001) An environmental management system standard for facilities that can be adopted to assist in assessing and mitigating the environmental risk of business processes, while setting a framework for ongoing continuous improvement.

When To Standardize

As described above there are several areas where standards have emerged or are under development that will impact the management of EV batteries throughout their journey.

There are additional topics some stakeholders have raised that could benefit from the development of standards. One example often cited is the EV battery itself. Those that support standardization suggest that if EV batteries were similar in terms of size, chemistry, and configuration, they could potentially become interchangeable between different vehicle models and different vehicle manufacturers. Although this standardization might have some appeal, it must be balanced against the need for certain vehicles to carry heavier loads than others, certain vehicles to travel farther than others, and still other vehicles to withstand more frequent charge cycles.

Those not supporting standardization recognize that not all EV batteries are designed for the same type of usage experience (resulting in various configurations), and therefore will not fit securely into every vehicle underbody frame produced by vehicle manufacturers.

Lithium-ion EV batteries have been on the market for roughly ten years. In that time there has been significant progress to increase the energy density to mass ratio (more power from lower weights of batteries), reduce cost, and improve safety. EV battery technologies continue to evolve, and one cannot conclude that the batteries of today have reached their pinnacle in terms of performance, size, weight, and capability. Therefore, developing standards are at best premature for this specific example, and potentially may never be appropriate.

Another area experiencing significant change and innovation is the processing of EV batteries after they are removed from a vehicle. Remanufacturers, repurposers, and recyclers are all innovating to adapt to changing batteries, improving their own processes, finding efficiencies, and increasing their competitiveness. This is another area where developing standards would do more harm than good at the current time.

It should be noted that the absence of a specific standard does not mean that a company or an industry is not following its own form of standardized best practice for an activity. Rather, it has likely implemented its own set of principles or policies.

Two areas highlighted by stakeholders that may benefit from greater standardization, or where there appears to be a general desire to see more guidance, are information labelling and emergency prevention & response (This includes best practices to prevent, contain, and extinguish EV thermal events).

Summary

When considering the development of any standard, the most important criteria to establish are:

1. What should be standardized? What aspect could be addressed or be improved to the benefit of the impacted stakeholders through development of a standard?
2. When should a standard be set so that it does not cause unintended consequences such as the premature stifling of innovation?
3. Who should collaborate to write the standard? This is especially important as it may help address if the standard should be global or more regionally focused.

Due to the global nature of supply chains for both the automotive and EV battery sectors, it may be appropriate for certain standards to be developed through global technical committees and then adopted domestically. In the absence of global standards, Canada should collaborate with the United States to develop appropriate integrated North American requirements to reduce the risks and costs that could negatively impact the development of a fully circular EV battery market.

Section 9

EV Battery Management Financial Considerations

An often-cited reason to create regulatory frameworks that manage EV batteries at end-of-vehicle life is associated with the environmental benefits of metals recovery and reuse as part of the circular economy. Therefore, it is instructive to address the potential financial considerations and infrastructure as it exists today, and some of the perspectives from those involved in this area (industry and other groups) as to what they may be in the future.

The costs associated with moving EV batteries between the various pathways vary significantly.

For example, there are likely no net costs when a high value EV battery is removed from a vehicle by an auto dismantler & recycler and is resold for reuse in another vehicle. Depending on the specific supply and demand for that particular battery, there is money to be made by the business that removed the EV battery and sold it. Likewise, repurposers are looking to obtain EV batteries that meet certain criteria that can be used to make and market a new for-profit product. In these scenarios there are no net costs to the holder of the EV battery and the party purchasing the EV battery would likely expect to pay to obtain it.

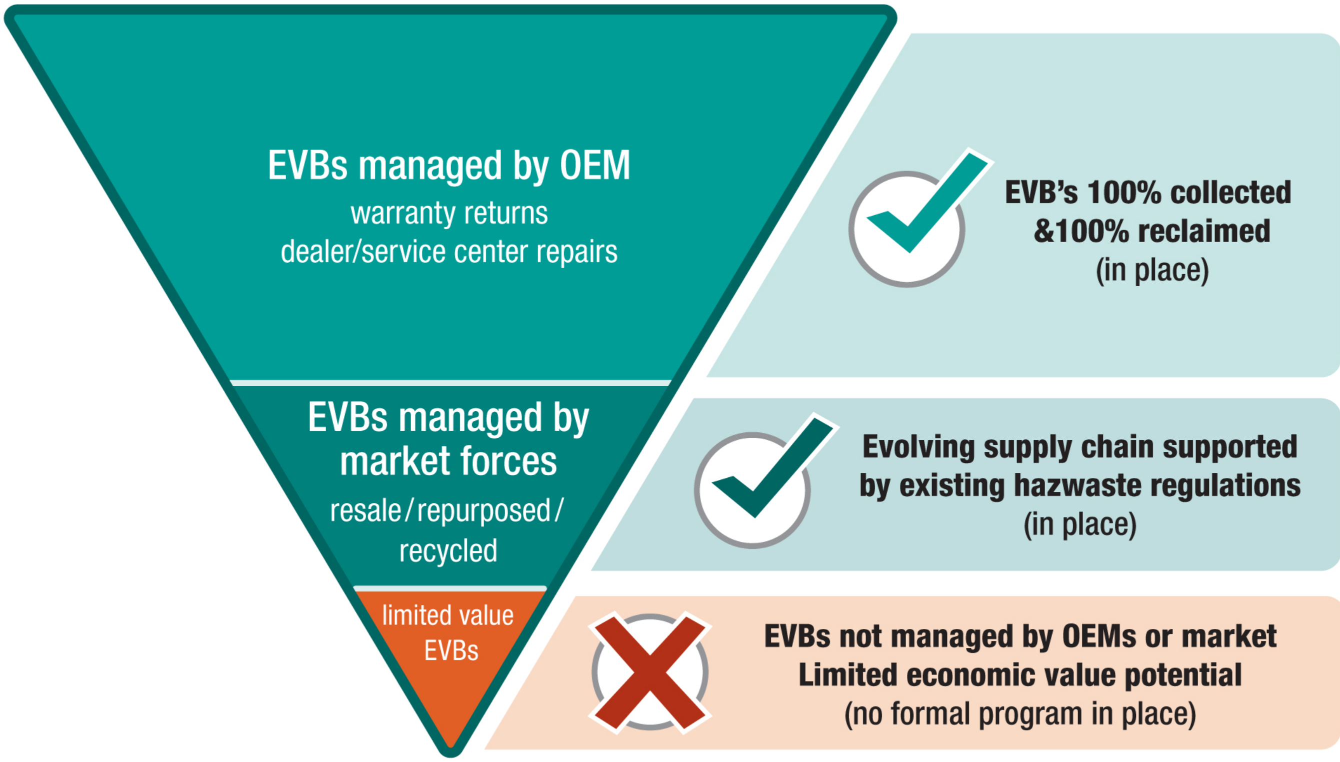
In another scenario wherein an auto dismantler & recycler purchases an EV from a vehicle auction, costs may be incurred associated with transportation, storage, and battery removal from the vehicle. If that battery is of lithium-ion chemistry and must be recycled, there may be an additional cost to recycle it in the current market conditions. If the battery is of NiMH chemistry, there may be opportunities to generate revenue from recycling at U.S. recycling processors (offset by potentially higher freight costs). There are no NiMH processors in Canada at time of publication (See figure 1 in Section 3). The potential purchaser of an end-of-life electric vehicle will need to compare all the associated costs and potential revenue to determine the best value proposition for each EV and EV battery.

Currently the remanufacturing of EV batteries under warranty is managed by the vehicle manufacturers. In these cases, batteries removed at the vehicle manufacturer's dealers or service centres are sent to a consolidation centre or directly to the remanufacturer for assessment and processing. Many of the costs associated with this process are borne by the vehicle manufacturer. This represents most batteries removed from EVs today.

Many EV batteries removed from a vehicle outside of the warranty process, or by auto dismantlers & recyclers, are in large part managed by market forces and either sold as is, sold to a repurposer, or in certain circumstances sent for recycling.

The remaining are those EV batteries in a vehicle or removed from a vehicle that are either damaged/defective, or due to reduced capacity, age, or lack of demand, have reached natural end-of-life (as a battery) and need to be sent directly for recycling. Some of these batteries, depending on proximity to a recycler, market price for metals contained within, and other factors including not having the skills and/or resources on-hand, can be a net cost to collect, transport, and process, resulting in them being held in storage by their owner waiting for conditions to change. These are sometimes referred to as 'limited economic value' EV batteries. Figure 18 generally depicts the current EV battery management programs.

FIGURE 18: Current Management Programs for EV Batteries



Source: Call2Recycle®

The total costs for managing an EV battery can typically be divided into 3 categories:

1. Shipping materials (e.g. container; packing)*
2. Freight/logistics (e.g. freight from location to processor)
3. Processing costs or processing revenues (e.g. recycling or repurposing; lithium vs. NiMH)

**Transport Canada's regulations require end-of-life EV batteries be shipped in shipping containers (Section 4), whereas United States Department of Transportation's regulations do not always require shipping containers for end-of-life EV batteries.*

Shipping Materials

A company handling new EV batteries may be able to avoid the cost of procuring new TDG compliant packaging or shipping container(s) by reusing the incoming packaging with the outgoing EV battery. This packaging – sometimes referred to as a 'container', 'shipping container', or 'means of containment' – must meet all applicable Transport Canada requirements for the transportation of dangerous goods (Section 4 of Primer).

If there is no incoming new EV battery with packaging, the company will need to procure, rent, or otherwise obtain the use of TDG-compliant packaging (Section 4 of Primer). In this situation there will likely be an additional freight cost associated with obtaining the shipping container. Depending on the condition of the used EV battery, additional packing materials such as fire-retardants may be needed.

Freight/Logistics

EV battery freight and logistics costs are impacted by several different factors:

1. **Shipping a dangerous good vs. a hazardous waste or hazardous recyclable material.** At minimum all EV batteries must be transported as dangerous goods with the appropriate TDG-approved carriers. Depending on provincial regulations, the condition of the battery, and/or final destination, an EV battery may also be deemed a hazardous recyclable material (by ECCC) or hazardous waste (by province or territory). This means that in addition to the carrier requiring the appropriate TDG requirements, they may also need to be licensed to transport hazardous waste or hazardous recyclable materials, and these carriers may be more expensive.
2. **The volume of freight moving in both directions on a given shipping lane.** A shipping lane is a route between two geographic points. More freight moving between these two points in both directions generally results in lower costs to ship goods on this route.
3. **The distance being traveled between the point of generation and the final destination.** The further the distance traveled, the higher the cost as some carriers charge a per kilometre rate. As the number of EV battery recyclers, repurposers, and remanufacturers increases across North America, so too does the potential to reduce distances, which can reduce the costs.
4. **The number of EV batteries shipped at the same time on the same truck.** More EV batteries collected at the same point of generation or along the same route, usually will result in a lower average cost per battery of the shipment. This is due to:
    i. Having one pick-up charge per destination regardless of quantity;
    ii. Some carriers providing lower rates when more materials are being carried on the same truck;
    iii. The type of truck being deployed.
5. **Shipping an empty shipping container to meet the battery.** The cost to send an empty container is roughly 75% of the cost of sending a container with a battery inside to its destination. For example, if freight cost to move a battery halfway across Canada is $225, then the cost to send an empty container to meet the battery will be roughly $175. This additional freight cost needs to be included in the entire calculation of transporting the battery.

Shipping the EV battery just once to a destination is most often preferred, as the cost of freight is generally between 60% and 90% of the total cost of managing the battery at end-of-vehicle life (per Call2Recycle's recent experience). If the battery is moved twice to reach its destination, then likely any potential off-setting revenue earned will not be realized.

Processing Costs/Revenues

The final recycling destination and chemistry of the battery will influence whether there is a cost to be paid or revenue to be earned (referred to within the industry as the metals recovery value). Depending on the chemistry of the battery, the amount of disassembly required, and the type of battery recycler (Section 3 of Primer), there is variability which can range from a positive revenue to a negative cost.

As more and more recycling facilities are constructed, it is believed the value proposition for lithium chemistry EV battery recycling will continue to improve given the inherent value of the metal content they contain, and the recycler's ability to sell these as output products on the global commodities market. This is already the case for similar types of batteries that have been on the market longer, such as NiMH EV batteries and lead acid vehicle starter batteries.

Recycling processors' pricing structures (to recycle EV batteries) varies by chemistry, company, volume, and country. Fees are generally quoted as either a total net price or as an itemized disassembly and processing price, which is typically expressed as price/pound or price/kilogram. Furthermore, some processors have a minimum or fixed fee per battery.

Currently, the quantity of nickel in a battery influences the price quoted by the recycling processor. The more nickel in an EV battery, the better the price or revenue to recycle the battery. Nickel is considered a global commodity whose market value influences the value for the EV battery metal recovery.

Estimated Costs/Revenues

The information presented here reflects data from Call2Recycle's 2021 operations. Most stakeholders surveyed felt the cost to recycle would continue to decrease, while the cost of logistics would remain constant or rise due to increasing fuel costs and inflation. As a result, it is expected that logistics costs will remain a sizeable and growing proportion of the net costs for handling EV batteries.

Figure 19 shows the current estimated costs of managing EV batteries.All numbers in Canadian dollars unless otherwise noted.

FIGURE 19: EV Battery Management Estimated Costs

Containers/Means of Containment	Costs (Revenue when noted)
Single use wood shipping container	$300 - $500
Multi use wood shipping container	$2,000 - $5,000
Multi use steel container (DDR appropriate)	$10,000 - $30,000 USD
Freight	
Shipping empty container (half country LTL)	$175 - $250
Shipping battery in container (half country LTL)	$200 - $250
Shipping battery in container (half country TL)	$150
Battery Recycling	
Lithium battery recycling (PHEV, HEV)	$250 - $500
Lithium battery recycling (BEV)	$500 - $1,000
NiMH battery recycling (PHEV, HEV) Canada	$500 (includes freight cost to ship to U.S.)*
NiMH battery recycling (PHEV, HEV) U.S.	Up to $0.50/lbs USD revenue
Four Remaining Rs	
Resale as is	$2,500 - $5,000 revenue
Repurpose	Variable revenue
Remanufacture by OEMs agent under warranty	Variable cost
Remanufacture in the aftermarket outside of warranty	Variable revenue (selling price less procurement cost less expenses)

*United States battery processors of NiMH batteries may pay for batteries as noted above based on commodity values.

Strategies that can be used to minimize expenses include:

- Minimize handling: Establish workflow so that the EV battery is transported just once
- Minimize distance: Ship the battery to the nearest processing facility to minimize distance travelled
- Consolidate shipments: Ship multiple batteries within the same less-than-truckload (LTL) shipment
- Reusable packaging: Reuse existing packaging or deploy re-usable shipping containers where and when possible

Freight industry nomenclature

LTL – Freight industry acronym implying 'less than truckload'. The goods on this truck were collected from multiple shippers on a pick-up and drop-off route. Generally, the cost to ship LTL is more expensive than full truckloads.

TL – Freight industry acronym implying 'truckload'. The goods on this truck were collected from one shipper at one location and filled the trailer. Generally, the cost to ship TL is less expensive than LTL.

Half country – A term used here to figuratively describe shipping roughly up to halfway across Canada. The authors offer this as a guide for estimating costs; actual freight rates will vary greatly due to the sum of these factors: shipping route, weight of item being transported, quantity of items being pick-up at same location, distance in kilometers, and fuel costs.

Resale as Is

There are increasing opportunities to generate revenue by selling used EV batteries for use as replacement batteries in vehicles or as energy storage batteries, with this potentially yielding a net positive value to the seller. Online reselling marketplaces are often used by automotive dismantlers & recyclers and independent garages to find buyers. This is an indication that market forces are further developing 5Rs Pathways.

EV batteries from vehicles that have been in market for some time and sold in relative higher volumes appear to command the highest prices. From reviews of used vehicle parts websites (e.g. ebay.ca, ebay.com, and oara.com/parts-locator/), an EV battery could typically be priced between $2,500 and $5,000 depending on age, use, and vehicle model.

Repurposing

The revenue generated when selling an EV battery to a professional repurposer can vary. Repurposers tend to prefer certain makes/brands of EV battery packs or modules, as they have been designed and engineered for integration into their own product(s) accordingly. These repurposers in turn create demand for those specific EV battery packs and modules; the more successful the marketing of their new product is, the higher the demand for and therefore price of the specific used EV battery will be.

As repurposers want to ensure the success of their manufactured product, they preferentially work with EV batteries that have a larger potential inventory in the market as compared to EV batteries with smaller market volume availability.

Chemistry, availability, and ease of disassembly all influence the potential demand for EV batteries by the non-transportation repurposing industry.

OEMs will caution that EV batteries should not be repurposed without significant technical training, tools, and engineering knowledge to ensure both software and hardware modifications are done safely and without risk to the environment, the community, and the employees.

Summary

The lifecycle of an EV battery has more pathways compared to other manufactured products and with this comes a unique set of cost and potential revenue streams. Presently the management of EV batteries at end-of-vehicle life has little or no out of pocket expense for the vehicle owner, however it does impact the resale value of the vehicle at wholesale auction (it tends to be lower per Cox Automotive – see section 5).

The costs outlined in this section are real, and as potential for revenue generation continues to evolve and grow, additional for-profit businesses will likely be established. Policies that aim to protect the environment and foster an economically profitable market-driven circular economy should be considered and endorsed. Likewise, if policy considerations hinder the development of a profitable circular economy supporting any of the five pathways, they should be seriously reconsidered.

Thank you to the auto dismantlers & recyclers, vehicle manufacturer dealerships, and companies who during normal course of business worked with Call2Recycle in the collection, transportation, and recycling of hybrid and full electric vehicle batteries. The economics of handling EV batteries shared in the section has come in part from this work.

Section 10

Roles and Responsibilities in EV Battery Management

The are many different groups and entities with evolving and varying roles and responsibilities along the EV battery management ecosystem. This section will address which entity directs batteries along their individual journey, or in other words, who makes the decision or has a role in the fate of EV batteries through the various pathways.

The vehicle owner most often starts the EV battery's journey with their purchase of an electric vehicle, how and where they use the vehicle, the type of charging, and where they service the vehicle when they own it.

Given the Primer is focused post vehicle owner, it considers this topic from the following perspectives:

1. Primary Management Entities
2. Secondary Support
3. Governments/Agencies

1. Primary Management Entities

Organization	Roles and Responsibilities
EV OEMs and/or Battery Manufacturers	• Supplying safe EV battery removal instructions for manufacturer dealers, service centres, automotive dismantlers & recyclers, or other stakeholders • Record keeping for warranty purposes • Providing information that supports processes for safe handling through recycling (e.g., battery chemistry, safety data sheets, emergency response) • R&D on EV batteries (e.g., improved durability, capacity, chemistry, etc.) • Management of batteries returned by dealers under "warranty" for repair/replacement/remanufacturing • Evolving: management of batteries when they start to be returned to dealers via service outside warranty • Tracking of batteries within their network

Organization	Roles and Responsibilities
Manufacturer Dealers, Service Centres, Fleet Managers, Vehicle Auctions, or Independent Repair Garages	• Procuring the appropriate tools and training to safely assess, service and/or remove batteries from vehicles • Assessment and removal of batteries for potential remanufacturing, repurposing, or recycling • Preparing batteries for shipping • Compliance with local fire marshal and/or government by-laws for adequate safety precautions and proper battery storage requirements • Record keeping or participating in vehicle manufacturer's tracking network
Auto Dismantlers & Recyclers	• Procuring the appropriate tools and training to safely remove batteries from EVs • Assessment of batteries for potential resale as is, remanufacturing, repurposing, or recycling • Preparing batteries for shipping • Compliance with local fire marshal and/or government by-laws for battery storage requirements • Record keeping or tracking of batteries within their network
Remanufacturers	• Proactively acquiring used EV batteries and/or receiving EV battery packs or modules into their business • Assessing battery packs and modules for potential remanufacturing, repurposing, or recycling • Remanufacturing battery packs and modules • Preparing and shipping remanufactured battery packs/modules • Arranging for recycling of battery packs/modules/cells that have reached end-of-life or are damaged-defective • Compliance with local fire marshal and/or government by-laws for battery storage requirements • Record keeping or participating in vehicle manufacturer's tracking network

Organization	Roles and Responsibilities
Repurposers	• Proactively acquiring used EV batteries and receiving packs or modules into their business • Manufacturing new products made from previously used EV battery cells, modules, or packs • Management and proper recycling of EV packs, modules or cells not used to create the new product • Management of returned batteries (through warranty of their new product or through their sales/service model) • Supplying information that supports recycling and safe handling of their new product • R&D on new products and services • Compliance with local fire marshal and/or government by-laws for battery storage requirements • Record keeping or tracking of batteries entering and circulating in their network
Battery Recycling Processors	• Receiving EV battery packs, modules, and cells • Processing batteries to recover desired metals and other battery materials • Management of all materials processed • Marketing the recycled materials • R&D related to process and output improvements • Compliance with local fire marshal and/or government by-laws for battery storage requirements • Record keeping or tracking batteries and materials processed in their network

2. Secondary Support

Organization	Roles and Responsibilities
Shipping, Logistics and Battery Management Service Providers	• Facilitating compliant movement of EV batteries between locations which may include: o Supplying appropriate Transportation of Dangerous Goods compliant shipping containers o Hazmat certification training and/or general lithium-ion/NiMH battery management education o Supplying safety material used in shipping, storage, thermal event containment, and fire extinguishing (e.g., flame-retardant materials) o Supporting export of hazardous recyclable materials outside of Canada • Having appropriate certificates from TC and ECCC • Providing services for process mapping EV battery logistics workflow • Providing temporary storage location for EV batteries • Compliance with local fire marshal and/or government by-laws for battery storage requirements • Record keeping and/or tracking batteries within the network
Battery Diagnostic Companies	• Manufacturing, supplying, and possibly operating appropriate hardware and software to diagnose an EV battery pack, module, or cell for state of performance/health
Tracking and Tracing Companies	• Providing software and/or hardware tools that enable the tracking and/or tracing of batteries within a defined network or from mining to recycling
Standards Organizations	• Consulting, developing, and publishing relevant standards to support EV battery management

3. Governments/Agencies

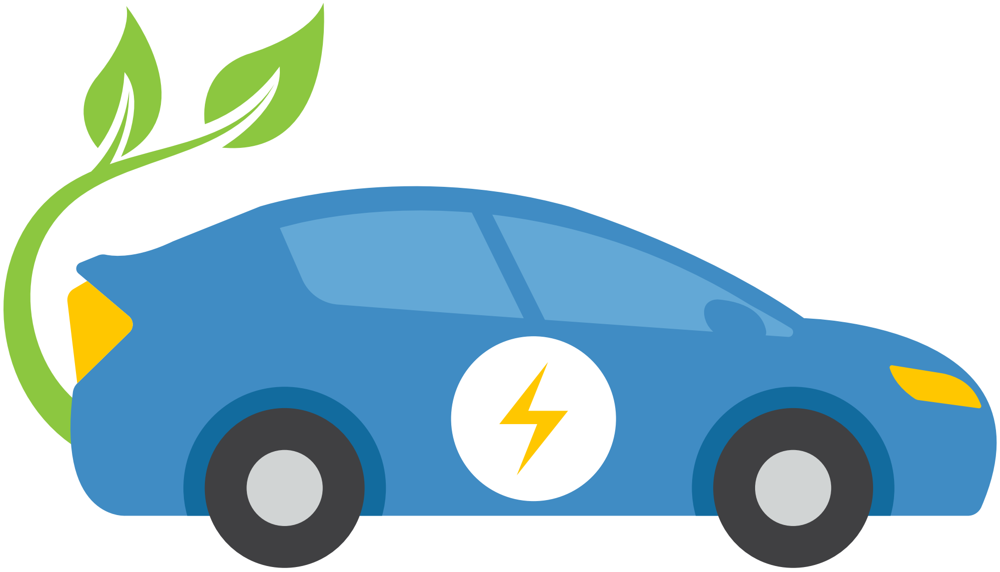
Organization	Roles and Responsibilities
Federal Government	• Setting policy and regulations for the transportation of dangerous goods • Setting policy and regulations for the import and export of hazardous recyclable materials • Setting policy and regulations for the inter-provincial movement of hazardous waste or hazardous recyclable materials • Keeping policies and regulations current • Issuing permits (e.g., import/export permits, equivalency certificates) • Compliance and enforcement • Removing barriers to the efficient and environmentally sound management of EV batteries • Supporting end-of-life EV battery management (e.g., investing in new innovative technology) • Setting policy to promote circular economy • Providing consumer incentives for adoption of EVs • Providing industry infrastructure investment incentives • Promoting nationally consistent management of EV batteries
Provincial Governments	• Regulating waste / landfill bans • Establishing recycling regulations • Setting policy and direction for provincial EV battery management • Permitting / regulating recycling facilities, auto recyclers & dismantlers, others in the EV battery supply chain within province • Supporting end-of-life EV battery management (e.g., investing in new technology/industry) • Providing consumer incentives for adoption of EVs • Providing industry infrastructure investment incentives • Setting policy to promote circular economy • Working with the federal government towards nationally consistent management of EV batteries

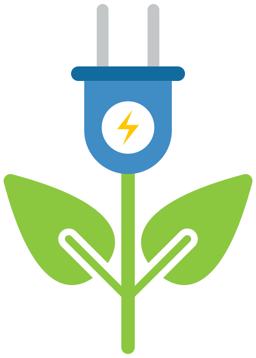
Organization	Roles and Responsibilities
Municipalities	• Application of the federal and provincial regulations at the local level • Charging station bylaws

Summary

It is recognized there are many different participants that have a role to play in the management of EV batteries at end-of-vehicle life, and this number is growing. Equally important is the real need for collaboration amongst all those listed here and any new market entrants.

Arguably the most important aspect to collaboration is the mitigation of a patchwork of solutions that creates complexity while reducing the number of available pathways for EV batteries to travel within.





Section 11

Development of the Primer: Industry Stakeholder Input

The Primer was driven by the need to consolidate all current information on EV battery management in Canada in one document so that there is a common foundation.

The authors have spoken with and listened to more than 100 individuals with experience in this topic over the past 18 months. The topics discussed covered EV battery repair, remanufacturing, resale as is, repurposing, recycling, transportation, logistics, safety, diagnostics, tracking, tracing, regulatory policy, standards policy, and ancillary topics. These individuals represent vehicle manufacturers, auto dismantlers & recyclers, repair garages, government, journalists, and companies working in each of the topic areas listed above. We acknowledge and thank those that participated for sharing their expertise, knowledge, and perspectives which covered the entire EV battery management ecosystem.

A variety of methods were used for the gathering of input including formal interviews, business meetings, webinars, research, and through the normal course of business and information sharing. Both the private and public sectors are represented. Journalistic articles rounded out the input that was reviewed.

While most of the technical information collected has been incorporated directly into the body of the Primer, this section summarizes additional input/ideas that were provided. Some of the information provided has been paraphrased.

Safety (See sections 4, 8, 10, 11, and 12)

- Many stakeholders identified a desire to see more information or consolidated information relating to safe EV battery handling, storage, transportation, fire prevention, firefighting, available fire safety material, and emergency response tools.

Logistics (See section 4)

- The packaging, transportation, storage, and training requirements for EV battery management within the TDG regulations are often being applied for the first time, taking extended time to figure out and implement efficiently, consistently, cost effectively, and accurately.
- The overlap of regulated requirements between Transport Canada, Environment and Climate Change Canada, the provinces, territories, and municipalities, and the fire code makes EV battery management more complicated and potentially more costly than it could be.
- Transporting EV batteries from Canada to United States and vice versa is administratively burdensome and would benefit from being streamlined. Additionally, the regulations for when to use specific shipping containers differ between the two countries and would benefit from alignment.
- Providers of TDG compliant shipping containers for EV batteries and their availability are not well known.

Diagnostics and Battery Health Certificates (See section 5)

- Some stakeholders expressed a strong desire to see greater adoption of diagnostic tools and/or battery health certificates, even pressing for regulated use.
- Other stakeholders believe this should be a business tool for use by those working to differentiate themselves in the market and not regulated.
- Early adopters are already using diagnostic tools, generally within the remanufacturing and repurposing sectors.
- R&D and pilots are underway to develop tools for in-field use to allow diagnostics to occur anywhere an EV or EV battery is located (e.g., vehicle auctions) or where a battery is removed from the vehicle (e.g.: auto dismantler & recyclers). Such in-field diagnostics have the potential to increase an EV/EV battery's value and reduce its handling costs.
- Stakeholders acknowledge that centrally located diagnostic tools and in-field diagnostic tools will co-exist as they serve a different purpose. Price point, level of diagnostic, and business strategy will drive different decisions for each stakeholder group.

Economics (See section 9)

- There is a general lack of clarity on how to assign value to end-of-life electric vehicle batteries, both today and when evaluating what these batteries may be worth a decade out.
- Some stakeholders stated they believe the value of used electric vehicles are roughly 10% to 15% less than that of comparable internal combustion engine vehicles due to uncertainty about battery condition. The costs associated with managing EV batteries at end-of-vehicle life are depressing the used EV car market, which has been holding back the new EV car market from expanding. (This situation was discussed prior to the current chip shortage that has reduced the availability of new vehicles, thus increasing the value of used vehicles.)
- Repurposing EV batteries appear to be more successful in certain jurisdictions like California, as the state offers incentives/subsidies to promote the development of this industry.
- Auto dismantlers & recyclers recognize the change that is occurring in the vehicle market, and they are seeing some opportunities to monetize EV batteries even now. However not all EV batteries have the same value or any value at all; it depends on the battery chemistry, vehicle model, and demand for that generation of battery.

Processing/Recycling (See section 3)

- Some recycling facilities process a variety of lithium-based batteries, such as those found in electronics and power tools, alongside EV batteries to maximize the capacity of the operations. Other recycling facilities expect to focus on batch processing EV batteries to maximize the quality of output products.
- Scrap production material from cell manufacturing process was identified as the single biggest source of feed stock for battery recyclers today due to the low volume of EV batteries reaching end-of-life.

Innovations (Not discussed in this Primer)

- Significant R&D and investment is occurring to improve EV battery performance and reduce total costs.

Battery Longevity (See sections 2, 3, 7)

- EV batteries on average are lasting between 15 and 18 years in service with some expected to last greater, up to 21 years.[13]
- Vehicle and cell manufacturers continue to extend the life of battery packs through their R&D work.
- Batteries removed from a vehicle may have significant capacity for alternative uses such as energy storage which may extend the life of a battery by up to 10 additional years per one repurposer the authors spoke with.

Implementing effective EV battery management (See section 12)

- A variety of perspectives were shared with respect to the need for regulating EV battery management, with a common emerging theme that EV batteries are a unique product and likely do not fit into existing extended producer responsibility regulatory approaches.
- Some stakeholders felt regulation is not necessary, while others thought that some level of regulation would be beneficial in keeping end-of-life EV batteries from being stored indefinitely.
- A patchwork of different provincial requirements across Canada is not desired. Most stakeholders would like to see a national or at least harmonized approach.
- The EV battery end-of-life supply chain, what the authors are now calling the 5Rs Pathways, should be allowed to form naturally.
- Governments can and should help by regulating for necessary safety standards.
- Regulations should be safe, efficient, economical to execute, simple to implement, and allow for new, remanufactured, repurposed, or those in transit for recycling batteries to move between provinces, as well as more broadly within North America, in a simplified and aligned manner.

Summary

Research into what is now this Primer began by first interviewing specific business leaders already working in the EV battery end-of-vehicle life ecosystem throughout North America to gain an understanding of how their piece of the ecosystem operates, what they liked about the industry that is forming, and where they feel change would be beneficial.

One year later as the Primer takes its final shape, it is comforting to see common themes emerge between these first interviews and the now 100+ conversations that have occurred. The authors have been able to address almost all the points the first interviewees made, while tying it all together in a concept called the 5Rs Pathways.

Sharing the stakeholders input here just prior to the recommendations is a good way to remind us there are real entrepreneurs pioneering new technology in a fast-evolving circular economy.

The research and interviews have informed the development of the Primer and the 5Rs Pathway concept.
The recommendations that follow are intended to address the areas of opportunity identified in the current collection and management ecosystem.

Section 12

Policy Considerations and Business Recommendations for EV Battery Management at End-of-Vehicle Life in Canada

The Primer has discussed how the circular economy for EV batteries at end-of-vehicle life is evolving across the 5Rs Pathways. This section presents policy considerations and business recommendations that if adopted will help further facilitate the safe and economical movement of EV batteries in Canada and within North America.

The recommendations are intended to provide direction for an economically viable circular economy for all EV batteries, avoid missed opportunities, and mitigate unintended consequences.

A circular economy for EV batteries has many benefits including:

- Safe and environmentally supportive end-of-life management for EV batteries
- Efficient resource management (using resources for their full capable life and making resources available for reincorporation into the next EV battery or new product)
- Reduction in the need for mining of new minerals
- Greater EV adoption supporting the move to a low carbon, net-zero emissions future
- Development of a strong and innovative domestic industry
- Reducing logistics and regulatory cost structures along the 5Rs Pathways, while developing opportunities for revenue generation
- Decreasing the environmental footprint of EV batteries

The authors ask policy developers to consider working with industry in implementing the following recommendations.

Recommendations

To address the opportunity for one national approach to managing EV batteries at end-of-vehicle life:

1. Develop one national EV battery end-of-vehicle life management policy to be adopted across all Canadian jurisdictions and aligned where possible on a continental basis. A patchwork of provincial or regional requirements is likely to impede the evolving and efficient management of EV batteries because:

a. The low initial volume of EV batteries available for remanufacturing, repurposing, and recycling may require facilities to consolidate batteries over larger geography.

b. Battery manufacturers and vehicle manufacturers are looking to create closed loop material flows (where recycled materials are reused back in the automotive business) to support electric vehicle service, as well as expand production of EVs at the lowest possible costs. As a result, OEMs are working with selected partners to remanufacture batteries for their service and replacement operations or directing EV batteries to specific battery recyclers that could work with their battery suppliers to produce new battery materials typically on a continental basis.

c. Due to battery variability, repurposers, remanufacturers, and to some extent recyclers, may specialize in certain battery chemistries or batteries removed from specific makes and models of vehicles. This will mean batteries may have to travel to other regions to support these processes.

d. As vehicles are designed, tested, and sold for a common and integrated North American market, so too should the management of EV batteries be harmonized to support the development of common processes, efficiency of scale and a competitive market.

To address the opportunities presented for extended battery life across all 5Rs Pathways:

2. **<u>Ensure all policies impacting EV batteries support their entire useful life across all pathways</u>**; or avoid restricting EV battery pathway options and limiting full battery life. For example:

   a. Specifically define the beginning and end-of-vehicle life for an EV battery to differentiate between 1st and 2nd life or subsequent life stakeholders.

   b. Properly define the producer or responsible party for each stage of the battery's journey across the five pathways.

   c. Due to the long life of EV batteries, avoid mandating recovery rates or specific retirement dates of EV batteries as this will prematurely force batteries to be removed from the market.

   d. Avoid mandating management processes within a limited geographic area such as a province. Limiting the scope of management activities will decrease competition and likely disrupt efforts to create a circular economy. It may also increase the cost of vehicles by adding inefficiencies and duplication into the battery management network.

   e. Avoid mandating specific management methods such as repurposing prior to recycling. Due to the changing value of EV batteries, market forces of supply and demand, along with increasing knowledge of battery health, will influence the pathway each battery will follow and will likely change based on commodity prices, geographic region, and distance batteries need to travel.

To address the need for less regulatory complexity across borders:

3. **<u>Review and amend current regulations,</u>** including the applicable transportation and waste management regulations, to remove barriers and facilitate EV battery movement across provinces, states, and North America.

   a. Ensure federal and provincial regulations allow the movement of EV batteries as dangerous goods without complex hazardous waste restrictions unless the battery is damaged, defective or has been deemed full end-of-life (vs. end-of-vehicle life). It would be beneficial if the XBR more explicitly defined end-of-vehicle life EV batteries (but not damaged-defective) destined for remanufacturing, resale as is, or repurposing as simply 'dangerous goods' and not as 'hazardous recyclable material'.

   b. Review ECCC permit requirements in the Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations (XBR) for the import and export of hazardous recyclable materials to remove the need for permit holders to ship EV batteries between one specific facility in Canada and one specific facility in United States and vice versa. Allow for permit holder to collect EV batteries from their network regardless of location and transport directly to a destination in the other country. This will reduce double handling and the need to establish temporary storage locations.

   c. Align Transport Canada regulations with the USDOT regulations 49 CFR § 173.185 (b) 5 to permit end-of-life batteries that are not damaged or defective and contain a hard outer shell, to be shipped on pallets or other handling devices without the need for a separate shipping container and without the need to apply for an Equivalency Certificate to obtain this alignment.

   d. Amend the TDG 'means of containment' regulations to change from use of volume in identifying small, single large, or non-standard means of containment to one common EV battery pack definition. This change will move some EV hybrid batteries from requiring a small means of containment into the same group of larger EV batteries requiring a non-standard means of containment. This change will simplify processes for transporting EV battery packs, while taking a step toward alignment with USDOT which in turn will assist with cross border shipments of EV batteries. (If battery packs are disassembled to modules or cells, the current means of containment may still apply)

To address the need for temporary storage of EV batteries:

4. **Review and assess storage requirements to support EV batteries management, while minimizing risk to human health, the environment, and property.**

   a. Set storage and safety requirements for facilities storing any EV batteries indoors or outdoors to ensure batteries are managed in a way to minimize risk of thermal events, environmental impacts, and preserve the integrity of the battery.

   b. Facilitate the consolidation of EV batteries into larger transportation loads by creating a federal or harmonized provincial temporary storage allowance of up to 12 months for end-of-vehicle life batteries in transit. This will enable fuller trailer shipments leading to lower net carbon footprints while providing for a reduced freight cost per battery. (Note: damaged-defective-recalled batteries may need to move in a more expedited fashion).

To address the need for common information across the EV battery management ecosystem:

5. **Assess and support information sharing between EV battery stakeholders working within the EV battery management ecosystem, leading to effective and environmentally sound management of the batteries along the 5 pathways:**

   a. Vehicle and battery information: Manufacturer, make, model, year, NiMH vs. Lithium-ion, size, weight, kilowatt hours, amp hours, and voltage

   b. Safe removal information: how to depower; steps to remove battery from vehicle

   c. Communication method: labeling, websites, guidelines

To address concern that low value EV batteries with no potential for other use will be abandoned:

6. **Support initiatives under development by OEMs and their industry partners** that address batteries at risk of falling outside of the developing collection and management pathways, thus ensuring they are appropriately handled at end-of-vehicle life. Such a recovery program would be limited to batteries that haven't already been repurposed for 2nd life use, as these batteries would be the subject of their own take-back programs and managed by each repurposer as a new product.

To address concerns about EV battery management safety:

7. **Develop training standards and/or safety requirements** for those along the EV battery management ecosystem (including but not limited to remanufacturers, repurposers, automotive dismantlers & recyclers, dealerships, and independent repair garages) that cover proper handling, storage, transportation, and emergency response related to EV batteries.

   a. Battery removal procedures

   b. Storage procedures

   c. Battery evaluation criteria

   d. Safety materials and tools being used

   e. Emergency response plan

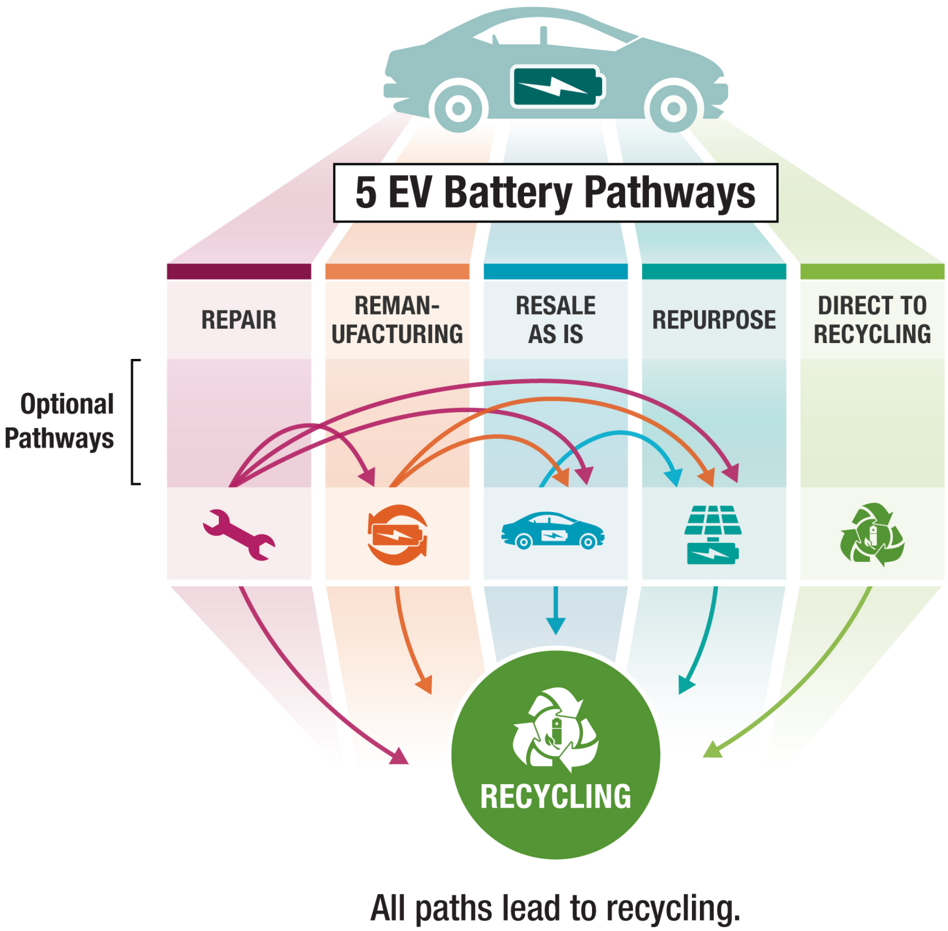
To address the need for a common hierarchy language relating to the journey of an EV battery:

8. **Adopt the 5Rs Pathways presented in this Primer as the foundation for business decision making and adoption of policy,** and designed to:

a. Keep all the battery pathways open

b. Maximize the full life of EV batteries

c. Ensure maximum economic benefit to society



Source: Call2Recycle®

Endnotes

Introduction

1. Statistics Canada – (includes hybrid, plug-in hybrid, full electric, and fuel cell powered vehicles) - https://www150.statcan.gc.ca/n1/pub/71-607-x/71-607-x2019028-eng.htm Table 20-10-0021-01, New motor vehicle registrations
2. Canadian EV and Battery Investments, Google search on June 2, 2022

FIGURE 20: Canadian EV and EV Battery Investments

Investors	Value in B$	Investment	Date	Province
GM	1.0	Brightdrop EV production	15-Jan-20	ON
Ford	1.8	Oakville EV production	28-Sep-20	ON
Lion	0.2	Battery manufacturing	15-Mar-20	PQ
NovaBus	0.2	Quebec EV bus production	18-Jun-21	PQ
GM/Posco	0.5	Cathode active material manufacturing	01-Dec-21	PQ
BASF	na	Purchase of land for cathode active material manufacturing	04-Mar-22	PQ
Honda	1.4	Alliston hybrid EV production	16-Mar-22	ON
Stellantis & LGES	5.0	Battery manufacturing	23-Mar-22	ON
Stellantis	3.6	Ontario EV production	02-May-22	ON

Source: Google source as of June 2, 2022

Links

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- https://www.newswire.ca/news-releases/ford-commits-to-investing-1-8-billion-to-become-first-manufacturer-in-canada-to-build-full-battery-electric-vehicles-837541520.html
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3. Circular Energy Storage – at 7:18 of the video, Hans Eric Melin, November 4, 2021, https://youtu.be/czwuxBnPIGY

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4. Statistics Canada – https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002101
5. Source For FCEV & OTHER FUELS (NGVs): IHS
6. A Healthy Environment and a Healthy Economy, Environment and Climate Change Canada, page 15, published 2020 - https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf. There are currently over 75 models available in Canada - https://ev.plugndrive.ca/vehicles

Section 2

7. Circular Energy Storage – at 7:18 of the video, Hans Eric Melin, November 4, 2021, https://youtu.be/czwuxBnPIGY

Section 3

8. Nature – Recycling lithium-ion batteries from electric vehicles, Gavin Harper, Roberto Sommerville, Emma Kendrick, Laura Driscoll, Peter Slater, Rustam Stolkin, Allan Walton, Paul Christensen, Oliver Heidrich, Simon Lambert, Andrew Abbott, Karl Ryder, Linda Gaines, Paul Anderson, November 6, 2019, www.nature.com/articles/s41586-019-1682-5

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9. Transport Canada website, Transporting Batteries, Means of Containment – https://tc.canada.ca/en/dangerous-goods/transporting-batteries

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10. Geotab, Inc. (EV Battery Health) – What can 6,000 electric vehicles tell us about EV battery health?, Charlotte Argue, July 7, 2020, https://www.geotab.com/blog/ev-battery-health/
11. Geotab, Inc. (EV Range) – To what degree does temperature impact EV range?, Charlotte Argue, May 25, 2020, https://www.geotab.com/blog/ev-range/

Section 6

12. Global Battery Alliance, Battery Passport, site visited June 2, 2022 - https://www.globalbattery.org/battery-passport/

Section 11

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EV battery management at end-of-vehicle life is a new and fast evolving activity that is part of the bigger transformation to electrify transportation. It is hoped this Primer serves as the foundation which will facilitate educated discussions and confident policy and business decisions.

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Please contact Vice President Marketing at Call2Recycle:
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About the Canadian Vehicle Manufacturers' Association and Call2Recycle

Canadian Vehicle Manufacturers' Association

The Canadian Vehicle Manufacturers' Association (CVMA) develops consensus-based public policy positions and undertakes advocacy to create a better understanding of the importance of a healthy and technologically innovative automotive industry to Canada's economic well-being and prosperity.

The CVMA creates a framework within which member companies work together to achieve shared industry objectives on a range of important issues such as innovation, international trade, consumer protection, the environment and vehicle safety.

The CVMA's membership includes Ford Motor Company of Canada, Limited; General Motors of Canada Company, and Stellantis (FCA Canada Inc).

Collectively its members operate 5 vehicle assembly plants as well as engine and components plants and have over 1,300 dealerships. 136,000 jobs are directly tied to vehicle assembly in Canada. Direct and indirect jobs associated with vehicle manufacturing are estimated at over 792,000 across Canada.

President: Brian Kingston
Vice-President: Yasmin Tarmohamed

Canadian Vehicle
Manufacturers' Association
Association canadienne
des constructeurs de véhicules

Call2Recycle

Call2Recycle is the leading North American battery recycling network for industry, committed to safe and responsible collection, transportation, sorting, and recycling of batteries and related devices, whether at end-of-life, damaged or defective, or brought out of market due to a recall.

A non-profit organization in both Canada and United States, the company has safely and responsibly recycled more than 209M pounds / 95M kilograms of batteries across multiple chemistries since 1994.

The business works with roughly 400 clients from the household battery, hearing aid, power tool, cell phone, laptop, outdoor power equipment, electric bicycle, and electric vehicle industries. Clients choose Call2Recycle for the company's effective cost management, safety focused approach, and regulatory compliance.

Call2Recycle Canada, Inc. is headquartered in Toronto, Ontario while Call2Recycle, Inc. is headquartered in Atlanta, Georgia, USA.

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