Improving the Circularity of Batteries Used in E-Buses

A Measures Catalogue

12.09.2023 Fred Adjei

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Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Agenda

1. E-buses & circular economy
2. Challenges around end-of-life management
3. Economics of Li-ion battery recycling
4. Measures to improve the circularity of e-buses and their batteries

Chapter 1

E-buses & circular economy

A **circular economy** aims at maintaining the value of products and materials for as long as possible, minimising the use of resources and generation of waste, and to keep resources within the economy after products have reached their end-of-life.

Adapted from European Commission (2015): Circular Economy Package: Questions & Answers.

The 5-step Waste Hierarchy

most preferred

1 Prevention

2 Reuse

3 Recycling

4 (Energy) Recovery

5 Disposal

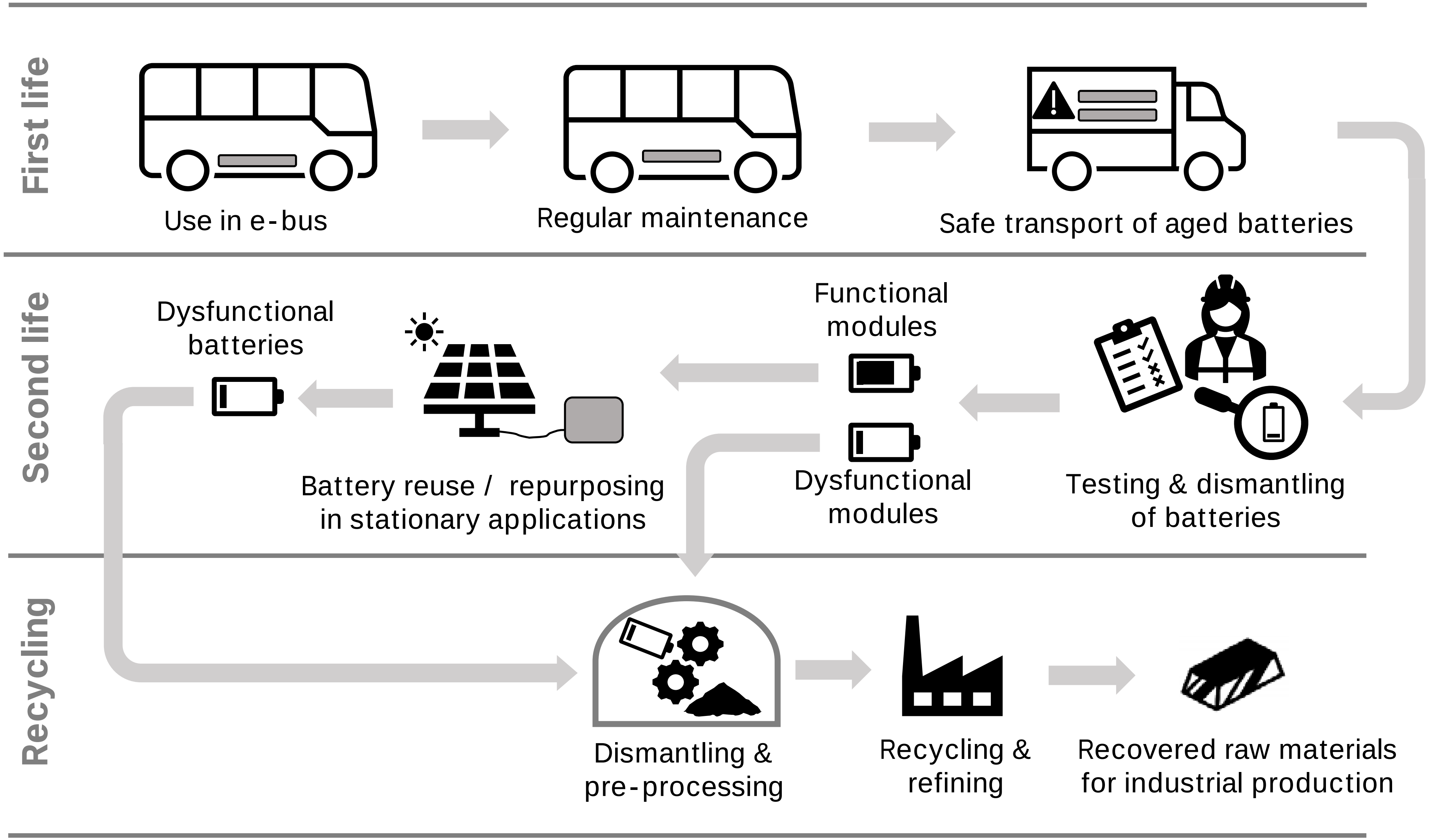
least preferred

The "3Rs":

Reduce, Reuse, Recycle

Source: Oeko-Institut

Ideal management pathway of e-bus batteries



Source: Oeko-Institut

Chapter 2

Challenges around end-of-life management

End-of-life challenges of selected e-bus components

Tyres:
- Difficult to recycle
- Often disposed uncontrolled or burned to recover the steel mesh

Cables:
- Often burned openly to recover the copper

Electronic components:
- Contain various hazardous substances

Plastics:
- Recycling often difficult due to chemical additives or other properties (e.g. coated plastic)

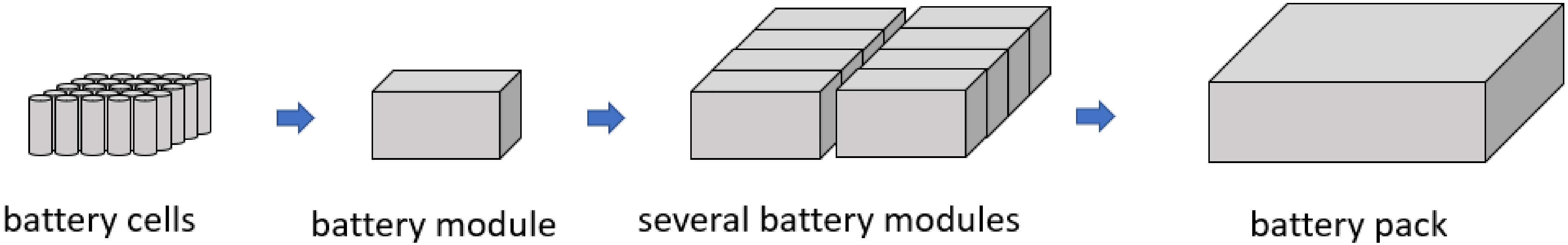
Refrigerants:
- Some refrigerants have a very high global warming potential
- Leakages during use & decommissioning

Source: Oeko-Institut

End-of-life challenges of e-bus batteries

1. **Hazardous substances:** All types of Li-ion batteries contain various constituents that can have considerable negative impacts on human health and the environment if not managed properly.
2. **Embedded raw materials:** Li-ion batteries contain raw materials that are considered as critical for economic development and expansion of green-energy technologies (lithium, graphite, cobalt, nickel…).
3. **Fire risks:** Batteries with residual charge may overheat, catch fire and even explode after damages (‘thermal runaway’). This may occur days or weeks after a damage happened.

End-of-life challenges of e-bus batteries



- The weight of e-bus batteries ranges between 400 kg and 3200 kg per bus
- E-bus batteries consist of a large number of cells
- If one cell ignites fire may propagate to adjacent cells and vehicles

➡ Logistical efforts (for transport of used batteries to further treatment) should not be underestimated

Packaging & transport requirements

Used Li-ion batteries must be packed in systems that are

- Heat-insulating
- Leak-resistant
- Stabilising / shockproof
- Appropriately labelled

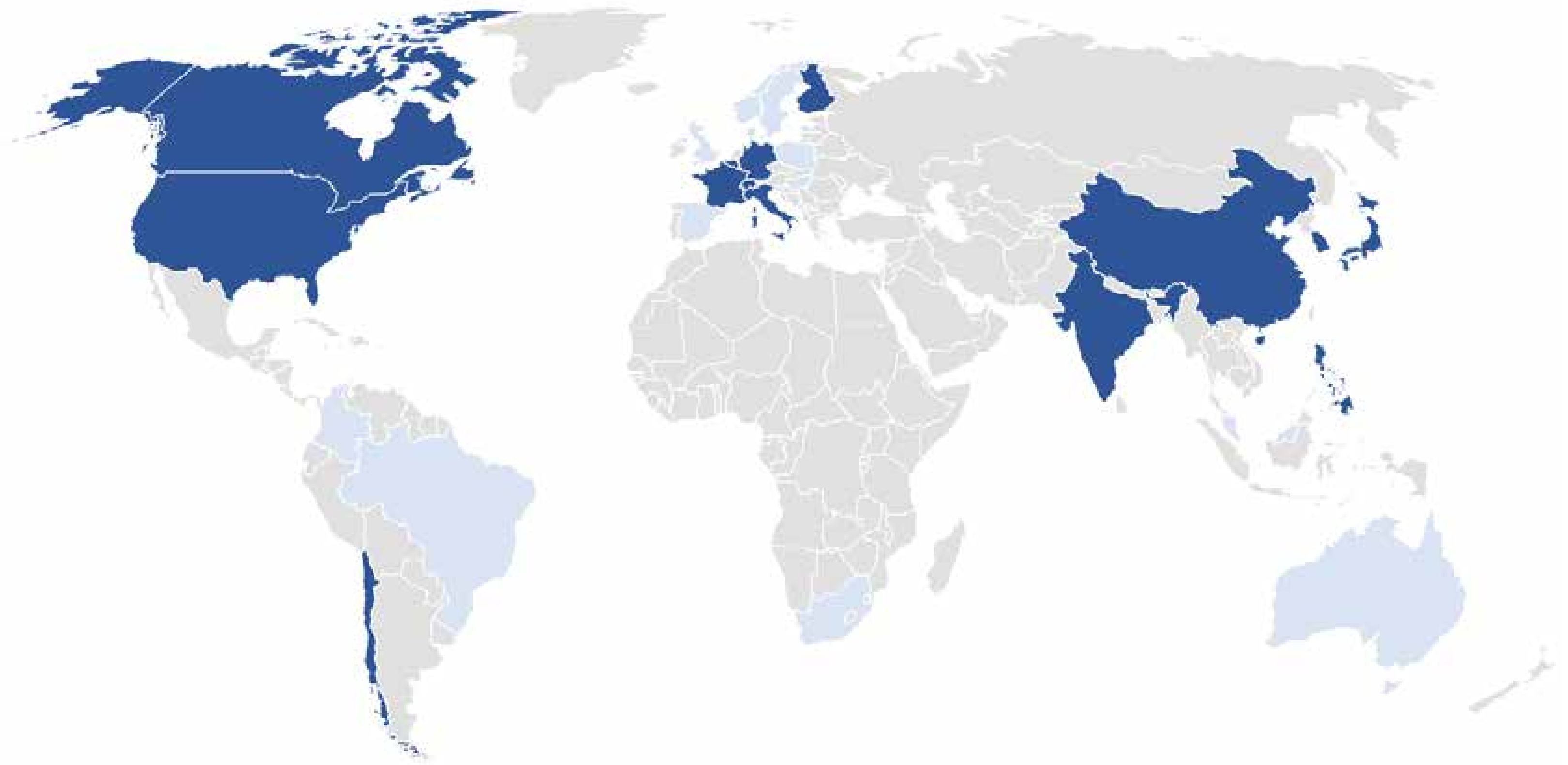
UN3480

Lithium Batteries
for Recycling

➡ Packaging & transport requires special know how & transport containers

Any movement across international boundaries requires compliance with the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*

Recycling capacities for Li-ion batteries



Full recycling capacities

Partial recycling capacities

No recycling capacities

- Many countries have no capacities for treating waste Li-ion batteries
- In such cases, shipments to other countries (in line with Basel Convention) are required

Chapter 3

Economics of Li-ion battery recycling

Economics of Li-ion battery recycling

Indicative material composition of a NMC electric vehicle battery

Element	Content	Application
Aluminium	25.2 %	Cell & module case, cathode current collector
Graphite	12.5 %	Anode active material
Co, Mn, Ni	13.6 %	Cathode active material with Co (2.7%), Mn (2.7%), and Ni (8.2%)
Copper	14.0 %	Cables, anode current collector
Lithium	1.5 %	Cathode active material, conductive salt
	…	Plastic, organic substances…

Source: Brückner et al. (2020): Industrial Recycling of Lithium-Ion Batteries – A Critical Review of Metallurgic Process Routes.

- A broad variety of sizes, designs and sub-chemistries
- No clearly dominating material
- The name giving Lithium is only contained in small traces
- Recyclers focus on recovering Cobalt, Nickel & Copper

Economics of Li-ion battery recycling

Main types of Li-ion battery chemistries used in e-buses

	NMC (Lithium nickel manganese cobalt oxide)	LFP (Lithium iron phosphate)
Energy density	150-260 Wh/kg	90-180 Wh/kg
Cathode materials	Li, Ni, Mn, Co	Li, Fe, P
Copper content	~ 7 %	~ 7-8 %
Cobalt content	~ 6 %	0 %
Nickel content	~ 4 %	0 %
Trends	Used in demanding applications (high required mileage)	Rapidly growing market shares (~5% in 2019, ~40% in 2022)
Indicative recycling costs (gate fees)	~ 0 - 1650 €/t + additional charges for larger batteries (~ 500 €/t)	~ 1000 - 2000 €/t + additional charges for larger batteries (~ 500 €/t)

Sources: Weyhe & Yang (Accurec); Battery University 2021, Wunderlich-Pfeifer 2022, electrive.net 2022

Economics of Li-ion battery recycling

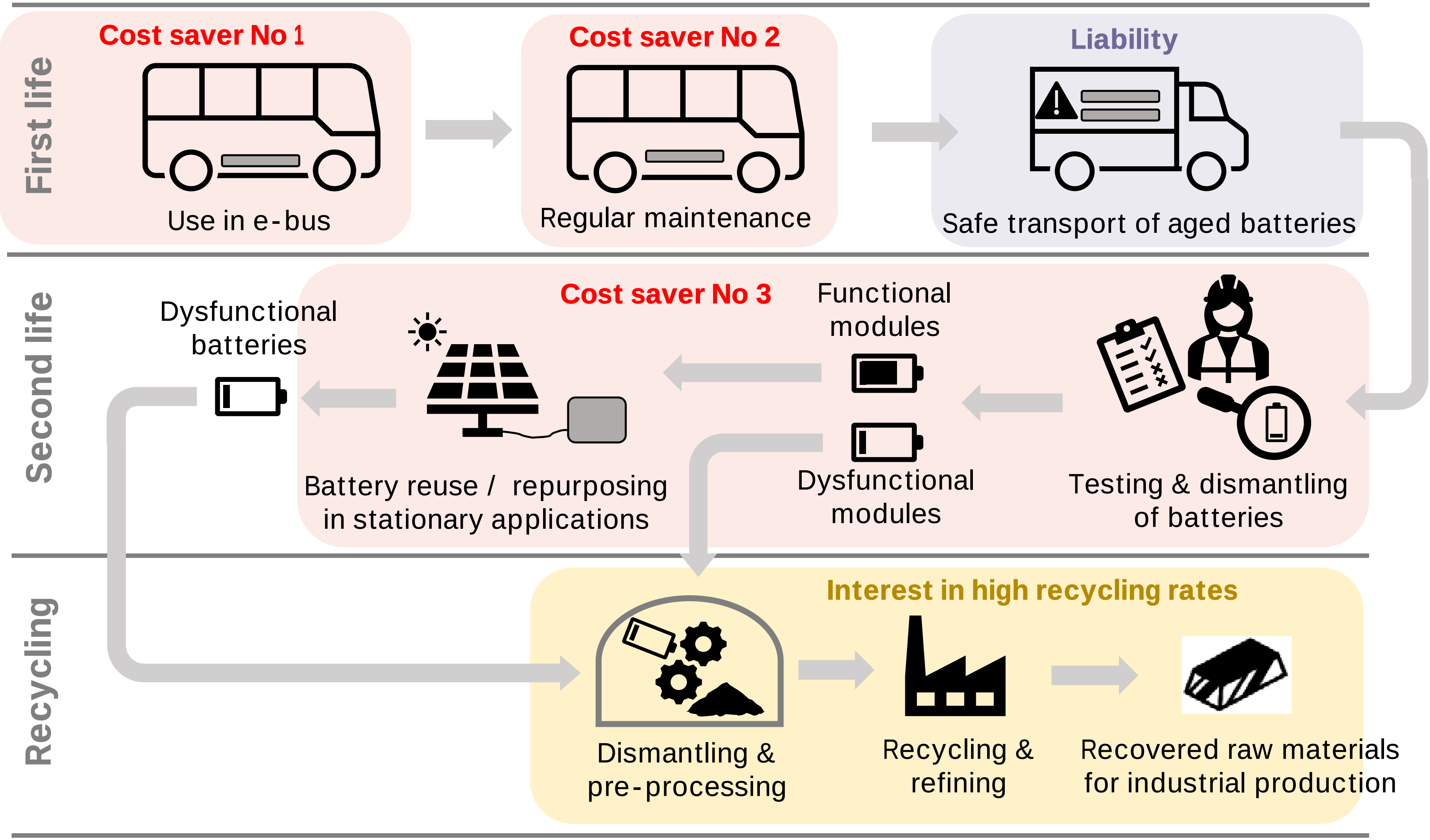
Interim conclusion:

End-of-life management of e-buses and batteries may be associated with **significant net costs!**

The good news:

- With some forward looking (circular economy) measures, these costs can be reduced significantly and/or retained with the producers

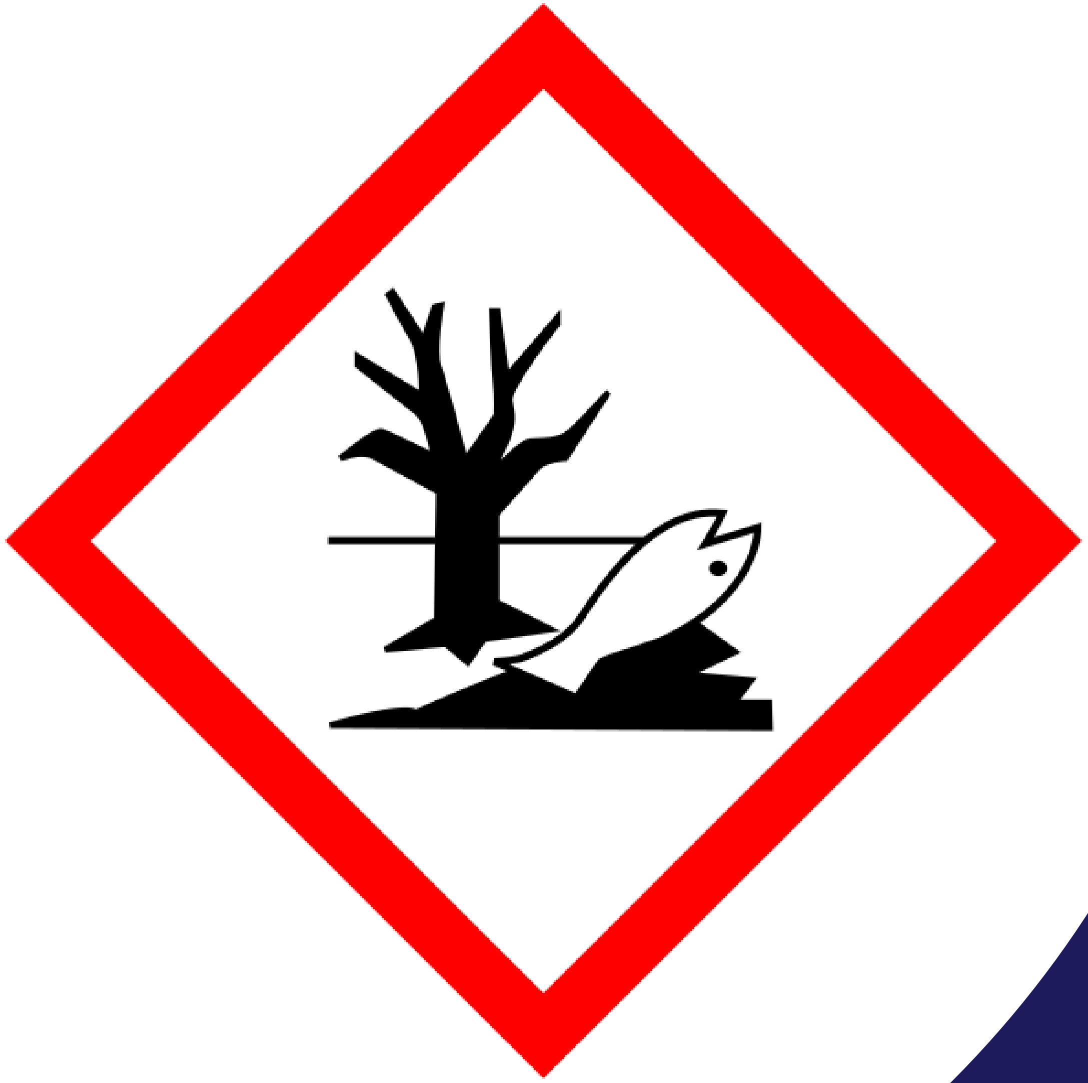
Only about the environment...? What about costs...?



Source: Oeko-Institut

Chapter 4

Measures to improve the circularity of e-buses and their batteries

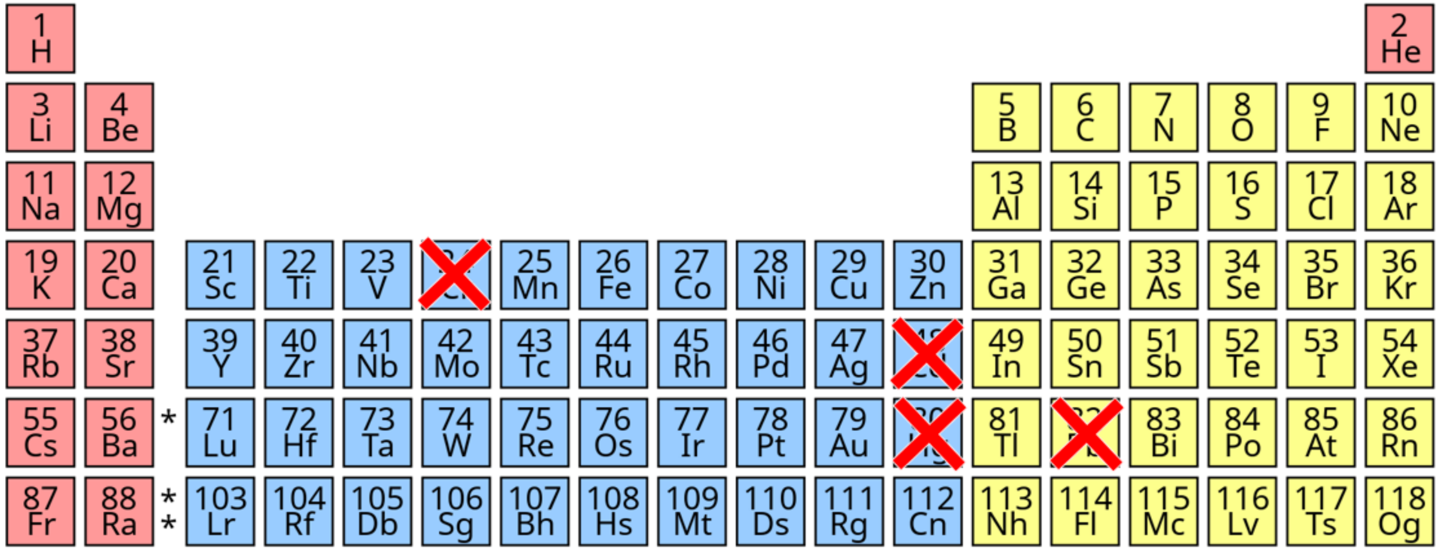


Measure 1:

Reduced concentrations of harmful substances

Procuring E-buses with reduced concentrations of harmful substances

- Vehicles can be manufactured widely free **lead**, **cadmium**, **mercury** & **chromium VI**
- This is already existing standard in the European Union and some other jurisdictions
- Also air conditioning without strong greenhouse gases is possible and established

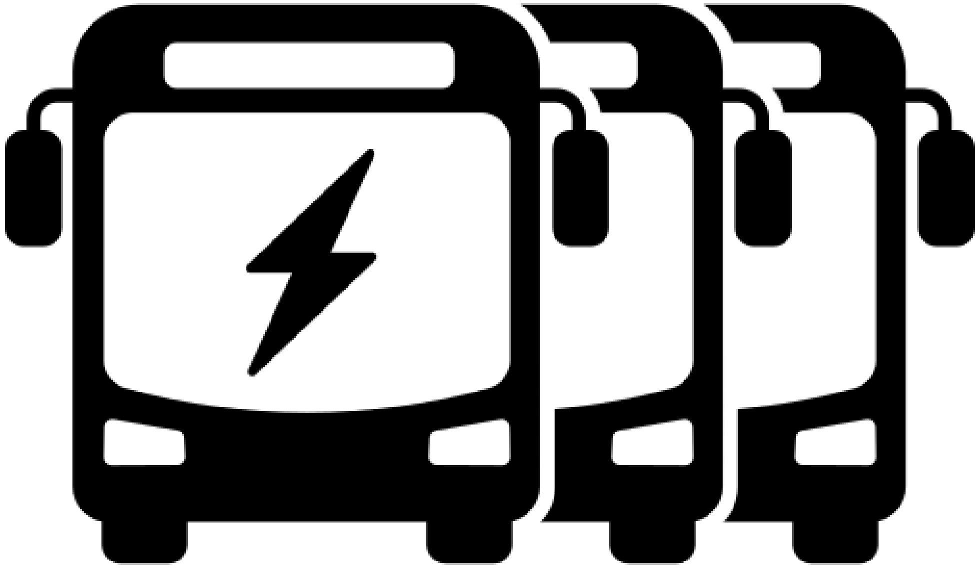


The air conditioning of buses shall use a refrigerant with a global warming potential not higher than 150 CO_2-equivalents.

In addition, electric buses shall not contain lead, mercury, cadmium or hexavalent chromium. Exemptions are possible for:

- *Lead as an alloying element in the following applications:*
  - *Steel for machinery purposes and batch hot dip galvanised steel components containing up to 0.35% lead by weight*
  - *Aluminium alloys with a lead content up to 0.4% lead by weight*
  - *Copper alloys containing up to 4% lead by weight*
- *Lead and lead compounds in the following components:*
  - *Lead in lead-acid batteries*
  - *[...]*

In case further exemptions for the use of lead, mercury, cadmium or hexavalent chromium are needed, they should be specified in the offer, including a technical justification for each requested exemption. An exemption may only be granted in case it is convincingly explained that substitution would either have negative impacts on product safety or would create more environmental harm.



Created by Bence Bezeredy
from the Noun Project

Measure 2:

Appropriate sizing of buses and batteries

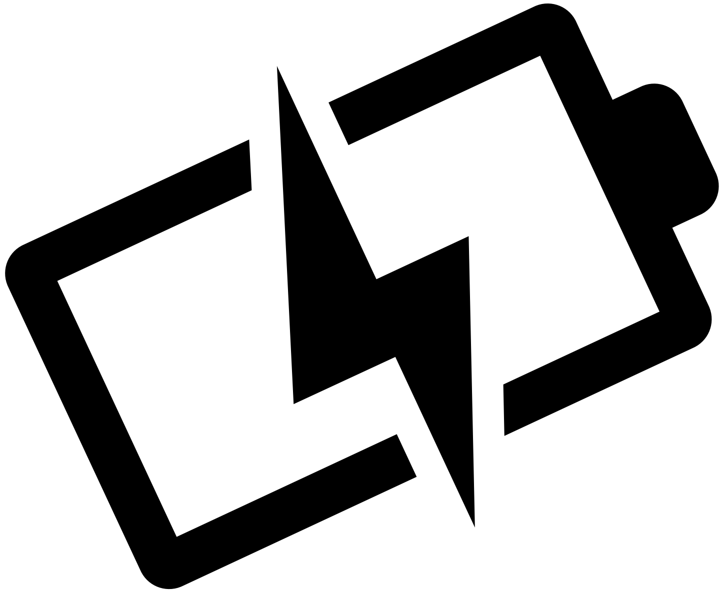
Appropriate sizing of buses and batteries

- Ensure that the e-buses to be procured fit to the local needs
- Be aware that catalogue specifications on mileage (km per charge) might diverge from ground realities:
  - Cold & hot climates impact mileage (up to 40% less)
  - Terrain matters less mileage in hilly terrain
  - Battery capacity (and mileage) reduces over time

Specify real-life operating requirements in tenders (temperature ranges, terrain, distances…)

Require bidders to guarantee a defined e-bus mileage for the given conditions and a pre-defined time-period

In operation: Use older e-buses to less demand routes to extend total e-bus life-time



Measure 3:

Battery durability & warranties

Battery durability & warranties

- The previous requirements (appropriate sizing of buses and batteries) can theoretically be fulfilled by producers through regular exchange of low quality batteries
- To avoid this, minimum battery durability requirements should additionally be specified

Vehicle age/km	State of Certified Energy
From start of life to 5 years or 100,000 km, whichever comes first	80 %
Vehicles more than 5 years or 100,000 km, and up to whichever comes first of 8 years or 160,000 km	70 %

Source: UNECE 2022

➡ Currently established basic minimum standard

➡ Significantly more ambitious levels should be considered

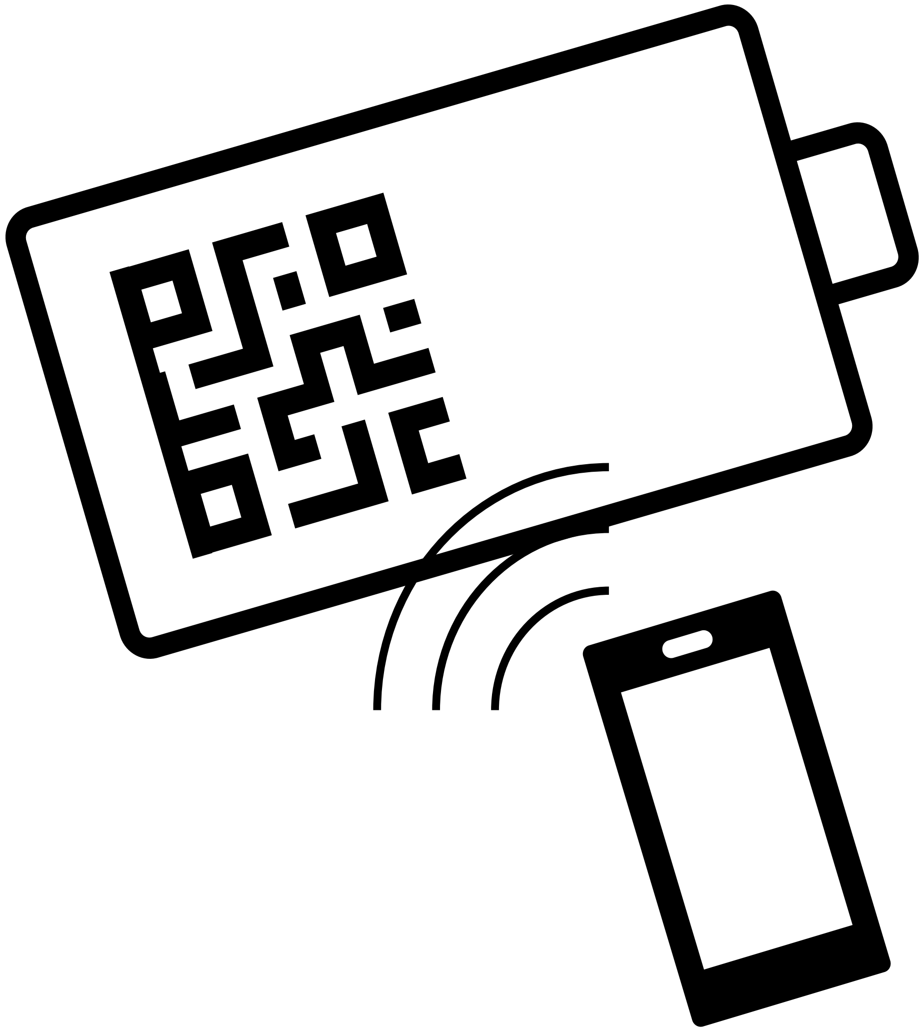
Battery durability & warranties

Box 3-3: Draft criteria for procuring e-buses with durable batteries

The supplier shall ensure that the e-bus batteries' State of Certified Energy (SOCE) is in-line with the following minimum performance requirements or better:

Vehicle age/km	*State of Certified Energy*
From start of life to [6] years or [400,000] km, whichever comes first	*80 %*
Vehicles more than [6] years or [400,000] km, and up to whichever comes first of [10] years or [500,000] km	*70 %*

The supplier shall submit evidence of compliance through independent test protocols in-line with verification methods and procedures set out in the 'United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles'.



Measure 4:

Battery labelling

Battery labelling

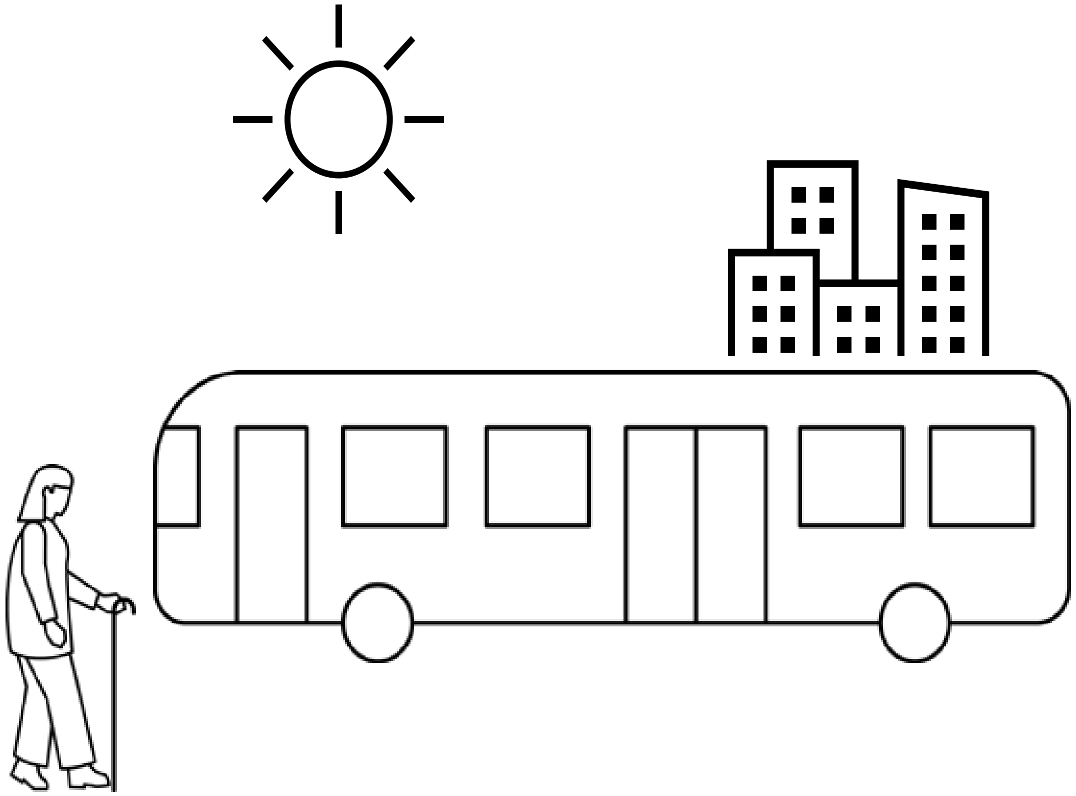
- There is wide agreement that vehicles batteries shall be labelled to give basic information on the battery type to facilitate end-of-life management.
- There is no standardised label content or format yet
- All suggestions on battery labelling entail (as a minimum) the following information requirements
    - the battery chemistry (cathode and anode type)
    - the manufacturer
    - the date of manufacture
    - the minimum voltage
    - the rated capacity
    - freely accessible via QR code

The producer shall equip all battery packs with a well visible and accessible label / digital identifier (e.g., QR code) linked to a data website given information on at least the following battery characteristics:

- *the battery chemistry (cathode and anode type)*
- *the manufacturer*
- *the date of manufacture*
- *the minimum,*
- *the rated capacity*

The website shall retain the information for at least 15 years from the date of manufacture and shall be made publicly accessible without any charge and registration procedure.

The labelling and information provided shall further be aligned with common industry formats for this purpose, including the size, design and placement of the labels, and the format of digital data provision. Information on further battery characteristics shall be additionally provided through the system in line with established practices and legal requirements.



Measure 5:

Real-life testing

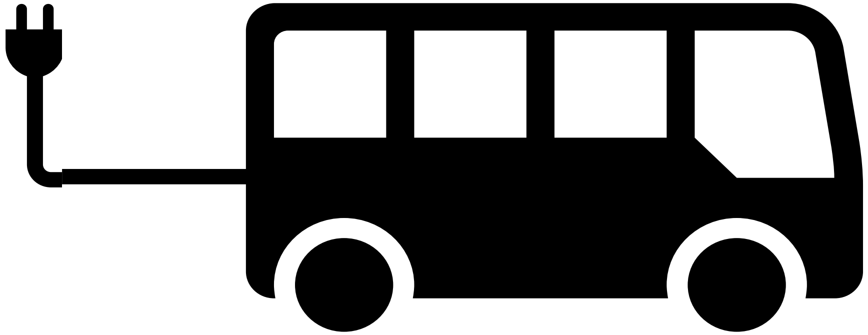
Real-life testing

- Buses must suit local needs and be capable to robustly operate in the given environment (see Measure 2)
- Numerous relevant details of bus characteristics can be overlooked in the process

➡ Ask for prototype testing prior to purchasing decisions

➡ Basic option: Testing in controlled environment (not in day-to-day operation)

➡ Ideal option: Testing in day-to-day operation & comparison of various models



Measure 6:

Interoperability of charging infrastructure

Interoperability of charging infrastructure

Procurement of e-buses and provision of charging infrastructure is often tendered as a package:

- Tenders must ensure that charging infrastructure is interoperable with e-buses of other producers
- Otherwise, deployment of other e-bus models my require the set-up of an additional parallel charging infrastructure (not resource efficient)

Step 1: Decide on intended charging modalities

- Plug-charging / Pantograph charging / inductivity charging
- Depot charging / depot charging + on-route charging

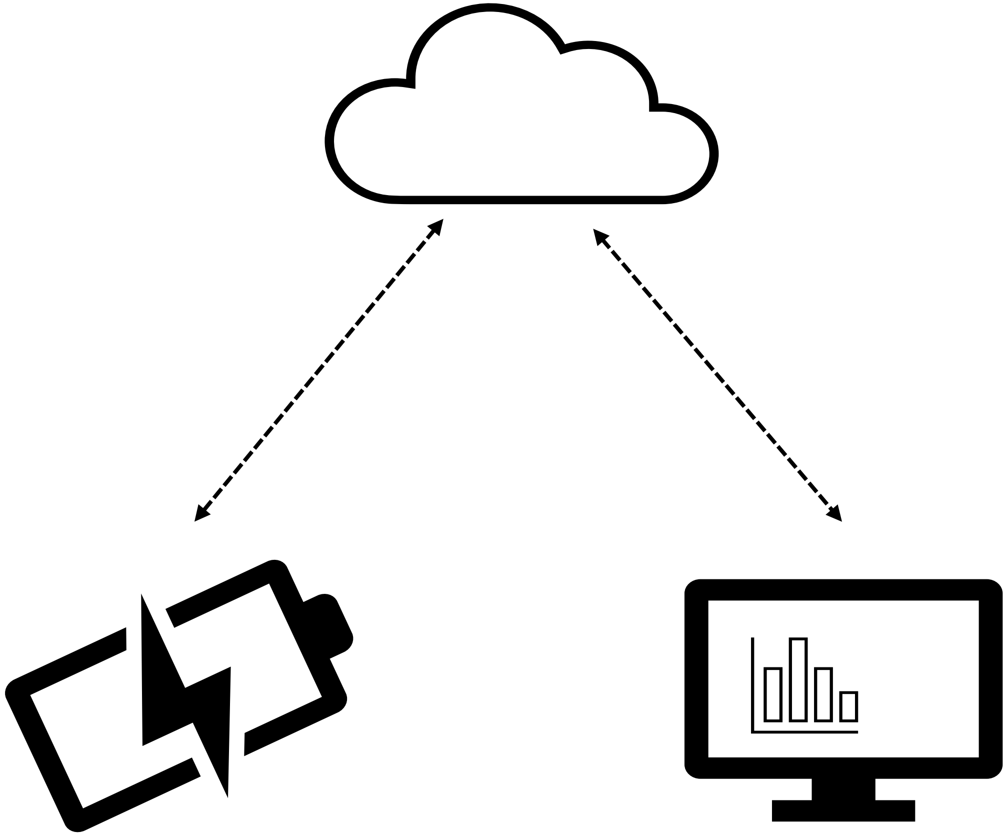
Step 2: Specify interoperability criteria in tender documents

- International norms and standards for the charging interfaces (hardware interface)
- International norms and standards for the charging protocol (software interface)

Interoperability of charging infrastructure

IEC 62196	International standard series for plugs and sockets for electric vehicle charging
SAE J1772	North American standard for electrical connectors for electric vehicles maintained by SAE International: SAE Electric Vehicle Conductive Charge Coupler.
GB/T 20234	Chinese national standard for Connection Set for Conductive Charging of Electric Vehicles.
CHAdeMO	Japanese DC charging standard for electric vehicles.

	International standard defining a protocol for the management of electric vehicles charging and discharging infrastructures (currently under development)
	Open Charge Point Protocol (OCPP)



Measure 7:

Access to battery operational data

Access to battery operational data

Operational data on e-bus batteries is important for many decisions:

- Is a bus fit enough to serve a certain route?
- When and how should a battery be serviced / conditioned?
- What is the expected remaining lifetime of a battery?
- What can be done to expand the battery-life time and ensure safe operation?
- If or when a battery swap is economical and sustainable?
- Is the battery performing according to the agreed warranties?
- What is the remaining value of a battery and is it suitable for a second-life application?

E-bus producers should give access to battery diagnostic data to their customers, including the right to pass-on this data access to independent third parties (e.g., service providers for battery diagnostics, maintenance and reuse/repurposing).

Access to battery operational data

Signal	Unit	Value resolution	Time resolution
Battery current over time	A	0.1 A	
Battery voltage over time	V	0.1 V	
Cell temperature (avg/min/max) over time	°C	0.1°C	
Cell voltage (avg/min/max) over time	V	0.001 V	
Battery state of charge (SoC) over time	%	0.1 %	
Accumulated charge throughput	As	0.1 As	

To be continuously sampled, time-synchronous, provided through a standard output interface, in a digital format compatible with publicly available software.

Measure 8:

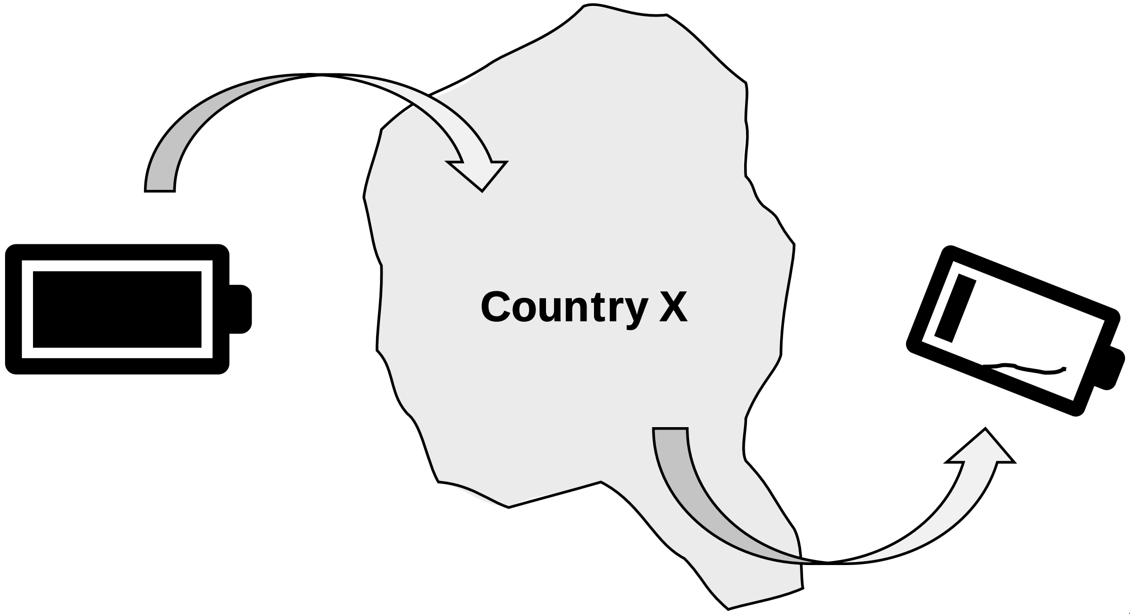
Profound battery monitoring & maintenance

Profound battery monitoring & maintenance

Use data on e-buses (and particularly the battery) well. Data allows you to plan and conduct various measures that support a long battery life:

- Planning and conduct of cell balancing
- Use of an e-bus on a certain route (lower capacity / charge less demanding routes)
- Conduct – wherever possible – battery-health-preserving charging:
  - avoid deep-discharging and full-charging
  - Avoid quick charging
- Exchange of certain models or cells

Special service agreements may be useful



Measure 9:

EPR-based decommissioning agreements

EPR-based decommissioning agreements

Generic life-cycle of products:

Production › **Use** › **End-of-life**

“Traditional” Producer Responsibility:

- Sound production
- Functionality
- Product safety
- ...

Extended Producer Responsibility:

- Sound end-of-life management

➡ Producers shall take over logistical & financial responsibility to pick-up and soundly manage obsolete batteries

➡ Either individually, or through a Producer Responsibility Organisation (PRO)

EPR-based decommissioning agreements

Main challenge:
How to ensure that the producer is still available when the batteries will require sound end-of-life management? E.g. in 5, 10 or 15 years?

- Problem is typically resolved through mandatory Extended Producer Responsibility schemes that require producers to join a Producer Responsibility Organisation and pay “future-prove” EPR fees.

- Take-back and sound end-of-life management still secured in case a producer does not exist any more.

But: Mature EPR systems are not yet available in all countries

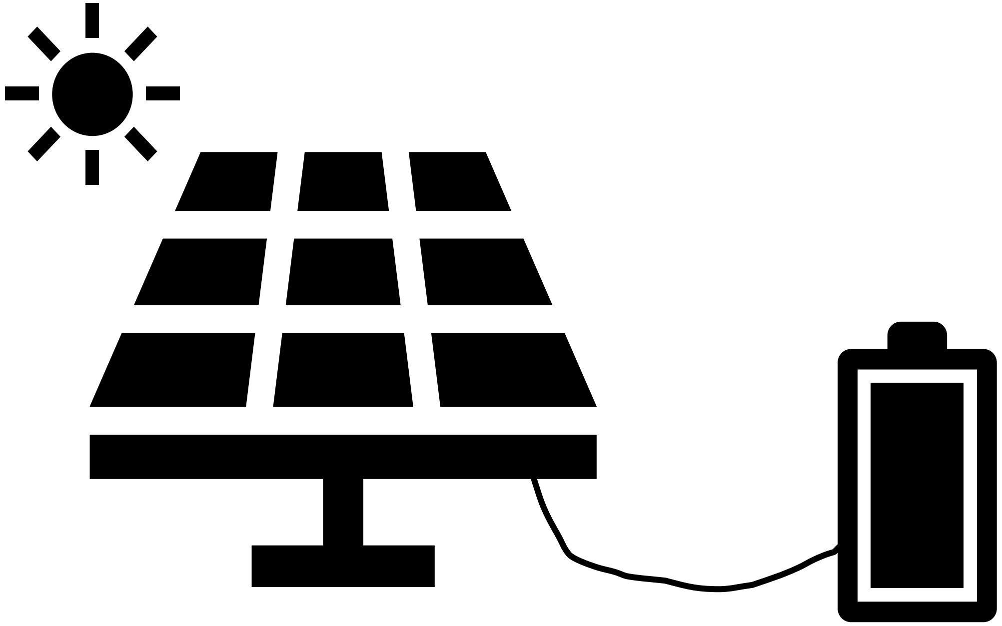
The supplier shall take over full responsibility for the end-of-life management of the batteries after their first use in e-buses.

The responsibility will accrue once the e-bus owner and the supplier or a third party in charge for battery maintenance, jointly come to the conclusion that a battery does not fulfil its intended function anymore and cannot be restored through conventional maintenance measures anymore (decommissioning decision).

Once one or more e-bus batteries cannot fulfil their intended functions anymore, they shall be extracted from the vehicles and managed in a safe and responsible manner in-line with the requirements specified in section [link to respective section].

The supplier's responsibilities encompass all logistical, administrative and financial aspects related to these tasks and shall be conducted in a timely manner and within [X] weeks after having been informed about the decommissioning decision. The supplier's responsibilities may be fulfilled through a third party assigned by the supplier, presupposing this entity can prove capability to conduct all related tasks with due care and in-line with given provisions.

The supplier shall give evidence that he has sufficient capacities to fulfil this requirement in [name of city and country] and guarantee availability for at least [12] years starting from the date of commissioning of the e-buses and batteries. This evidence may refer to adequate provisions made with a Producer Responsibility Organisation for vehicle-batteries that is registered as such in [name of country].



Measure 10:

Encouraging battery reuse

Encouraging battery reuse

Suppliers can be encouraged (but not forced) to plan a second-life applications for the batteries in the production phase

Challenges:

- Temperature management systems, protective housing and BMS are design for the needs of e-buses. Stationary applications require different designs
- ‘Design-for-reuse’ theoretically possible, but unclear business perspectives: Will there be enough used batteries and enough demand in e.g. 10 years in a certain location?

Suppliers are encouraged to design e-bus batteries in a way they can be reused/repurposed after their first life as e-bus batteries, and to integrate reuse/repurposing into their business model. Design strategies might involve (but might not be limited to) battery packs that can be transferred to other power storage applications without physical modification, and the use of battery management systems allowing interoperability with one or more common stationary applications. Related business models might involve (but might not be limited to) to efforts to take-back used batteries with the intention of deploying them in second-life applications such as stationary power storage.

The supplier shall indicate whether he follows one or more such approaches and provide background explanations and underlying concepts, including links to relevant documents and websites. In addition, the supplier shall give background whether these initiatives

- *Are applicable to the e-buses and batteries offered under this tender*
- *Are implemented or planned for the setting of [name of city and or country]*

Measure 11:

Sound battery end-of-life management

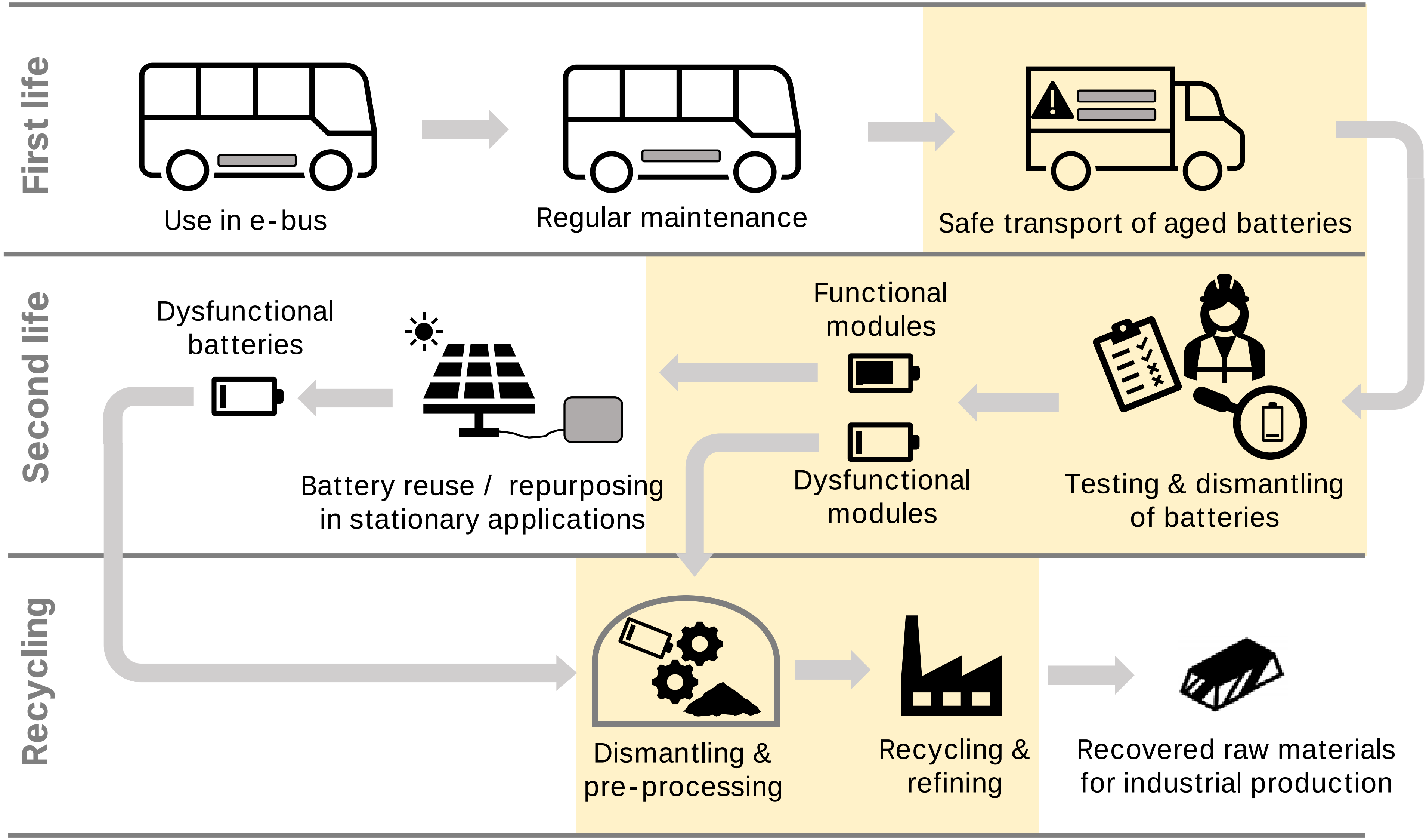
Sound battery end-of-life management

Any end-of-life management partner taking over obsolete e-bus batteries should ensure the sequence of safe transport, testing, reuse and recycling

End-of-life management partner can be:

- The producer of the e-buses (in case he is assigned end-of-life management responsibility see recommendation on EPR-based decommissioning agreements).
- A company with the capability and legal registration to handle used and end-of-life Li-ion batteries.

Partners can be held responsible for a sound conduct of the steps market yellow:



Source: Oeko-Institut

The batteries shall be picked-up, transported and processed according to international good practices in all related fields, including fire safety, road safety and occupational health and safety. All batteries shall undergo a state-of-health assessment with a view to determine their reuse/repurposing potentials. Batteries, battery modules and battery cells found suitable for reuse/repurposing shall be used accordingly.

Batteries, battery modules and battery cells found unsuitable for reuse/repurposing shall be recycled. Recycling is to be conducted in-line with international good practices and with the aim to effectively prevent emissions of hazardous substances, recover embedded raw materials and reduce waste volumes for disposal.

The applied recycling processes shall at least achieve a recycling efficiency of 50% (at least 50% of the mass of the battery is recycled) and enable the recovery of copper, cobalt and nickel. All conducted steps shall be conducted in full compliance with applicable national and international laws and regulations.

The operator taking over the batteries shall submit evidence for compliance with the requirements above. As a minimum, the operator shall provide the following documentation to the client:

- *All licences and permits as required by national law (to be provided prior to taking over the batteries).*
- *A certificate over sound management of all received batteries […]*

Overview of measures

1. Reduced concentrations of hazardous substances
2. Appropriate sizing of buses and batteries
3. Battery durability & warranties
4. Battery labelling
5. Real-life testing
6. Interoperability of charging infrastructure
7. Access to battery operational data
8. Profound battery monitoring & maintenance
9. EPR-based decommissioning agreements
10. Encouraging battery reuse
11. Sound battery end-of-life management

Thank you for your attention!

Contact:

Fred Adjei (f.adjei@oeko.de)

Andreas Manhart (a.manhart@oeko.de)

Viviana López Hernández (v.lopez@oeko.de)

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology