IDENTIFYING AND ASSESSING OPTIONS FOR END-OF-LIFE DISPOSAL/REUSE OF ELECTRIC BUS BATTERIES

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DISCLAIMER

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of TransLink staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of TransLink or the University of British Columbia.

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EXECUTIVE SUMMARY

The wave of transitioning to electric vehicles from gas vehicles is as revolutionary as the transition was from landlines to mobile phones. The one dark side which is common in both industrial revolution is the battery disposal. The total estimated batteries at EOL (End of Life) by 2030 will be 1,081,640[8] in the US. As TransLink is moving towards electric buses, the number of electric bus batteries reaching end-of-life (EOL) will start to increase and is projected to grow dramatically in the next 5 to 10 years. In this project, a detailed analysis is done for TransLink - the regional transportation authority for Metro Vancouver, to research " the current and potential future state of electric-vehicle battery end-of-life disposal or reuse practices to inform TransLink's future electric bus battery EOL strategy**.** The vehicle batteries generally have a lifespan of 8 years or 100,000 miles, and the OEM's typically offer battery warranties that cover at least this service life.

The most used electric bus battery chemistry is Lithium-ion batteries due to its favorable design characteristics, they are light weight, have good life cycle performance and large life span. Among these, LFP (Lithium-Ion Phosphate, NMC (Nickel Manganese Cobalt) and LNMO (Lithium Nickel Manganese Cobalt Oxide) are the most widely used chemistries.

When the battery pack reaches its EOL, they retain about 70 percent of their initial capacity, they tend to be pulled from vehicles because they've lost some of their ability to deliver quick bursts of power, or quickly recharge. The two options to deal with EOL batteries are discussed in this report - Recycling and Reusing. Reusing the EOL EV batteries in ESSs (Energy Storage Systems) can reportedly extend the life of the EV battery or some of its cells for a time of anywhere from 6 to 15 years or more depending on the exact application. On the other hand, recycling the lithium-ion batteries and using the recycled materials from spent batteries has potential to decrease cost by 40%, energy use by 82% and the SO_x emissions by 91%[3] in comparison to using freshly extracted raw material.

Recycling - Battery recycling process is explained in detail below along with a cost estimation of the recycling process comparing the two-leading lithium-ion battery chemistry – NMC and LFP. The net profit to recyclers for the LFP and NMC battery chemistries is estimated at $645 CAD and $3340 CAD per metric ton respectively[12].

In comparison of the total cost associated with recycling these batteries, it is concluded that the LFP batteries provide very little revenue compared to the NMC chemistry. There is a recycling cost calculator called Everbatt[9] developed by Argonne National Laboratory which can be used to estimate initial recycling costs. Kindly note these values are associated with estimations from the market and research analysis and is nowhere representation of TransLink's cost analysis. This analysis provides a bird eye view to initial estimates.

Reusing – Re-using electric vehicle batteries for second-life applications could contribute to a 56% reduction in CO2 emissions compared to natural fuel gas, especially during peak demand in grid storage for utility applications.[13] The DOD (Depth of Discharge) is found to be heavily influencing the lifespan of SLB (Second life batteries). Thus, the right application and suitable DOD are to be considered when implementing SLB. There are various methods to repurpose the EOL batteries. Few of which includes using in electric vehicle charging stations, reuse in electric vehicles, grid scale energy storage, commercial and industrial energy storage. There is a B2U Repurposing Cost Calculator[14], a tool for estimating the costs associated with reusing retired vehicle batteries. According to the NREL study, the batteries can be reused for as little as $20/kWh or $500 each. Another study by Elemental energy predicted the estimated price paid by the end-customer for repurposed batteries would be $40.4/kWh[15] compared to the purchase price of $70/kWh for new electric vehicle batteries. The cost analysis is performed to estimate reuse revenue including consideration of extended producer responsibility (EPR) fees paid by obligated producers.

Recycling vs Reusing – The economic benefits of recycling and reusing were analyzed keeping two battery chemistries as the base case – NCA and NMC. It was observed that recycling a battery that weighs 400 kg and has 50% of its capacity left can cost between $500 and $1,500 per battery. However, putting the battery to reuse can generate earnings of at least $50/kWh. A more detailed analysis is performed in the report.

Stakeholders – The OEMs were interviewed for the sake of this report and understand their perspective towards the current situation. A lot of valuable insights have been received by New Flyer, BYD, Nova Bus and Proterra. It was brought to notice that Nova bus has been in talks to collaborate with Li-Cycle/ Lithion (Canadian Recycler firms) to meet their EPR goals. New Flyer has an existing partnership with Li-cycle to recycle their existing EOL (End of Life) batteries. BYD has an internal setup to deal with the EOL batteries in China. Proterra has plans to use its own battery in storage application at EOL. They also have a setup for recycling of the dead batteries in their facility at Redwood's in Carson City, Nevada. Other stakeholders were also interviewed to understand their contribution towards disposal of the EOL batteries of electric bus. They were mostly refurbishers and recyclers who are market leaders in this domain. This included firms like Moment Energy, Repurpose Energy, Li-Cycle, American Manganese. While Moment Energy and Repurpose Energy provides repurposing EOL battery solutions, Li-Cycle deals in recycling to extract useful material to add back in supply chain. The details of their business model and collaboration options are listed below in the report.

Policies – While deciding on the path to deal with EOL batteries, it's important to understand the policies associated with it. EPR (Extended product responsibility) is one among the few regulations currently in place in few of the provinces in Canada. Under this regulation, the producer is responsible for proper disposal of the battery material at its EOL. The product responsibility can be transferred to other stakeholders providing legal documentation. The implementation timeline for EPR is from 2021-2026. There are certain other policies which are currently under review and has been discussed in detail. The information regarding various policies across countries has been collected to provide understanding of regulations regarding battery disposal. The countries whose policies has been taken into consideration include China, European Union, USA, and Canada.

Future work - This project involved a detailed literature review as well as interviews to identify the current and near-term future processes employed for the reuse and recycling of retired batteries.

Electric vehicle battery reuse is a much more economically attractive option for electric vehicle battery owners for the foreseeable future compared to electric vehicle battery recycling.

For initial cost estimate for Reusing the batteries, National Renewable Energy Laboratory (NREL) developed the B2U Repurposing Cost Calculator[14] which can be referred for preliminary estimates.

TransLink is currently managing EOL batteries through the warranties with the OEMs, but they should continue to monitor the EOL battery industry and evaluate whether they need to change this practice to achieve better value for money.

TransLink shall monitor the regulations and determine how and when they apply to Battery electric Buses and specifically TransLink.

TransLink shall develop long term, midterm, and short-term plans (based on financial and feasibility analysis) on whether to:

- Continue warranty based EOL battery takeback by the OEMs
- Consider battery leasing
- Consider outsourcing the retired batteries to recyclers and refurbishers
- Establish a reuse and refurbishment capability in-house like its existing diesel engine refurbishment capabilities and capacity

INTRODUCTION

Most electric vehicles currently use Lithium-ion (Li-ion) batteries due to their favorable design characteristics: lightweight, high specific energy, low self-discharge rate, and good life cycle performance. Current research and development (R&D) efforts are concentrated on upgrading Li-ion battery chemistries to develop the next generation of electric bus battery technologies since Li-ion batteries are projected to remain the favored battery chemistry for vehicles. However, according to current projections, the world's lithium stocks can only create about one billion 40 kWh batteries for Electric vehicles, so recycling or reusing vehicle batteries will be necessary to sustainably fulfil projected future electric vehicle demand. The management of electric vehicle batteries near the end of their first life will be significantly impacted by the rising demand and constrained supply in the various Li-ion supply chains. When the battery State of Health (SOH) reaches about 80%, the first life of an Electric vehicle battery ends. The batteries can no longer consistently achieve the high-performance standards required for use in Electric vehicles at this SOH, although they can still be recycled or utilized in less demanding applications.[5]

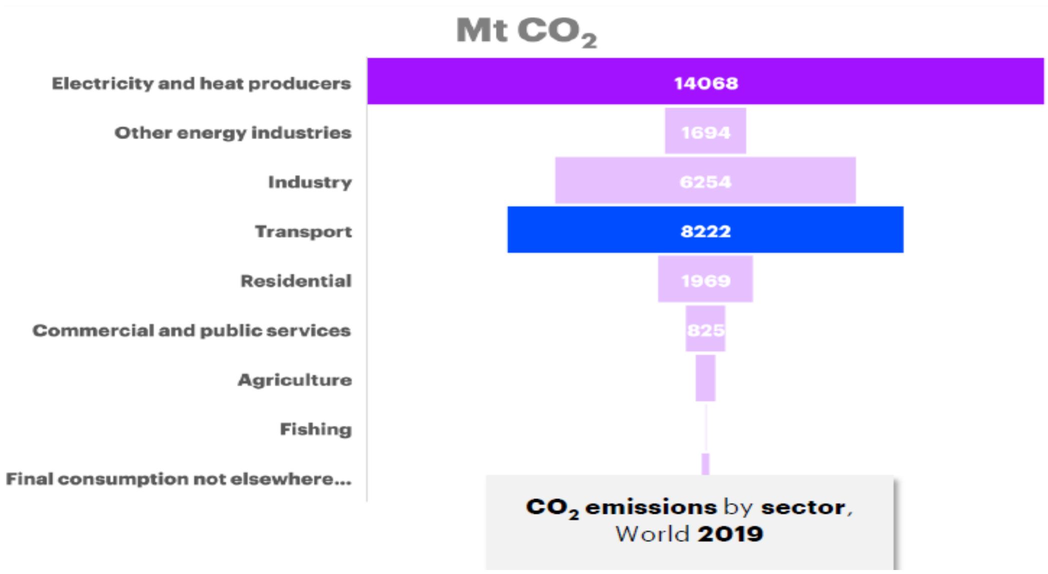

Figure 1: Emissions by various sectors, World

BACKGROUND

Compared to most traditional lead-acid batteries, lithium-ion battery lifespans are three times longer. This lifespan is due to factors like the battery management, very low self-discharge, the absence of memory effect, and a discharge of up to 20%. Batteries are normally covered by warranties from the vehicle companies for at least this period. The quality and duration of the retired electric vehicle batteries are determined by the battery chemistry, state of charge (SOC), DOD swing, number of cycles, charge, and cell temperature.[5]

In 2019, there were reportedly 29,000 tonnes of lithium-ion batteries (LIBs) available for recycling in the US. Lithium cobalt oxide (LCO) accounted for 59% of these, followed by lithium, nickel, manganese, cobalt oxide (NMC111), 18%, lithium iron phosphate (LFP), 10%, lithium manganese oxide (LMO), and 2% lithium (nickel, cobalt, aluminum) oxide (NCA). Figure 2 shows how Toyota is installing the second life batteries from the electric vehicles to power a 7-Eleven Store in Japan.[23]

Figure 3 compares various lithium battery types on basis of energy density, price, specific power, life span, safety, and performance.[6]

Figure 2: Reused Electric vehicle batteries Power a 7-11 Store in Japan[23]

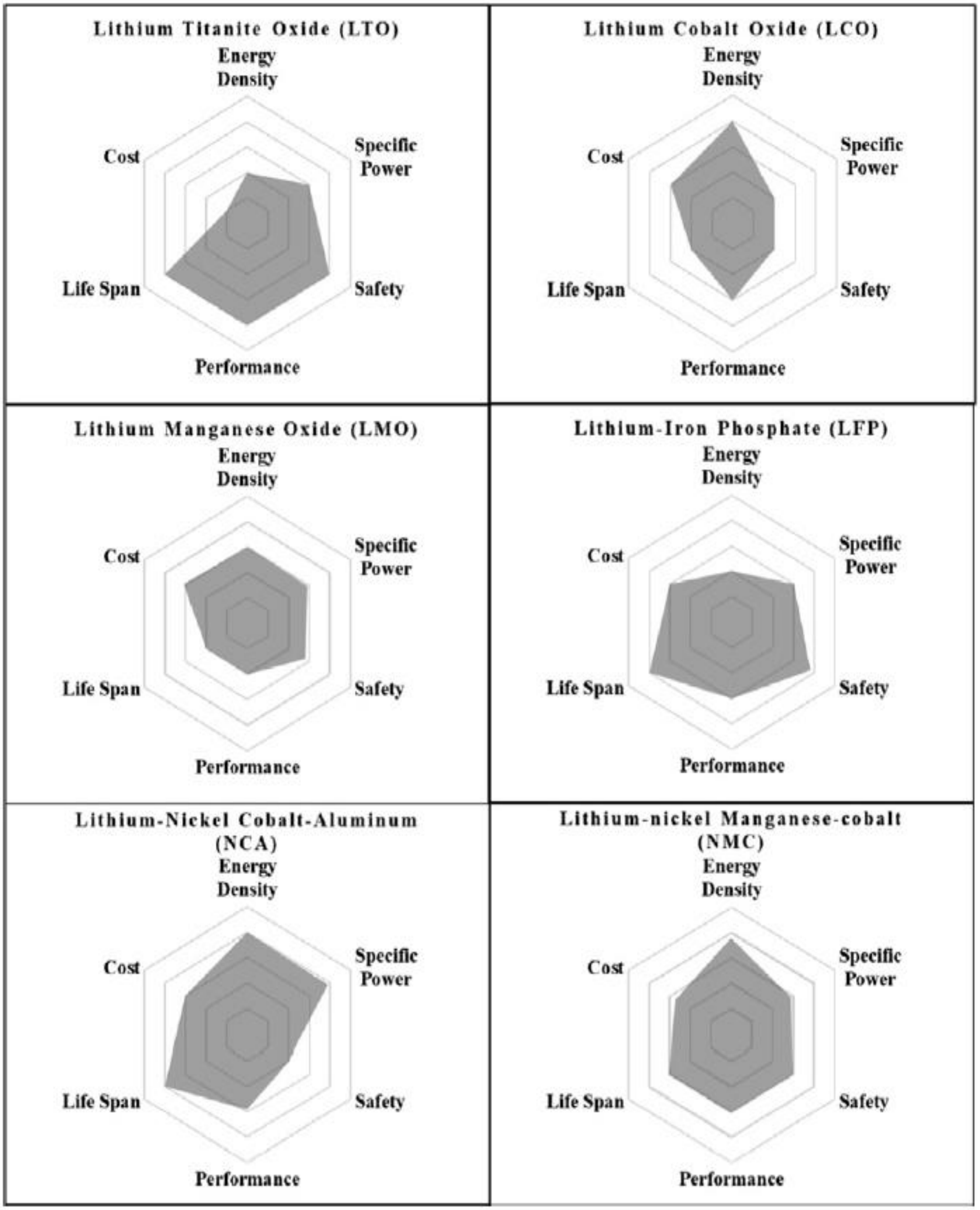

Figure 3: Comparison of the different types of lithium-ions batteries[7]

NMC	LNMO	LFP
Nickel -Manganese - Cobalt	Lithium, Nickel-Manganese-Cobalt Oxide	Lithium Iron Phosphate
Layered oxide cathodes	Spinel-type cathodes	Olivine-type cathodes
▪ Mixed layered oxide with Li,Ni,Mn and Co ▪ Industry standard that was derived from LCO ▪ Ni-rich NMC for higher energy ▪ Mn-rich for cost and safety improvement ▪ Li-Mn-rich layered oxides ▪ Players: LG energy sol.,Samsung SDI,SK Innovation	▪ Cobalt-free materials with manganese and nickel ▪ Results in high cell voltage (> 5,0 V) ▪ Require large- scale high-voltage electrolytes ▪ Materials under development with first adopters ▪ Players: Morrow with Haldor Topsoe	▪ Low-cost and intrinsically safe material without Co & Ni ▪ Rapidly gaining popularity in a wide range of applications from stationary to traction batteries ▪ Improvement: LMFP with Mn as high-energy version ▪ Players: CATL,BYD,Gotion, EVE

Table 1: Lithium-Ion battery chemistries: NMC, LNMO, LFP

When a battery pack reaches the end of its useful first life on the electric vehicle, it has following options-

- REPAIR
- RECYCLE VALUABLE MATERIALS
- REUSE

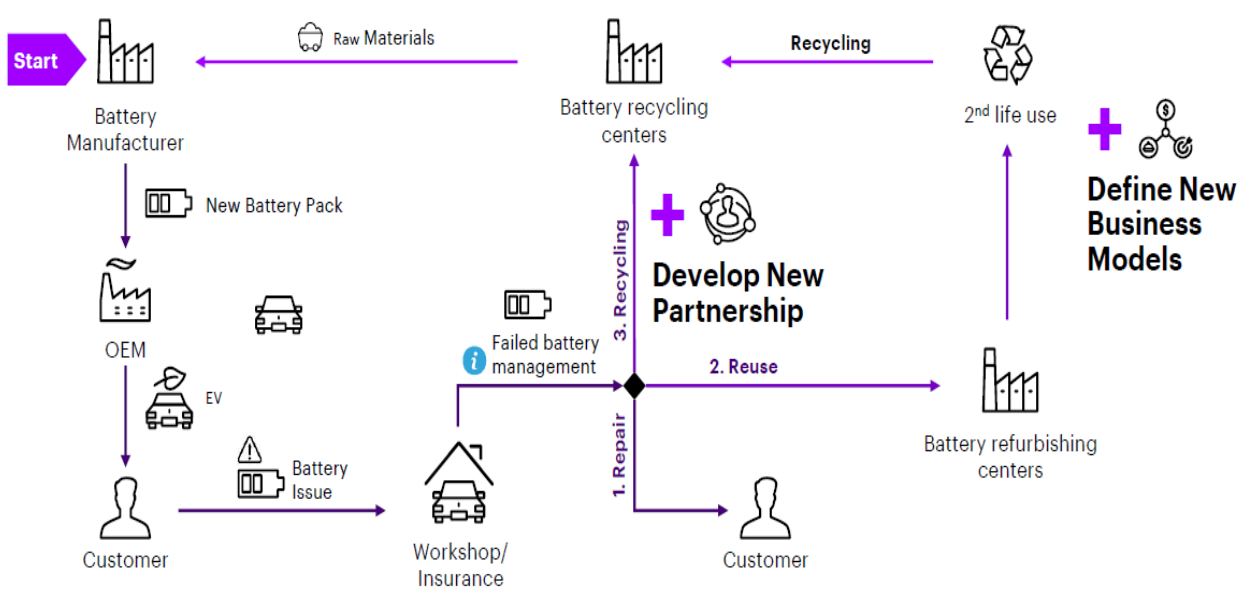

Figure 4: Battery life cycle

These options are further explained in the project and potential analysis is performed to compare these options.

Table 2 shows the estimated battery life expectancy from 2019 to 2030. These estimates were created by Kelleher Environmental using a straightforward lifespan model, which is based on a linear projection of the number of batteries that will reach end-of-life, considering sales of electric vehicles from 2011 to 2018 and the following assumption regarding electric vehicle sales from 2018 to 2023 in the US.[8]

YEAR	ESTIMATED NIMH BATTERIES AT EOL (UNITS)	ESTIMATED LI- ION BATTERIES AT EOL (UNITS)	TOTAL ESTIMATED EV BATTERIES AT EOL (UNITS)
2019	229,694	50,635	280,328
2020	207,009	140,114	347,124
2021	198,852	254,699	453,551
2022	229,181	320,032	549,213
2023	221,277	333,280	554,557
2024	197,006	329,378	526,384
2025	183,632	341,797	525,429
2026	174,091	414,004	588,094
2027	170,779	517,228	688,007
2028	163,497	645,395	808,892
2029	163,497	774,438	937,935
2030	163,497	918,143	1,081,640

Table 2: Preliminary estimate of electric vehicle batteries reaching EOL in the US (2019-2030)[8]

Lithium-Ion battery has various compositions of Nickel, Manganese and Cobalt, the evolution of the percentage composition is shown in Table 3. It is clear from Table 4 that the contribution of Cobalt Content in Lithium batteries is decreasing.

	2015	2020	2025	2030
NMC 111	90%	60%	25%	17%
NMC 433	5%	19%	20%	12%
NMC 532	3%	15%	30%	12%
NMC 622	2%	4%	15%	33%
NMC 811	0%	2%	10%	26%

Table 3: Evolution of Lithium Battery Chemistries (2015-2030)[27]

	2015	2020	2025	2030
Cobalt Content	4.4%	4.2%	3.6%	3.2%

Table 4: Evolution of Cobalt Content in Lithium Batteries (2015-2030) [27]

RECYCLE

Process

The initial step in the recycling of electric vehicle batteries is to sort and identify battery chemistries based on visual inspection and/or shipping information, and then direct the batteries to safe workbenches for dismantling. Trained technicians manually disassemble the battery packs down to the cell or module level 1. Actual battery cells are isolated from assembly components, wiring, and circuits. Small- to medium-sized hand and power tools are used for manual disassembly, but several stakeholders whose opinions were taken for this research noted that some battery packs, and even battery cells, are built with intricate, welded casings or mechanical fasteners that prevent removal. This raises the costs incurred because it is harder to get EOL (End of life) vehicle batteries ready for further processing. Anyone handling the storage or dismantling of vehicles must undergo safety training.

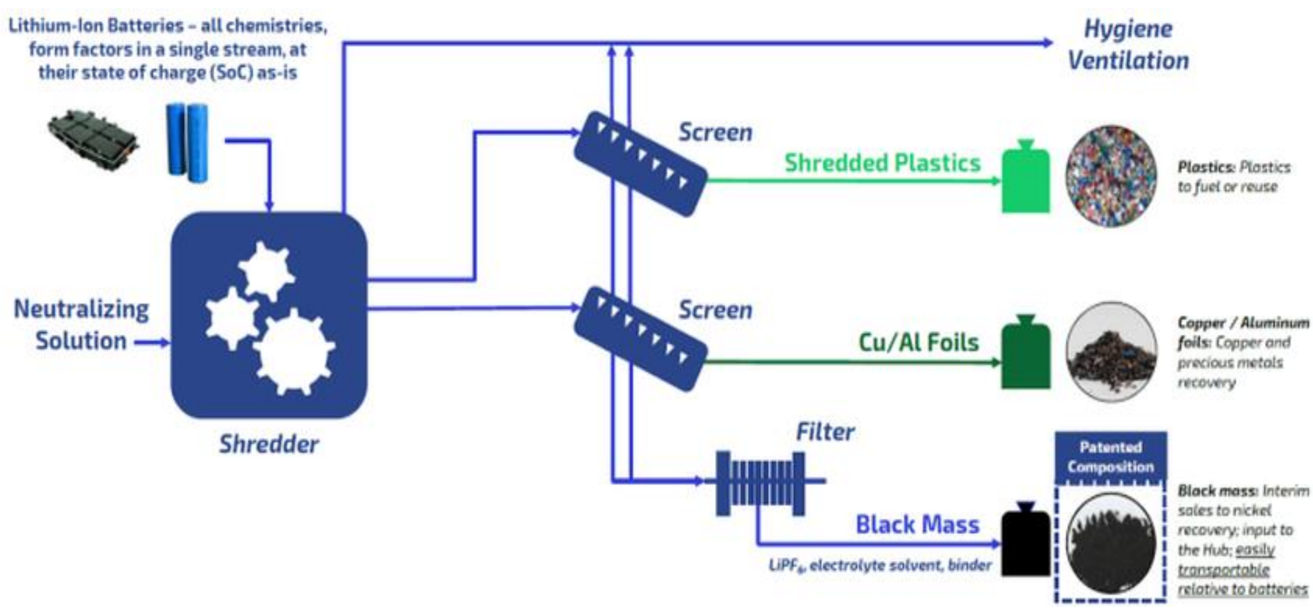

Figure 5 : Recycling process by Li-Cycle, mechanical and hydrometallurgical processing[2]

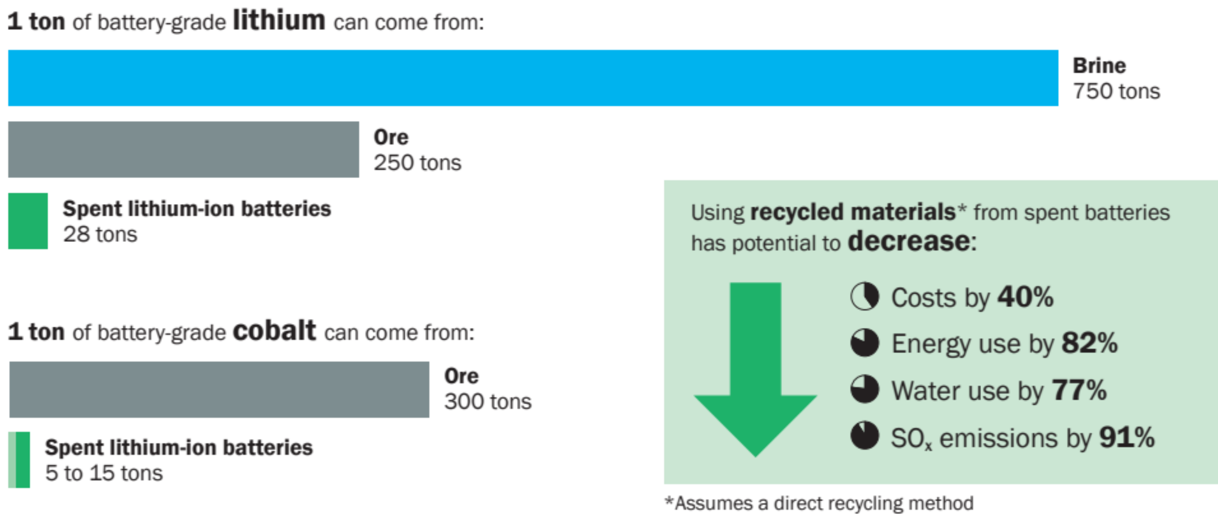

Figure 6: Benefits of recycling for lithium-ion batteries in comparison to using freshly extracted raw material [3]

Li-ion batteries contain a wider variety of materials in each cell, which makes the recycling process more complex, including:

- Zinc, lithium, manganese, copper, aluminum, steel, cobalt
- Plastic components: polypropylene, PET
- Graphitic carbon
- Solvent, electrolyte (sulfuric acid)
- Fiberglass
- Coolant/battery management system.

Cost of Recycling the battery

Vehicle battery recyclers contacted for this study declined to provide information on battery recycling costs due to confidentiality concerns. Costs were discovered through discussions with battery collectors, technical, market, and literary research, as well as a review of the business and financial strategies of firms working on electric vehicle battery recycling technologies.

Argonne National Laboratory (ANL) estimated recycling costs for li-ion batteries at $4,000 to $5,000/tonne[25]. ANL has a recycling cost model called Everbatt[9]. EverBatt is an Excel-based model that assesses the financial and environmental effects of a li-ion battery's various life cycle stages. It can be used to evaluate processes, detect sensitivity to different factors, and compare the effects of new batteries to those with recycled material.

Several variables affect the net cost of recycling. These factors include commodity pricing, the size of the recycling facilities and associated economies of scale, the value of the metals that are regularly retrieved by recyclers, the composition of the processed electric vehicle batteries, and the effectiveness of the recycling process.

LFP vs NMC

The costs of two battery types, LFP ($LiFePO_4$) and NMC, which together accounted for approximately 95% of the Chinese market in 2015, were the subject to compare cost of recycling. Since it makes up about 75% of NMC batteries in China, the NMC523 battery was selected for the calculations of recycling costs, revenues, and profits.

Battery composition and recovery rates assumed were taken from literature reviews and manufacturer data was considered theoretical. Commodity metals prices were taken from the Shanghai nonferrous metal website in November 2017 to estimate the values of cobalt, nickel, lithium, and other metals. The analysis assumed that the energy capacity of an electric vehicle is about 50kWh, and that the battery weighed 500 kg.

Table 5 presents the estimated costs of recycling the two chemistries. The table shows that the costs are the same for most activities except for the metal recovery cost for the NMC which is estimated to cost $2,285/ton. Depreciation was assumed to be 10 years for equipment and 30 years for buildings, with 5% asset value remaining at the end of the depreciation period. Labor rates and transportation costs were for Shenzhen, China. Costs were estimated with the recycling facility running at full capacity.[11]

			Cost (yuan/metric ton)		Cost ($CAD/metric ton)	
	Item	**Content**	**LFP**	**NMC**	**LFP**	**NMC**
Variable Costs	Material recovery cost	Spent battery	0	12,018	0	2,285
	Accessory material cost	Solution and extraction solvent	2,500	2,500	475	475
	Fuel cost	Electricity, natural gas	620	620	118	118
	Pre-treatment cost	Crushing and separation	500	500	95	95
	Environmental expenses	Wastewater treatment	330	330	63	63
	Handling expenses	Residue and ash disposal cost	120	120	23	23
	Labor charges	Salary	470	470	89	89
	Transportation expenses	Fuel fees, Toll, etc.	2,000	2,000	380	380
Fixed Costs	Fixed costs	Maintenance of equipment	100	100	19	19
		Depreciation	536	536	102	102
Total Costs			7,176	19,194	**1364**	**3,649**

Table 5: Estimated Recycling Costs for LFP and NMC523 Batteries from electric vehicles [12]

Table 6 estimates the potential revenue from recycling the two battery chemistries. Recycling rates assumed for each material are also shown in the table. No attempt has been made to adjust the values in the table; it is simply presented as one of the few publicly available cost assessments for electric vehicle battery recycling. Notwithstanding some limitations, the table is very useful to show that **the LFP chemistry provides very little revenue compared to the NMC523 chemistry** which contains cobalt, nickel and copper at amounts which yield positive revenues. The amount of aluminum is minimal. The table also shows that recovery of manganese provides minimal revenue.

		Composition (kg/100kWh)		Recycling Rate (%)	Recycling Revenue ($CAD/100kWh)	
Metal	$CAD/ton	LFP	NMC		LFP	NMC
Cobalt	84,221	0	48	89%	0.00	3633.84
Nickel	18,683	0	80.8	62%	0.00	935.97
Lithium	163,498	9.	10.	80%	1175.86	1254.36
Manganese	2,072	0	30	53%	0.00	33.09
Iron	125	72	0	52%	4.56	0.00
Aluminum	2,924	65	87	42%	79.85	106.84
Copper	10,173	82	112	90%	750.76	1025.48
Total					**2011.03**	**6989.62**

Table 6: Recycling Commodity Value and Recycling Rate Assumed for Financial Analysis of Recycling LFP and NMC Batteries from electric vehicle[12]

Table 7 presents the net profit analysis. The analysis is theoretical with higher than realistic recovery rates for the metals. The value for lithium used is for a pure lithium – likely medical grade – which is not produced by battery recycling which produces lithium carbonate. If these adjustments are made, then recycling of the LFP battery would incur a net cost. Labor rates used for China would be much lower than for North America, but this is one of the few cost analyses that could be found through the literature search.[11]

CAD labor rates, lithium carbonate costs, and materials recovery rates were not considered beyond converting reported costs to CAD $ because these costs fluctuate often, and there are numerous additional aspects that are unknown in the analysis. To make the cost estimate more accurate for a Canadian context, it is advised to conduct a thorough financial analysis of various recycling methods for electric vehicle batteries using CAD labor rates, commodity values, and other regional characteristics.

EV battery chemistry	Net Profit ($CAD/metric ton)	Revenue ($CAD/metric ton)	Cost ($CAD/metric ton)
LFP	645	2011	1364
NMC	3340	6989	3649

Table 7: Net profit from recycling LFP and NMC type Electric vehicle batteries for recyclers

REUSE (2nd life batteries)

Process

While second-life electric vehicle batteries retain about 70 percent of their initial capacity, they tend to be pulled from vehicles because they've lost some of their ability to deliver quick bursts of power, or quickly recharge.

Re-using electric vehicle batteries for second-life applications could contribute to a 56% reduction in CO2 emissions compared to natural fuel gas, especially during peak demand.[13] The battery chemistry, state of charge (SOC), DOD swing, the number of cycles, the charge, and the cell temperature are used to determine the quality and lifespan of the retired batteries.

DOD	Range	Lifespan at 70% EOL	Lifespan at 60% EOL
80%	95–15%	4 years	8 years
65%	85–20%	5.1 years	11 years
50%	65–15%	8 years	16 years

Table 8: Impact of DOD on SLB lifespan

The DOD is found to be heavily influencing the lifespan of SLB (Second Life Batteries). Thus, the right application and suitable DOD are to be considered when implementing SLB. The widespread of SLB is eventually facing some challenges such as the availability of similar SLB characteristics at large scale and difficulty in assessing SLB accurately. However, such challenges could be overcome with the rapid growth of the electric vehicle industry, SLB standards, automation of assessment and further economic studies.

I" life in electric vehicles	2nd life in Stationary Application
Voltage required: 400 V	Voltage required: — 800 - 1000 V
Operating hours for 10A: ~ 16,800 h (on)	Operating hours for 10A: max. 87,800 h (on)
Ambient temperature: -40 to 60 Degree Celsius	Ambient temperature: 10 to 35 Degree Celsius
C rates: •If Continuous: 2 to 3 C •If Peak: > 5C	C rates: •If Continuous: < 0.5 C •If Peak: 0.2 to 2 C
Thermal Management: Active (Air/Liquid)	Thermal Management: Passive (only active in specific use cases with critical temperatures)
Vibration: Yes (due EV Movement)	Vibration: None (Stationary)
SOH: 100% (at beginning of I^{st} life)	SOH: 70-90% (at beginning of 2nd life)

Table 9: Comparison of first and second life battery application requirements[7]

Various methods to reuse (details in appendix C)

- Reconditioning, which generally refers to replacing dead cells or packs to reuse the assembly as an electric vehicle battery.
- Repurposing in other applications (e.g., energy storage), where some cells and packs are replaced but the battery is directed to a stationary application.
- Reusing, where the battery is torn down to the pack or cell level, with the individual cells redeployed to a wide variety of applications which use battery cells.

Figure 7 shows the areas of usage of End-of-life battery as ESS (Energy Storage Systems)

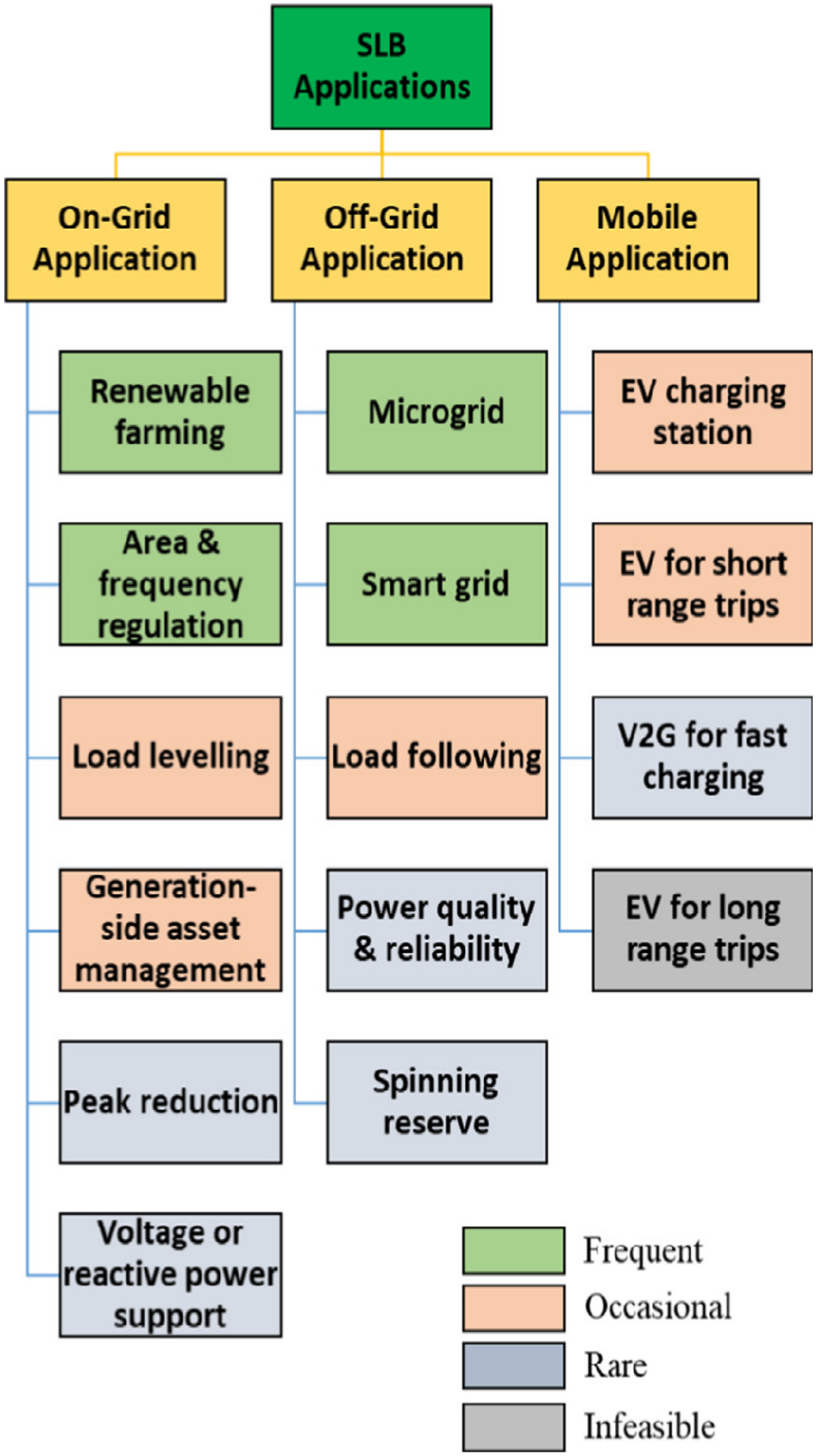

Figure 7: SLB ESS Applications

Reuse In Energy Storage

Energy storage systems (ESS) offer the electrical grid several advantages, including frequency regulation, load management, frequency reduction, and system peak shaving. Due to ESSs' ability to store generated energy for later use, energy storage also ensures the viability of renewable energy sources like solar and wind. Because of this, the development of the power system moving ahead in at least 11 US states now includes a requirement for energy storage. Setting regulations for procurement, creating incentives, and ensuring the inclusion of storage into long-term planning processes are all examples of state level energy storage policy measures. Maryland, New Jersey, Nevada, Oregon, New York, and Massachusetts are among the states that have established goals for energy storage and that are providing subsidies, mandating its usage, or both is currently 0.4 GWh of energy storage in California. An estimated 85% of this energy storage is supplied by li-ion batteries.

Depending on the specific application, using EOL batteries in ESSs is said to be able to prolong the life of the EV battery or some of its cells for a length of time ranging from six to 15 years or more.

The Tesla Powerwall, which offers backup power during power outages and can store energy produced by solar systems for later use in the home or to feed back into the electric grid at times of peak price, might be made using vehicle batteries.

Cost of Reusing the battery

The US Department of Energy (DOE)'s Vehicle Technologies Office provided funding to the National Renewable Energy Laboratory (NREL) to develop the B2U Repurposing Cost Calculator[14], a tool for estimating the costs associated with recycling Electric vehicle batteries[14] which came out in June 2015. TransLink could use it to determine the profitability of replacing EOL electric bus batteries as well as capital, labor, and other business costs. The model is easy to update with actual costs despite providing some basic recommendations on cost ranges for reusing electric vehicle batteries.

The main assumptions in the model are:

- Batteries would be collected from a catchment area within a round trip of 320 miles from the facility (8-hour round trip for collection).
- The facility would have a throughput of 1 million kWh each year.
- It would process 547 modules/day (200,000 modules/year).
- Capital costs are $15 million for a 15,000 sq. ft. building.
- Labor, testing, and material costs were estimated for a battery pack with a nameplate capacity of 5kWh; a nameplate energy density of 150Wh/L; nameplate specific energy of 115Wh/kg; and a mass of 43.5kg with remaining capacity of 3.5kWh at the time of repurposing; and
- The facility has 83 employees and 199 technicians.

According to the NREL study for which the model was created, batteries can be reused for as little as $20/kWh or $500 each. The model includes charges for battery purchase and repurposing of $24/kWh each for a total reuse cost of $44/kWh. In contrast, a brand-new battery costs roughly $135 per kWh[16], according to BloombergNEF's survey on battery prices for 2021. Also, BNEF continues to forecast that by 2024, battery prices might reach a low of $100/kWh.

The NREL study concluded the following regarding electric vehicle battery reuse which may also be applicable to TransLink:

- Compared to automotive service, use in peak shaving applications would entail relatively benign duty cycles, where the second-life battery would be expected to last an additional 10 years.
- Community benefits would include decreased cost of plant operation, reduced GHG emissions and fossil fuel consumption, and deferral of battery recycling.

Element Energy also carried out a recent European Union (EU) study on the relative economics of reuse vs. recycling of EOL Electric vehicle batteries. This study predicted that in 2030, under the baseline recycling case and baseline uptake scenario, the estimated price paid by the end-customer for repurposed batteries would be $40.4/kWh[15] compared to the purchase price of $70/kWh for new electric vehicle batteries. The economic analysis included consideration of extended producer responsibility (EPR) fees paid by obligated producers in Europe under various future scenarios and concluded that Electric vehicle battery reuse would considerably lower the producer's compliance costs with the legislation.[10] The cost components in the analysis are presented in figure 9.

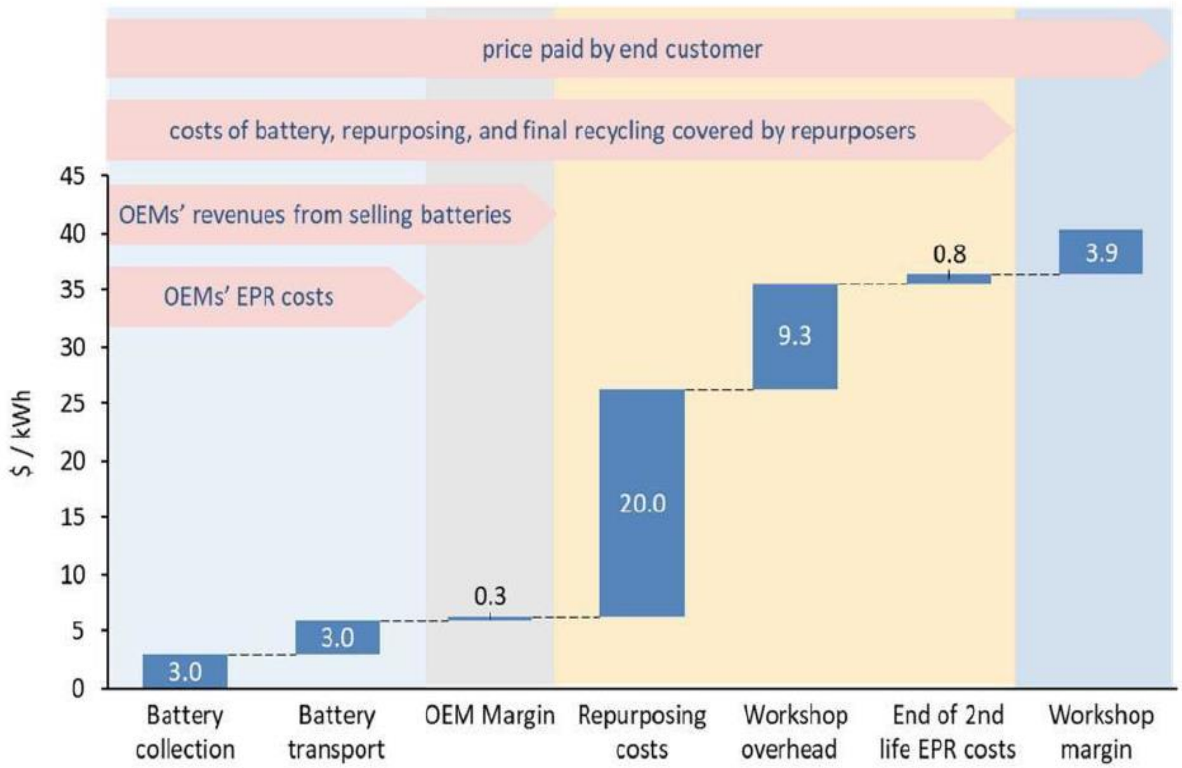

Figure 8: Cost Components for a Repurposed Electric vehicle Battery in the EU in 2030[10]

This graph in figure 8 clearly shows the costs associated with battery repurposing at all phases, including the EPR costs that OEMs must incur and the final price paid by the user in US dollars per kilowatt-hour.

COMPARATIVE ANALYSIS – REUSE VS RECYCLE

Since both options—recycling and reusing—are environmentally friendly. The economic comparison of these two solutions is crucial when making a final recommendation. Kindly note these values are associated with estimations from the market and research analysis and is nowhere representation of TransLink's cost analysis. This analysis provides a bird eye view to initial estimates.

Economic Impact

This illustration compares the economic effects of recycling and reuse. Based on above mentioned information, recycling a battery that weighs 400 kg and has 50% of its capacity left can cost between $500 and $1,500 per battery. However, putting the battery to reuse can generate earnings of at least $50/kWh. To compare the costs of recycling and reusing two well-known battery chemistries, NMC and NCA are considered.

For ease, the information is obtained at different battery capacities available. Since it is impossible to estimate costs precisely, a profit margin range of $10 per kilowatt hour to $30 per kilowatt hour is considered. Estimated reuse profits range from 50% to 70% cell redeployment. The recycling expenses are depicted without considering recovered materials revenues, which vary depending on the technique and battery content.

Chemistry	Battery Size (kWh)	Battery Weight (kg)	Reuse Value at 50% Reuse and $10/kWh Profit	Reuse Value at 60% Reuse and $20/kWh Profit	Reuse Value at 70% Reuse and $30/kWh Profit	Recycling Cost at $1,000/t	Recycling Cost at $2,000/t	Recycling Cost at $3,000/t
NCA	80.5	478	.+$403	+$966	+$1691	-$478	-$956	-$1434
C/NMC	60	435	+$300	. +$720	+$1260	-$435	-$870	-$1305

Table 10: Estimated Comparative Costs and Revenues for Reusing and Recycling EV Batteries[15]

For example, the net profit in the reuse market for a C/NMC type of battery chemistry with a 60kWh capacity would be $300 in the worst-case situation and over $1,300 in the best-case scenario. On the other hand, before material credits, recycling expenses per unit might range from $400 to $1,300.

As noted in the section on the cost of reuse, NREL calculated that reuse costs $24/kWh, with an extra $20/kWh considered for purchasing BEV batteries. This $20/kWh price may not reflect the state of the market right now. The scenarios in the table imply various revenues ranging from $10 to $40 per kWh, if the net cost of recycling the Electric vehicle batteries is $44/kWh. In the low range, this amounts to a retail price of $54 per kWh for the recycled battery instead of paying $145 per kWh for cells and $190 per kWh for packs in 2018 to buy a new battery.[15]

The repurposed battery would be sold for $84/kWh at the $40/kWh profit level, which is still significantly less than the cost of a brand-new battery. It is unknown what value used batteries will sell for when the cost of new lithium-ion batteries declines, but a Swedish analysis predicts that the reuse market will continue and that sale prices will fall to $40/kWh. [15]

The actual costs associated with recycling electric vehicle batteries are one of the key unknowns in this situation. These prices have been cited as ranging from $1,000 to $5,000/tonne in various references, with the latter figure coming from the Argonne National Laboratory (ANL), a respected source. Research conducted for this study was unable to identify firm expenses since recyclers and customers thought the information was confidential and commercially sensitive. The research shown in the Table was done for recycling values ranging from $1,000 to $3,000/tonne. In contrast to the reuse analysis, which utilizes kWh, battery pack costs are assessed based on weight.

The fact that the battery recycling gives businesses like Tesla access to supplies of important commodities, particularly cobalt, is one of the main strategic concerns. Therefore Tesla believes recycling is preferable to reuse and is already setting up an electric vehicle battery recycling facility at one of its locations. On the other hand, significant businesses with limited financial resources to invest are hesitant to do so at this moment until there is greater clarity regarding potential battery chemistries and a guaranteed supply of materials through a well-established infrastructure for collection.

STAKEHOLDERS

Various stakeholders were contacted to do an industry scan and understand stakeholders' contribution towards bus electric batteries (BEBs) disposal, reduce and recycle strategies. Kindly note, the information is based on discussion and some information might not be validated.

S.No	Name	Company	Designation	Contact information
1	**Chad Sanowy**	**New Flyer**	**Regional sales manager**	chad_sadowy@newflyer.com
2	**Stephen Sang**	**BYD**	**Regional sales manager**	stephen.sang@byd.com
3	**Matt Nadon**	**Nova Bus**	**Regional sales manager**	mathieu.nadon@volvo.com
4	**Mike Bismeyer**	**Proterra**	**Regional sales manager**	bismeyer@proterra.com

Table 11: List of OEM's

S.No	Name	Company	Designation	Contact information
1	**Sumreen Rattan**	**Moment Energy**	**Co-founder**	sumreen@momentenergy.com
2	**Tobi Adesanmi**	**Li- cycle**	**ESG and sustainability manager**	Tobi.Adesanmi@li-cycle.com
3	**Leonard Olien**	**(CREA) Canadian Renewable Energy Association**	**Director, energy storage**	lolien@renewablesassociation.ca

Table 12: OTHER STAKEHOLDERS (recycler/refurbisher)

OEM's

NEW FLYER

New Flyer provides the warranty on the battery packs for typically 12 years. **The battery manufacturer for New Flyer is XALT.** The battery chemistry which they most commonly use are Lithium, Manganese, Cobalt, and Nickle (NMC). The average weight of the battery is 1250 lbs. **NF has developed a partnership with Li-Cycle**, a recycling subject matter expert, to continuously research battery recycling technologies as part of their EPR strategy.

New Flyer, under parent company NFI Group Inc., currently has 1,900 zero-emission buses in operation and a total of 8,600 buses with electric motors and battery propulsion.

NOVA BUS

As per Nova Bus, they typically provide warranty of around **6-8 years**. The design life of the battery is 8-10 years. The battery manufacture for Nova Bus is Volvo in association with AKASOL.

The **EPR policy is under consideration**, and they have started working on it following the parent company Volvo initiatives. Nova Bus is in talks with recyclers for pilot projects to discuss their battery disposal solutions.

The battery chemistry which they most commonly use are Lithium Ion Nickle, Cobalt Oxide Aluminum (NCA). The average weight of the battery is 1179 lbs.

BYD

The battery chemistry mist commonly preferred by BYD is LFP (Lithium, Iron, Phosphate) chemistry. Major applications that BYD batteries are repurposed as second life is **forklift** and **some energy storage application.** The company has started taking into consideration the EPR policy in Canada but hasn't finalized anything yet. Though they have existing EPR system in China.

Current laws in China accounts for tracking the battery system from cradle to grave and everything needs to be accounted before the left-over material goes to the landfill which is followed by BYD as well. BYD collect spent vehicle batteries from dealerships across China, drawing from buses, taxis and other vehicles manufactured by the automaker, and deliver them to Shenzhen Startup **Pandpower** for performance tests.

PROTERRA

The company offers a battery leasing program that guarantees replacement after **six years** — which means plenty of useful life will remain in the battery, as much as 80-90% charging capacity. **To exploit the remainder of this capacity, Proterra has plans to reuse the batteries in second-life applications**. The batteries are later sent to Redwood's facilities for recycling in **Carson City, Nevada**. Proterra has sent around 26,000 pounds of battery material to Nevada for recycling, though this does not represent the pace of future deliveries.

With that option, the cost of the electric bus will be equivalent to the diesel bus fleet and hence can be easily transitioned without any extra cost. **Under the 12-year battery lease**, Proterra will own and **guarantee the performance** of the batteries throughout the life of the vehicle. The battery lease agreement provides a battery performance warranty which includes battery replacement at mid-life. Replacing batteries at midlife will help to ensure consistent vehicle performance, lock in battery costs, and provide customers access to Proterra's latest battery technology as it improves over time.

The Federal Transit Administration specifically includes battery-leasing in the FAST Act as well as the Low-No grant program . Metrolink and Part City are the two major examples who have entered into a battery service agreement with Proterra.

OTHER STAKEHOLDERS (Recyclers/Repurposers)

Moment Energy

Moment Energy provides lean, affordable, and reliable energy storage solutions by repurposing retired electric vehicle batteries.

Moment Energy gave insights on the challenges they face to recycle the retired batteries, the success rate and other key information. As per them, repurposing the retired batteries is a solution which require more attention than the recycling of batteries for recovering raw materials. The carbon footprints are lower when we repurpose the retired items. As they convert the retired battery to energy storage solutions, they use packs **of 60 kwh** each and add as per the requirements. **The preferred composition is NMC.** They provide a guaranty of **7 years on these solutions and the cost is 2/3rd compared to the new battery installation cost.** Before using the batteries, they test the batteries by constant charging and discharging techniques.

The minimum requirement for the battery is to be not less than 70% charging capacity for it to be repurposed for energy storage. The normal voltage requirement is 600 volts.

Along with the electric vehicle batteries, they recently tested the BEB's for repurposing.

The company works on two models:

- **Project based approach**: In this, they design the retired batteries for to be used in energy storage application within the industry/company.
- **Buy retired batteries:** They buy the retired batteries and repurpose it and sell it to other clients.

Li-Cycle

Li-Cycle is a lithium-Ion battery recycling company. It provides sustainable process for recovery of critical materials from all types of lithium-Ion batteries.

Li-Cycle have agreement with clients to recycle the battery. **They receive battery packs directly from the client. They claim a recovery rate of 95%** of the valuable material. Per the government norms, **Li-cycle holds the responsibility of disposing the hazardous material of any battery** that comes under their considerations. The responsibility is shifted from the battery owner to Li-Cycle.

Metrolink, Ontario also has agreement with them for their EOL solutions along with other OEM's as mentioned above. There are certain subsidies which are available for the recycling of these retired batteries. There may be some tax benefits for the company as well. The company follow all the regulations related to waste management. Li-Cycle capacity is to recycle 10,000 tonnes annual capacity, targeting 90,000 MT/Y by 2023**. GLENCORE** recently invested $200 million in Li-cycle.

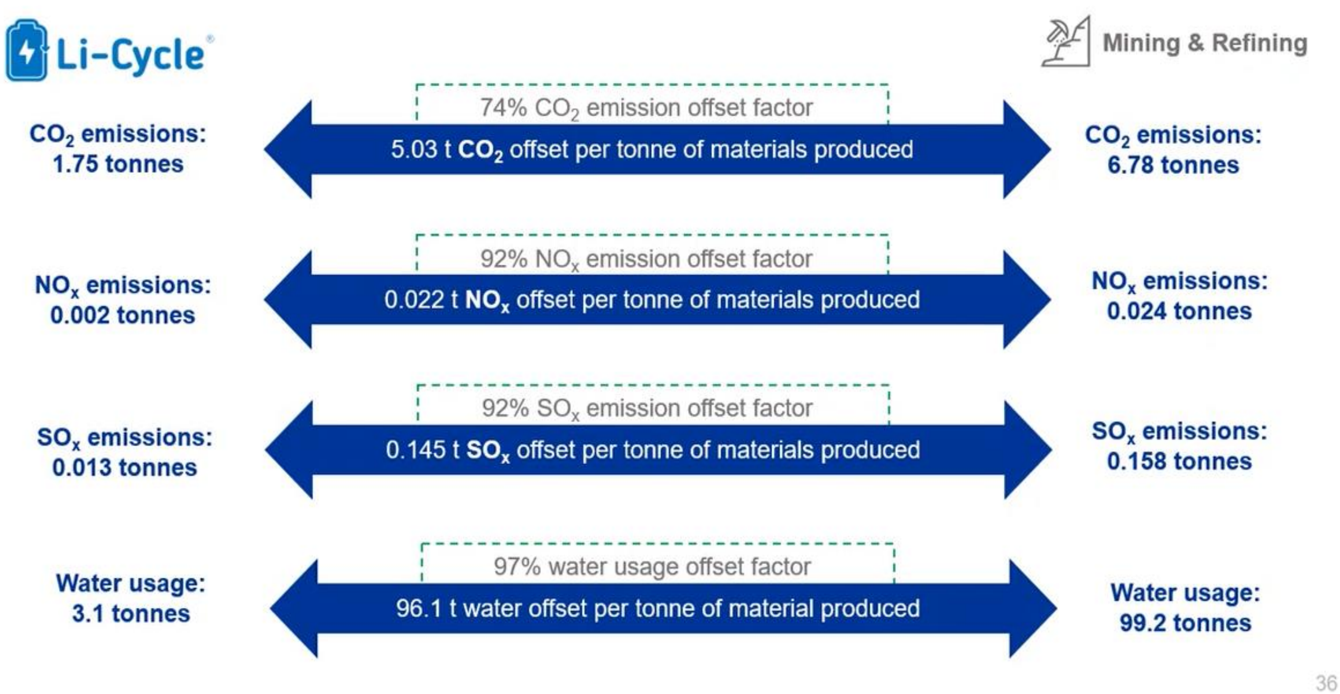

Figure 9 : Li-cycle emission reduction chart

Repurpose Energy

Repurpose Energy makes modular battery units for commercial and industrial applications from Nissan Leaf batteries. It is a second life battery industry in US. The approximately 150 kilowatt-hour units come complete with inverters and other components which they are ready to install. Prior to reuse, the batteries are thoroughly tested, and **the company's battery management system helps ensure performance and longevity**. They also come with energy-management controls that are optimized for use with renewable-energy systems and demand-response protocols.

The company works by replacing the most degraded cells in the battery which can be reused in another application outside of a vehicle for up to an additional 12 years based on Repurpose's initial calculations. Repurpose has developed a way to **test for battery degradation in about a minute — a process that traditionally takes a full day**.

Safety is one of the biggest barriers to attracting more capital into the nascent second-life battery industry. RePurpose is also developing a "nondestructive fire suppression system" that can detect an imminent battery failure and prevent the battery from overheating without damaging any of the electrical components. Mitigating risks to investors should help boost access to project financing.

The company is now engaged in validating **a 1.2-megawatt energy storage system in an industrial complex i**n Sacramento, thanks to a **$3 million grant from the California Energy Commission.** The need for such storage reserves in power is growing with the increased power outages in Northern California due to wildfire risk, especially in industrial applications with refrigerated goods.

POLICIES

POLICIES TOWARDS BATTERY RECYCLING/REPURPOSING

Canadian Regulations

The rules and standards for recycling used batteries are under provincial jurisdiction and are aimed at the businesses that take used batteries apart and recycle them, instead of the entire value chain. **Automotive Recyclers of Canada (ARC)** is an association that represents some 400 Electric vehicle recyclers and dismantlers throughout Canada. Its mission is to promote best practices in recycling. ARC members are required to follow the Canadian Automotive Recyclers Environmental Code created by ARC

Figure 11 shows the Canadian provinces which currently has battery stewardship and recycling regulations.

Several Canadian provinces are considering legislation imposing **extended producer responsibility (EPR) on battery manufacturers**. Province of Quebec and Ontario has released draft of EPR regulations in 2021 in addition to existing regulations. *This policy under the five-year action plan generally makes producers responsible for the collection and recycling of their products — to include the recycling of Electric vehicle and hybrid batteries.*

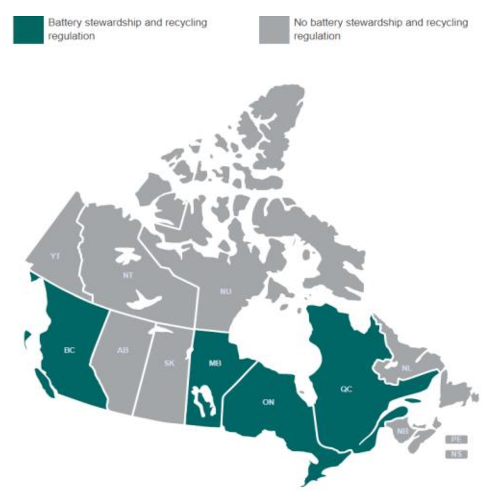

Figure 10 : Canada map with provinces which has battery stewardship[18]

What is an EPR plan?

According to the regulation, producers of designated products can appoint an agency to carry out their duties under an approved EPR plan. **The province reviews and approves the EPR plans** to make sure outcomes and regulatory requirements are met.

Every **five years**, the producer must review their approved plan. Following consultation, they must:

- Submit any amendments, or
- Advise the director in writing that the approved plan does not require changes

On or before July 1st each year, a producer with an approved plan must also:

- Provide an annual report
- Post the report on the Internet

Call2Recycle® and the Canadian Battery Association (CBA) both have National Stewardship programs for batteries. The CBA focuses on lead-acid batteries and Call2Recycle focuses on single use and small rechargeable batteries.

An EPR calculation tool has been created for reference. This can be used for initial EPR estimates. The recycling cost and transportation cost along with various other base values are taken based on stakeholder interviews and literature research. These can be updated in future w.r.t. changing cost estimates.[18]

The figure 11 below shows the EV battery lifecycle in an EPR system as followed currently in Quebec. The lifecycle starts when a battery is first sold and ends when it is processed for recycling or reuse (for energy storage or other).[19] Kindly note that the EOR flow is mainly for the electric vehicle and while comparing heavy fleet (buses), there might be more modifications to it.

The EV battery lifecycle in an EPR program differs mainly by:

• Batteries sent to automotive, and scrapyards also end up being recycled.

• Collection, sorting, and processing are all the financial and operational responsibility of the businesses (in the form of an individual program) or the management organization involved. Those three steps make up the EPR recovery program.[19]

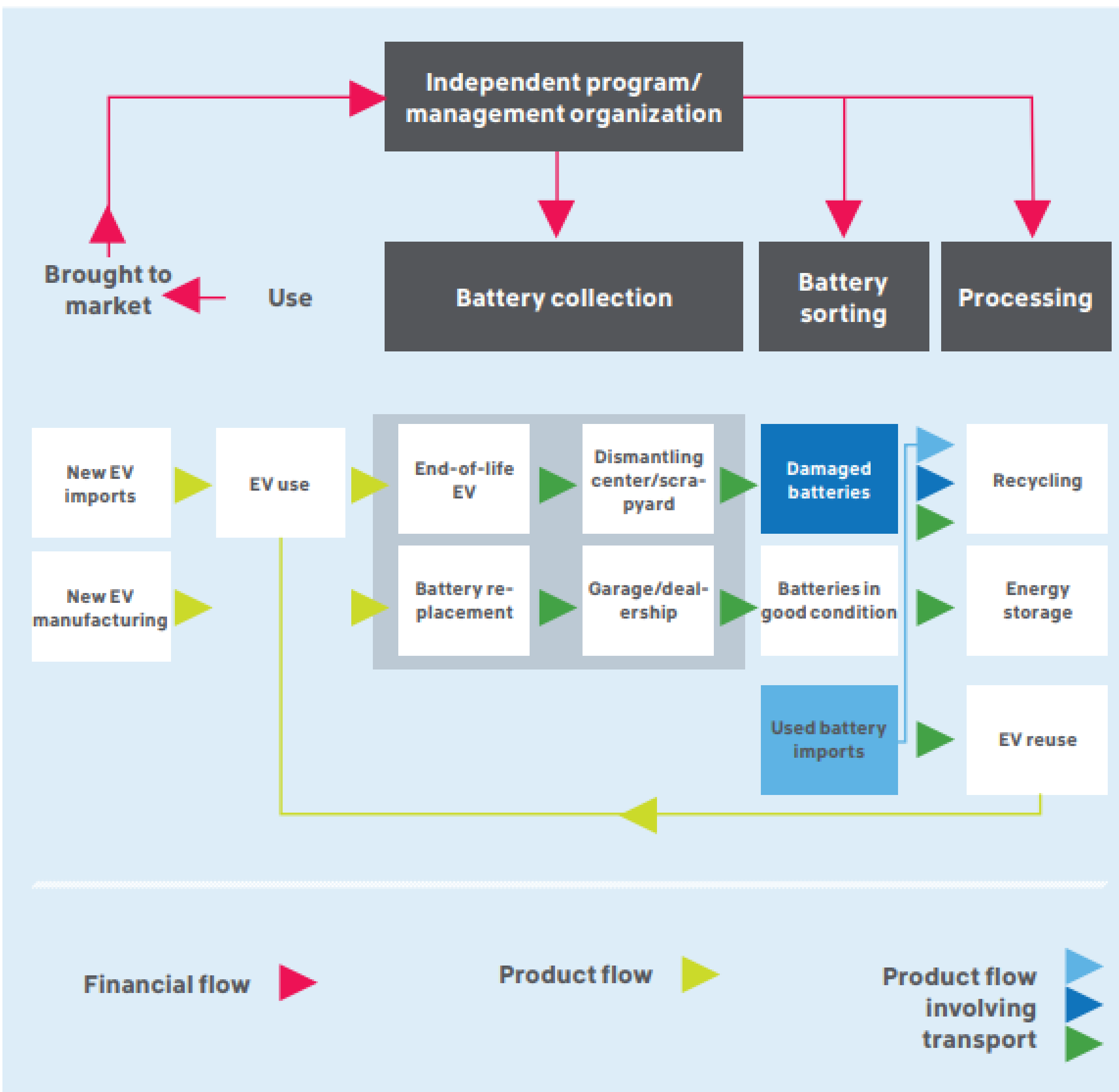

Figure 11: Battery life cycle under EPR Quebec[19]

BRITISH COLUMBIA

The Recycling Regulation under the authority of the Environmental Management Act sets out the requirements for Extended Producer Responsibility (EPR), formerly known as **product stewardship, in B.C.**

As B.C. aims to implement the first EPR Five-Year Action Plan program for electric vehicle batteries in Canada, it is anticipated that a phased-in approach will support advancements in reuse and recycling and establish B.C. as a leader in battery recovery and management. The changes under the EPR Action Plan will be phased in from **2021 to 2026** to give producers time to set up the necessary systems.

In British Columbia, the **Automotive Recyclers Environmental Association (AREA)** has developed an end-of-life vehicle recycling program for remote and First Nation communities.

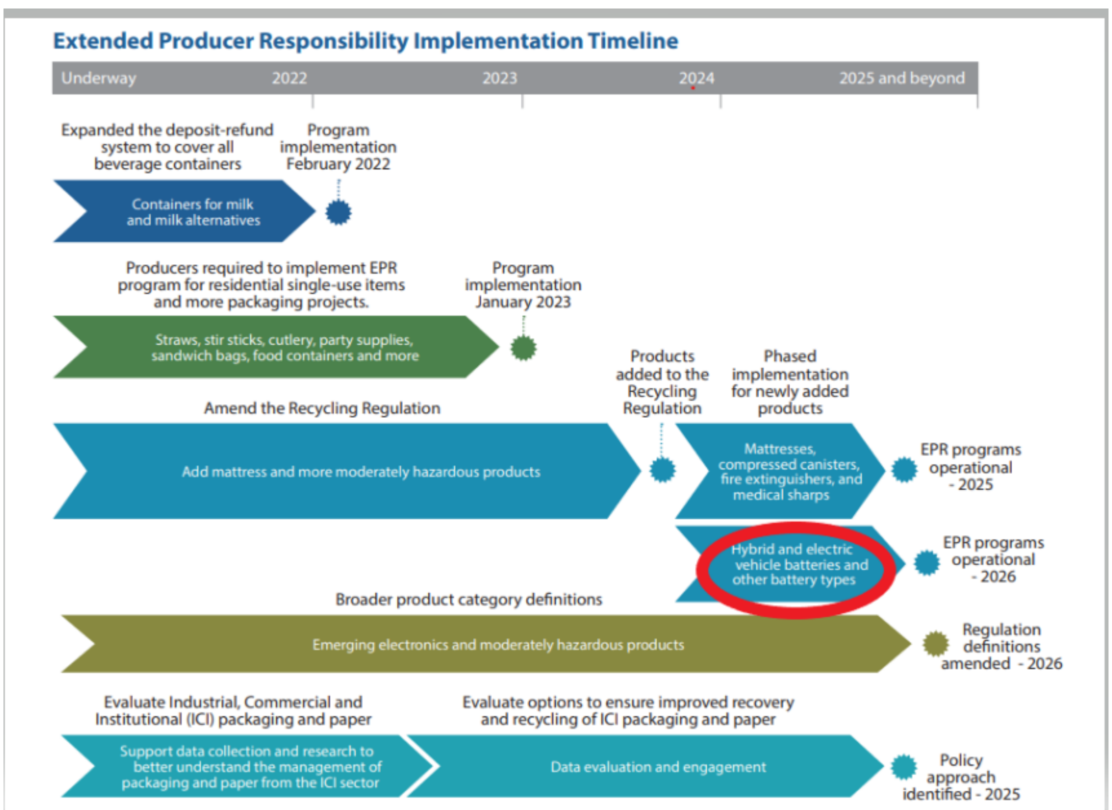

Figure 12 : EPR policy timeline[19]

USA

The situation in the United States is like that in Canada in the sense that there is not a federal law on end-of-life batteries recycling. National programs for the recovery of specific automotive parts are voluntary and are often for parts that contain regulated contaminants EOL batteries that are still under warranty. The two policies which have the maximum support are:

CORE EXCHANGE WITH A VEHICLE BACKSTOP

This policy defines responsibility **for out-of-warranty batteries** under two possible circumstances:

1. **For vehicles still in service**, if a battery pack, module, or cell is replaced before the vehicle reaches EOL, a core exchange program detailed by the vehicle battery supplier shall be used for the replacement battery (or any module or cell). According to this**, the entity removing the battery shall be responsible** for ensuring the used battery (or module or cell) is properly reused, repurposed, or recycled. The entity selling an electric vehicle battery shall use a core exchange program to track that the used battery has been properly managed.

2. **For electric vehicles reaching EOL,** a **dismantler** who takes ownership of an EOL vehicle is **responsible** for ensuring the battery is properly reused, repurposed, refurbished, or recycled. If an electric vehicle battery is directly reused in another vehicle with no alterations, the process for electric vehicles still in service shall apply. **If the battery is refurbished or repurposed, the responsibility transfers to the refurbisher or repurposer**.

PRODUCERS TAKE-BACK

1. The **auto manufacturer is responsible** for ensuring proper repurposing, reuse, or recycling of its electric vehicle traction batteries by a licensed facility at no cost to the consumer if they are no longer wanted by the owner, and in the event no other entity has taken possession of the battery.

2. Auto manufacturer responsibility initiates when the auto manufacturer has been notified the battery has reached its EOL and is available to be properly managed. If the battery is repurposed, the **EOL responsibility transfers to the repurposing company.** This responsibility includes arranging reverse logistics to transport the batteries to recycling hubs; being responsible for the recycling costs; and documenting the proper disposal of the battery.

Some identified advantages of both policies include

(i) Clearly defined responsibility for the EOL battery that transfers if it is repurposed.

(ii) The ability for batteries to be sold to a third party at EOL which provides opportunity for growth in the remanufacturing, refurbishing, and repurposing industry without requiring a partnership with the vehicle OEM.

Disadvantages include potentially higher costs for battery suppliers and vehicle OEMs who will likely only be called upon to manage LIBs with negative value.

SUPPORTING POLICY PROPOSALS

CATEGORY	POLICY	PURPOSE
Access to battery information	Physical labeling requirement	Facilitate sorting to improve process efficiency; enable easy identification of battery and vehicle OEM
	Digital identifier	Identify LIB chemistry at EOL; identify responsible party for safe disposal; improve safety during disassembly
	Universal diagnostic system	Reduce cost of testing; enable performance guarantees for reused and repurposed batteries
Support repurposing, reuse, and recycling industry development	Recycling incentive packages	Mitigate upfront capital costs; encourage recycling within California
	DTSC permit timeline	Reduce cost of locating processing facilities within California
	Expand eligibility for battery storage systems	Enable cost-competitiveness with new batteries
Safe and efficient reverse logistics	Support enforcement of unlicensed dismantling laws	Prevent environmental hazards and stranded batteries due to unlicensed dismantling
	Develop strategic collection and sorting infrastructure	Reduce transportation cost

Table 13: Supporting policy proposal for US

EUROPEAN UNION

In Europe, EPR for electric vehicle batteries is governed by the Directive on batteries and accumulators (2006/66/CE) and the Directive on end-of-life vehicles (2000/53/CE). The EU Battery **Regulation** aims to decrease the environmental burden of batteries as well as increase the EU-based supply chain by creating **sustainability-based barriers-to-entry**, thus increasing the competitiveness of local companies.

The proposed EU Battery Regulation contains several measures specific to battery EOL, including:

- **Mandated extended producer responsibility (EPR)** for proper EOL management and attainment of collection and recycling targets
- **Transfer of EPR** when batteries are repurposed in second-life applications
- A reporting system for ELECTRIC VEHICLE and industrial batteries, and **target EOL collection rates of 65% in 2025** and 70% in 2030
- **Minimum material recovery rates** that must be met or exceeded during each recycling process for cobalt, nickel, lithium, and copper.

CHINA

China is the world leader in electric vehicle fleet size, and therefore one of the few countries in the world that is already concerned about the impacts caused by short- and long-term battery disposal.

Vehicle manufacturers are responsible for the recovery of batteries, requiring them to set up recycling channels and service outlets where old batteries can be collected, stored, and transferred to recycling companies.

Furthermore, since **2017 a new legislation forbids the import of electronic waste into China**, including batteries due to **health and environmental hazards.**

*FUN FACT: The city of Shenzhen **has developed a pilot program** that took place from 2018 to 2020. The program consisted of a **deposit-refund system** for batteries. By means of this strategy, the government charges retailers **the initial fee of 20 RMB** per kilowatt-hour for each electric vehicle sold.*

In 2018, the "Application of Financial Support Policies for New Energy Vehicles" in Hefei stated that ELECTRIC VEHICLE battery manufacturers, who are involved with used battery collection systems and ELECTRIC VEHICLE batteries recycling, was granted a **subsidy of 10 RMB per kilowatt-hour**

In 2020, China has implemented the **pilot electric vehicle Recycling Initiative** in 17 cities/regions, controlling the number of new enterprises involved in recycling to make full use of existing infrastructure. In addition, they launched a **Battery Traceability Management Platform** to better track ELECTRIC VEHICLE batteries throughout their life cycle. In 2018, China enacted the Interim Measures for the Management of Recycling and Utilization of Power Batteries of New Energy Vehicles which requires manufacturers to **work with recycling companies to improve the recycling process**, by **labeling batteries** and encouraging design for recycling.

Most recently, the Chinese government has put forward a **policy proposing to ban**, at least temporarily, the **use of repurposed batteries in large-scale energy storage applications** (National Energy Administration, 2021). The policy does not propose a permanent ban and still allows second-life batteries for small-scale energy storage applications. The energy regulator said the ban would last until after the industry "crosses a key threshold" in **utilizing batteries under different storage and cycling conditions**. The regulator also said it plans to set up a new review system to inspect battery performance.

The table 14 shows the relevant regulations for each stage of recycling/repurposing activities.

Regulated activity	Relevant regulations
Dismantling	● Facility licensing requirements: California Vehicle Code Division 5 ● Fire and building codes and standards: NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code
Transportation	● Hazardous materials regulations: 49 CFR §173.185 (special consideration for damaged batteries)
Storage	● Fire and building codes and standards: NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code ● Federal Universal Waste regulations: 40 CFR §273.[1] ● CA Universal Waste Laws: Chapter 23 title 22 of CCR
Disassembly	● High voltage equipment and personnel safety references: NFPA 70B/E; IEEE C2 and IEEE 3007.3; OSHA 29 CFR 1926 and 1910 ● Fire and building codes and standards: NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code ● Universal waste regulations: 40 CFR §273.[1] ● CA Universal Waste Laws: Chapter 23 title 22 of CCR
Energy Storage System (ESS) Installation	● Interconnection: CPUC Rule 21, CAISO/FERC Tariffs ● Electrical storage requirements: California Fire Code 1206; NFP 855; International Fire Code
Hazardous Waste Treatment	● Universal waste regulations: 40 CFR §273, Subpart E ● Permitting requirements: 40 CFR §§124 and 270 ● Standards for hazardous waste treatment, storage, and disposal facilities: 40 CFR parts 264, 265, 266, 268, 270, and 124 ● Notification requirement: section 3010 of RCRA. ● CA Universal Waste Laws: Chapter 23 title 22 of CCR ● CA specific: Health and safety division 20 chapter 6.5
Export	● EPA: RCRA export requirements for universal waste

Table 14: Formal Regulations in North America for Different Battery Repurposing Stages.

A code has been developed which details the specifications necessary for the design of stationary energy storage devices; however, the standard is meant to provide guidance for large Li-ion battery packs that store energy from massive photovoltaic systems or turbines. The table below show the details of codes applicable to the re-purposed electric vehicle battery packs. focusing on codes which are specific to the battery pack used in the stationary assembly.

CODE CATEGORY	CODE TITLE	CONNECTION TO RE-PURPOSED PACKS
BATTERY PACK	IEC 61960 Ed 3: Secondary lithium cells and batteries for portable applications	Covers criteria for the selection of secondary lithium cells for remanufacturing.
	IEC 62485-2: Safety requirements for secondary batteries and battery installations—Part 2: Stationary batteries	Covers protections from hazards with stationary battery packs with nominal voltages less than 1500 V
	IEC CD 62619: Secondary cells and batteries containing alkaline or other non-acid electrolytes. Safety requirements for secondary lithium cells and batteries, for use in industrial applications.	Under development, covers requirements on all aspects of stationary application use of Li-ion batteries including erection, use, inspection, maintenance, and disposal of cells
	IEC CDV 62620: Secondary cells and batteries containing alkaline or other non-acid electrolytes—Secondary lithium cells and batteries for use in industrial applications	Covers tests and requirements for Li-ion cells to be used in a stationary application
	ICE 62620 Ed: Large format secondary lithium cells and batteries, for use in industrial applications.	Cover specification for cells in secondary industrial applications
	IEEE 1660: Guide for Application and Management of Stationary Batteries Used in cycling services	Covers battery management strategies, with changes relative to cycling for stationary applications

	UL 1642: Lithium Batteries	Covers requirements for lithium batteries in stationary applications for safety of technicians, users, and other design features
	UL 1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	Covers requirements for battery systems for use as energy storage for stationary applications such as for PV, wind turbine storage, for uninterruptible power supply (UPS), etc., applications.
ENTIRE ASSEMBLY	ANSI C84.1: Electric Power Systems and Equipment—Voltage Ratings (60 Hertz)	Standard covers nominal voltage ratings and operating conditions for 60-Hz systems above 100 V
	IEC 62257-9-2: Recommendations for small renewable energy and hybrid systems for rural electrification—Microgrids	Standard covers requirements for how microgrids can be maintained and safety upheld
	IEC 62897: Stationary energy storage systems with lithium batteries—Safety requirements (under development)	Covers hazards that need to be mitigated for the use of a stationary pack with Li-ion cells
	IEEE 1375: Guide for the protection of stationary battery systems	Covers guidelines for options of protecting stationary battery systems
	NFPA 111-2013: Standard on stored electrical energy emergency and standby power systems	Covers safe operation of stationary energy storage systems with the grid in the event of service disruptions
	UL 9540: Outline for investigation for safety for energy storage systems and equipment	Covers safety for all energy storage systems, being charged and discharged at a later point in time to shift demand

Table 15: Applicable codes for re-purposed Li-ion battery packs in a stationary application and the repurposed battery pack assembly in the US.

RECENT INVESTMENTS IN BATTERY EOL INDUSTRY

Below are the recent investments done in Canada and Europe towards End-of-Life Disposal of batteries.

- Ngen Canada announces $76 Million in Zero-Emission Vehicle Investments on 3 May 2022. It includes various market leaders investing in the repurposing and recycling of the used vehicle batteries.
- The government of Québec unveiled its provincial budget which will commit $6.7 billion of funding over the next six years to a number of initiatives designed to combat the climate crisis and encourage the continued electrification of transportation. In this, $18 million over five years is to bolster the province's electric vehicle battery recycling capabilities.
- B.C. government committed $419 million towards climate action supporting mainly province's zero electric vehicle targets. From which a sum of $5 million will be dedicated to purchasing incentives for zero-emission buses.
- At the end of January 2021, the EU Commission allocated 2.9 billion euros of public support to study and innovate the entire battery value chain, the project is "European Battery Innovation".

CONCLUSION

This project involved a detailed literature review as well as interviews to identify the current and near-term future processes employed for the reuse and recycling of electric vehicle batteries. The various battery chemistries are briefly explained. The existing and projected electric vehicle battery technologies and chemistries, as well as any potential financial concerns with electric vehicle battery recycling and secondary usage, were discussed. Additionally, the regulations for recycling and reusing EOL batteries were thoroughly addressed in relation to different nations. The study's conclusions are enumerated below:

- There are various battery chemistries available in the market. Each type of battery has its own advantages and disadvantages. Currently, **Lithion-ion based batteries are most used in vehicles.**
- After the battery reaches its end of life, there are two options to deal with the EOL batteries – **Recycling and Reuse.**
- Although recycling of small-sized li-ion consumer batteries is well-established in the US, recycling of li-ion electric vehicle batteries is much more difficult due to the units' weight (up to 400–500kg for various models), risk until fully discharged, and extensive disassembly. Electric vehicle battery recycling costs are not well known or understood; however, it appears that employing current technologies incurs a cost rather than generating income based on metal prices. Electric vehicle battery owners are charged a fee based on the time it takes to recycle the battery by conventional recyclers, who also provide a credit for any metals recovered.
- For initial cost estimates of recycling the batteries, the tool by Argonne National Laboratory - a recycling cost model called Everbatt[9] shall be considered.
- Battery recycling processed is a cost intensive process, The cost of recycling process is estimated by comparing the two-leading lithium-ion battery chemistry – NMC and LFP. It is concluded that the recycling cost of LFP provides very little revenue compared to the NMC chemistry battery type.

EV battery chemistry	Net Profit ($CAD/metric ton)	Revenue ($CAD/metric ton)	Cost ($CAD/metric ton)
LFP	**645**	2011	1364
NMC	**3340**	6989	3649

- The reuse of batteries has been discussed in detail, explaining potential reuse applications e.g., off grid storage, peak reduction etc. The cost of reusing estimates has been provided including EPR cost.
- **Electric vehicle battery reuse is a much more economically attractive option** for electric vehicle battery owners for the foreseeable future compared to electric vehicle battery recycling. As the supply of electric vehicle batteries increases, and more standards are imposed on the reuse industry, the cost structure may change.
- For initial cost estimate for Reusing the batteries, National Renewable Energy Laboratory (NREL) developed the B2U Repurposing Cost Calculator[14] which can be referred for preliminary estimates.
- It is anticipated that the economics of the reuse stream will remain favorable even at a new li-ion battery cost of below $100/kWh and that up to 70% of EOL electric vehicle batteries could enter this pathway. Concerns raised about liability and insurance risks related to reconditioned units in energy storage applications could impact these predictions[17]
- Using EOL batteries in ESSs (Energy Storage Systems) is said to be able to prolong the life of the electric vehicle battery or some of its cells for a length of time ranging from six to 15 years or more.
- The various OEM's, New Flyer, BYD, Nova Bus and Proterra are currently focusing on ways to deal with the EOL batteries. Some are also taking EPR policy into considerations. It is also found that a few of them have already collaborated with recyclers and refurbishers for addressing their EOL battery solutions.

- Certain other stakeholders who deal in recycling and repurposing of the EOL batteries were interviewed and it has been found that there are local stakeholders in Vancouver which are already in this business of repurposing and recycling of the EOL batteries. E.g., **Moment Energy, American manganese**, **Li-Cycle** etc. which can be a starting point for collaboration to TransLink in future.
- TransLink is currently managing EOL batteries through the warranties with the OEMs, but they should continue to monitor the EOL battery industry and evaluate whether they need to change this practice to achieve better value for money.
- The Canadian regulations and standards towards battery recycling/repurposing are not very stringent currently but the regulations have started to form and there are certain policies towards EPR which has already been implemented in 2021. TransLink shall monitor the regulations and determine how and when they apply to Battery electric Buses and specifically TransLink.
- Mostly, the policies in Canada will be following similar pattern as of Europe and United States. The Chinese policies towards battery disposal have a similar pattern as well.
- There are huge recent investments in Canada towards battery EOL solutions e.g., NGen Canada announces $76 Million in Zero-Emission Vehicle Investments on 3 May 2022. It includes various market leaders investing in the repurposing and recycling of the used vehicle batteries.

The opinions in this report are based on best available information available as of mid-2022. The battery industry is evolving rapidly therefore the information in this report needs to be updated in mid- 2023 to remain current.

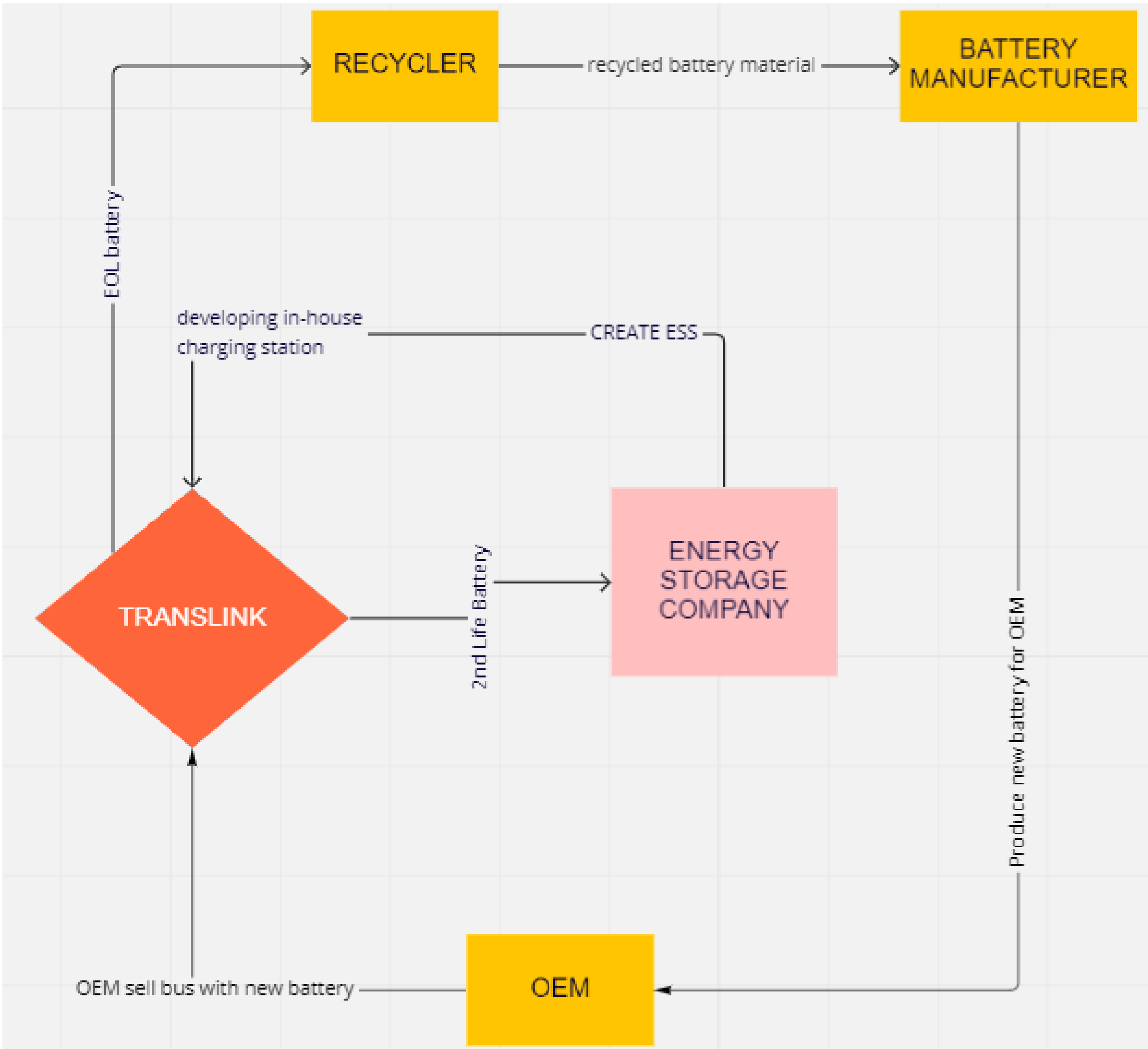

Figure 13 Possible LONG-TERM Scenarios

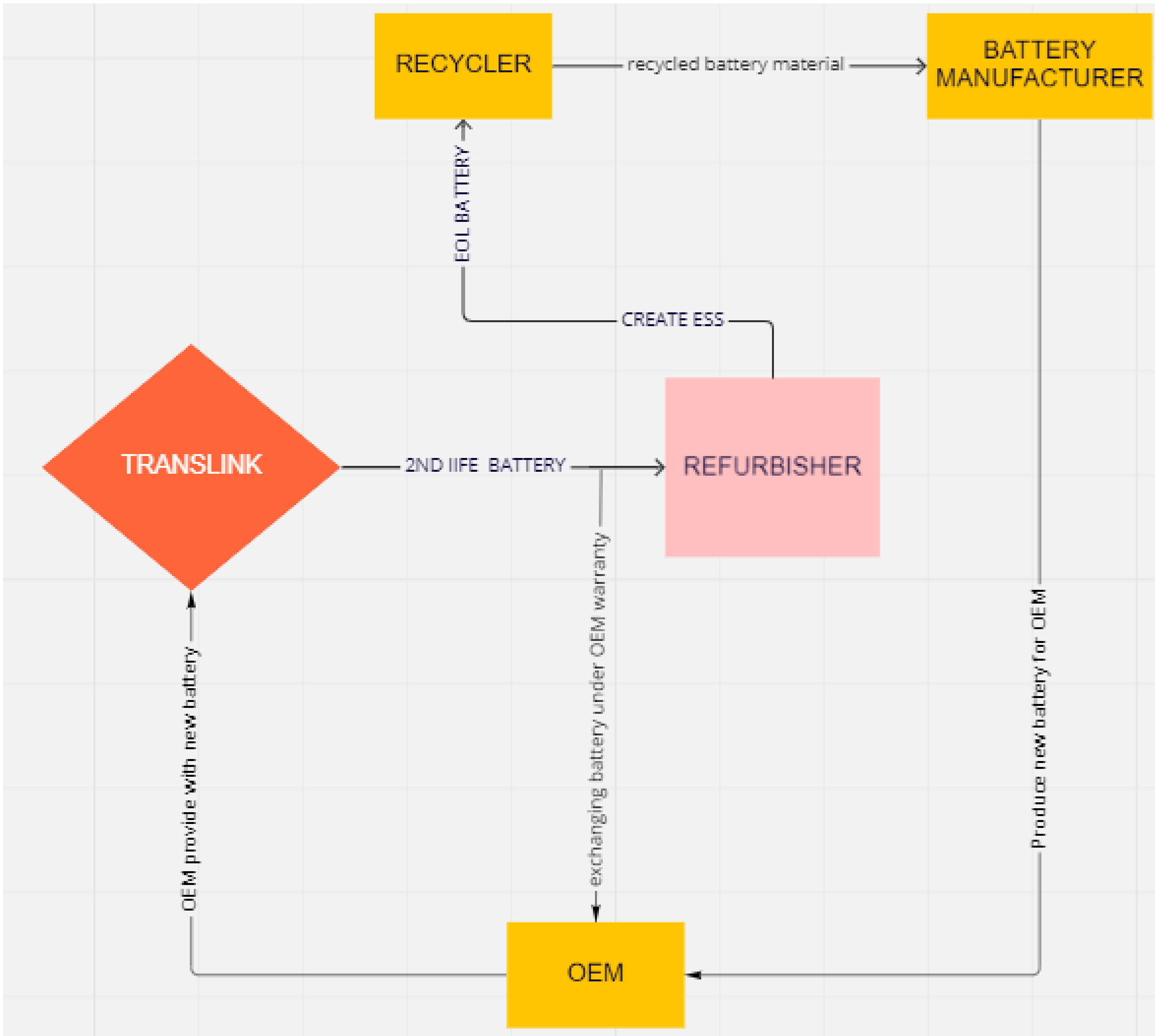

Figure 14: Possible SHORT-TERM Scenarios

Recommended Next Steps

A future recommendation is to carry out a detailed financial analysis of different recycling/reusing approaches for TransLink electric bus batteries using Canadian labor rates, commodity values and other regional factors to make the cost estimate more realistic for Canadian setting.

Though a possible short- and long-term scenarios are provided above in figure 13 and 14, TransLink should:

- Determine, based on future projection of bus procurement, the volumes of EOL batteries that will need to be handled.
- Developing long term, midterm, and short-term plans (based on financial and feasibility analysis) on whether to:
    - Continue warranty based EOL battery takeback by the OEMs
    - Consider battery leasing
    - Consider outsourcing the retired batteries to recyclers and refurbishers
    - Establish a reuse and refurbishment capability in-house like its existing diesel engine refurbishment capabilities and capacity
- Continue tracking OEM initiatives and practices to inform future financial and feasibility analysis and TransLink's options
- Seek advice from CUTRIC on the current policies and peer practices elsewhere in Canada and USA

REFERENCES

1 – *Underwriters Laboratories. UL 1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications; UL: Northbrook, IL, USA, 2018.*

2 - https://www.ratelconsulting.com/gigascrap.html

3. Gaines L, Dai Q, Vaughey JT, Gillard S. Direct Recycling R&D at the ReCell Center. Recycling. 2021; 6(2):31. https://doi.org/10.3390/ recycling6020031. Accessed May 27, 2021.

4. Haram, M. H. S. M., Lee, J. W., Ramasamy, G., Ngu, E. E., Thiagarajah, S. P., & Lee, Y. H. (2021, March 31). *Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges*. Alexandria Engineering Journal. Retrieved August 3, 2022, from https://www.sciencedirect.com/science/article/pii/S1110016821001757

5. Horesh, N., Quinn, C., Wang, H., Zane, R., Ferry, M., Tong, S., & Quinn, J. C. (2021, May 13). *Driving to the future of energy storage: Techno-Economic Analysis of a novel method to recondition Second Life Electric vehicle Batteries*. Applied Energy. Retrieved August 8, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S030626192100475X

6. Gaines, L., & Dai, Q. (n.d.). *Direct recycling R&D at the ReCell Center - Researchgate.net*. www.researchgate.net. Retrieved August 2022, from https://www.researchgate.net/publication/351587781_Direct_Recycling_RD_at_the_ReCell_Center

7 Haram, M. H. S. M., Lee, J. W., Ramasamy, G., Ngu, E. E., Thiagarajah, S. P., & Lee, Y. H. (2021, March 31). *Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges*. Alexandria Engineering Journal. Retrieved August 3, 2022, from https://www.sciencedirect.com/science/article/pii/S1110016821001757

8 environmental, k. (2019). KELLEHER RESEARCH STUDY ON REUSE AND RECYCLING OF BATTERIES EMPLOYED IN ELECTRIC VEHICLES.

9 Argonne National Laboratory. “EverBatt Download.” <https://www.anl.gov/egs/everbatt-download>

10 Element Energy. June 2019. “Batteries on wheels: the role of battery electric cars in the EU power system and beyond.” <https://www.transportenvironment.org/sites/te/files/publications/2019_06_Element_Energy_Batteries_on_wheels_Public_report.pdf

11 Xiaoming Ma et al. (2018). “The Recycling of Spent Power Battery: Economic Benefits and Policy Suggestions” IOP Conference Series: Earth and Environmental Science, 159. https://iopscience.iop.org/article/10.1088/1755-1315/159/1/012017

12 The Recycling of Spent Power Battery: Economic Benefits and Policy Suggestions, Xiaoming Ma et al., 2018 IOP Conference Series: Earth and Environmental Science, 2017

13 Haram, M. H. S. M., Lee, J. W., Ramasamy, G., Ngu, E. E., Thiagarajah, S. P., & Lee, Y. H. (2021, March 31). Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges. Alexandria Engineering Journal. Retrieved August 3, 2022, from https://www.sciencedirect.com/science/article/pii/S1110016821001757

14 https://www.nrel.gov/transportation/battery-second-use.html

15 Hanley, S. December 7, 2018. “Envision Energy Says EV Battery Cell Costs Will Fall Below $50/kWh by 2025.” <https://cleantechnica.com/2018/12/07/envision-energy-says-ev-battery-cell-costs-will-fall-below-50-kwh-by-2025/>

16 https://www.bloomberg.com/news/articles/2021-11-30/even-the-battery-boom-can-t-escape-world-s-supply-chain-woes

17 Catton, J.W.A., Walker, S.B., McInnis, P., Folwer, M., Fraser, R.A., Young, S.B., and B. Gaffney. (2019). “Design and Analysis of the Use of Re- Purposed Electric vehicle Batteries for Stationary Energy Storage in Canada.” Batteries, 5(14), 1-19.

18 https://propulsionquebec.com/wp-content/uploads/2020/11/ETUDE-REP-EN-FINAL-WEB.pdf?download=1

19 https://propulsionquebec.com/wp-content/uploads/2020/11/ETUDE-REP-EN-FINAL-WEB.pdf?download=1

20 Sustainable Lithium-ion Battery Recycling - American Manganese Inc.

21 Fitzgerald, D. December 11, 2018. “American Manganese takes step toward forming lithium-ion reuse partnership with Battery Safety Solutions.” https://ca.proactiveinvestors.com/companies/news/210991/american-manganese-takes-step-toward-forming-lithium-ion-reuse-partnership-with-battery-safety-solutions-210991.html

22 The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries, Ahmad Mayyas, Darlene Steward, Margaret Mann, National Renewable Energy Laboratory. Published in Sustainable Materials and Technologies 17 (2018) e00087.

23 ”First raft of EV batteries hits the end of the road. Here’s where they go to ‘die.’ January 18, 2019. <https://nationalpost.com/news/first-batch-of-ev-batteries-hitting-the-end-of-the-road-so-where-do-they-go-to-die>

24 https://www.nrel.gov/transportation/battery-second-use.html

25 Battery University. “BU-705a: Battery Recycling as a Business.” <https://batteryuniversity.com/learn/article/battery_recycling_as_a_business>

26 Arbabzadeh, M et al. May 2019. “Green principles for responsible battery management in mobile applications.” https://www.sciencedirect.com/science/article/pii/S2352152X19302956>

Appendices

APPENDIX A:

City or County (Transit Agency)	BEB[5] Purchased	Delivery Date (Manufacturer)
Stockton, CA (SJRTD)	17	2017 (Proterra)
Los Angeles, CA (LADOT)	95	2015 - 2017 (BYD)
Northern Los Angeles County, CA (Antelope Valley Transit Authority)	112	2018 (35 from New Flyer, unknown numbers from Proterra and BYD)
Los Angeles, CA (LA. Airports Authority)	20	April 2018 (BYD)
San Gabriel and Pomona Valleys, CA (Foothill Transit)	15	2017 (Proterra)
Boulder, CO	1	Summer 2018 (unknown)
Washington, DC (WMATA)	14	April 2018 (Proterra)
Chicago, IL (CTA)	20	2019-2020(Proterra)
New York, NY (NYC Transit Authority)	10	Date unknown (5 from Proterra, 5 from New Flyer)
Dallas, TX (DART)	7	July 2018 (Proterra)
Columbus, OH (COTA)	10	2019 or 2020 (Proterra)
San Francisco, CA (SF Metropolitan Transit Authority)	9	Fall 2018 (various manufacturers)
St Louis, MO	2	Late 2020 (Gillig)
Anchorage, AK (MOAPTD)	1	January 2018 (Proterra)
Hoboken, NJ (Columbia University shuttle system)	6	2018 (New Flyer)
Seattle, WA (King County Metro Transit)	20	2018, 2019 (Proterra, BYD, and New Flyer)
Louisville, KY (River City Transit Authority)	15	2017 (Proterra)
Madison, WI (Metro Transit)	3	2019 (unknown)
Indianapolis, IN (IndyGo)	21	2018 (unknown)
Philadelphia (Southeastern Pennsylvania Transportation Authority)	25	2019 (Proterra)
Rhode Island Public Transit Authority (RIPTA)	3	2018 (Proterra)

APPENDIX B:

DAIMLER (in-house solution)

Systems from second-generation smart electric drive vehicles are combined to create a stationary storage unit with a total capacity of 13 MW.

Process

- Daimler's subsidiary **ACCUMOTIVE** produces and prepares the battery systems.
- Daimler offers the corresponding electric and plug-in hybrid vehicles.
- The **Mobility House** and **GETEC** install and market the stationary battery storage unit.
- **Remondis** recycles the battery systems and reintroduces the valuable raw materials into the production cycle.

Benefits

- Give a second life to Vehicle Batteries
- Maintain the Battery Pack inside the automotive business

Location - Germany

HONDA & SNAM (Partnership)

Honda Motor Europe announced the partnership with French recycling specialist SNAM for collection of the end-of-life batteries from dealers/authorized partners in 22 countries.
After the collection SNAM investigate if batteries are suitable for 2nd life application or extract raw materials offers to the market for the production of new batteries.

Benefits

- Recover raw materials from battery packs

Location – France

APPENDIX C:

The types of reuse options already in place for EOL electric vehicle batteries include

- Reuse in electric vehicles
- Reuse of cells or packs in other battery applications (e.g., drones, wheelchairs, etc.)
- Residential energy storage (combined with solar PV system)
- Commercial and industrial (C&I) energy storage.
- Grid scale energy storage.
- Energy storage for renewable energy systems (solar and wind)
- Back-up power.
- Electric vehicle charging (stationary or mobile)

Examples Of EV Batteries in Reuse Applications'		
Company	EV Battery Reuse Application	Location
Acceleron	Energy storage	UK. Barbados
Audi	Forklifts and factory tugs	Ingolstadt, Germany" (see image below)
Audi	Battery storage	Berlin, Germane (see image below)
BJEV (b)	EV charging and back-up power	Not identified
BMW (a)	Energy storage farm	Leipzig, Germany
BMW (b)	Grid scale energy storage, back-up power	Not identified
BMW and Pacific Gas and Electric (PG&E) (a)	BMW i ChargeForward Project to use second-life EV batteries and EVs themselves to stablilize grid through demand response (DR)	San Francisco Bay Area
Box of Energy	Stores energy from rooftop solar panels to run elevators and lights	Sweden';
BYD (Build Your Dream), China (a)	Energy storage	Shenzhen, China
BYD	Grid scale energy storage, back-up power	
Chengan (b)	Back up power	
Chevrolet (a)	Back up power at a GM's Enterprise Data centre Grid scale energy storage; commercial and industrial (C&I) energy storage	Michigan, US
Daimler (b)		
Eaton (a)	Energy storage	South Africa
EcarACCU (a)	Solar energy storage	Cameroon
EVgo (a)	EV charging	California, US
Florida Power & Light (a)	Grid management	Florida, US
Fiat/IT Asset Partners (ITAP)	With ITAP. batteries are broken down into the individual cells which are then resold or repurposed	

General Motors	Remanufacturing	
GreatWall Power	Backup power, energy storage	Shanghai
Hyundai/W3rtsil8	Grid scale energy storage; C&I energy storage	
Honda/American Electric Power (a)	Grid integration of energy storage"	Ohio
ITAP (IT Asset Partners)	Salvaged solar panels and combined with EV batteries to supply power for recycling facility	Chatsworth, California
Mitsubishi	C&I energy storage	
Nissan	Remanufacturing, C&I energy storage, EV charging	
Nissan/Eaton/Mobility House (a)	Energy storage	Amsterdam, Netherlands
Nissan/Eaton with EDF Energy (a)	Commercial energy storage with French firm Powershift platform	UK
Nissan/Sumitomo (a)	Street lighting	Namie, Japan
Nissan/Sumitomo (a)	Large-scale power storage	Japan
Nissan	Back-up power for camping trailers	Not identified"
PSA	C&I energy storage	
Relectrify	I Residential solar storage, commercial peak shaving, grid support	Australia"
Renault (b)	EV charging, residential energy storage, grid scale energy storage	
Renault (a)	Renewable storage	Porto Santo Island
Renault (a)	Backup power for elevators	Paris, France
Renault / Connected Energy (a)	EV charging	Belgium
Rivian Automotive/Honnold Foundation	Stationary energy storage units in a microgrid project	Adjuntas, Puerto Rico."
SAIC	Back-up power	
Toyota	C&l energy storage, grid scale energy storage (NiMH)	
Toyota	Reuse of Prius hybrid batteries to run refrigerators in 7- Eleven stores	Japan"
Volkswagen Audi	C&I energy storage	Wolfsburg, Germany"
Volkswagen	Mobile charging station	
Volvo	Residential energy storage	
Yin-Long	Back-up power; C&I energy storage	

APPENDIX D:

GENERAL MOTORS

GM is using repurposed Chevrolet Volt batteries for energy storage from solar and wind generation at its vehicle testing facility in Milford, Michigan. The Volt batteries supply power to its Milford data center, and excess energy is returned to the grid supplying the rest of the facility. A similar scheme is in place in Japan, where Japanese trading company **Sumitomo** has a joint venture with Nissan Motors to reuse electric vehicle batteries.

RENAULT

The Advance Battery Storage system can store at least 60 MWh and providing 70 MW worth of power. In the long term, this system split between several sites in France and Germany will provide a reserve capable of **meeting the annual consumption needs of more than 5,000 households.**

Benefits

- Give a second life to electric vehicles batteries
- Reduce energy dispersion from the grid

Location – Europe

NISSAN LEAD BATTERIES

In January 2019, researchers UC Davis commissioned a commercial-scale assembly of used Nissan Leaf batteries to store energy from a local solar array. The second-life storage system, developed by Professor Jae Wan Park and his graduate students at the UC Davis Green Technology Laboratory, is reducing the on-peak energy use and carbon footprint of the UC Davis Robert Mondavi Institute – a combined winery, brewery, and food processing complex. The team **assembled 15 used Nissan Leaf battery packs** (combined energy capacity of 300kWh, or an average of 20kWh per pack) in a shipping container next to the winery, and control algorithms direct the batteries to charge with excess power from a 200kW rooftop solar system. **The batteries discharge during the evening to reduce the facility's energy use by at least 20%.**

APPENDIX E:

Specifications	Lead-acid	NiCd	NiMH	LCO	LMO	LFP
Specific energy density (Wh/kg)	30–50	45–80	60–120	150–190	100–135	90–120
Internal resistance (mX)	<100	100–300	200–300	150–300	25–75	25–50
Cycle life (80% discharge)	200–300	1000	300–500	500–1000	500–1000	1000–2000
Fast charge time	8–16 h	1 h	2–4 h	2–4 h	1 h or less	1 h or less
Overcharge tolerance	High	Moderate	Low	Low		
Self-discharge/ month (room temp.)	5%	20%	30%	<10%		
Nominal cell voltage (V)	2	1.2		3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.4	Full charge detection		4.2 V		3.6 V
Discharge cutoff voltage (V/cell)	1.75	1.00		2.5–3.00		
Peak load current	5 C	20 C	5 C	>3 C	>30 C	>30 C
Best result	0.2 C	1 C	0.5 C	>1 C	<10 C	<10 C
Charge temperature (^{o}C)	20 to 50 20 to 50	0–45 20 to 65		0–45 20 to 60		
Discharge temperature (^{o}C)	3–6 months	30–60 days		Not required		
Maintenance requirement			60–90 days			
Safety requirements	Thermally stable	Thermally stable		Protection circuit mandatory		
Toxicity	Very High	Very High	Low	Low		
In use since	Late 1800s	1950	1990	1991	1996	1999

APPENDIX F:

American Manganese:

American Manganese is **based in Surrey, British Columbia**, Canada and has been in business since 1987.[20] They are a critical metals and technology driven company, focused on lithium-ion battery recycling using its RecycLiCo™ Patented Process. They are a part of a consortium involved in the Lithium-Ion Battery Disassembly, Remanufacturing and Lithium and Cobalt Recovery Project lead by the Critical Materials Institute (CMI) which in turn is an Energy Innovation Hub, led by Ames Laboratory and supported by the US DOE, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office.

Their current efforts are focused on NMC and NCA chemistries. They take metal salts of nickel, cobalt and manganese, recover these from cathodes and reformulate the recovered chemical mixtures to meet battery manufacturers' specifications. This reduces production costs for the battery manufacturers. **The capacity of the plant is currently more than 1200 ton/**year (need to be confirmed at time of collaboration).

Retreiv Technologies (Cirba Solutions):

Retriev is one of the EV battery recyclers in North America having offices and battery receiving facilities at various locations across NA, receiving not just lithium but all EV batteries and chemistries, and directing them to its various facilities depending on location and capacity. The company's lithium battery recycling services started over 25 years ago by processing lithium primary (non-rechargeable) batteries only. The company uses its in-house database to track all cells, modules and packs received to date. Many battery manufacturers have multiple different packs depending on the vehicle for which the battery was designed. To date, Retriev has disassembled, analyzed, and processed over 100 distinctly different battery packs for EVs, including one-off experimental designs by battery makers that did not go into full production. There **capacity for the Trail, BC facility is 4500 tonne[22]** . **There Canada office is in Trail, BC. This makes this company second in list as a potential recycler.**

Retreiv Technologies is the only player in the market today that has an operational, differentiated business with a full suite of capabilities to address lithium-ion and cross-chemistry battery demand

Lithion

Lithion Recycling Inc. (Lithion) is developing a solution to recover and **isolate over 95% of battery components**, including high value elements like cobalt, lithium and graphite. With a CAD$3.8 million grant from SDTC, Lithion is planning a three-phase scale up to commercialization, beginning with a pilot plant. Lithion technology uses an innovative combination of hydro- and electrometallurgy-based extraction processes. The result is a low-carbon process generating zero effluent. The plants operating this technology will be very compact, modular, and affordable. Lithion is supported by a strong consortium of partners in the SDTC funded project consisting of: Seneca experts-conseils; Call2Recycle; Hydro-Québec's Center of Excellence in Transportation

Electrification and Energy Storage (CEETES) and Centre d’étude des procédés chimiques du Québec (CÉPROCQ).
They accept **lithium cobalt oxide (LCO), lithium nickel manganese cobalt oxide (NMC), lithium manganese oxide (LMO), lithium nickel cobalt aluminum oxide (NCA), and lithium iron phosphate (LFP).**
They have their **processing facility in Quebec, Canada which is a pilot plant with a capacity of 200 tons/year. This brings it third in the list of recyclers.**

Li-Cycle

*information provided in the report

Moment Energy

*information provided in the report

Repurpose Energy

*information provided in the report