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THE IMPORTANCE OF INVERSE LOGISTICS FOR PUBLIC TRANSPORT COMPANIES OPERATING A LARGE BATTERY ELECTRIC BUS FLEET

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Abstract: *Electric vehicles are becoming increasingly popular to reduce environmental impact and to make logistics systems more cost-effective. This trend is affecting not only passenger cars but also public transport, especially in developed countries. For electric buses, the recycling of high-capacity batteries is becoming an increasingly important issue, as no generally applicable recycling model has yet been developed in this area. The paper presents a literature analysis in this field and identifies the main trends in battery recycling. In essence, it opens the way for future research, i. e. the elaboration of different operational models.*

Key words: *Public transport, inverse logistics, electric buses.*

1. INTRODUCTION

Public transport operators with large bus fleets should not only focus on efficient and energy-saving operations, but also on decarbonization efforts in other areas, in addition to the electrification achieved through the introduction of electric vehicles. The batteries used in electric vehicles play a prominent role in this respect. The use of reverse logistics and the circular economy model can be a breakthrough in achieving battery sustainability goals [1]. Dynamic changes can be predicted for the area. Electrification of buses will increase, due to its positive environmental and economic impact. For Volánbusz Zrt., the share of battery-powered buses could reach 50% by 2032. This target seems rather ambitious, but a few measures will help to achieve it [2].

The paper will present the role of sustainability in collective transport, followed by an overview of the economic developments in the world. The focus of the paper is on the potential of battery recycling issues, outlining the possible elements of an operational model for Volánbusz Zrt.

2. THE ROLE OF VOLÁNBUSZ ZRT. IN THE SUSTAINABILITY OF DOMESTIC PUBLIC TRANSPORT

Volánbusz Zrt. is a key player in domestic road passenger transport. Fig. 1 shows the main indicators of the company. With its fleet of approximately 5,100 intercity and more than 800 local and suburban buses, it transports 443 million passengers per year with a performance of 1.2 million kilometres daily mileage. With 18,000 employees, Volánbusz Zrt. is Hungary's 3rd largest employer.

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Recently 95% of the current fleet of vehicles are diesel-powered buses, a smaller number of CNG and LNG vehicles also operate, and the introduction of electric buses has also begun.

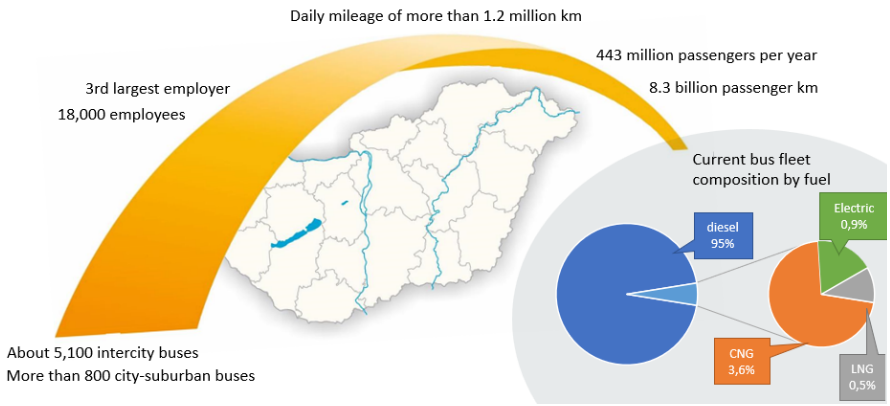

Figure 1. Main indicators of the Company (source: Volánbusz Zrt.)

Fig. 2 shows the expected composition of the vehicle fleet of Volánbusz Zrt.

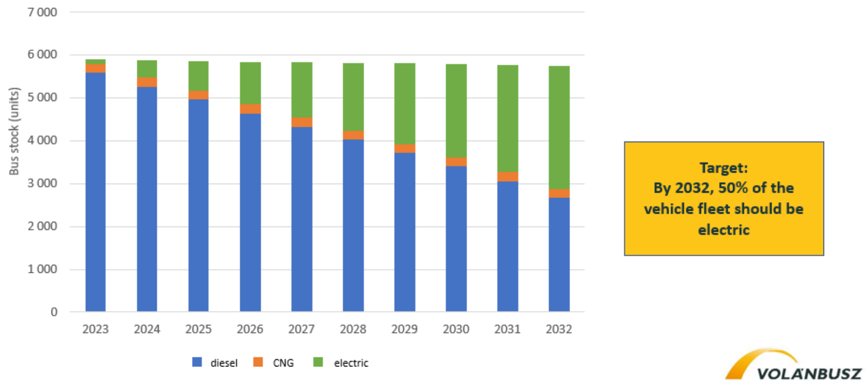

Figure 2. Expected composition of the vehicle fleet of Volánbusz Zrt. (source: Volánbusz Zrt.)

According to the company's plans, the share of battery electric buses, which accounted for 0.9% of the fleet in 2023, could reach 50% by 2032.

From 2024, Volánbusz Zrt. will gradually renew its bus fleet of local and intercity vehicles and replace most of its diesel buses with electric ones. By 2032, 50% of the fleet will be electric buses. Figure 5 shows the proportion of buses with different propulsion systems by year. We don't have any plans to change the proportion of CNG buses, and the electric buses purchased will be used to replace diesels.

The purchase of new buses will improve the availability of vehicles, resulting in a minimal reduction in the number of buses in the total fleet over the next 10 years (a reduction of almost 3% in the fleet by 2032).

Based on the concept presented above, the increase in the number of electric buses will be accompanied by an increase in electricity consumption and a reduction in CO_2 emissions as diesel buses are replaced. This is illustrated in Fig. 3.

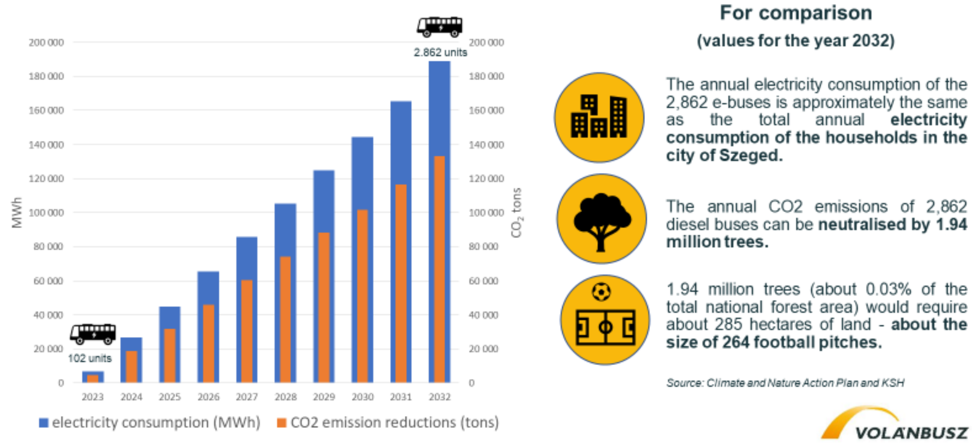

Figure 3. Expected reduction in CO_2 emission and electricity demand (source: Volánbusz Zrt.)

3. Outlook on global economic processes, with particular regard to the transport sector

Decarbonization efforts affecting means of transport contribute significantly to the reduction of CO2 emissions, but at the same time, the future of batteries used in electric vehicles raises new questions.

3.1. The rise of electric buses in public transport

Among the sectors, transport relies to the greatest extent on fossil fuels (Fig. 4), accounting for 37% of the CO2 emissions of end-user sectors in 2021. (https://www.iea.org/topics/transport). This fact justifies that the steps taken to decarbonize transport have a significant potential for reducing CO2 emissions [2].

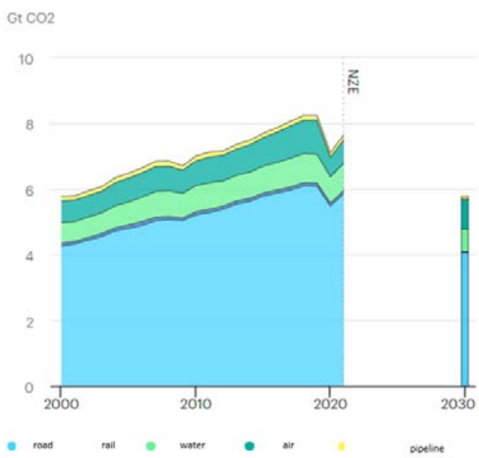

Figure 4. Global CO2 emissions (Gt) from transport by sub-sector according to the Net Zero emission scenario, 2000-2030 (source: IEA [2])

In 2015, 103,000 electric buses were registered in China, and 25% of the buses sold were electric (Fig. 5). In 2021, the number of buses registered in the European Union increased to 3,000 and accounted for 6% of the number of sales. The strong growth trend continues and predicts that questions related to the production, purchase price, use, lifetime and recycling of batteries used in electric buses will come to the fore [3].

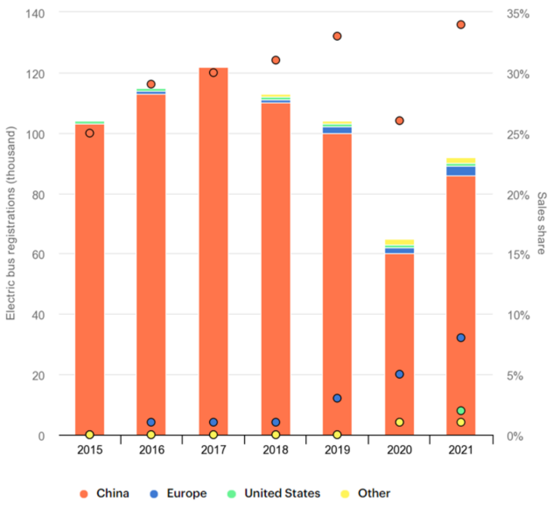

Figure 5. Registration and sales share of electric buses by region, 2015-2021 (source: IEA [3])

3.2. Batteries used in electric buses

In the 1990s, lithium-ion batteries were mainly used in consumer electronics, but the most dynamic growth was observed in the automotive industry. The development of battery technology has facilitated the rapid electrification of vehicles [4].

According to the forecast, in addition to light electric vehicles (Light EVs), the battery demand for electric buses will increase the most (Fig. 6).

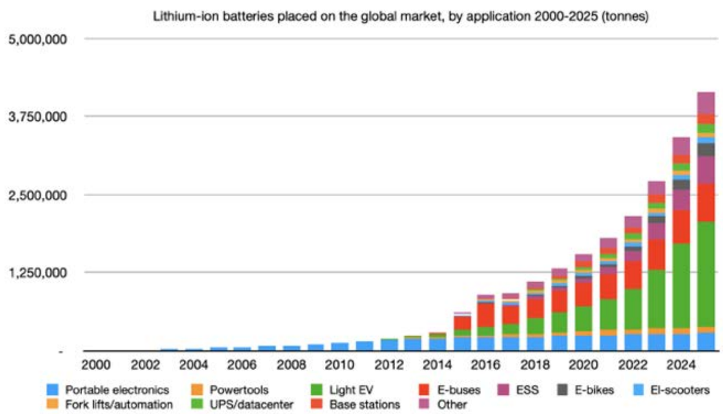

Figure 6. The extremely dynamic spread of lithium-ion batteries in the global market [4]

By 2030, global demand for batteries will increase by 14 times the value of 2018 and may exceed 2,600 GWh (Fig. 7). Within this, the demand for electromobility batteries has increased by 26 times [5].

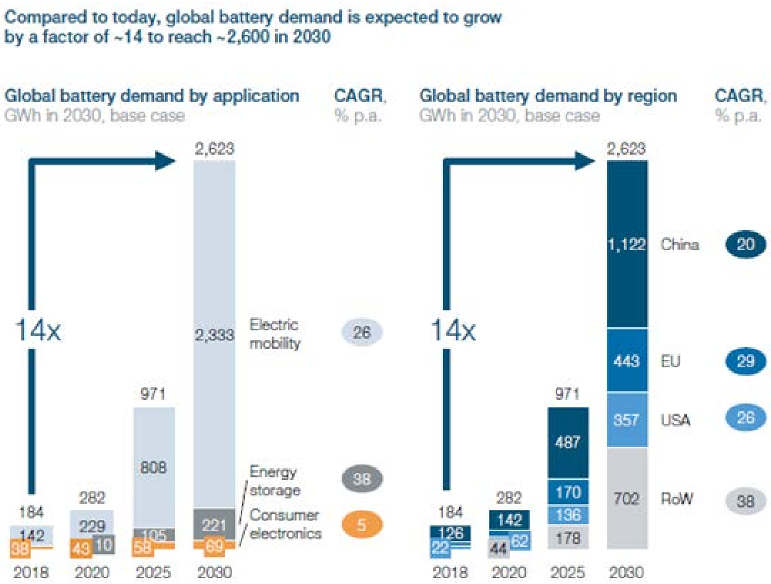

Figure 7. Estimate of global battery demand until 2030 [5]

The drastic increase in demand significantly raises sustainability issues, which are described in the next chapter.

4. SUSTAINABILITY ISSUES RELATED TO ELECTRIC BUS BATTERIES

With the increase in the number of batteries entering the market, the need to extend the life cycle of batteries has increased. We also had to face the fact that although lithium-ion batteries are not toxic in the same sense as lead-acid or nickel-cadmium batteries, they contain elements that must be prevented from entering the environment. But the recovery of reusable materials from used, scrap batteries is at least as important. With the unprecedented growth of the market, the demand for raw materials has increased significantly, and recycling can greatly promote environmental and economic aspects.

For manufacturers of electric vehicles (EVs), including electric buses, the contradiction is becoming increasingly clear that while electric vehicles can be considered clean from the point of view of decarbonization, the production of their batteries is a highly carbon-intensive activity. From the perspective of sustainability, the problem arises not only from the side of climate protection efforts, but also from the economic side. The raw materials and mineral resources required for the production of batteries are in short supply, so in the long term even the lack of batteries may hinder the spread of electric vehicles.

At the 2022 World Economic Forum (Fig. 8), this challenge is formulated as follows: "The world needs 2 billion electric vehicles to reach the net-zero goal. But is there enough lithium to make all the batteries?” [6] (According to Argonne National Laboratory, the science and engineering research centre of the US Department of Energy, an electric car's lithium-ion battery contains about 8 kilograms of lithium.)

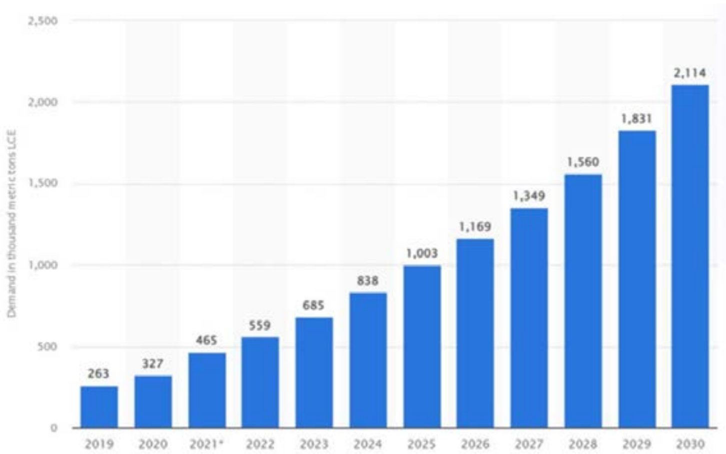

Figure 8. Projection of worldwide lithium demand from 2019 to 2030 (in 1,000 metric tons of lithium carbonate equivalent) [6]

Calculations show that global reserves are barely enough to produce 2.5 billion batteries. According to the IEA's Net Zero 2050 roadmap, the world will need 2 billion battery electric, plug-in hybrid and fuel cell electric light-duty vehicles by then to reach net zero emissions. However, all of the world's lithium cannot just go into electric vehicle batteries. The metal is also used in many other items such as laptops and cell phones, as well as airplanes, trains, and bicycles.

In addition, the shorter lifetime of batteries relative to the vehicle can hamper efforts to reduce the total lifetime cost (TCO) of vehicles. According to an analysis carried out in 2023 [7], batteries are responsible for nearly 60% of the greenhouse gas emissions generated during the production of electric vehicles (Fig. 9).

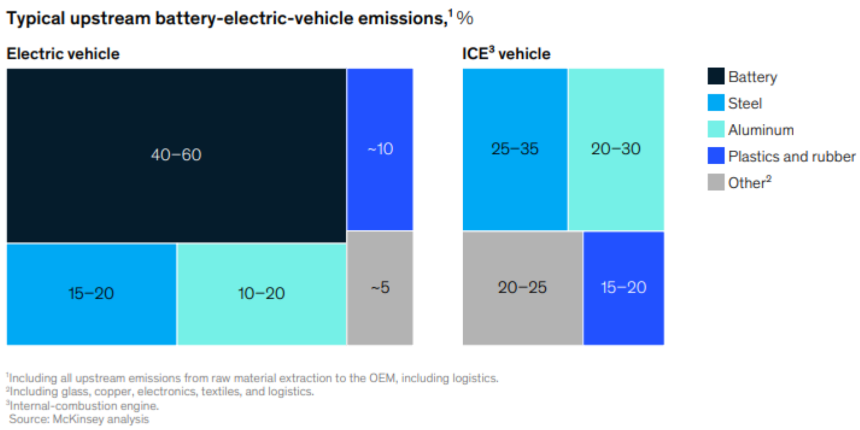

Figure 9. Typical upstream emission % values of battery electric vehicles (BEV) [7]

The global volume of end-of-life lithium-ion batteries could reach 7,000 tons by 2025. However, this does not mean that they will automatically become available for recycling. In fact, only about 50 percent of end-of-life batteries worldwide make it to recycling. There are many reasons for this: batteries are stored or accumulated, they are disposed of but not recycled, or they are reused in other applications. In many cases, although they are disposed of, they are not reused, or they are utilized in another way (Fig. 10).

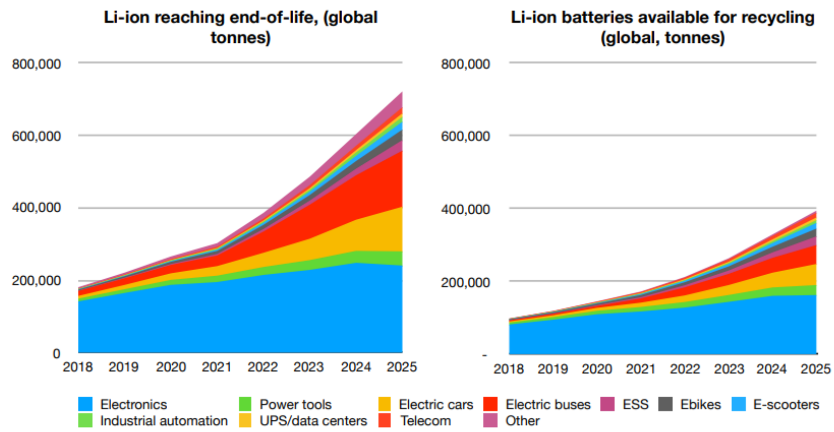

Figure 10. Recyclability of lithium-ion batteries until 2025 [4]

A significant amount of reusable lithium-ion batteries, estimated at nearly 400,000 tons by 2025, can be returned to the supply chain through reverse logistics.

5. THE ROLE OF REVERSE LOGISTICS IN THE CASE OF ELECTRIC VEHICLE BATTERIES

Volánbusz Zrt. intends to implement the operation of electric buses according to the principles of a complex circular economy model, which implements transport services relying on processes related to the energy sector and the battery industry (Fig. 11).

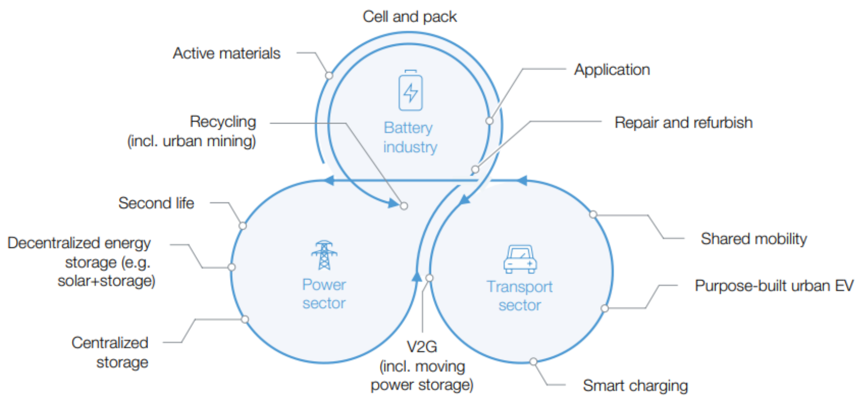

Figure 11. Circular battery value chain that couples the transport and power sectors [5]

According to the vision presented at the World Economic Forum in 2019, the favourable economic impact can be multiplied by implementing a sustainable battery value cycle.

„The cost reduction stems from using batteries more intensively (e.g. through V2G and shared mobility), repurposing, recycling and technological improvement, resulting in a reduction of battery pack costs from $90 per kWh to $70 per kWh in 2030" [5].

The introduction of reverse logistics processes and the transformation of the battery life cycle also greatly contribute to the achievement of cost reduction goals, and the second battery life cycle plays a major role in this.

5.1. The concept of reverse logistics

The introduction of the concept of reverse logistics (inverse logistics, recycling logistics) goes back to the 1980s. Since then, the conceptual definition has become more and more complex.

In the field of logistics, the international professional body dealing with reverse logistics, the Reverse Logistics Executive Council [8] (RLEC) (RLEC), created the definition at the end of the 1990s, according to which "reverse logistics is nothing more than the movement of products from their typical end-use destination, in some other direction, for the purpose of obtaining value or waste management. Returns include taking back damaged products, seasonal stocks and waste, handling returns due to the renewal or expansion of stocks, recycling packaging materials, recycling containers, tidying up and refurbishing products, proper disposal of outdated equipment and tools renovation."

At the University of Miskolc, reverse logistics was considered one of the dynamically developing new trends in logistics research [9].

The rapid expansion of electric vehicles is forcing a complete rethinking of supply chains. Electric vehicle batteries reach the end of their service life earlier than other vehicle components, so there is social and economic pressure on vehicle manufacturers, but also on the service providers who use the vehicles, to dispose of dangerous batteries, or even more, recycle them.

The traditional supply chain usually focuses on the forward supply chain, ignoring end-of-life (EOL) management of products. Reverse logistics should be considered an integral part of the supply chain, and thus a "closed loop supply chain" (CLSC) can be created, which includes both forward and reverse supply chains.

The European practice of reverse logistics solutions for electric vehicle batteries was mapped by research conducted in 2020 at the University of Lund [10].

5.2. Battery recycling programs in the European Union

In order to create a recycling market for EV batteries in Central and Eastern Europe, the EBRD, in cooperation with EIT InnoEnergy, has started laying the foundations for a suitable ecosystem. EIT InnoEnergy, leader of the European Battery Association (EBA250), has supported innovative companies in the cleantech and battery segments and created the EBA Academy, which trains future workers for the sector.

"Batteries are recognised as one of the key technologies for transition to a low-carbon and resilient economy, which is a top priority for the EBRD. Developing markets for secondary raw materials for batteries will be crucial to accelerate the transition to low and zero-carbon vehicles. It will also allow the production of materials in Europe and out of waste, with the objective to deliver significant circular economy benefits for everybody, from citizens to investors” [11].

In Europe, Germany plays a pioneering role in the establishment of lithium-ion battery recycling plants, but significant capacities are also planned in Scandinavia. Hungary is included in the EUWID lithium-ion battery recycling ranking with the Sung EEl Hitach plant established in Bátonytereny in 2019 [12].

6. VOLÁNBUSZ ZRT.'S BATTERY LIFE CYCLE STRATEGY

Figure 2 shows that Volánbusz Zrt. intends to continuously increase the share of electric vehicles in its bus fleet until 2032, until it reaches 50%. In terms of the life cycle of buses, it is a significant challenge to coordinate the life cycle of the batteries with the life cycle of the electric vehicle, therefore it is necessary to define the company's battery management strategy at the beginning of the electrification process.

After the vehicles arrive, Volánbusz Zrt. continuously collects and evaluates data on the batteries of electric buses - by battery type - in order to determine the expected life as accurately as possible. It collects batteries that are no longer suitable in buses in an organized manner and determines the method of their utilization and, where applicable, the battery's second life cycle.

In addition to the intention of the transport service provider, the method of recycling is basically determined by the recycling capacities and plants built for this purpose, and also by the extent to which the development of the circular economic model has been realized in the company's operations.

After the end of the battery's first life cycle, there are basically three options for a second life as shown in Fig. 12.

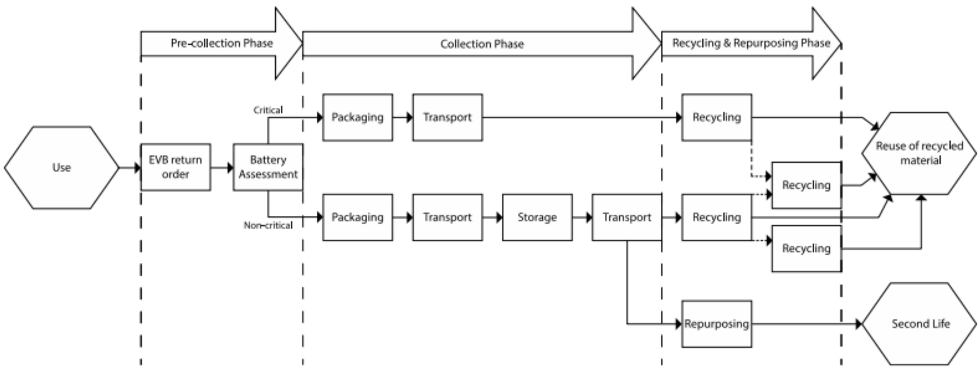

Figure 12. Electric Vehicle Battery Reverse Logistics Chain [13]

Repurposing: Assembling battery packs selected based on the remaining condition and capacity for recycling for energy storage purposes.

Refurbishment: Packs are disassembled and then single cells are reconditioned and repacked in new modules.

Recycling: extracting the valuable metals in the battery and re-using them.

7. SUMMARY, CONCLUSIONS

Public transport providers operating large bus fleets must not only keep in mind the efficient and energy-saving operation of their business, but also implement decarbonization efforts in other areas, in addition to the electrification achieved by introducing electric vehicles. Batteries used in electric vehicles play a prominent role in this regard. The application of reverse logistics and the circular economy model can be a breakthrough in the implementation of battery-related sustainability goals. As Hungary's largest bus company, Volánbusz Zrt. intends to implement an operating model that enables the achievement of these goals.

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