



E-Bus Project Cost Optimization With Circular Economy: Unlocking Value Through Circular E-Bus Strategies

Best Practices Guide for
Contracting Authorities



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Best Practices Guide for Contracting Authorities

Background

The TUMI E-Bus Mission aims to create sustainable urban transportation systems, reduce air and noise pollution, and significantly lower CO₂ emissions from urban transport. Global sales of electric buses have reached more than 70,000 in 2024¹, and IDTechEX estimates that this number will reach more than 180,000 by 2045². Managing the resulting waste at the E-buses EoL is a growing challenge for governments and transport operators, especially in low- and middle-income countries. The global shift towards electric mobility provides a unique opportunity to rethink the design, procurement, and management of urban transportation systems. Although waste management can be included in E-Bus procurement strategies, it receives little attention from decision-makers who prioritize maximizing mobility access. Incorporating circular economy principles is often viewed as an additional responsibility and cost.

This Best Practices Guide supports contracting authorities and public stakeholders in integrating circular economy principles into E-Bus projects to achieve both environmental and economic benefits. By highlighting actionable strategies, real world examples and international case studies, the guide demonstrates how procurement, and lifecycle planning can reduce costs, conserve resources, and minimize waste and takes a step further in TUMI's aim to enable action on the topic of circularity. The Best Practice Guide adds real-life examples and best practices from around the world to the previously developed measures catalogue³. Through collaboration across the public and private sectors, this guide aims to empower municipalities, transit agencies, and regulators to lead a more sustainable and resilient mobility transition.

Alongside the Best Practices Guide, a series of interactive capacity-building workshops were organized in Durban, Mexico-City, and Surat to discuss E-Bus implementation and circular

¹ International Energy Agency (IEA), <https://www.iea.org/reports/global-ev-outlook-2025/trends-in-heavy-duty-electric-vehicles>

² IDTechEx, Electric and Fuel Cell Buses 2025-2045: Markets, Players, Technologies and Forecasts

³ TUMI E-bus mission (2023), Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses, [eBusMission_Battery-Circularity-Measures-Catalogue.pdf](#)

economy principles with governments, public agencies, national and city municipalities, private enterprises, and academia. The results of these workshops have been incorporated into this Best Practices Guide.

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List of Abbreviations

BESS	Battery Energy Storage Systems
BRT	Bus Rapid Transit
E-Bus	Electric Bus
E-mobility	Electric Mobility
CE	Circular Economy
CESL	Convergence Energy Services Limited
CO₂	Carbon Dioxide
CRM	Critical Raw Material
EOL	End-of-life
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
LIB	Lithium-ion (Li-ion) Battery
LFMP	Lithium Manganese Iron Phosphate
LPF	Lithium Iron Phosphate
kWh	Kilowatt-hour
OEM	Original Equipment Manufacturer
T&T	Tracking and Tracing
US\$	US Dollar

1. Introduction

The transition to electric mobility is a vital step toward sustainable transportation and decarbonisation, which comes with significant challenges but also opportunities. For E-Bus projects, circular economy principles can be utilized to maximize environmental and economic benefits. Traction batteries, the heart of E-Buses, contain valuable materials such as lithium, cobalt and nickel that can be efficiently recovered, reducing the need for virgin resources and lowering the overall environmental footprint of E-Buses. Similarly, the materials contained in the bus chassis, starter battery and tires have residual value at the end of the bus's life and must be handled with care. Without proper end-of-life management, electric buses can become a costly environmental and operational liability. Improper disposal practices risk fire hazards, loss of resources and environmental degradation.

To address these challenges, robust frameworks—such as clear end-of-life terms and requirements in tender documents and legislation—are critical. These can define responsibilities for take-back, repurposing, treatment, and recycling, while also promoting transparency through measures like mandatory disclosure of battery data. International best practices show that proactive approaches, engaging OEMs and operators of E-Buses at the end of life, can mitigate risks and create opportunities for innovation in repurposing and recycling.

1.1. Purpose of the Best Practices Guide

The transition to E-Bus fleets presents a timely opportunity to embed circular economy (CE) principles into public transport systems. The purpose of this best practices guide is to present international examples and proven approaches for integrating circularity into E-Bus projects—particularly through the procurement process. It focuses on how legal frameworks and tender documents can be designed to support resource conservation, improve cost-efficiency, and minimize waste across the vehicle and battery lifecycle. The guide consolidates insights from global case studies, such as India's centralized E-Bus tendering, Santiago's public-private partnership model, and policy mechanisms in the EU and China. These examples illustrate how CE principles can be institutionalized through policy and procurement to enhance both environmental and economic outcomes in public mobility systems.

1.2. Scope and Audience

This guide is intended for a broad range of stakeholders involved in the planning, procurement, operation, and regulation of E-Bus systems:

- Transport and transit agencies: To support integration of CE strategies in operational

planning, procurement procedures, and lifecycle management of vehicles and infrastructure.

- Policy makers and regulators: To inform the design of enabling legal frameworks, such as Extended Producer Responsibility (EPR) mandates, second-life battery policies, and recycling standards.
- Private sector representatives: Including E-Bus OEMs, battery suppliers, recyclers, second-life operators, and digital service providers—who are key in delivering circular solutions such as modular vehicle design, battery diagnostics, reuse, and material recovery.

The guide aims to foster a shared understanding of how CE can create long-term value and operational resilience, while reducing environmental impact in the transport sector.

1.3. What we consider to be a Best Practice

A best practice, in the context of this guide, is defined as a legal or procedural requirement that directly addresses key CE goals: resource efficiency, waste minimization, and lifecycle value preservation. Specifically, this includes:

- Inclusion of CE criteria in tender documents, such as requirements for end-of-life management plans, battery second-life potential, and component warranties,
- Mandating real-time battery monitoring, enabling better asset management, reuse, and recycling;
- Use of EPR frameworks to ensure that manufacturers are responsible for the collection and treatment of batteries and other critical components;
- Standardized and centralized procurement models that promote uniformity, cost reduction, and consistent CE obligations (e.g., India's CESL model).

Collaborative arrangements between municipalities, OEMs, recyclers, and analytics providers to ensure traceability and optimal material recovery.

2. How Circular Economy applies to E-Buses

2.1. Principles of Circular Economy

Resources, such as minerals, metal ores, and fossil energy sources, are consumed in the production of the everyday life goods surrounding us. Their extraction and conversion into goods form the basis of today's industrial societies (Krausmann et al., 2018). At the same time, several of the pressing issues facing our society today, such as climate change and biodiversity loss, are linked to the very extraction and use of resources. As the United Nations Environment Program (UNEP) and International Resource Panel state in their most recent publication on global resource consumption "Extraction and processing of material resources (fossil fuels, minerals, non-metallic minerals and biomass) account for over 55 per cent of greenhouse gas emissions (GHG) and 40 per cent of particulate matter health related impacts" (United Nations Environment Programme & International Resource Panel, 2024).

Extraction and consumption of resources meanwhile is not linearly related to population size but rose significantly faster than population but grew in line with GDP. Compared to the 1970s, the global population has more than doubled, reaching approximately 8 billion people today, growing at an average rate of over 1.5% annually. Meanwhile, resource extraction has increased 3.4 times with no trend to decouple economic and population growth from resource extraction foreseeable (United Nations Environment Programme & International Resource Panel, 2024).

As early as 1970 the Club of Rome warned in its report "The Limits to Growth" that the limited resources and regenerative capacity of the planet would be overstepped if continuing to extract and use resources at this rate (Meadows et al., 1972).

As finite resources become depleted and environmental degradation accelerates, traditional economic models, where raw materials are extracted, transformed into products, used for a limited time, and then discarded as waste (linear economy) will prove unsustainable. Applying a linear economic model to the case of E-buses, this would result in

- Depletion of finite natural resources such as lithium, cobalt and nickel used in E-bus traction batteries.
- Large amounts of waste, particularly from end-of-life bus components and battery systems.
- Environmental pollution, as discarded materials end up in landfills and may release harmful substances.

A non-linear model, also known as the circular economy, offers a transformative solution by promoting efficient resource use, minimizing waste, and reducing environmental impact. As illustrated in Figure 1, the circular economy model aims to relieve the pressure on nature by reducing the need for extraction and consumption of natural resources, avoiding waste to landfill and incineration and reducing pollution. It thereby provides a way to decouple economic activity

from the consumption of finite resources, promoting sustainability and long-term economic growth.

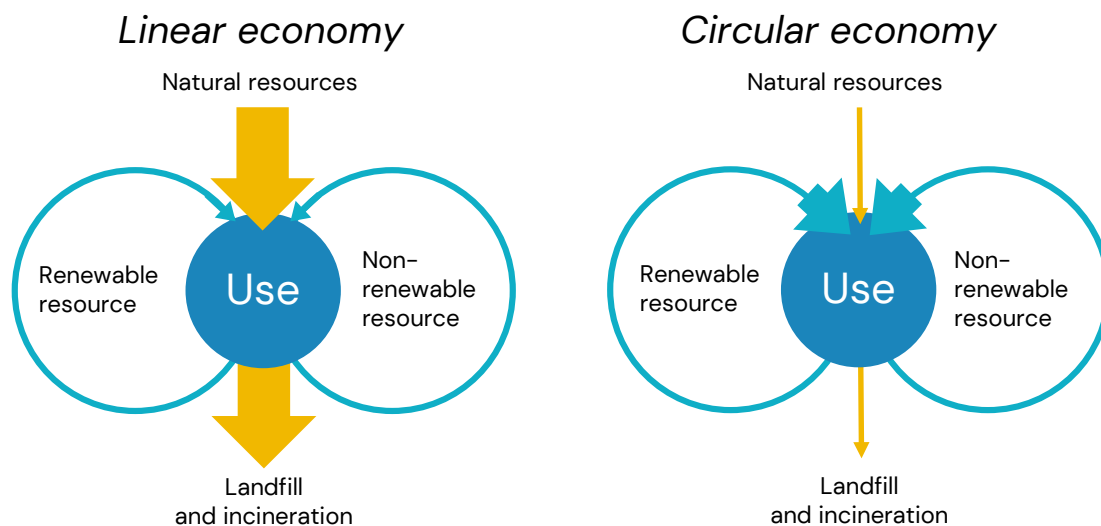


Figure 1: Transition from a linear towards a circular, Source: Ramboll 2025, based on (Potting et al., 2016)

The circular economy is based on three principles (*Circular Economy Principles, 2024*):


- Eliminate waste and pollution,
- Circulate products and materials (at their highest value),
- Regenerate nature.

Applied to E-Buses can be put into practice through processes like re-designing components such as batteries to require less or more sustainable resources and to reduce waste by design by allowing for repair, refurbishment and reuse. Waste can furthermore be reduced by extending an E-bus's lifecycle through maintenance and repair, reuse, refurbishment, and remanufacture. Lastly resources contained in E-buses and their components, such as metals, plastics, and battery minerals, can be recovered at their end-of-life for new production through recycling.

These processes or measures towards a more circular economy have been systematized in the so called "R-strategies" introduced by (Potting et al., 2017) illustrated in Figure 2. These strategies follow a priority order, starting with the most resource-efficient approaches (reduce, reuse, repair) before moving toward more energy-intensive processes such as recycling and recovery. Implementing R-strategies in E-bus projects ensures optimal utilization of materials, enhances cost efficiency, and minimizes environmental impact.

In addition to environmental pressures, regulatory pressures, evolving customer expectations, and the quest for supply chain resilience serve as further powerful secondary drivers of the circular transition. Governments worldwide are enacting stricter regulations while consumers increasingly demand sustainable products and practices. Simultaneously, businesses recognise the need for

robust supply chains capable of withstanding disruptions, prompting a shift towards circular models that enhance compliance, meet market demands, and build long-term operational stability (Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition, 2013). Potential business opportunities applying the depicted R-strategies within the E-Bus value chain are presented in the following section.



Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g., by sharing product)
	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and minerals
Extend lifespan of product and its parts	R3	Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfills its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore an old product and bring it up to date
	R6	Remanufacture	Use parts of discarded product in a new product with the same function and quality of a new product.
	R7	Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality of recycled material
	R9	Recover	Incineration of material with energy recovery

Figure 2: R-strategies for the transition to a circular economy, Source: Ramboll 2025, based on (Potting et al., 2017)

2.2. E-Buses Can Form an Urban Mine

An E-Bus transit system commonly consists of charging infrastructure, electric busses, and their traction batteries. Such a system incurs sizeable capital costs and contains relevant amounts of natural resources, such as metals and plastics.

Electric buses, like conventional busses, are made of steel chassis, glass windows, rims, cables, refrigerants, metal and plastic interior fittings (railings, chairs, buttons). In addition to this, electric busses also contain electric motors, electrical and electronic components, including other auxiliary devices such as charging ports and cables, and batteries⁴. The International Copper Association estimates that a battery electric bus (Ebus BEV) contains 224–369 kg of copper (depending on

⁴ TUMI E-bus mission, Circular Economy in Electric Buses, https://transformative-mobility.org/wp-content/uploads/2023/07/Infographics_EN_Circular-economy-batteries.pdf

the size of the battery), which is about three to four times more copper than in combustion engine vehicles, mainly due to the copper used in the rotor induction motor, but also in the foil and bus bars and in the power cables.⁵

The traction battery constitutes a substantial portion of the overall costs and contains critical raw material (CRM) that are particularly relevant in a circular economy due to their limited availability in natural reserves and considerable energy requirements in extraction (Mathieux et al., 2017). Recovering CRM from waste batteries through recycling can significantly contribute to meet the future demand for the raw materials and to reduce the environmental impact of raw material extraction (Maisel et al., 2023). Hence, E-Buses can effectively be considered an urban mine, a reserve of valuable resources on wheels.

According to an analysis by (Bloomberg New Energy Finance, 2018), the cost of the lithium-ion battery (LIB) accounted for 26% of the total cost of an E-Bus in 2016 and is expected to drop to 8% in 2030. The material value of battery cell components is technology-dependent and therefore also application-dependent. While the anode is commonly made out of graphite the cathode materials have a significant material value. In addition to aluminium and copper foils for conduction of electricity and heat, the cost of lithium-ion cells depends on the cathode material as shown in Table 1.

Table 1: Major current sub-types of lithium-ion battery cell chemistries (Gutsch & Leker, 2024; Kampker et al., 2023a; Krishna, 2024)

Battery chemistry (based on cathode materials)		Energy densities (Wh/kg)	Cost (US\$/kWh) ¹
LFP	Lithium iron phosphate	160-220	50-70
LMFP	Lithium manganese iron phosphate	200-240	70-80
NMC	Lithium nickel manganese cobalt oxide	240-320	60-100 ²
NCA	Lithium nickel cobalt aluminum oxide	200-260	60

¹ Costs as of August 2024 for battery cells manufactured in China and South Korea for EV applications. Spread in costs can be attributed to manufacturing cost differences in different regions and from different sources

² Cost for NMC811 prismatic cell

Considering the current recycling technologies and raw material prices, the cobalt and nickel

⁵ International Copper Association, <https://internationalcopper.org/resource/copper-the-material-of-choice-for-vehicle-manufacturers/>

contents widely determine both cost and material value at end-of-life of the battery, as lithium is not recovered in many processes yet (Manhart et al., 2023). Cobalt is the most expensive of the battery materials and its price has been volatile and susceptible to supply constraints. Furthermore, ethical concerns related to human rights and environmental impacts related to its extraction have moved manufacturers to reduce their dependence on cobalt for battery manufacturing (Global Battery Alliance, 2019).

As a result, especially the LFP chemistry, which is longer lasting than other chemistries, nickel- and cobalt-free, and about 25% cheaper than other Li-Ion chemistries⁶, has established itself in the market. According to the Battery Atlas 2023, published by RWTH Aachen, LFP are also expected to be the dominant cathode chemistry with around 42% (LFP + LFMP) of market share by 2030 (Kampker et al., 2023).

NMC cells on the other hand, which now have nickel contents of more than 90%, can achieve energy densities of 240–320 Wh/kg, the highest among Li-ion cell chemistries. Different new NMC technologies are expected to make up to 30% of the cell demand by 2030 (Kampker et al., 2023).

LIB are likely to remain the dominant technology for use cases requiring high energy densities, such as electric vehicles (EV) and E-Buses (Kampker et al., 2023). Growing EoL battery volumes are expected to allow economies of scale in battery recycling, which will likely reduce treatment costs in the future. Nevertheless, net-costs are believed to persist for LFP batteries (Manhart et al., 2023).

Apart from the battery cell chemistry, also the design of battery packs and modules has a strong influence on the residual value (EV Lifecycle Optimization through Battery Repair, 2024; Krishna, 2024). In the battery pack for EV and E-Buses, current- and heat-conducting copper elements are particularly valuable, as are housing structures made of aluminium or other metals. On the other hand, there are plastic components as well as adhesives and foams, some of which can only be recycled at great expense and do not have a high material value themselves.

Given the substantial influence of battery packs on the costs and overall resource consumption of E-Bus projects, maximizing the utilization of both the product and the materials contained within (“urban mine”), can yield noteworthy advantages for OEMs, customers, and society at large.

⁶ Contemporary LFP cells, when produced at an industrial scale, are obtainable at around 70 US\$/kWh since recent price drops in battery raw material (86% price reduction between January 2023 and August 2024 for lithium, iron phosphate declined by 53% over the same time) (Kampker et al., 2023; Krishna, 2024)

3. Circular Economy Business Opportunities

Circular economy business opportunities exist across the entire e-bus value chain, from the sourcing of raw materials to extending the lifetime of traction batteries and to the EoL management of waste batteries, chassis and other (electrical) components.

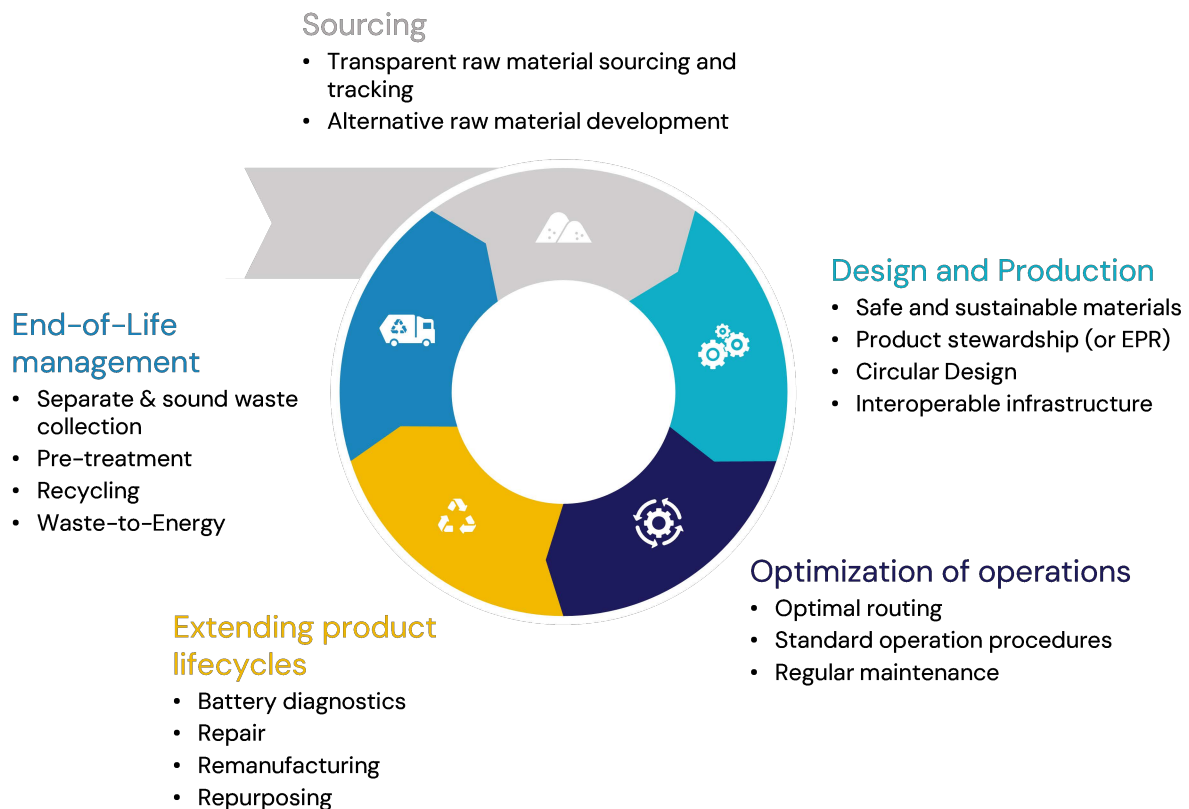


Figure 3: Cost Optimization Opportunities for E-Buses within a circular economy (Source: Ramboll, 2025)

3.1. Business Opportunities in Sourcing

Ensuring the sustainability of E-Buses goes beyond their operation and starts at the very first stage of the value chain, the sourcing of raw materials. Critical materials such as lithium, cobalt and nickel, essential for E-Bus batteries, are sourced through mining practices that can present environmental and social challenges. Responsible mining/ sourcing, material substitution, and closed-loop supply chains (Baars et al., 2020; Deberdt & Billon, 2021), present solutions for these challenges. Companies implementing responsible sourcing practices are able to better manage risks like supply shortages, price volatility, and reputational damages linked to unethical mining practices (Smith et al., 2019). Given the societal role public transport takes up, responsible sourcing practices should be considered as part of the equation when it comes to the shift towards higher sustainability through electrification of bus transport.

Further, ethical sourcing can also have economic benefits, as it can stabilise long-term supply

chains and attract premium customers as cooperating partners. Here the criteria set in the procurement process can influence the choice of the selected bus producers, that could impact the battery types used and the locations from which the battery materials are sourced (Jannesar Niri et al., 2024). Thereby, municipalities and public transport operators can play a crucial role in advancing responsible sourcing practices by using their procurement power to set upstream requirements for traceability, ethical certification, and origin disclosure of battery materials in bus tenders. This allows municipalities to set market signals that favour producers adhering to circular sourcing principles. However, as municipal actors often lack capacity to perform necessary analysis (Stefan & Chirumalla, 2025), joining international transparency and circularity initiatives—such as the Global Battery Alliance or similar multi-stakeholder coalitions—can offer municipalities access to shared standards, tools, and verification mechanisms for responsible sourcing.

To map different approaches for municipalities and related actors, this section explores the key business opportunities and emerging innovations that are reshaping materials sourcing for the next generation of electric buses.

3.1.1. Transparent raw material sourcing through tracking and tracing (T&T)

As the World Resource Forum states in its whitepaper (Powering the Future: Overcoming Battery Supply-Chain Challenges with Circularity, 2025) “You can’t manage what you can’t see and measure”. Implementing T&T technologies enables battery manufacturers and automakers to follow a battery and its materials from extraction through processing, refining, and production to end-of-life. Different data points are collected and recorded at all stages of the value chain and tracked through different technologies such as Radio-Frequency Identification (RFID), QR or barcodes attached to materials, or products (Sommer et al., 2024).

At the raw material sourcing stage, data collected by T&T technologies may include the following:

- Origin of materials (e.g. mine location, country of extraction)

- Supplier information (e.g. certifications, compliance with ethical sourcing standards)
- Material composition (e.g., lithium, cobalt, nickel content)
- Environmental & social impact data (e.g., CO₂ emissions, human rights compliance)

This data can help battery manufacturers and automakers make responsible purchasing decisions in line with their corporate social responsibility (CSR) (Deberdt & Billon, 2021) and to ensure compliance with environmental and human rights principles and regulatory requirements on how the EU Digital Battery Passport obligations have driven T&T for batteries. Traceability of history, application, or location of an object (ISO 9000:2015) or material through the supply chain is also proving to be essential for quality control and for dealing with issues such as e.g., recalls or quality defects in batteries, reducing costs for manufacturers.

From a municipal perspective, cities can actively shape supply chain practices by requiring digital traceability features in their bus procurement criteria. This can also align municipal actions with existing or upcoming regulatory standards, such as the EU Battery Passport.

Tracking and tracing initiatives

Several companies have established themselves in the field of T&T for batteries, offering different data collection and processing services along the value chain, including Circularise (Netherlands), Circular (United Kingdom), RCS Global (Germany) and Peaxy (United States of America), to only name a few.

- Circularise, for example, offers a blockchain-based system that enables secure tracking of battery material origin, composition, and carbon footprint, enhancing transparency and auditability (Circularise, 2023).
- RCS Global's Claritas initiative integrates real-world audits with blockchain traceability, offering a digital battery passport that aligns with EU regulations, particularly the requirement for verifiable environmental and social sourcing data (RCS Global, 2023).
- Similarly, the Global Battery Alliance, includes 170 organizations that work toward standardized battery passports and interoperable data systems. Such initiatives support the scaling of T&T across diverse actors and regions, fostering harmonized circularity frameworks (GBA, 2025).

3.2. Business Opportunities in Circular Design and Production

Circular design is key to maximizing resource efficiency and enabling second-life business models and end-of-life recovery. By using modular designs, manufacturers can simplify repairs, refurbishment and component replacement (Ellen MacArthur Foundation, 2017). Using recycled and sustainable materials reduces environmental impact, while lightweight designs improve energy efficiency (Sustainable Bus, 2023). In addition, designing batteries for second-life applications, such as stationary energy storage, increases their economic value beyond vehicle use (Vu et al,

2020). Overall, circular design strategies can economically benefit municipal actors by lowering lifecycle costs through fewer replacements, reduced downtime, and increased residual value of components, lighter weight of the vehicle, to name a few examples.

In a broader perspective, principles such as design-for-recycling can reduce waste generation and decrease virgin material consumption by facilitating easier recycling at end-of-life. Other strategies include design-for-disassembly and design-for-repair that are discussed in the following.

3.2.1. Lightweight product design

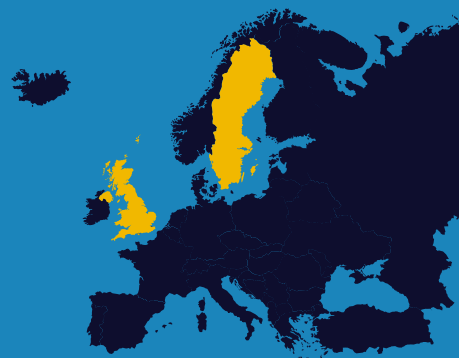
Using recycled plastics reinforced with carbon fiber and fiberglass for the e-bus chassis, improves durability and reduces energy consumption as demonstrated by Vejo Projektai's "Dancer" E-Bus⁷. The Dancer E-Bus, operating commercially in Lithuania, replaces traditional metal structures with a lightweight composite chassis and body. According to the manufacturer, this design achieves around 20% weight reduction compared to traditional electric buses, reducing the empty weight of the E-Bus to a value lower than 10 tonnes (Sustainable Bus, 2023).

Reduced weight enables the use of smaller battery packs without compromising range, thus decreasing initial costs and operational energy demands. Overall, the lightweight design reportedly results in energy consumption as low as 1 kWh/km (Sustainable Bus, 2023). Albeit using lightweight composites

Recycled plastics in electric vehicles

Swedish EV manufacturer Polestar and MBA Polymers UK announced a collaboration in December 2024 aimed at integrating recycled plastics into vehicle interiors.

- **Objective:** The collaboration ensures compliance with upcoming EU targets for recycled plastic content of 25% provided by a new regulatory initiative (EU EoL vehicles regulation).
- **Implementation:** The recycling company MBA Polymers recycles technical plastics from EoL vehicles and electrical and electronic appliances. Their UL certified ABS (Acrylonitrile Butadiene Styrene) polymer contains over 95 per cent post-consumer recycled content and can be used to replace "virgin" plastics in automotive applications.
- **Impact:** According to MBA Polymers, their recycling processes save 75–86% of the energy needed to produce "virgin" polymer equivalents. It also tackles the 900,000 MT of plastic from ELV that goes to landfill or incineration every year in Europe alone.



⁷ See their website, last visited on 10.01.2025, <https://dancerbus.com/dancer-bus/>

has positive effects on the environmental footprint of the use phase (Ateeq, 2023), the use of carbon fiber and fiberglass to reinforce the composites in turn might reduce the recyclability of the materials at their end-of-life (Ateeq, 2023).

3.2.2. Use of secondary materials

In addition to lightweight design, the use of secondary materials—such as recycled metals, recycled polymers, and bio-based composites—can reduce the environmental footprint of bus production and support circular value chains. Examples include recycled aluminium frames and natural fiber composite interiors, which offer substantial reductions in embodied energy and material impact, while increasing market demand for secondary materials (Sustainable Bus, 2023). The benefits of using secondary materials have to be outweighed against potential disadvantages due to lower material strength, durability, or recyclability, or due to higher weight.

Municipal transport operators can actively support the use of secondary materials in E-Bus development by including minimum recycled content requirements in tender documents or by rewarding bidders that demonstrate verifiable use of low-carbon, recycled or bio-based materials in their vehicle designs.

3.2.3. Design for repair

Ensuring buses and their components are designed for easy repair, remanufacturing and recyclability can support business models along the value chain. Components that are modular, easily accessible, and compatible with diagnostic tools reduce labor time and lower service costs. As an example, at Volvo Group, the aim is to increase repairability by placing the LIB-electronics together to allow quick access for the repair of faulty parts such as contacts or the fuse (Albertsen et al., 2021).

Webasto's "Green Battery" concept incorporates biodegradable oils for cooling and easily disassembled designs, via modular, bolted assemblies instead of permanent bonding methods. This facilitates simple disassembly of the battery into its modules, cells and further components not only for repair, but also for remanufacturing and recycling at end-of-life.

3.2.4. Design for second life

Apart from enabling the extension of battery lifetime, modular designs may facilitate second-life battery repurposing, e.g., the disassembly and remanufacturing for battery energy storage systems (BESS). According to (Vu et al., 2020), second-life applications may require the disassembly of battery packs to the cell level, e.g., to assess their state of health (SoH). The availability of usage history and diagnostic data is also essential to evaluate the remaining

performance and to safely integrate second-life batteries into new systems. These aspects must be supported by appropriate design choices and system architectures from the outset to enable efficient testing, sorting, and redeployment.

However, designing batteries for second-life applications requires consideration of technical and operational factors that affect their performance during operation. Each battery is designed by the battery manufacturer and automotive OEM to be best suited to a given EV model, resulting in a wide variety of battery designs. Insulation material, glue and cell to pack designs may hinder disassembly and hence also refurbishment and remanufacturing but otherwise provide substantial benefits during operation such as higher energy efficiency and battery durability (Langøy, 2022). There are currently no examples of automotive OEMs or battery manufacturers developing their battery with second life in mind. There are nevertheless business opportunities in disassembly and repurposing of batteries, as outlined in section 3.4.

For municipalities second-life readiness offers economic benefits through improved asset utilization, and the potential to remanufacture and integrate used batteries into local energy infrastructure (e.g. depots with photovoltaic charging systems). Public procurement processes can reinforce this by requiring OEMs to document second-life options or offer second-life, repurposing or remanufacturing, partnerships within their proposals.

3.3. Business Opportunities in Optimization of Operations

Traceability and diagnostics data on battery health and performance are essential for a variety of applications:

- 1) As touched upon in the previous sections and highlighted by (Albertsen et al., 2021), to assess whether batteries can safely and efficiently be reused in second life applications, and which applications they are most suitable for (e.g. frequency regulation, backup storage, or peak shaving).

Increasing operational efficiency of e-bus operations and tracking down errors and anomalies as well as monitoring ageing and safety of the batteries. The importance of mandating suppliers to share data from the vehicle with the bus operator through procurement requirements has also been elaborated on in the TUMI E-Bus Mission Battery-Circularity Measures-Catalogue⁸, specifically Measure 7 and 8.

3.3.1. Data Analytics for Optimal Charging and Routing

Using data analytics to increase the efficiency of operation of electric buses is critical to cost-

⁸ TUMI (2023), Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses, [eBusMission_Battery-Circularity-Measures-Catalogue.pdf](#)

effective operations. This requires battery data collection and sharing with the relevant actors to enable modeling of optimal routes, charging intervals, and charging depths. Sources of data relevant for electric bus evaluation include⁹:

- Data from the vehicle such as GPS, speed, consumption figures (energy, power signals, etc.), battery data (SOC, SOH, temperature, max/min/avg cell voltage, etc.)
- Data from charging infrastructure as well as charging plans.
- Data from communications between vehicle and E-Bus Depot Management System.
- Operations data from fleet control like information on trip, route and block (incl. trip times and delay).

There are various software solutions transforming and analysing the different data sources. Companies such as Optibus/PTV, and other specialized providers include digital tools that enable to strategically plan routes and charging intervals, improving bus reliability and maximizing energy efficiency.

One example of the use of battery diagnostics software in urban electric transportation systems is the integration of Volytica Diagnostics software into the charging stations for e-buses in Mexico City, described in the info box. The data collected is data from the charging infrastructure.

Another real-world example of data analytics implementation in urban electric transportation systems (data from the charging infrastructure) is Enel X's comprehensive smart charging infrastructure in Santiago, Chile, where centralized management systems coordinate over 1,500 electric buses and 312 smart chargers. These systems automate charging schedules to utilize off-peak energy rates and renewable energy availability, resulting in lower electricity costs and improved grid stability (Enel X, 2021).

One challenge to using real-time battery diagnostic data is accessing it. Battery data available at the OEM from the BMS and BMTS needs to be made available to the appropriate stakeholders, be they municipal transit agencies or software vendors, for analysis and integration into the charging infrastructure or need to be measured independently during charging and discharging. One option of how to implement the requirement for data provision into the procurement process is provided in the TUMI E-Bus Mission Battery-Circularity Measures-Catalogue¹⁰, specifically Measure 7 and Box 7. Additionally, the German Association of Transport Companies prepared recommendations VDV 238 and VDV 435 on vehicle data to be recorded and data ownership arrangements between suppliers and transport companies, which can be accessed in English¹¹.

⁹ TUMI (2023), Evaluating Electric Bus Operation, Presentation by Philipp Sinhuber, ebusplan and Ricardo Tejada, IVU

¹⁰ TUMI (2023), Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses, [eBusMission_Battery-Circularity-Measures-Catalogue.pdf](#)

¹¹ VDV 238: vehicle data in buses in PT, available in English at [VDV-Schrift Nr. 238: Fahrzeugdaten in Bussen des ÖPNV / vehicle data in busses in PT \[PDF\] - beka GmbH](#)

Two best practice examples, one from India and one from the European Union, of how access to battery diagnostic data can be included as requirement in procurement documents or included in legislation is given in chapter 6.2 and 6.3 respectively.

3.4. Business Opportunities in Extending Product Lifecycles

3.4.1. Data Analytics for second life suitability assessment

Effective second-life applications of batteries rely on advanced data analytics to assess their remaining performance and potential reuse value. This can be for second life suitability assessment or for due diligence process in the case of transactions of bus fleets, where in the example of a BYD e-bus fleet to a new PTO, the company Volytica diagnostics together with the independent inspection company TÜV Nord Mobility provided battery quality assessment of the 259 vehicles. The assessment focuses on quality, safety and value determination of the whole vehicle including charging infrastructure, with a particular focus on the battery¹².

The evaluation process includes battery diagnostics using real-time monitoring and historical performance data to estimate the state of health (SoH) and state of charge (SoC).

Modern battery management systems (BMS) and artificial intelligence (AI)-driven analytics can optimize second-life applications by:

- Identifying degradation patterns across different battery chemistries (e.g., LFP, NMC).
- Predicting expected lifespan based on historical usage and thermal management.
- Assessing suitability for alternative applications such as a Battery Stationary Energy Storage (BESS) or repurposing in less demanding transport settings.
- Reducing costs by enabling targeted refurbishments rather than blanket replacements.

According to (Albertsen et al., 2021), the availability of quality diagnostic data is a key success factor and enabler in unlocking circular business opportunities in the battery value chain.

Examples of the use of batteries from end-of-life e-buses for Second Life applications are given in section 3.4.5.

3.4.2. Retrofitting

Retrofit scenarios often arise at the end-of-life of a fossil fuel driven bus fleet during the transition to more sustainable public transport solutions. Instead of decommissioning current buses and procuring new E-buses, municipalities and transit authorities can transition to an electric fleet by retrofitting old buses. Retrofitting old buses, involves converting existing diesel

¹² Sustainable Bus News (20. September 2022), <https://www.sustainable-bus.com/news/byd-e-buses-netherlands-volytica-diagnostics-tuv/>

or gasoline-powered buses into electric vehicles, either at mid-life or end-life. This process starts with the removal of traditional diesel components such as the engine, fuel tanks, and exhaust systems. These are replaced with an electric powertrain system, including electric motors.

High-capacity batteries are integrated to supply the necessary power for the new electric drivetrain. The vehicle's control systems are also updated or replaced to manage the electric powertrain and battery system effectively. Comprehensive testing ensures that the retrofitted bus meets performance and safety standards, optimizing efficiency and reliability. Retrofitted buses typically come with a warranty and certified batteries, providing ranges similar to new E-Buses.

Retrofitting not only extends the operational life of current bus fleets but also significantly reduces emissions and reliance on fossil fuels, providing a cost-effective and sustainable alternative to procuring new electric buses. (*Home - to Zero Electric Vehicles GmbH*, n.d.)

According to literature, depending on the cost of the retrofitting and the comparative cost of a new e-bus, retrofitting can make the transition to sustainable public transport more economically viable, offering potential economic benefits (Gungor & Satoglu, 2024). The costs of retrofitting depend on the required effort to electrically and mechanically adapt the new elements to the bus. "Kits" that include, for example, the modular battery system, powertrain, charging infrastructure, vehicle control unit, heating and air conditioning, telematics unit, and HMI display are typically available for high-volume bus models from well-known manufacturers¹³. If the base bus is too old (>15 years as a rule of thumb), the level of corrosion and usage might be such that the cost of refurbishment becomes too high. Additionally, the technology might be outdated and lack essential functionality.

An important consideration in retrofitting is that the company retrofitting the buses should be able to provide spare parts and service and maintenance support for the life of the retrofitted bus. Since the bus OEMs do not currently offer retrofit services themselves, start-ups and companies offering such services should be selected on the basis of their technical experience and financial strength in case of warranty cases and long-term maintenance services.

¹³ Institut Neue Mobilität (2022) M. Groher, T. Teschner

Retrofitting of ICE vehicles

Key Details:

- Cape Town, South Africa
- Stakeholders: SANEDI, Stellenbosch University, Golden Arrow Bus Services, Rham Equipment, government departments

Case Study Highlights:

- Prototype developed with Stellenbosch University
- Cost Savings: 70% fuel, 55% maintenance
- Challenges: Regulatory approvals, grid instability.
- Plan to retrofit 60 buses annually

Environmental Impact:

- Energy Savings: 70% reduction.
- Environmental: Improved air quality



As the price of new electric buses is likely to fall as battery costs fall, the price gap between retrofitting and new purchases is likely to narrow. Exemplary savings compared to the purchasing price of new E-Buses range between 40–50% (*ECitaro RETROFIT – Paul Passau, n.d.*). In terms of Total Cost of Ownership (TCO), retrofitted buses would result in lower costs after several years of usage compared to new combustion engine busses due to their lower cost per kilometer. However, compared to new electric vehicles, the TCO of retrofitted buses may be higher due to the new e-busses' higher overall efficiency (*Umrüstung von Bussen: Mit Verbrennungsmotor Zum Elektrobus Im Lichte Des BMDV-Förderstopps – BUS2BUS, n.d.*)

An example of retrofitting buses can be found in South Africa, where funded by the South African National Energy Development Institute (SANEDI) and the Transport Services at Stellenbosch University, a retrofitted minibus taxi has been developed as depicted in the info box (*SU & Partners Retrofit First Minibus Taxi in SA to Run on Electricity – Electrical and Electronic Engineering, n.d.*).

Challenges for retrofitting are age specifications

for vehicles in tenders and lack of funding to demonstrate technical and economic viability of retrofitting for individual bus models and city environments.

3.4.3. Repair and refurbishment

Repairing damaged or prematurely aged battery modules, to ensure they achieve their expected lifespan, offers both environmental and economic advantages over completely replacing and recycling entire battery packs.

In the context of batteries, repair scenarios often arise in the context of warranty or recall cases for OEMs. Presently, it is common for the entire battery pack to be replaced. However, instead repairing the pack by replacing only faulty modules can present a potentially cost-efficient option

for extending the lifetime of a battery (EV Lifecycle Optimization through Battery Repair, 2024). Notably, during the warranty period, repair usually emerges as the more economically and environmentally efficient course of action. Even after the warranty period has ended, repair is still a viable option. Only shortly before the end-of-life of the battery it can become the less economical alternative (EV Lifecycle Optimization through Battery Repair, 2024).

Battery repair hubs, such as those implemented by MAN Truck & Bus presented in the info box, replace faulty modules rather than entire battery packs, reducing costs and waste. In addition to this, routine maintenance and repair of electronic components, powertrains, and structural parts extend vehicle lifespans.

In addition to batteries, other critical systems in electric buses—such as inverters, power electronics, drivetrains, and control systems—can be maintained and repaired to extend the vehicle's operational life. Regular inspection and targeted repair of components like electric motors, cooling systems, and electronic control units (ECUs) help avoid costly full-system replacements and maintain performance over longer lifespans (Albertsen et al., 2021).

Moreover, the reuse of recovered components from retired vehicles as replacement parts – such as powertrain elements and control modules – can be integrated into fleet maintenance strategies, especially when supported by remanufacturing or certified reuse programs.

Municipalities and transit agencies can further strengthen repair practices by incorporating circular maintenance provisions into service contracts. In addition, transit agencies can integrate digital maintenance and reporting tools, such as “1st reporting” software, with their fleet

Use of AI for cost-efficient dismantling and diagnosis

Circu Li-ion is a startup that uses digital replicas of batteries to train robots to automatically disassemble and diagnose them.

- **Objective:** Automatic, cost-efficient disassembly opens pathways for repair, refurbishment and remanufacturing for e.g., application in applications such as stationary energy storage systems (BESS).
- **Implementation:** The AI-powered system diagnoses cell health within seconds, enabling safe repurposing, reducing the demand for newly extracted materials, and generating cost-effective, separate material streams for recycling.
- **Impact:** Li-ion states that they can achieve a cost reduction of 47% and 95% component recovery.



management software to better monitor fleet condition, schedule repairs to vehicle components, and potentially extend the life of their buses. In addition, municipalities can leverage this by requiring OEMs to disclose the reparability of their designs or service infrastructure coverage in procurement procedures.

3.4.4. Remanufacturing

Remanufacturing involves complete disassembly, testing and reassembly, often using a mix of new and salvaged materials. Unlike repair and refurbishment, remanufacturing is a more comprehensive and standardized process that restores performance to that specified for new products, including warranty.

For batteries, startups like Circu Li-Ion, summarized in the infobox, are looking to increase the cost and material efficiency of the remanufacturing process through the use of AI-driven diagnostics and automated battery disassembly (Circuli-ion, 2025).

Commercial vehicle tires can be remanufactured multiple times using retreading technologies that replace only the worn tread while retaining up to 90% of the original casing. This process reduces raw material consumption and extends tire life at 30–50% of the cost of new tires. In North America, retreads account for over half of all replacement truck tires, demonstrating their reliability and acceptance in high-demand fleet operations (Rematec, 2023).

In France, public transportation fleets are required to consider retread options, reflecting growing regulatory alignment with CE principles¹⁴. As sustainability pressures rise and logistics demands increase, retread tires offer an effective solution to balance cost, performance, and environmental goals.

In addition to tires and batteries, key vehicle components such as driveshafts, brake calipers, electrical components, shock absorbers and many others can be remanufactured (Mercedes-Benz, 2025).

3.4.5. Repurposing of batteries

Repurposing involves taking a used product and extending its lifecycle by employing it in a different application. The gradual loss of capacity in a battery over time can render it unsuitable for its original application while still being viable for alternative use-cases. Repurposing can also be a subsequent step of repair and refurbishment.

When batteries lose sufficient capacity for E-Bus use, they can be repurposed in different

¹⁴ Since 2020, Article L. 2172-6 of the Public Procurement Code obliges local authorities to give preference to retreaded or remanufactured tyres when renewing their fleets.

applications, including in BESS for grid stabilization, microgrids, and renewable energy integration but also as traction batteries in lower-energy transport applications. Some cities also integrate repurposed bus batteries into charging hubs or other municipal energy applications.

One notable example of an E-Bus battery to BESS project is the project “Anubis” in the Netherlands, presented in the info box on this page. According to (Stefan & Chirumalla, 2025), batteries with 70–80% of their original capacity may still operate efficiently in stationary systems for 5–10 additional years. This opens up new revenue streams for fleet operators and OEMs through energy-as-a-service models or by selling second-life storage systems to third parties. It also represents the most sustainable solution to reuse or repurpose the battery after the first use cycle, before the battery is directed to a recycling process (Stefan & Chirumalla, 2025).

Another example of the second life application of used electric vehicle batteries in BESS is the Renault Advanced Battery Storage (France) and Connected Energy (UK) cooperation. Connected Energy has developed BESS solutions based on used electric vehicle batteries. The partnership with Renault and Connected Energy aims to create Europe’s largest BESS system using second-life batteries from electric vehicles. The system is designed to stabilize the grid by offsetting fluctuations from renewable energy production. Even though the batteries do not stem from electric busses but vehicles, it shows how partnerships and the use of battery data analytics plays a central role in evaluating battery fitness for repurposing, supporting both safety compliance and economic feasibility (Renault Group, 2020).

From a policy perspective, public authorities can accelerate repurposing markets by creating regulatory frameworks for second-life

Project Anubis, Netherlands

The “**project Anubis**” is an initiative aimed at repurposing batteries from electric buses. This project is a collaboration between RWE, an energy company, and VDL Bus & Coach.

- **Objective:** The project aims to demonstrate and validate a stationary energy storage system using end-of-life e-bus batteries.
- **Implementation:** Batteries from 43 electric VDL buses operated by Transdev Netherlands are being repurposed. These buses, which have been in operation since 2016, are receiving new and larger battery packs. The used batteries, which still have sufficient capacity, are being utilized in a central storage system at the RWE power plant in Moerdijk
- **Capacity and Impact:** The combined storage capacity of these batteries is 7.5 megawatts. This system helps balance the transmission network and supports the integration of renewable energy sources.



certification, liability, and performance standards. Procurement contracts can also require OEMs to take back used batteries and assess repurposing feasibility before recycling, thus creating more circular lifecycle loops.

3.5. Business Opportunities in End-of-Life Management

Effective end-of-life management of batteries is essential for environmental sustainability and cost efficiency. As E-Bus fleets expand, managing end-of-life batteries responsibly becomes increasingly critical. Effective strategies in recycling not only mitigate environmental impacts but also represent economic opportunities through material recovery, compliance incentives, and new business models for battery processing (European Commission, 2022).

3.5.1. Recycling of batteries

Recycling represents the final step to close the lifecycle of a product and if possible, should be carried out after considering lifetime extending steps such as refurbishment, repair, and remanufacture. During the recycling process, the primary focus is on recovering materials from the product to use them in the manufacturing process of new products. The product undergoes a loss of function and structure, breaking down into its individual material (EV Lifecycle Optimization through Battery Repair, 2024).

When batteries reach their end-of-life, valuable materials such as lithium, cobalt, nickel, and copper, depending on the respective battery chemistry as presented in section 2.2, can be recycled through mechanical and hydrometallurgical processes. As stated in a publication from RWTH University Aachen, "for the recovery of the high-grade cathode materials, no continuous economic recycling process currently exists industrially, and no industrial recycling solution exists for the anode materials." It further states that "the raw materials lithium, cobalt, nickel and manganese [contained in the anode] are primarily the focus of current and future recycling processes". (Heimes et al., 2021) According to Fraunhofer ISI, LiB recycling can be carried out using different combinations of processes, so there is no "one" recycling route. Lithium-ion battery recycling facilities can be divided into "spokes" and "hubs" according to the depth of recycling, i.e. the input and output materials of the recycling processes performed (*Europe Expands Recycling of Lithium-Ion Batteries: Focus on Capacity Development, Demand Analysis and Market Players - Fraunhofer ISI*, n.d.). The pre-treatment activities are carried out in decentralized facilities, "spokes", in order to minimize the logistics costs of the waste batteries (transport of dangerous goods). This includes discharging, dismantling and further mechanical or thermal deactivation and processing into the so-called black mass (a mixture of cathode and anode active materials), which contains valuable metals such as Li, Ni and Co. Black mass is then further processed and refined into raw materials in central, larger-scale facility, "hubs", where using pyro- or hydrometallurgical

processes or electrochemical processes, valuable metals are recovered (Baum et al., 2022).

Challenges remain for cost-effective recycling, including fluctuation of raw material prices, high handling and dismantling costs, safety concerns in handling and disassembling waste batteries, high recovery targets set by regulations, and the need keep up with battery technology developments (Neef et al., 2021). Possible financing pathways include government subsidies, tax credits and grants for battery recycling such as those introduced by the Inflation Reduction Act (IRA) of 2022 in the United States of America. Furthermore, in countries, in which EPR schemes for batteries are in place, these require manufacturers to take care of proper disposal and treatment at end-of-life of batteries, creating a regulatory pressure to cooperate with recyclers or invest in own recycling facilities.

1. Battery Recycling-as-a-Service (United States)

Companies such as Cirba Solutions (United States) offer battery recycling as a service, enabling battery producers and fleet operators to outsource recycling logistics, compliance management, and material recovery. This business model simplifies regulatory compliance, reduces risks, and provides a predictable cost structure (Cirba Solutions, 2023).

2. Redwood Materials (United States)

Redwood Materials operates advanced recycling facilities that utilize hydrometallurgical processes to achieve recovery rates of over 95% for critical battery materials such as lithium, nickel, and cobalt. Redwood's partnerships with major automotive manufacturers and fleet operators demonstrate scalable and economically viable recycling pathways, supporting closed-loop supply chains (Redwood Materials, 2023).

3. Umicore (Belgium)

Umicore is only one example of a company that specialized in large-scale battery recycling, utilizing proprietary technologies to recover critical raw materials from lithium-ion batteries efficiently. With recycling capacities expanding significantly, especially with the planned 150,000-tonne battery recycling plant, Umicore provides a robust solution for battery recycling at scale (Umicore, 2023).

4. Accurec (Germany)

Accurec uses a mechanical and hydrometallurgical (for black mass) recycling process. Its facilities are currently operating at a capacity of 4,500 tons per year in 2025, with announced capacity increases to 20,000 tons per year in 2027¹⁵.

¹⁵ Battery Atlas, LiB Recycling Projects in the EU in March 2025, <https://battery-news.de/batterierecycling/>

4. Measures and Activities for Municipalities to implement Circular Economy in E-Bus Projects

Municipalities play a central role in embedding circular economy (CE) principles into E-Bus projects. Their responsibilities span the entire value chain, from procurement and operations to end-of-life management. Key actions include integrating CE requirements into tenders, facilitating collaboration among stakeholders, and reinforcing regulatory frameworks.

Procurement can be used strategically to promote circularity by requiring lifecycle warranties, end-of-life plans for batteries and vehicles, and real-time monitoring of battery health. Municipalities can also fill gaps in national legislation by including extended producer responsibility clauses in contracts, mandating manufacturers to handle collection, repurposing, or recycling of batteries.

Workshops and best practice exchanges with transit agencies and manufacturers further support municipalities in identifying cost-saving circular strategies, particularly at the planning, procurement, and operations stages. These insights can be formalized into guides that support future project implementation.

4.1. Enhanced Public Procurement Strategies

Public procurement is a key enabler of CE practices in E-Bus projects. Municipalities can shape environmental and economic outcomes through well-designed tenders that prioritize circularity.

Examples include India's centralized tender, which reduced E-Bus costs by up to 48% while incorporating CE obligations such as battery warranties, IoT-based real-time monitoring, and defined battery reuse criteria. Similarly, Santiago's IFC-backed PPP model required suppliers to manage battery replacement, maintenance, and end-of-life disposal in compliance with environmental standards.

Procurement strategies should also anticipate upcoming regulations like the EU Battery Passport by requiring transparent battery tracking and lifecycle data. Centralized and harmonized procurement can further drive economies of scale and ensure consistent implementation of CE standards.

4.2. Municipal and Public-Private Institutional Collaboration

Successful CE implementation depends on collaboration between municipalities, the private sector, and development institutions. International partnerships, such as the IFC supported project in Santiago, demonstrate how financing can be tied to CE compliance, including waste

management planning and battery lifecycle tracking.

Municipalities can also support innovation by partnering with technology providers offering battery diagnostics, repair, and recycling solutions. Collaborations with companies like Volytica or Circu Li-ion help extend battery life and reduce material waste.

Additionally, municipalities should coordinate with national authorities to enforce take back and recycling standards and ensure a level playing field for compliant recyclers. Access to reliable battery data is essential for enabling safe reuse and second-life applications, and municipalities can facilitate this by promoting open, secure data-sharing protocols in their procurement and policy frameworks.

5. Common Obstacles in implementing Circular Economy in E-Bus Projects

While the Circular Economy presents significant opportunities for cost optimization and sustainability in E-Bus projects, its successful implementation is hindered by various challenges. These obstacles range from limited market development to gaps in legislation, enforcement, and funding. Addressing these challenges requires a coordinated effort between policymakers, industry players, and financial institutions to create an enabling environment for CE principles.

5.1. Obstacles related to Market Development

The level of market maturity plays a critical role in the feasibility of CE applications in E-Bus projects. Key obstacles include:

- **Limited Market Players and Competition:** In numerous regions around the world, there are few actors in the battery recycling, remanufacturing, and repurposing sectors. This lack of competition limits innovation and cost efficiency, making it difficult to develop economically viable CE solutions.
- **Immature Treatment Technologies:** Many second-life and recycling technologies are still in early development, particularly for newer battery chemistries such as lithium-iron-phosphate (LFP), which currently lacks cost-effective recycling solutions. The absence of large-scale, efficient recycling methods means that end-of-life batteries often end up in landfills or informal recycling sectors.
- **Insufficient Collection Volumes:** CE business models, such as battery recycling or remanufacturing, require high volumes of end-of-life batteries to be economically viable. However, due to the relatively recent adoption of e-buses, the volume of batteries available for recycling remains low. Without economies of scale, the cost of CE implementation remains high, discouraging private sector investment.

5.2. Obstacles related to Lack of Legislation

The absence of a well-defined regulatory framework creates uncertainty for investors and operators seeking to implement circular economy solutions. Key challenges include:

- **Lack of Standards for Collection and Treatment:** In many regions, the absence of clear regulations governing the collection, remanufacturing, repurposing, or recycling of electric bus batteries poses substantial challenges. The lack of standardization leads to inconsistent treatment methods, which in turn allows certain players to operate at lower costs while underperforming in environmental and safety compliance. This inconsistency

hinders the development of a robust and sustainable CE for battery management. environmental and safety compliance facing the following challenges:

Challenges:

1. **Inconsistent Treatment Methods:** Without standardized procedures, different recyclers may adopt varying methods for battery management, some of which may be unsafe or environmentally damaging. This inconsistency can result in poor quality recycling outputs and increased health risks for workers and local communities.
 2. **Environmental Non-Compliance:** The absence of stringent regulations means that some operators may bypass essential environmental protections to reduce costs. This can lead to harmful practices such as improper disposal of hazardous materials, contributing to pollution and ecological degradation.
 3. **Safety Concerns:** Lack of safety protocols in battery handling and treatment can pose significant risks, including fires, explosions, and exposure to toxic substances. This not only endangers workers but also the public and the environment.
- **Lack of Level Playing Field:** Without clear rules, unregulated actors may dispose of or repurpose batteries in unsafe ways, undercutting companies that invest in environmentally responsible treatment. The EU's **Battery Passport initiative** aims to prevent this by ensuring transparency in battery materials and end-of-life management, but many countries lack such mechanisms.
 - **Regulatory Gaps in Second-Life Applications:** There are no universal criteria for determining when a battery is no longer fit for vehicle use but can still serve in energy storage applications. Without clear guidelines, second-life applications remain limited, even though projects like the "**project Anubis**" in the Netherlands (Transdev, 2022) have successfully repurposed bus batteries for stationary energy storage.

Even when CE regulations exist, their effectiveness is often compromised by weak enforcement and limited financial support.

Key challenges include:

- **Weak Enforcement of CE Standards:** Countries with regulations on e-waste and battery recycling often struggle with enforcement due to inadequate monitoring and penalties. This has led to a thriving **informal battery recycling sector** in many regions, where environmental and safety standards are ignored to minimize costs;
- **High Costs of Collection and Treatment:** Many end-of-life lithium-ion batteries do not have sufficient material value to cover the costs of reverse logistics and proper recycling operations. Without **Extended Producer Responsibility** policies or financial

incentives, the burden of collection and treatment falls on municipalities or informal actors;

- **Limited Public and Private Investment:** CE models require significant upfront investments in infrastructure, such as **battery testing, repair hubs, and automated disassembly plants**. However, financial support mechanisms—such as **green financing, subsidies, and CE-specific incentives**—are often lacking, making it difficult for businesses to scale up these solutions;
- **Uncertainty in Future Business Models:** Because CE regulations are still evolving, investors are hesitant to commit capital to business models that may be rendered obsolete by future policy changes. Clear, long-term policy roadmaps—such as China’s **national collection and repurposing requirements for EV batteries**—help reduce investment risks, but such frameworks are absent in many other countries.

5.3. Obstacles related to Level of Market Development

Early-stage technologies, especially for the treatment of lithium-ion batteries and emerging chemistries such as LFP (Lithium Iron Phosphate), remain commercially and technically challenging to scale. While countries like China have advanced recycler whitelists, many other markets have not yet reached the technological readiness to support safe, scalable treatment solutions. Santiago’s experience shows how international financing can bridge this gap temporarily, but long-term success requires a self-sustaining industrial base.

Another critical issue is insufficient collection volumes, especially for EoL batteries. The India case illustrates that even with centralized procurement across multiple cities, battery retirement happens over staggered timeframes, which delays aggregation and economies of scale for recycling or repurposing facilities. In the absence of reliable collection streams, circular technologies such as closed-loop recycling or second-life applications remain economically unfeasible, particularly in decentralized or low-density urban contexts.

Key Points:

- Limited number of actors and weak competition restrict innovation and cost reduction;
- Battery treatment technologies are still in early stages, especially for newer chemistries;
- Low and fragmented EoL battery volumes make recycling and reuse economically unviable;
- Market ecosystems for CE practices are underdeveloped in most regions.

5.4. Obstacles related to Lack of Legislation

The absence of clear and enforceable legislation for battery collection, treatment, and reuse introduces major structural weaknesses into CE systems. Without regulatory standards, actors in the battery value chain often operate with minimal oversight, leading to a fragmented landscape where some players cut corners to reduce costs. This is particularly problematic in countries lacking EPR frameworks or where EPR exists only on paper. For instance, the Dakar SunuBRT case study does not reference a national EPR policy for batteries, and battery lifecycle planning relies instead on voluntary or project-specific clauses.

In jurisdictions without clear guidance on remanufacturing or second-life applications, there is no incentive to design products for disassembly or to maintain battery health data for future reuse. This gap enables "free riders"—market players who operate at a lower environmental standard and can therefore offer cheaper services. Such behavior distorts competition and discourages responsible operators from investing in CE innovations.

Moreover, even in regions where regulation exists, a lack of harmonized technical standards poses challenges. The EU case, through the introduction of the Digital Battery Passport, begins to address this by mandating uniform data protocols. However, most countries have yet to adopt such detailed policies, resulting in divergent practices and uncertainty across markets. In effect, the lack of robust and universally enforced legislation prevents the emergence of a level playing field and undermines trust in battery lifecycle management.

Key Points:

- Absence of standards enables low performing "free riders" in the battery value chain.
- Lack of EPR or second-life regulation hinders design-for-reuse and material recovery.
- Non-harmonized rules across jurisdictions create market uncertainty.
- Without legislation, CE efforts remain fragmented and voluntary.

5.5. Obstacles related to Lack of Enforcement and Funding

Even where legislation is in place, weak enforcement mechanisms often render regulatory frameworks ineffective. Without proper monitoring, reporting, and penalties for non-compliance, many actors disregard collection and recycling requirements. In China, the success of the whitelist system for battery recyclers is attributable not only to regulation but also to MIIT's strong enforcement and periodic updates. In contrast, the Indian context illustrates how variability in city-level capacity affects the implementation of national procurement and battery monitoring guidelines. Some cities lack the institutional resources or expertise to enforce extended producer responsibilities effectively.

Lack of funding further compounds enforcement challenges. Municipalities and regional authorities may not have the financial means to invest in inspection systems, data tracking tools, or training programs for staff overseeing CE implementation. In Santiago, it took the intervention of a global financier—the IFC—to embed sustainability standards into procurement. Without such support, even progressive cities struggle to hold suppliers accountable for circular practices.

Moreover, CE infrastructure—such as battery collection centers, diagnostic labs, or repurposing facilities—requires substantial upfront capital investment. In Dakar, for instance, the integration of solar-powered charging and battery monitoring systems was only possible due to international grants and public-private financing. In markets lacking access to concessional or green finance, circular economy projects remain aspirational rather than executable, particularly in lower-income regions.

Key Points:

- Weak enforcement leads to poor compliance even where laws exist.
- Local governments often lack capacity to oversee battery lifecycle requirements.
- Funding gaps prevent investment in CE infrastructure and monitoring tools.

6. Best Practices in E-Bus Procurement and Policy Approach to Case Study Selection

This section presents a set of international case studies that reflect emerging best practices in integrating CE principles and cost optimization strategies into E-Bus procurement and policy design. The selected cases represent different geographies, institutional frameworks, and mechanisms ranging from regulatory tools and digital innovations to centralized procurement and green financing models.

Each case was selected based on its practical demonstration of how specific policy instruments, contracting frameworks, and partnerships that have been employed to address implementation challenges, such as lifecycle battery management, procurement standardization, private sector engagement, and long-term operational sustainability. The goal is to provide replicable insights for public authorities, transit agencies, and financiers looking to embed CE principles into the full lifecycle of E-Bus deployment.

Justification for the selection

The four case studies were chosen to provide a balance between regulatory, institutional, technological, and financial innovations:

- China's Whitelist for Battery Recyclers was selected for its pioneering regulatory model that enforces EPR and promotes compliant battery recycling through a certified national network. This example illustrates how government oversight and technical standards can foster a level playing field and scale circularity.
- India's Centralised E-Bus Procurement Model showcases a procurement-led strategy that reduces costs while embedding lifecycle sustainability obligations, including battery health monitoring and EPR commitments. It exemplifies how centralized tenders can be used to aggregate demand and standardize environmental accountability.
- The EU Battery Regulation and Digital Battery Passport was included for its innovative use of digital infrastructure to enable transparency, traceability, and compliance across the battery lifecycle. This case provides insight into how regulatory frameworks can harness data to promote circularity at scale.
- Santiago's E-Bus PPP and IFC Circular Economy Requirements highlights the role of international green finance in enforcing sustainability and circularity through contractual and funding conditions. It demonstrates how public-private partnerships can align financial incentives with environmental performance benchmarks.
- Dakar's electric bus initiative under the BRT system, highlighting how the creation of a new urban transport network offers a unique opportunity to embed CE principles from the ground up. Selected for its forward-looking planning approach, Dakar's model

demonstrates how early local capacity-building, and donor-aligned sustainability criteria can set a strong foundation for long-term environmental and operational resilience in emerging markets.

Together, these cases offer complementary perspectives on how to operationalize CE goals within the complex value chains of E-Buses, making them valuable learning models for policy and project contexts.

6.1. Case Study: Creating a Level Playing Field – China’s Whitelist for Battery Recyclers

Introduction

This case explores China’s national whitelist system for certified recyclers of EV batteries. It highlights the role of regulation in establishing transparent and accountable end-of-life battery management, essential to achieving CE objectives.

Purpose of the Case Study

China’s approach offers a practical example of how EPR and strict technical standards can be combined to promote compliant and efficient recycling at scale.

Project Background

In response to growing volumes of end-of-life EV batteries, China enforced EPR obligations requiring EV manufacturers to establish battery collection and recycling systems through approved recyclers listed on a national whitelist.

Location and Stakeholders

The policy applies nationwide, with key stakeholders including the Ministry of Industry and Information Technology (MIIT), EV manufacturers, recyclers, and local governments.

Focus of the Case Study

The focus is on the creation and enforcement of a certified list of recyclers, ensuring quality

Details

Location:
Nationwide (China)

Stakeholders:
Ministry of Industry and Information Technology (MIIT), EV Manufacturers, certified recyclers, local governments

Case Study Highlights:

- National whitelist system regulating over 150 certified battery recyclers
- EV manufacturers must establish collection points and contract exclusively with whitelist recyclers.
- Over 10,000 collection service outlets established across 327 regions by the end of 2023
- Strengthens Extended Producer Responsibility (EPR) and supports safe, scalable battery recycling

Environmental Impact:

- Improved battery recovery rates and reduced environmental risks
- Minimized informal sector leakage, promoting safe and efficient recycling practices
- Enhanced economic opportunities and strengthened recycling infrastructure
- Regulatory model that improves business predictability and investor confidence



standards and providing a framework to improve compliance and material recovery

Implementation

Process Description

EV manufacturers must set up collection points and work exclusively with recyclers from the national whitelist. These recyclers must meet strict technical criteria for dismantling and recycling, regularly updated by government authorities.

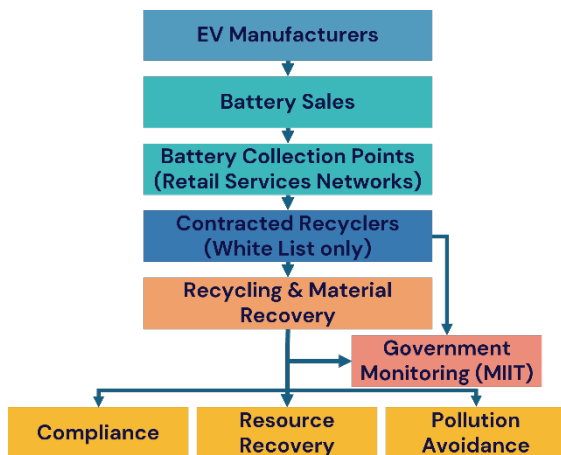


Figure 4: China recycling flow chain (Source: Ramboll 2025)

Challenges Faced

The main challenges included nationwide coordination, regulatory enforcement, and preventing informal or non-compliant recycling practices.

Results

Project Outcomes

Over 150 certified recyclers now operate across China, with widespread adoption improving battery recovery rates and compliance with environmental norms.

Impact Analysis

The initiative has improved the traceability of battery flows, supported the development of a formal recycling industry, and reduced illegal disposal practices.

Conclusion

Key Learnings

National-level EPR policy and technical certification can create a level playing field and enable circular outcomes at scale.

Solutions and Best Practices

The whitelist system ensures recyclers meet technical standards, with over 10,000 collection points established. This model promotes scale and consistency in battery treatment while reducing environmental risks.

Recommendations

Other countries should consider similar whitelist approaches tied to EPR mandates and supported by regulatory updates and performance enforcement.

Table 2: Summary Table Case Study Creating a Level Playing Field

Requirement	Description
Certified Recycler Mandate	EV manufacturers are required to contract exclusively with recyclers listed on the national MIIT whitelist.
Technical Compliance Standards	Whitelisted recyclers must meet stringent dismantling, environmental, and technical standards regulated by the government.
Nationwide Collection Network	Over 10,000 collection service outlets have been established across 327 regions to support battery take-back.
Lifecycle Responsibility	EV manufacturers are responsible for establishing collection points and ensuring batteries are properly recycled.
Government Oversight and Updates	MIIT regularly updates the whitelist criteria and enforces compliance to maintain high environmental and technical standards.

6.2. Case Study: Scaling Sustainability – India’s Centralised E-Bus Procurement Model

Introduction

India’s centralized tendering approach for E-Bus procurement under the Grand Challenge initiative demonstrates how strategic procurement can integrate CE principles. This case study showcases how public policy and market aggregation can drive down costs while embedding sustainability into large-scale mobility projects.

Purpose of the Case Study

Selected for its strategic integration of sustainability criteria in procurement, this case illustrates how lifecycle thinking can be applied at the contract level, aligning economic efficiency with environmental outcomes.

Project Background

The Grand Challenge, launched by Convergence Energy Services Limited (CESL), centralized the procurement of 5,450 E-Buses across five Indian cities. The tender focused not only on cost aggregation but also required OEMs to commit to battery health monitoring and end-of-life planning.

Location and Stakeholders

The project covers multiple Indian cities, involving CESL, city transport authorities, OEMs, and national government agencies

Details

Location:

India (multiple cities under CESL’s Grand Challenge initiative)

Stakeholders:

Convergence Energy Services Limited (CESL), City Transport Agencies, National Government of India, Original Equipment Manufacturers (OEMs)

Case Study Highlights:

- Centralized procurement of 5,450 E-Buses
- Standardized contracts including performance guarantees, battery lifecycle monitoring, and digital diagnostics
- Supports India’s clean energy and sustainability targets through a scalable, cost-effective model
- CESL aims to deploy 50,000 E-Buses by 2027 across India

Environmental Impact:

- Embedding battery state-of-health monitoring enables responsible reuse and recycling pathways
- Significant lifecycle CO₂ savings compared to diesel buses (exact metric tons not specified in the document)
- Near-zero particulate matter emissions; improved NO_x, CO, and HC emission profiles through electrification
- Promotes CE principles through mandatory EoL battery handling and reuse assessments



under the PM-eBus Sewa Scheme.

Focus of the Case Study

The tendering model’s innovation lies in embedding EPR, battery performance tracking, and end-of-life planning into the procurement lifecycle, ensuring CE principles are applied from planning through operations.

Implementation

Process Description

CESL issued a unified tender, setting standardized technical and environmental requirements across cities. OEMs were required to provide warranties, enable real-time monitoring, and report quarterly battery health metrics.

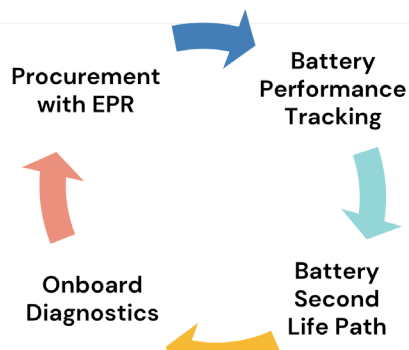


Figure 5: Integrating Circular Economy in GCC India E-Bus Battery Procurement (Source: Ramboll 2025)

Second-life feasibility for batteries: Cost optimization was achieved through demand aggregation and standardization.

Results

Project Outcomes

The tender led to price reductions between 15–48% across cities. It also established a framework for monitoring battery health and implementing circular practices in public transit.

Impact Analysis

The initiative promoted environmental accountability, fostered inter-agency cooperation, and demonstrated how procurement can drive systemic sustainability improvements.

Challenges Faced

Cities had varying infrastructure and operational preferences. Ensuring lifecycle monitoring and enforcing warranties added complexity to contracts and required capacity-building at the city level.

“The adoption of the Gross Cost Contract (GCC) model under a Public-Private Partnership framework has been a transformative milestone in our electric bus mission. It underscores BMTC’s commitment to sustainable, green urban mobility while aligning with circular economy principles to ensure long-term environmental and operational resilience for Bengaluru.”

Ramachandran Ramasamy, Managing Director, Bengaluru Metropolitan Transport Corporation (BMTC)

Solutions and Best Practices

The tender included real-time data access requirements, performance-linked monitoring, and lifecycle accountability. This ensured optimal use, safety, and reliability of the public transport systems.

Conclusion

Key Learnings

India's centralized E-Bus procurement under the Grand Challenge integrated CE principles, including EPR and battery lifecycle management.

Recommendations

Future tenders should expand circular criteria, provide training for transport agencies, and adopt digital battery.

Table 3: Summary Table Case Study Scaling Sustainability

Requirement	Description
Certified Recycler Mandate	OEMs must plan for end-of-life battery handling, including reuse or recycling as part of contractual obligations.
Technical Compliance Standards	OEMs must provide real-time battery health monitoring, quarterly reporting, and meet standardized environmental performance targets.
Nationwide Collection Network	E-bus deployment across multiple cities requires local collection, diagnostics, and recycling network development.
Lifecycle Responsibility	OEMs hold Extended Producer Responsibility (EPR) across the battery's full lifecycle, including reuse or final disposal.
Government Oversight and Updates	CESL centrally monitors compliance with battery tracking and sustainability clauses, updating standards through future tenders.

6.3. Case Study:

Driving Transparency and Circularity – The EU Battery Regulation and Digital Passport

Introduction

The European Union's Battery Regulation, including the Digital Battery Passport (DBP), is a groundbreaking policy promoting full lifecycle transparency for EV and industrial batteries. This case shows how regulation and digital tools can jointly advance circular economy goals.

Purpose of the Case Study

Selected to highlight digital integration in circular policy, the EU case demonstrates how lifecycle data access can empower all actors in the battery value chain—from manufacturers to recyclers.

Project Background

Passed in July 2023, the EU Battery Regulation (2023/1542) applies across all member states. It includes sustainability requirements such as recycled content targets, carbon footprint disclosure, and the creation of digital passports for batteries.

Location and Stakeholders

Applies across the EU, involving battery producers, recyclers, regulators, and IT service providers. The DBP becomes mandatory for EV and industrial batteries >2kWh by 2027.

Details

Location:
European Union

Stakeholders:
Battery producers, recyclers, regulators,
IT service providers

Case Study Highlights:

- EU Battery Regulation (2023/1542) mandates sustainability requirements including recycled content targets, carbon footprint disclosure, and a DBP
- The DBP becomes mandatory by 2027 for EV and industrial batteries >2kWh
- Battery data stored in a decentralized system, accessible via QR codes, covering material composition, state of health (SoH), carbon intensity, and EoL instructions
- Enhances traceability, supports reuse, repurposing, and safe recycling across the battery lifecycle

Environmental Impact:

- Expected to boost material recovery rates and reduce carbon emissions
- Promotes safe, efficient recycling and reuse by making battery lifecycle data accessible
- Drives green innovation and strengthens CE practices across the battery value chain.
- Sets a global precedent for digital traceability and CE regulation



Focus of the Case Study

The Digital Battery Passport is the centerpiece, enabling traceability of material use, battery condition, and treatment options throughout a battery's lifecycle

Implementation

Process Description

Manufacturers must store battery data in a decentralized system, accessible via QR codes. Specific data fields include material composition, SoH, carbon intensity, and end-of-life instructions. Access levels vary based on user role.



Figure 6: Battery Passport App (Source: Batteries European Partnership Association (2023))

Challenges Faced

Challenges included standardizing data formats across industry, ensuring cybersecurity, and creating a legally compliant system usable by actors across the EU.

Solutions and Best Practices

The DBP improves information flows across the value chain. By providing battery condition and lifecycle details, it supports reuse, repurposing, and safe recycling while reducing environmental risk.

Results

Project Outcomes

The regulation has set a global precedent, creating an actionable framework for circularity in battery use and recovery. It also paves the way for similar passports in other sectors (e.g., electronics, textiles).

Impact Analysis

Expected to increase material recovery, reduce carbon emissions, and encourage green innovation across the supply chain.

Conclusion

Key Learnings

Mandatory data sharing and lifecycle visibility can drive circular transformation, especially when linked with enforceable standards.

Recommendations

Countries designing circular battery

regulations should adopt interoperable digital systems and create phased implementation plans to ensure industry readiness.

Table 4: Summary Table Case Study Driving Transparency and Circularity

Summary Table	
Requirement	Description
Certified Recycler Mandate	Battery producers must enable access to certified recyclers by providing battery end-of-life information through the Digital Battery Passport (DBP).
Technical Compliance Standards	Batteries must meet sustainability requirements, including recycled content, carbon footprint disclosure, and lifecycle traceability.
Nationwide Collection Network	Regulation facilitates coordinated collection and recycling through standardized digital data accessible to relevant parties across the EU.
Lifecycle Responsibility	Battery manufacturers are responsible for full lifecycle data reporting, promoting reuse, repurposing, and recycling.
Government Oversight and Updates	The EU regularly updates technical standards and regulatory requirements, with phased DBP implementation becoming mandatory by 2027.

6.4. Case Study: Financing for the Future – Santiago’s E-Bus PPP and IFC Circular Economy Requirement

Introduction

Santiago de Chile’s Public-Private Partnership (PPP) for electric buses, supported by the International Finance Corporation (IFC), is a landmark case demonstrating how financing mechanisms can embed circular economy principles into E-Bus deployment. It highlights how policy, procurement, and funding can align to ensure lifecycle sustainability.

Purpose of the Case Study

This example was chosen to illustrate how financial institutions like the IFC are increasingly using environmental and circular economy benchmarks to guide investment decisions – encouraging responsible battery and vehicle lifecycle management through funding conditions.

Project Background

Santiago launched its E-mobility transition through the Red Metropolitana de Movilidad (RED), integrating hundreds of electric buses into its transit system. The IFC provided over US\$300 million in loans to support the procurement of nearly 1,000 electric buses.

Location and Stakeholders

The project is based in Santiago de Chile and involves the Ministry of Transport and Telecommunications (MTT), private bus operators, the IFC, the Global Environment

Details

Location:
Santiago, Chile

Stakeholders:
Ministry of Transport and Telecommunications (MTT), International Finance Corporation (IFC), Global Environment Facility (GEF), private bus operators, E-Bus manufacturers

Case Study Highlights:

- IFC provided over US\$300 million to support the procurement of nearly 1,000 electric buses
- Contracts require adherence to CE standards, including lifetime battery warranties and waste management plans
- Integration of battery tracking, second-life use encouragement, and environmentally sound disposal into project contracts
- IFC financing conditions set a new precedent for sustainable transit procurement in Latin America

Environmental Impact:

- Active battery performance monitoring and enforced warranties ensure longer battery life and responsible replacement
- Transparent management of waste streams and hazardous materials aligned with IFC environmental standards
- Supports substantial emission reductions and air quality improvements in Santiago
- Institutionalized circular economy principles into Santiago’s transit system, promoting long-term sustainability



Facility (GEF), and multiple E-Bus manufacturers.

Focus of the Case Study

The focus is on the IFC’s role in mainstreaming CE standards into contract design and funding conditions, particularly around battery management, end-of-life vehicle disposal, and capacity-building for sustainable operations.

Implementation

Process Description

As part of the financing terms, E-bus suppliers and operators must adhere to circularity-focused requirements, including lifetime warranties, battery replacement clauses, and comprehensive battery and waste management plans. Contracts separate vehicle supply from operations,

ensuring specialized accountability.

Solutions and Best Practices

The IFC’s approach included conditions for suppliers to manage final disposal or repurposing of batteries and buses. Operators must train staff in diagnostics and maintenance, replace batteries as performance declines, and implement waste and hazardous materials management plans aligned with IFC’s environmental performance standards.

This integrated approach supports battery tracking, encourages second life uses, and ensures environmentally sound disposal at the end of the buses’ useful life.

Results

Project Outcomes

The project delivered one of Latin America’s largest E-Bus fleets, while setting a precedent for how international finance can shape sustainability standards. Battery performance is actively monitored, warranties are enforced, and waste streams are managed transparently.

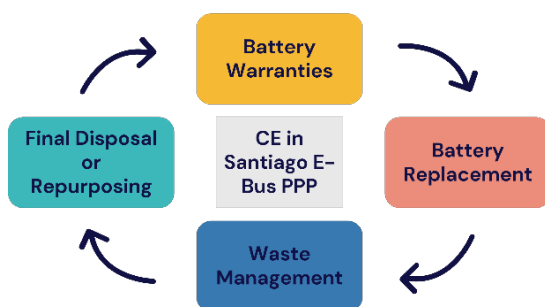


Figure 6: Santiago Battery life management (Source: Ramboll 2025)

“I think it’s very important to show that this is a business opportunity. Many of them that were initially very reluctant, over time realized that this is an opportunity and it’s good for business and for them”

Ricardo Giesen, PhD, Professor (Associate), Department of Transport Engineering and Logistics, BRT+ Centre of Excellence, Pontificia Universidad Católica de Chile, Macul, Santiago, Chile

Challenges Faced

Introducing circular requirements into a complex PPP model required significant coordination between public and private actors. Ensuring compliance with both Chilean environmental law and IFC’s sustainability standards demanded robust oversight mechanisms and clear contract language.

Impact Analysis

Beyond reducing emissions and improving air quality, the project catalyzed institutional change by embedding circularity into transit procurement. It demonstrated how public-private cooperation, backed by green financing, can mainstream sustainable practices across the value chain.

Conclusion

Key Learnings

Santiago’s case shows that international financing institutions can play a decisive role in promoting CE principles. Clear sustainability conditions, when tied to capital, incentivize best practices in battery management, maintenance, and end-of-life planning.

Recommendations

Future projects should leverage green finance not just for cost reduction, but to drive policy transformation. Including circularity clauses in tender and funding documents is a powerful way to ensure long-term environmental and economic resilience in E-mobility investments.

Table 5: Summary Table Case Study Financing for the Future

Requirement	Description
Certified Recycler Mandate	E-bus contracts require environmentally sound battery disposal and second-life use planning, aligned with IFC sustainability standards.
Technical Compliance Standards	Suppliers must adhere to IFC environmental guidelines, including lifetime battery warranties, tracking, and recycling plans.
Nationwide Collection Network	Bus operators must implement battery management and monitoring systems within their operational frameworks.
Lifecycle Responsibility	Manufacturers and operators are responsible for battery tracking, second-life use encouragement, and proper disposal at end-of-life.
Government Oversight and Updates	IFC financing terms act as oversight, with compliance tied to financing disbursements and project continuation.

6.5. Case Study: SunuBRT Dakar: Pioneering Electric Urban Mobility with Renewable Energy

Introduction

The BRT project “SunuBRT” in Senegal’s capital, Dakar, aims to modernize urban transport between Dakar and Guédiawaye through the development of a green BRT corridor using electric buses powered by renewable energy. It is the first all-electric BRT system in Sub-Saharan Africa, launched on January 14, 2024. The BRT integrates with the regional commuter TER (Train Express Régional) system to create a seamless public transportation network. This integration includes enhancing the functionality of different transport modes, streamlining transfers between TER, BRT, and existing bus networks, formalizing informal transport, and improving modal integration. SunuBRT marks a key project in the Emerging Senegal Roadmap, an ambitious 25-year development plan aimed at transforming the nation into a high-income economy by 2049. This project also highlights how emerging economies can apply CE practices in public transportation.

Overview of the Case Study

This case study examines the SunuBRT project in Dakar, a pioneering initiative aimed at creating a sustainable and green urban transport system. The project focuses on deploying fully electric buses powered by renewable energy to address rising congestion, pollution, and urban mobility challenges.

Details

Location:
Dakar, Senegal

Stakeholders:
Executive Council for Sustainable Urban Transport (CEDUT); World Bank Group, Agence Française de Développement, Senegal Sovereign Fund (FONSIS), Meridiam; Dakar Mobilité SA; bus manufacturers

Case Study Highlights

- Deployment of 144 articulated electric buses equipped with 560 kWh lithium-ion batteries
- Integration of solar-powered charging stations and real-time energy optimization systems
- Dedicated BRT lanes and express services to reduce congestion and promote faster, cleaner transit
- Project designed to serve approximately 300,000 passengers daily, supporting broader sustainable urban mobility goals

Environmental Impact

- Use of renewable solar energy to power charging infrastructure, reducing reliance on fossil fuels
- Significant reductions in CO₂ emissions and urban air pollutants compared to traditional diesel buses
- Real-time monitoring systems optimize energy use and extend battery life, supporting CE principles
- Improved air quality through near-zero particulate matter emissions and reduced greenhouse gases



Purpose of the Case Study

The SunuBRT was selected to illustrate how emerging economies can integrate CE practices into large-scale public transportation initiatives. It highlights practical applications of environmental sustainability, technological innovation, and cost optimization.

Project Background

The SunuBRT was developed in response to increasing urban congestion and deteriorating air quality caused by aging transport modes such as the Car Rapides and Ndiaga Ndiaye minibuses. By replacing these diesel buses with a fleet of electric buses and creating a Mass Rapid Transit system, the city aims to transition towards a zero-emission public transport model while promoting greater energy efficiency. The BRT buses are powered by solar-generated renewable energy. The transition to an all-electric fleet also involved managing battery recycling and ensuring reliable power sources.

Location and Stakeholders

The project is based in Dakar and involves a wide range of stakeholders, including the Government of Senegal, the Executive Council for Sustainable Urban Transport (CEDUT) as the implementing authority,

international financial institutions such as the World Bank Group, Agence Française de Développement, Senegal Sovereign Fund (FONSIS), and Meridiam, as well as bus manufacturers. The concessionaire, Dakar Mobilité SA (70% owned by Meridiam and 30% by FONSIS), is a Senegalese company responsible for the acquisition of the buses, and the operation and maintenance of the BRT system.

Focus of the Case Study

The focus centers on the implementation of an electric BRT system supported by renewable energy integration, real-time data optimization, and lifecycle sustainability strategies, including CE principles for battery management. This project provides a model for other emerging cities.

Challenges Faced

Several challenges emerged during the implementation of the SunuBRT project. The initial reliance on buses from Tata Motors was reconsidered after operational evaluations, leading to a switch to buses from Xiamen King Long United Automotive Industry Co. to better align with the project's technical and operational goals. Additionally, establishing a robust and reliable charging infrastructure required substantial upfront investment to support the fleet of electric buses.

“We launched Dakar’s BRT with the ambition to deliver zero-emission, modern, and truly inclusive mobility. Even with the most rigorous planning, challenges are inevitable — what matters is the ability to adapt. By progressively ramping up operations, we ensured Dakar’s residents had access to a reliable, safe, and high-capacity public transport service while continuing to upgrade infrastructure. From the very first phases, this approach delivered a high-performing system for users. We are proud to lead Africa’s first large-scale electric BRT and remain committed to advancing further by gradually integrating the informal sector, strengthening local expertise, and aligning public policies to secure lasting success.”

Ramatoulaye Mbaye, Ingénieur Systèmes, Projet BRT de Dakar,
Conseil exécutif des Transports urbains Durables (CEDUT)

Implementation

Process Description

The SunuBRT project in Dakar spans 18.3 kilometers, connecting the northern suburb of Guédiawaye to the Petersen bus station in central Dakar. It serves 23 stations, incorporates one depot, and includes four charging infrastructure facilities. Dakar Mobilité SA manages the BRT system as a Public-Private Partnership (PPP) with a 15-year concession. The project includes the procurement and maintenance of a fleet of 144 articulated electric buses, each equipped with 560 kWh lithium-ion batteries. The buses are charged using solar-generated electricity, ensuring that renewable energy powers a significant portion of operations. Real-time monitoring systems have been implemented to optimize energy use according to dynamic passenger demand patterns. Dedicated BRT lanes and express lines were developed to reduce congestion and improve travel times by 50% (from 90 to 45 minutes from Dakar city center to Guédiawaye). Special attention was given to the inclusive design of both stations and vehicles to ensure accessibility and safety for all user groups.

Coordinating among international partners, local authorities, and multiple stakeholders proved complex and required strong project management and communication strategies.

Solutions and Best Practices

Innovative Solutions

The integration of real-time data systems enabled efficient energy management and operational optimization. Drawing inspiration from international best practices, such as China's recycler whitelist and the EU's battery passport initiatives, the project incorporated sustainable lifecycle management principles for its battery systems.

Cost Optimization Measures

The use of solar energy helped to significantly lower long-term energy costs. Standardizing bus models and spare parts reduced maintenance expenses, while regenerative braking technology further contributed to energy efficiency and operational cost savings.

Results

Project Outcomes

The SunuBRT is projected to serve approximately 300,000 passengers daily, substantially reducing dependence on private vehicles. The system has achieved notable reductions in CO₂ emissions and improvements in urban air quality. By leveraging renewable energy and advanced operational technologies, the project delivered major energy savings.

Impact Analysis

The economic impact includes reduced fuel and maintenance costs, enhanced efficiency in public transportation, and positive contributions to the local economy. Environmentally, the SunuBRT has significantly lowered greenhouse gas emissions and improved air quality, contributing to better public health outcomes for the city's residents.

Key Learning

The SunuBRT demonstrates that integrating renewable energy sources into public transport infrastructure can significantly improve sustainability. CE practices, such as real-time optimization and proactive lifecycle management, are feasible and highly beneficial in emerging markets. Flexibility in project execution, including supplier changes, and robust stakeholder coordination are critical success factors.

Recommendations

Future transport projects should incorporate comprehensive lifecycle planning for electric vehicle batteries to maximize sustainability benefits. Governments should offer incentives for renewable energy integration within transport infrastructures. Finally, effective stakeholder engagement and adaptive project management are essential to accommodate technological advancements and market developments.

Requirement	Description
Certified Recycler Mandate	The project incorporates lifecycle sustainability strategies for battery management, drawing on international best practices, though a formal recycler mandate is under development.
Technical Compliance Standards	Electric buses must meet real-time monitoring, battery health optimization, and renewable energy integration standards.
Nationwide Collection Network	Charging infrastructure is integrated citywide, powered by solar energy; real-time optimization supports efficient energy use across the network.
Lifecycle Responsibility	Battery lifecycle and energy usage are actively monitored, supporting circular practices and extending battery lifespan.
Government Oversight and Updates	The Government of Senegal, alongside international financiers, oversees implementation with a focus on adaptive management and continuous improvement.

7. Recommendations

Before launching a CE strategy for E-Bus projects, several key factors must be addressed to ensure feasibility, efficiency, and long-term sustainability. These recommendations cover data analytics, repair, remanufacturing, repurposing, recycling, and revenue streams from e-waste to optimize the lifecycle of E-Bus batteries and infrastructure.

1. Establishing a Robust Data Analytics Framework for Second-Life Applications

- **Implement Advanced Battery Management Systems (BMS):** Ensure that vehicles are equipped with **real-time monitoring and diagnostics** to track battery performance and degradation patterns. AI-driven analytics should be integrated to predict battery lifespan and identify optimal second-life applications.
- **Standardize Data Collection & Sharing:** Develop **harmonized data formats** to facilitate battery diagnostics, ensuring that state-of-health (SoH) and state-of-charge (SoC) assessments are comparable across different battery chemistries and manufacturers.
- **Develop Predictive Models for Suitability Assessments:** Utilize historical usage data and thermal performance analysis to **determine the best-fit application** for second-life batteries (e.g., stationary storage, microgrids).
- **Ensure Regulatory and Technical Standards Compliance:** Collaborate with policymakers to **define second-life battery criteria** and establish standardized performance metrics for repurposed batteries.

2. Establishing Battery Repair and Maintenance Infrastructure

- **Develop Regional Repair Hubs:** Minimize logistics costs and vehicle downtime by creating **local battery repair centers**, modeled after **MAN Truck & Bus's European repair network**.
- **Incentivize Battery Repair Within Warranty Periods:** Encourage OEMs to integrate battery **repair clauses in warranty agreements**, ensuring that batteries are maintained rather than prematurely replaced.
- **Adopt Module-Level Repair Approaches:** Instead of replacing entire battery packs, establish processes for identifying **faulty modules** and replacing them selectively.
- **Train and Certify Technicians in High-Voltage Battery Repair:** Develop specialized workforce training programs to equip technicians with **skills in diagnosing and repairing lithium-ion battery systems**.

3. Scaling Up Remanufacturing Operations

- **Develop Efficient Disassembly Processes:** Remanufacturing requires **automated disassembly lines** and robotic diagnostics to inspect individual battery components.
- **Standardize Testing and Quality Control:** Define **industry-wide performance benchmarks** to ensure that remanufactured batteries perform comparably to new units.
- **Incentivize OEM Participation:** Encourage **battery manufacturers to design products with remanufacturing in mind**, using modular designs that simplify disassembly and reuse.

- **Encourage AI-Based Condition Assessment Tools:** Implement **AI-driven analytics**, similar to **Circu Li-Ion's automated disassembly system**, to enhance cost-efficiency in remanufacturing.

4. Designing Effective Strategies for Battery Repurposing

- **Align Second-Life Applications with Energy Storage Needs:** Work with **utilities, grid operators, and municipalities** to determine optimal use cases for repurposed batteries (e.g., renewable energy storage, peak shaving solutions).
- **Establish Safety and Performance Standards for Repurposed Batteries:** Develop guidelines to ensure that **batteries used in second-life applications meet reliability and safety criteria** before being redeployed.
- **Promote Public-Private Partnerships for Infrastructure Deployment:** Encourage partnerships with energy companies to **deploy second-life battery storage solutions**, similar to the **Project Anubis initiative in the Netherlands**.
- **Ensure a Legal Framework for Liability & Ownership:** Define clear **ownership and liability regulations** for second-life batteries, outlining responsibilities of the original manufacturer, repurposing entity, and end-user.

5. Strengthening Battery Recycling Ecosystems

- **Develop Comprehensive Collection and Logistics Networks:** Establish **battery take-back systems** with designated collection points to ensure proper recycling. China's model of **10,000+ collection centers** provide a useful benchmark.
- **Support Advanced Recycling Technologies:** Promote **hydrometallurgical and direct recycling** techniques that maximize material recovery while reducing energy consumption.
- **Ensure Compliance with CE Policies:** Align recycling strategies with **EU Battery Passport initiatives** and **Extended Producer Responsibility frameworks** to track end-of-life materials.
- **Overcome Recycling Cost Barriers:** Provide **government subsidies and financial incentives** to encourage battery recycling, especially for low-value chemistries like LFP batteries.

6. Identifying and Monetizing Revenue Streams from E-Waste

- **Material Recovery & Resale:** Extracted materials (lithium, cobalt, nickel, copper, and aluminum) should be **resold to battery manufacturers** or reintegrated into production.
- **Battery Leasing & Secondary Market Development:** Develop leasing models where used batteries are refurbished and **leased to commercial or industrial energy users** instead of being prematurely scrapped.
- **Government Incentives for CE Business Models:** Implement tax incentives or **green financing mechanisms** for companies engaging in battery repair, remanufacturing, and repurposing.

- **Encourage Retrofitting as a Cost-Saving Measure:** Electrification of existing diesel fleets through retrofitting (e.g., **Golden Arrow’s retrofitting initiative in South Africa**) offers an affordable transition to E-mobility.



Figure 7: Key take aways from Workshops in Asia, Africa and Latin America (Ramboll 2025)

A comprehensive, well-planned approach is required before implementing CE strategies in E-Bus projects. Robust data analytics, repair and remanufacturing infrastructure, policy support, financial incentives, and market coordination must be established to ensure economic feasibility and environmental sustainability. Governments, OEMs, transit agencies, and the private sector must collaborate to create a structured, financially viable, and scalable CE framework for E-Bus projects.

8. Further Reading

The following references are considered useful material for planning measures directed at improving the Circular Economy of E-Bus projects.

Name	Type of publication	Content	Reference
<i>Solar PV and second life batteries powered EV charging station: case study for India.</i>	Scientific paper	This paper examines India's promotion of EV through policies and subsidies, the need for battery repurposing, and a solar-powered EV charging station project near Bengaluru International Airport.	A. Ramanan, M. Sekhar and S. Mehra, "Solar PV and second life batteries powered EV charging station: case study for India," 7th E-Mobility Power System Integration Symposium (EMOB 2023)
<i>Battery Monitor 2024/2025¹⁶</i>	Industry Report	Roland Berger's annual Battery Monitor provides an assessment of the state of the battery industry, the most pressing challenges and transformative changes.	Roland Berger (2025)
<i>Global EV Outlook 2022. International Energy Agency</i>	Market & Policy Report	An annual flagship publication that provides insights into EV adoption, infrastructure, battery demand, and second-life use potentials.	IEA (2022)
<i>A New Circular Vision for Electronics: Time for a Global Reboot</i>	Industry Report	Explores challenges and circular opportunities across the electronics and battery industries, offering parallels for E-Bus systems	World Economic Forum (2019)
<i>Battery Pass Consortium – Value Assessment¹⁷</i>	Technical Research Report	Establishes a qualitative and quantitative analysis of the battery passport's economic, environmental, and	Battery Pass Consortium (2024)

¹⁶ See report: https://battery-news.de/wp-content/uploads/2025/03/Battery_Monitor_2025-03-25.pdf (last visited 30.06.2025)

¹⁷ See report: <https://thebatteryass.eu/resources/> (last visited 30.06.2025)

		social benefits across the value chain.	
<i>Towards the Circular Economy</i>	Industry Report	A foundational report introducing the concept of a circular economy, with applications across transport, infrastructure, and manufacturing sectors.	Ellen MacArthur Foundation (2015)
<i>Retrofitting Urban Buses to Electric: Costs, Benefits, and Challenges</i>	Technical Policy Brief	Examines the economic and operational potential of converting diesel buses to electric, aligned with circular economy strategies.	ICCT (2023)
<i>Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU.</i>	Research paper	With a focus on circular business model elements and influencing factors, this research reviews literature on CE strategies for LIBs and benchmarks their current adoption amongst European vehicle manufacturers.	Albertsen, L., Richter, J. L., Peck, P., Dalhammar, C., & Plepys, A. (2021). Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU. <i>Resources, conservation and recycling</i> , 172, 105658.

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