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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

E-waste and circular economy

Sustainable management of batteries

Recommendation ITU-T L.1035

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ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.1035

Sustainable management of batteries

Summary

Recommendation ITU-T L.1035 provides guidance on the sustainable management of used batteries from information and communication technology (ICT) equipment and their environmentally responsible management, including waste prevention, minimization, recycling, recovery and final disposal. This Recommendation also provides information on best practices in recycling batteries for dissemination.

Batteries are crucial for the functioning of ICTs. Improving their design, prolonging their lifespan, improving their recyclability and preventing the dumping of waste batteries can lower their overall energy consumption, reduce exposure of humans and the environment to hazardous substances, as well as reducing global greenhouse gas emissions.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1035	2022-02-13	5	11.1002/1000/14848

Keywords

Batteries, e-waste, recycling, sustainable management of used and waste batteries.

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Introduction

Waste electrical and electronic equipment (WEEE), such as waste phones, laptops, refrigerators, sensors and TVs, is also known as e-waste. E-waste is a growing challenge, matching the growth of the information and communication technology (ICT) industry.

- About 80% of e-waste is discarded in landfill, burned or illegally traded every year.
- E-waste contains substances that can be hazardous to human health and the environment if not dealt with properly – including mercury, cadmium and lead.
- ITU member states have set a global e-waste target for 2023 to increase the recycling rate of e-waste to 30% and raise the percentage of countries with e-waste legislation to 50%.
- By adopting the Connect 2030 agenda, ITU member states have also committed to reduce the volume of redundant e-waste by 50%.
- Addressing e-waste helps to address the Sustainable Development Goals, in particular Nos. 3, 8, 9, 11, 12 and 13 [b-ITU media e-waste].

The challenges

E-waste is used to refer to almost any discarded household or business item with circuitry or electrical components with a power or battery supply [b-ITU media e-waste]. Waste batteries fall within this category.

Latest estimates show that, as ICT networks and services have grown, the world now discards approximately 57 Mt of e-waste per year (2019), of which less than 20% is recycled [b-ITU media e-waste].

Batteries are important components of portable electrical and electronic devices. For example, the use of the lithium-ion (Li^+) batteries (LIBs) in portable electronic devices, such as mobile phones, laptop, cameras, toys, e-cigarettes, and electric and garden tools, has doubled from 2014 to 2019 [b-Mossali].

The LIB has been used widely for a wide range of applications because of its high performance in a number of important functional criteria, e.g., battery life, high storage capacity, small size, low mass, efficient self-discharging capacity to withstand different climatic and temperature environments. However, due to the demand for new gadgets and the availability to buy them, tonnes of LIBs have been discharged when they were still functional. It is anticipated that 11 Mt of end-of-life LIBs will be produced cumulatively by 2030. The flows of waste LIBs from portable electrical and electronic devices will be augmented by waste LIBs employed in electric vehicles (EVs), with their annual waste flow reaching 340 000 t by 2040 [b-Chandran]. Because of their use in EVs, the projected requirement for LIBs is enormous, and this may lead to risk of short supply in the trade market due to the natural supply limitations of lithium metal resources after 2023. It is anticipated that the call for lithium carbonate will rise from 265 000 t in 2015 to 498 000 t in 2025. This may create a gap between demand for lithium against market supplies that ultimately may lead to a price hike of lithium carbonate. To address the risk of short supply and to reduce the cost of production, it appears crucial to recover lithium metal from all potential resources [b-Mohanty].

Batteries contain dangerous substances, including mercury, cadmium and lead, which can end up polluting land, air and water, and pose health risks, especially if they are not treated properly.

- Untreated used batteries put the health and lives of some of the world's poorest adult and child workers at risk: those who dispose of dangerous waste, risking exposure to toxins and poisoning.
- Improper management of used batteries can result in the unnecessary loss of scarce and valuable natural materials, through failure to recycle other less toxic, but high-value rare materials, such as gold, platinum and cobalt, putting pressure on the limited natural resources available.

Only 30% to 50% of the population properly dispose of portable LIBs, being unaware of the potential harmfulness of post-use products. Metallic lithium, resulting from incorrect recycling of LIBs, is highly reactive with moisture, and in the presence of a flammable electrolyte could can explosive reactions and the emission of harmful gases (such as hydrogen fluoride) in case of mechanical damage, overheating or degradation phenomena, exposing people to the risk of serious injury [b-Mossali].

Opportunities

On the upside, e-waste could represent an opportunity worth over USD 62.5 billion per year if treated through appropriate recycling channels and methods, with the potential of creating millions of "clean and green" jobs worldwide.

Through greater collaboration among multinationals, small- and medium-sized enterprises, entrepreneurs, academia, trade unions, civil society and associations to create a "circular economy" for electronics, including batteries, where waste is designed out, the environmental impact could be reduced, and decent work created for millions.

A system in which all discarded products are collected and then the materials or components reintegrated into new products will:

- reduce the need for new raw materials, waste disposal and energy;
- potentially create new economic growth, "green" jobs, and business opportunities;
- reduce carbon dioxide (CO_2) emissions;
- promote a shared responsibility for waste batteries along the full supply chain, including consumers.

For example, although the amounts of produced and sold portable LIBs are huge, only 29.5% of the population properly collect them, versus 59.6% that store LIBs at home and 15.9% who throw them into dustbins [b-Mossali].

In a circular economy scenario for batteries, design should facilitate second use and final disposal of the product. For LIBs, for example, through appropriate labelling (e.g., quick response (QR) codes, radio frequency identification device tags), a standardization of formats, structure and component materials, a reversible assembly strategy and a clear classification of inner hazardous components. On this topic, the US Society of Automotive Engineers and the European EUROBAT have created a series of working groups to discuss and develop solutions for sustainable re-design of LIBs [b-Mossali]. Consumers can try to: get ICT equipment repaired instead of replaced; delay upgrading or exchanging functional smartphones for the latest model; use certified recycling points or disposal firms; consider giving ICT equipment a second life through resale.

Recommendation ITU-T L.1035

Sustainable management of batteries

1 Scope

This Recommendation focuses on managing used and waste batteries in information and communication technology (ICT). The main objectives include the following:

– criteria for the recyclability of different types of batteries.
– identification of hazardous substances in batteries;
– safe handling of batteries by recyclers and workers;
– best practices for battery recycling and final disposal;
– minimization of the environmental impact generated by heavy metals and other hazardous chemicals in used and waste batteries that are disposed of both as municipal solid waste and as hazardous waste and during battery recycling.

This Recommendation examines methods for recycling of batteries effectively. This Recommendation also includes proposals for worker safety in the management of waste batteries, as well as policies, legislation and management plans for batteries.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[IEC 60086-4] IEC 60086-4:2019, *Primary batteries – Part 4: Safety of lithium batteries*.

[IEC 62133-2] IEC 62133-2:2021, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications – Part 2: Lithium systems.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 battery capacity [b-ISO/TS 23625]: Capacity of the battery, expressed in ampere-hours (Ah) at a nominal voltage or in watt hours (Wh), from the manufacturer's specified fully charged to discharged voltage levels.

NOTE – Ah capacity rating at a given discharge rate or time.

3.1.2 electrochemical cell [b-IEC 60050]: Composite system in which the supplied electric energy mainly produces chemical reactions or, conversely, in which the energy released by chemical reactions is mainly delivered by the system as electric energy.

3.1.3 waste electrical and electronic equipment [b-Basel TG]: Electrical or electronic equipment that is waste, including all components, sub-assemblies and consumables that are part of the equipment at the time the equipment becomes waste.

3.1.4 recycling (Appendix I of [b-Basel Manuals]): Recycling operations usually involves [*sic*] the reprocessing of waste into products, materials or substances, though not necessarily for the original purpose. Resources are saved by recovering material benefits from the waste. Recycling is to be distinguished from operations that recover energy from the waste. In some countries, where material is used once merely for its physical properties e.g., for backfilling, this does not amount to recycling. An example is used lubricating oil re-refined which could result in high grade oil which is valuable for its chemical properties and hence that would be a recycling operation. Used oil could also simply be used as a fuel so that the recovery operation would be energy recovery and not recycling.

NOTE – Recycling may be defined by national legislation differently in each country.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 battery: Any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more primary battery cells (non-rechargeable) or consisting of one or more secondary battery cells (rechargeable).

NOTE – [b-EU Battery] reviews the new EU regulatory framework in this field and is expected to contain a similar definition.

3.2.2 battery pack: Energy storage device, which is composed of one or more cells or modules electrically connected together inside a mechanical pack with electronics as required for safety and operation. The battery pack may incorporate a protective housing and be provided with terminals or other interconnection arrangement. It may include protective devices and control and monitoring required for safe and proper operation. It may provide detailed information (e.g., cell voltage, temperature, capacity) to a higher-level battery system management device.

3.2.3 box; casing: Container subdivided with intermediary walls where the individual elements will be inserted along with electrolyte.

3.2.4 cap; cover: Part intended to close the box of the battery.

3.2.5 charge: Operation through which electrical energy is supplied by an external electrical source and converted into chemical energy in the battery.

3.2.6 connector: Metallic lead conductor used to interconnect not only the individual plates, forming elements, but also the elements between each other forming the internal electric circuit.

3.2.7 electrical accumulator: Device constituted by an electrolyte, an element, and a container housing them, capable of storing the electrical energy as chemical energy and releasing this energy when connected to an external consuming circuit.

3.2.8 lead-acid accumulator; lead-acid battery: An electrical accumulator in which the active material of the positive plates is made up of lead compounds and that of the negative plates is essentially lead, the electrolyte being a dilute sulphuric acid solution.

3.2.9 electrolyte: Ionic conductor into which the plates are submerged. In lead-acid batteries, the electrolyte is a dilute sulphuric acid solution. In other batteries, such as lithium-ion, the electrolyte is a polymer.

3.2.10 element: A series of negative and positive plates, placed consecutively and isolated between each other with plate separators. Plates of the same polarity are electrically connected. Therefore, an element may be considered as a set of electrochemical cells in parallel connection.

3.2.11 negative plate; anode: Plate where the oxidative reactions take place.

3.2.12 positive plate; cathode: Plate where the reductive reactions take place.

NOTE 1 – A rechargeable battery is also often described as accumulator.

NOTE 2 – Batteries can be connected together or encapsulated within an outer casing, sometimes with additional parts such as a battery management system, to form a complete unit that the end user is not intended to split up or open. This is also called a battery pack.

3.2.13 disposal: Includes refurbishment, recycling, material recovery and final operations, such as incineration, incineration with energy recovery and landfill.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC Alternating Current

BIGP Battery Identity Global Passport

DC Direct Current

ESM Environmentally Sound Management

EV Electric Vehicle

HTMR High Temperature Metal Recovery

ICT Information and Communication Technology

IMDG International Maritime Dangerous Goods

LCO Lithium Cobalt Oxide

LFP Lithium Iron Phosphate

LIB Lithium-Ion Battery

LMO Lithium Manganese Oxide

LMR Lithium- and Manganese-Rich

LTO Lithium Titanium Oxide

NCA lithium Nickel Cobalt Aluminium oxide

NMC lithium Nickel Manganese Cobalt oxide

PPE Personal Protective Equipment

QR Quick Response

SELV Safety Extra Low Voltage

UPS Uninterruptable Power Supply

WEEE Waste Electrical and Electronic Equipment

WLAB waste lead-acid battery

5 Conventions

None.

6 Types of battery used in ICTs

A battery consists of one or more cells that can undergo a chemical reaction that causes electrons to flow in a circuit. Research is under way and advances are being made in many areas of battery technology. Advanced battery technology is therefore being tested or deployed around the world. Batteries have gained in significance because of the increasing need to store electrical energy. While the capacity to generate electrical energy is important, so is the ability to store it for extended periods of time when generation is not available, particularly for applications that need to be operated independently from a power grid. It should be noted that batteries on their own can only be used to store direct current (DC) power, and not alternating current (AC) power.

Batteries are commonly classified according to various criteria: chemical process used and composition; size; form factor; application; and rechargeability.

For example, in mobile computing and mobile telecommunication equipment, the most common types of battery are based on lithium-ion chemistry. The use of lithium-ion batteries (LIBs) in portable electronic devices, such as mobile phones, laptop, cameras, toys, e-cigarettes, and electric and garden tools, are reported to be mainly of three main chemical compositions: 37.2% are lithium cobalt oxide (LCO), 29% lithium nickel manganese cobalt oxide (NMC) and 5.2% lithium iron phosphate (LFP) [b-Mossali].

In stationary ICT, lead-acid batteries are also used to ensure uninterrupted power supply. Nickel metal hydride and zinc-based primary batteries can be found in a limited number of appliances and accessories. Batteries have different compositions depending on their types. Lithium batteries, as mentioned in [b-ITU-T L.1221], are becoming more deployed for stationary use in both classical telecommunication installations and sites (see [b- ITU-T L.1382]), than in ICT installations. Some types can be treated in the same process, whereas others need different treatment ones.

Clauses 6.1 to 6.3 highlight the most common types of battery used in ICTs.

6.1 Primary (non-rechargeable) batteries

If the chemical reaction within it that produces electricity is not reversible, the battery is not rechargeable. Battery disposal is required once all chemical energy has been consumed in its electrical form. For example, not only zinc-based technologies, such as alkaline manganese and zinc carbon, but also lithium metal chemistry are not rechargeable.

6.2 Secondary (rechargeable) batteries

If the chemical reaction within it that produces electricity is reversible, the battery can be recharged via the input of electricity and used repeatedly. The available capacity might deteriorate over time, but this depends on the chemical system, the use and charging patterns. Examples are batteries based on lead-acid, lithium-ion, and nickel-based chemistries.

6.3 The categorization of batteries based on type and composition

Batteries vary in their composition and applications. Table 1 classifies batteries based on their rechargeability and composition.

This Recommendation uses the categorization in Table 1 for clarity.

Table 1 – Composition of batteries

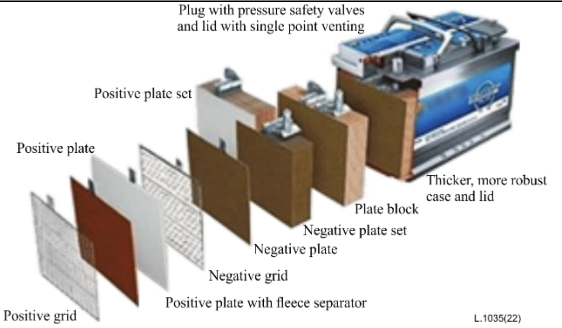
<table>
<tr><th>No.</th><th>Type of battery</th><th>Composition</th></tr>
<tr><td>1</td><td>

Figure 1 – Content of a rechargeable lead-acid battery</td><td>Consists of toxic lead plates, and an electrolyte that is a mixture of water and sulphuric acid (H_2SO_4), plastic.
Applications:
Uninterruptable power supply (UPS), mobile boosting stations and other electronic setups.
Hazardous substances
Lead, sulphuric acid</td></tr>
<tr><td>2</td><td>

Figure 2 – Rechargeable nickel-cadmium battery</td><td>Consists of nickel(II) hydroxide ($Ni(OH)_2$) in the positive and cadmium in the negative electrode, which is a non-spillable toxic heavy metal.
Applications:
Telephones (corded/cordless).
Hazardous substances
Cadmium</td></tr>
<tr><td>3</td><td>

Figure 3 – Smart phone lithium-ion battery

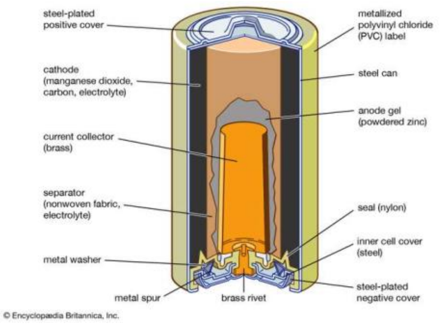
Figure 4 – Laptop lithium-ion battery</td><td>Consists of lithium, nickel, iron, manganese cobalt, aluminium and plastic.
Applications:
Smart mobile phones, laptops and other portable electrical and electronic ICT devices.
Hazardous substances
Cobalt oxides, depending on the battery chemistry: hydrogen fluoride, lithium-ion</td></tr>
<tr><td>4</td><td>

Figure 5 – Components of alkaline battery</td><td>Mainly consists of manganese(IV) oxide (MnO_2) in the positive electrode, zinc in the negative electrode and an alkaline electrolyte of potassium hydroxide (KOH).
Applications:
MP3 players, CD players, digital cameras, toys, lights, and radios</td></tr>
</table>

Table 1 – Composition of batteries

<table>
<tr><th>No.</th><th>Type of battery</th><th>Composition</th></tr>
<tr><td></td><td>

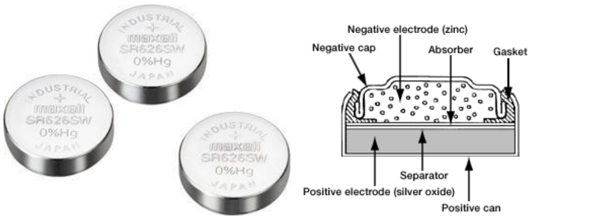

Figure 6 – Alkaline batteries</td><td></td></tr>
<tr><td>5</td><td>


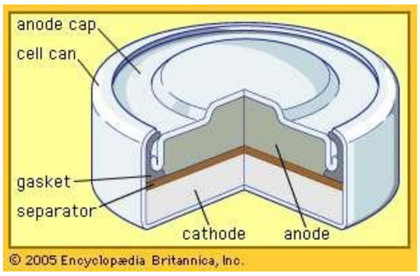
Figure 7 – Silver-oxide batteries</td><td>This button cell battery mainly consists of silver oxide in the positive electrode, zinc in the negative electrode and an alkaline electrolyte. This electrolyte is usually sodium hydroxide (NaOH) or potassium hydroxide.
Applications:
Watches and calculators</td></tr>
<tr><td>6</td><td>


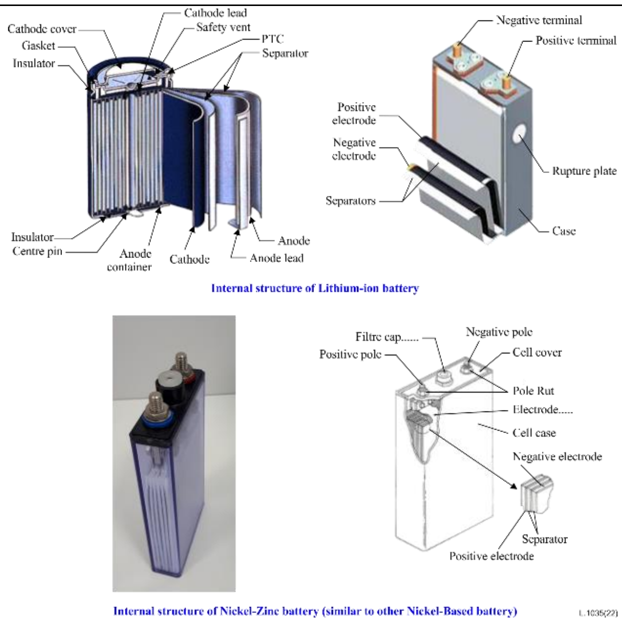
Figure 8 – Mercuric oxide-zinc cell battery</td><td>These non-rechargeable button cell batteries mainly consist of mercury oxide in the positive electrode, zinc in the negative electrode and an alkaline electrolyte. This electrolyte is usually sodium hydroxide or potassium hydroxide.
Applications:
Watches, hearing aids, cameras and calculators.
Hazardous substance
Mercury</td></tr>
<tr><td>7</td><td>


Figure 9 – Rechargeable lithium-ion battery</td><td>These rechargeable batteries are based on different chemical composition: lithium-ion (LCO, lithium manganese oxide (LMO), lithium nickel cobalt aluminium oxide (NCA), NMC, LFP, lithium titanium oxide (LTO; Li_2TiO_3))
Typical applications are as follows:
– telecom rectifier-battery DC systems;
– AC UPS;
– renewable energy systems with charge-controller between generator, battery and hybrid engine generator set with battery;
– power supply with back-up for fixed terminals;
– peak power shaving:
– Customer premises equipment back-up network in a safety extra low voltage (SELV) circuit</td></tr>
</table>

Source: [b-BAT/BEP Egypt] and for entry 7 the text is derived from [b-ITU-T L.1221] with some editorial modifications.

7 Steps in the environmentally sound management of waste batteries

This clause provides guidance on the following topics:

a) the general process of collecting and managing wasted batteries;

b) the safety requirements for handling waste batteries by recyclers and workers;

c) the best technology for recycling waste batteries based on their types.

The purpose of the collection and recycling of batteries of various types is to recover residual metals that are toxic, scarce, of economic value or battery components (acids and plastic, in particular).

Its purpose is also to reduce the number of batteries found in household waste – even where waste sorting exists – and the public is informed and reminded that they should not dispose of them in that way.

Batteries are one source of certain heavy metals and other hazardous chemical substances that accumulate in the environment and can lead to soil contamination and water pollution.

The process of recycling waste batteries can be very polluting and can endanger human health and the environment if sound practices for the recycling of non-ferrous metals are not followed.

The environmentally sound management (ESM) of waste batteries of various types is best achieved by the following activities. These activities are divided into different stages and sub-activities within each stage, see Figure 10.

Pre-processing:

- collection and transport from collection sites to temporary storage and pre-treatment facilities;
- reception, sorting and weighing;
- storage at the recycling site.

Processing (recycling):

- manual or mechanical dismantling;
- sorting by type of equipment and storage by type of material;
- recovery and resale of materials and components;
- treatment and final disposal.

7.1 Pre-processing

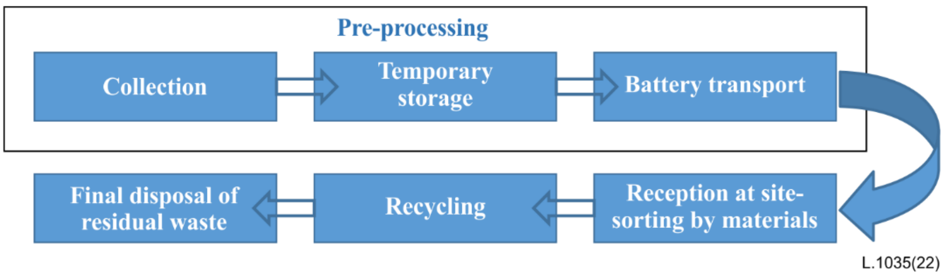


Figure 10 – Steps for the environmentally sound management of waste batteries

7.1.1 Collection and transport from collection sites to temporary storage and pre-treatment facilities

Batteries are collected in many different ways, depending on the type of batteries. Some countries have a collection and deposit system or take back procedures in place. Some countries apply extended producer responsibility policies, whereby a fee is collected for each battery sold, so that retailers and collectors can take back the batteries and deliver them to authorized recyclers. Small and family businesses also informally collect batteries Especially for WLABs and others containing hazardous substances, handling should be done by trained personnel who are able to distinguish the different chemistries involved, so that cells can be separated immediately after collection.

7.1.1.1 Collection of nickel-cadmium

Careless disposal of nickel-cadmium batteries can result in the corrosion of the metallic cell cylinder in landfill. Cadmium then dissolves and seeps into the water supply. For this reason, nickel-cadmium batteries are banned in some countries, like those of the European Union [b-BU]. Nickel-cadmium batteries should be separated from the household waste stream and recycled in permitted facilities.

7.1.1.2 Collection of lithium-ion batteries

In batteries, lithium-ions move from the negative electrode through an electrolyte to the positive electrode during discharge, and back when charging. LIBs use an intercalated lithium compound as the material at the positive electrode and typically graphite at the negative electrode.

The typical composition of LIBs, net of the variability due to different manufacturers, consists of two electrodes wound by lamination to a polymeric separator and impregnated by a suitable electrolyte, allowing ionic conductivity of lithium-ions. During the use of LIBs, the lithium ions generated through reversible reactions at the negative electrode, move towards the cathode, where they combine to form metal oxides (Figure 11). Vice versa, during the charging mechanism, an external power supply provides electrons that combine with lithium-ions to form metallic lithium (Li^0), stored between anodic graphite layers through intercalation mechanisms. Due to the intrinsic properties of materials, LIBs operate between 1.5 and 4.2 V: a lower voltage degrades the copper (Cu) foil, while a higher one forms reactive lithium dendrites increasing the potential safety hazards of the product. Besides the active material of electrodes, fundamental LIB components are the highly dielectric solvent allowing the transfer of lithium-ion, the polymeric separator preserving electrodes from direct contact and copper and aluminium (Al) current collector foils, on which active powder is adhered through an organic binder [b-Mossali].

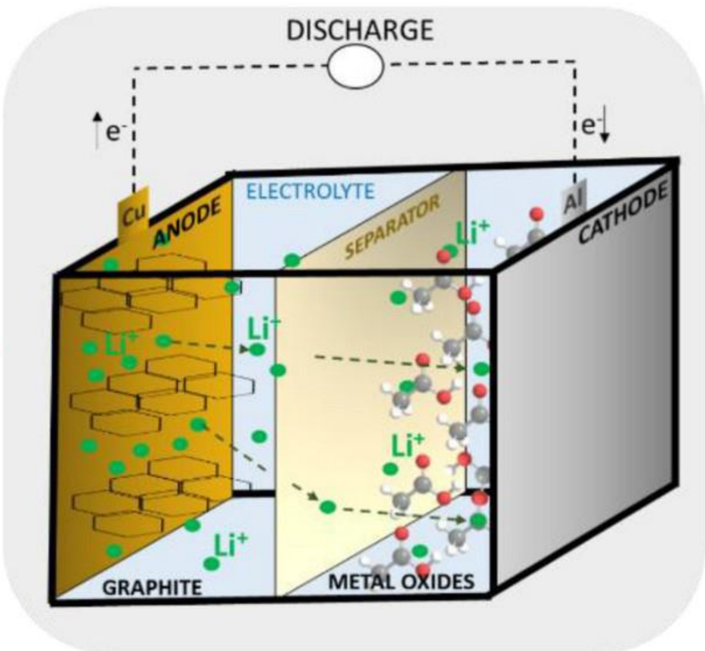


Figure 11 – Electro-chemical operating mechanism of an LIB cell [b-Mossali]

The batteries have a high energy density, no memory effect (other than LFP cells) and low self-discharge. They can, however, be a safety hazard since they contain flammable electrolytes, and if damaged or incorrectly charged can lead to explosions and fires. Chemistry, performance, cost and safety characteristics vary across types of LIB. Handheld electronics mostly use lithium polymer batteries (with a polymer gel as electrolyte), an LCO ($LiCoO_2$) cathode material, and a graphite anode, which together offer a high energy density. LFP ($LiFePO_4$), LMO ($LiMn_2O_4$ spinel, or Li_2MnO_3-based lithium-rich layered materials, e.g., lithium- and manganese-rich-NMC (LMR-NMC)), and NMC ($LiNiMnCoO_2$) may offer longer lives and may have better rate capability. Such batteries are widely used for electric tools, medical equipment, and other roles. NMC and its derivatives are widely used in electric vehicles (EVs). [b-W-LIB]. In late 2013, smelters started to report increased numbers of LIBs mixed with lead-acid, especially in starter batteries. This can cause fires, leading to explosion and personal injury. The physical appearance of lead-acid and lithium-ion packs are similar and sorting at high volume poses a challenge. As more lead-acid batteries are replaced with lithium-ion, the problem will only escalate. From 2010 to 2013, there has been a 10-fold increase in reported incidents of infiltration of lithium-ion with lead-acid. Lithium-ion is more volatile when stripped than lead-acid. Presorting is done for safety reasons: lead is highly toxic, lithium-ion is explosive [b-BU].

7.1.1.3 Collection of lead-acid batteries

Lead-acid batteries are also collected through the dual system of distribution-collection when manufacturers, retailers, wholesalers, service stations or other retailing points provide new batteries to users and receive used ones for forwardeing to recycling plants. The following important control measures should be adopted.

a) **Batteries should not be drained at collection points**. With the exception of a few dry batteries that may arrive at the collecting point, almost all used batteries will retain their sulphuric acid electrolyte. Drainage of this liquid may pose several threats to human health and the environment: 1) it contains high lead levels, as soluble ions, and particulate forms; 2) its acidity is very high and may cause burns and damage if accidentally spilled; 3) it requires special acid-resistant containers for storage; 4) its drainage requires workers to be protected in order to minimize any risk of injury, etc. Thus, battery drainage may be considered a potentially hazardous activity that demands, not only special tools, containers and safety equipment, but also trained personnel. Since these requirements may often be lacking, which greatly increases the risk of an accident, the drainage at collection points should be avoided. [b-Basel WLABTG].

b) **Batteries must be stored in proper places at collection points**. The ideal place to store used lead-acid batteries is inside an acid-resistant container that may simply be sealed and used as the transport container, as well as minimizing the risk of an accidental spillage.

c) **Collectors or dealers must not break the waste lead-acid batteries into separate components and ship or transport the grids or paste separately**. Only whole waste lead-acid batteries **(**WLABs) complete with case, electrolyte and the plates and paste can be transported to a WLAB recycling plant. There must be no intermediate steps in the process where paste is separated and sent to one plant and the grids sent to another in a different location or country. This principle also applies to the breaking up of WLABs to ship the plates with the paste without the electrolyte or the case. Such practices are not environmentally sound.

7.1.1.3.1 Transport of lead-acid batteries

WLABs must be considered as hazardous when transport is needed. Again, the main problem is the electrolyte, which in transit may leak from used batteries, requiring control measures in order to minimize the risk of spillage and specify the actions to be taken in event of an accident.

Batteries should be handled as follows.

- Palletized in neat rows with thick cardboard placed between each layer of batteries to absorb any minor leakage of electrolyte.

- Shrink wrapped with plastic film and strapped on all four sides with heavy-duty plastic strapping to hold the waste batteries in place without any movement during transport to the smelter.
- Alternatively, WLABs can be placed upright in a purpose built or moulded leak-proof plastic container designed to be moved by a fork truck and overhead crane.
- *The transport vehicle should be identified with symbols*: The vehicle, whether ship, truck or van, must be correctly identified, following international conventions, symbols and colours (e.g., [b-UNECE GHS]), identifying the fact that corrosive and hazardous products are being transported.
- *Specific equipment*: The minimum equipment necessary to combat any simple spillage or leakage problems should be provided, and the transport team trained on how to use it.
- *Drivers and auxiliaries should be trained*: Personnel dealing with hazardous wastes should always be trained in emergency procedures, including occurrences of fire and spillage, and how to contact emergency response teams. Personnel should also be aware of the specific kind of hazardous material that is being transported and how to deal with it.
- *Personal protective equipment* (PPE) should be provided for the transport team, who should be trained in the use of the equipment in case of accident.
- *Transport schedule and map*: If possible, routes that minimize the risk of possible accidents or other specific problems should always be chosen for hazardous waste transport. Following a certain predefined path and adherence to a known schedule makes this possible [b-Basel WLABTM].

7.1.2 Temporary storage

In the temporary storage facility, steps should be followed to prevent exposure to hazardous substances and incidents. These steps include inspection to prevent leakage or isolate broken batteries, especially for WLABs. Batteries should be stored in covered areas, protected from water and away from heating sources. The collection site should have an acid resistant foundation with adequate ventilation. The temporary collection site should have a reasonable volume of batteries stored and the storage time should be limited.

The batteries should be labelled and segregated by chemistry type also in the storage step. Discarded LIBs, in particular, are often not labelled as such and are difficult to identify through visual inspection. These batteries present a significant safety hazard when they are intermingled with waste lead-acid batteries in the lead recovery process, as they are highly reactive and can explode violently. Because of the serious danger they present to workers, discarded LIBs should never enter the waste lead-acid batteries recycling stream [b-CEC].

7.1.2.1 Temporary storage of lead-acid batteries

In the temporary storage facility, emergency preparedness procedures should be used. Facilities should be equipped with an emergency shower for personnel and with cleanup material to address any spills that may occur. In addition, fire extinguishers should be available to handle small fires, should they occur (ESM of lead-acid batteries in North America [b-WLABNA]).

The entrance to the temporary storage facility must be restricted and carry a notice indicating storage of hazardous materials.

Any other lead materials which may possibly be present, such as plumbing, should be conveniently packaged and stored in accordance with their characteristics.

Collection points must not store large quantitiess of used batteries: Even after creating a protected storage place, a collection point should not store a large number of used batteries and must not be considered as permanent. The right storage quantity depends, of course, on the trade rate of the establishment and it must have the dimensions to accommodate specific demands. Nevertheless, the storage of used batteries in large quantities or for a long time increases the risk of accidental spillage or leakage and must be avoided.

Collectors must not sell their batteries to unlicensed lead smelters: These are the main sources of lead contamination, both human and environmental [b-Basel WLABTG].

7.1.3 Storing at the recycling plant

Protection measures in the recycling plant are similar to the storage requirements at collection points, the striking difference between them is the quantity of batteries stored in these facilities, which could easily reach several kilotonnes. Therefore, a different approach should be adopted here.

a) *Batteries should be drained and prepared for recycling*: Better recycling rates and fewer environmental problems are created when batteries are drained. After drainage, the electrolyte is directed to an effluent treatment plant and the batteries are stored empty.

b) *Batteries should be identified and segregated*: Various batteries may require different recycling approaches. Therefore, they should be correctly identified, labelled, and stored in different places [b-Basel WLABTM].

7.2 Safety requirements for handling waste batteries by recyclers and workers

Batteries are electrochemical machines designed to store energy that can be released in response to user demand. Because of their energy-releasing features and chemical properties, batteries must satisfy a variety of safety requirements during manufacture, transport, storage, operational and end-of-life stages of the lifecycle.

The following safety measures are recommended for battery management.

- Personnel who work in recycling plants must be appropriately trained and provided with individual protective equipment, as well as washing and changing facilities.
- Recycling of used batteries must only be done in suitably equipped facilities allowing full automation for certain operations.
- Recycling of used batteries must be a regulated activity, governed by standards that are verified and well defined, particularly with regards to the siting and operation of recycling plants.
- A programme must be in place to monitor exposure of workers to hazardous substances contained in batteries (e.g., lead, cobalt) and take corrective measures if the exposure limit is exceeded.
- Review international standards regarding the sustainable management of e-waste, including [b-ITU-T L-Suppl.4].
- Consult with the United Nations provisions on the transport of batteries [b-UN TDG].
- Review international dangerous goods regulations [b-DGR] of the International Air Transport Association (IATA).
- Review the international maritime dangerous goods code [b-IMDG] of the International Maritime Organization (IMO).
- Review regulations concerning the international carriage of dangerous goods by rail [b-RID].
- Review international standards and directives such as:
  – [IEC 60086-4];
  – [IEC 62133-2].

7.2.1 Safety procedures for lead-acid battery handling to avoid and minimize exposure to hazardous substances [b-BaselWLABTM]

7.2.1.1 Hazardous chemicals in lead-acid batteries and health effects on humans due to acute and chronic exposure to lead

Lead-acid batteries contain components and chemicals that are toxic and can not only damage the environment, but also cause harm to people. There are two main substances of concern, lead and sulphuric acid.

Lead: Health effects from acute exposure to lead dust or fumes can include irritated eyes on contact. Inhalation of lead dust or fumes can irritate the nose and throat. Exposure can cause poor appetite, weight loss, upset stomach, nausea and muscle cramps, and in certain cases of acute exposure, death.

Chronic health effects [b-ATSDR] may cause kidney and brain damage and damage to blood cells causing anaemia. Lead is classified as a probable teratogen that can damage a developing foetus. Exposure may decrease fertility in males and females. Repeated exposure causes tiredness, trouble sleeping, stomach problems, constipation, headaches and moodiness, while higher levels may cause trouble concentrating and remembering events, as well as aching and weakness in arms and legs. Exposure increases the risk of high blood pressure. Lead accumulates in the body, particularly in bone, with repeated prolonged exposure.

The US Centers for Disease Control and Prevention [b-CDC] state that there is no safe level of lead exposure in children as determined by lead in blood analysis.

Sulphuric acid: Acute health effects of exposure to sulphuric acid include extreme corrosion, and it can severely irritate and burn skin and eyes. Inhalation can irritate the lungs, causing coughing or shortness of breath, while higher levels of exposure can cause a build-up of fluid in the lungs.

Chronically, there is limited evidence that sulphuric acid causes lung cancer in refinery workers [b-Beaumont]. Repeated exposure can cause bronchitis with a cough, phlegm and shortness of breath. Exposure may cause emphysema and can cause chronic runny nose, tearing of the eyes, nosebleeds and stomach upsets.

7.2.1.2 Occupational surveillance and prevention of lead exposure in the workplace

In 2003, the Occupational Safety and Health Administration introduced an e-tool ([b-OSHA] for secondary producers that describes ways to reduce occupational lead exposure at lead smelter plants. This Internet-based resource specifically targets the following operations:

- hygiene;
- protective work clothing and equipment;
- raw materials processing;
- battery breaking;
- charge preparation;
- smelting;
- refining and casting;
- environmental controls;
- dust collection systems;
- maintenance;
- housekeeping.

There are helpful diagrams with potential exposure sources highlighted and suggestions for either reducing the levels of lead exposure through an engineering solution, a change in working practice or PPE. Employers should also review test results for all workers by job, department, section, process, and shift in order to help identify jobs or work areas where there is a pattern of problems associated with elevated lead exposure occurring. While the emphasis is to examine and analyse increases in blood lead levels, it is also important to examine the working practices of one shift or crew if their blood lead levels are significantly lower than other shifts working in the same area or process. Comparing the working practices of the shift or crew with the lowest blood lead levels with those with the highest will lead to work practice improvements [b-Basel WLABTM].

7.3 Best technologies for recycling wasted batteries based on their types

7.3.1 Lead-acid batteries [b-BAT/BEP Egypt]

Since lead-acid batteries are used widely, they are recycled worldwide, using three technologies.

1) Pyro-metallurgical technology (direct secondary smelting)

Lead-acid batteries are recycled through an initial physical separation, followed by secondary smelting and a refining process. The lead-acid battery is recycled through an automated recycling process, starting with crushing by an enclosed high impact crusher to prevent fugitive lead dust emission; pieces of plastic are then separated from heavy metals and lead. First, the crusher effectively separates all battery components; the broken battery pieces are then placed in a water bath, where the lead and heavy materials fall to the bottom and the plastic floats. The pieces of plastic are then scooped away and the liquids drawn off, leaving the lead. Each material goes into a different recycling phase as follows.

a) *Plastic*: Fragmented pieces of plastic are washed, dried and sent to a plastic recycler where the pieces are fused. The molten plastic is put through an extruder that produces small plastic pellets of a uniform size, which are sent to a manufacturer to make battery cases and the process begins again. The byproducts of this process are fractions containing lead such as lead paste, lead oxide and lead cyanide.

b) *Lead*: Lead, lead oxide, and metals are cleaned and heated within rotary furnaces to about 1 300°C. Rotary furnaces are used as secondary smelting units for the recovery of lead out of lead-acid battery scrap, This process leads to maximum production efficiency of recovered lead by minimizing production costs, such as fuel, labour and power consumption.

c) *Sulphuric acid*: It can be treated by two methods.

- First method. The acid is neutralized in tanks using sodium hydroxide and air as an agitation medium for mixing. The reaction produces a sludge, principally containing sodium sulphate, and water; the water is then treated, cleaned, and tested in a wastewater treatment plant to be sure it meets cleanliness standards. The sludge resulting from the wastewater treatment is disposed of in hazardous waste landfill since it contains heavy metal impurities.
- Second method. The acid is processed and converted to sodium sulphate, an odourless white powder that is used in laundry detergents, glass and textile manufacturing.

2) Physical separation technology

This technology crushes batteries to the point where the separation of components is sufficiently and easily achieved. The separation techniques applied after crushing are based on the physical properties, mainly particle size, and density of the materials. The main constituents of the batteries after crushing are separated into the following.

a) Plastic waste which is 5% of the battery mass.

b) Lead, lead oxide and metals constitute 55% of the battery mass. They are separated, smelted and refined to meet the high-quality standards of the lead industry and to be further used again in new batteries.

c) The polypropylene from battery boxes which constitutes 5% of the battery mass.

d) The remaining solids consisting of lead grids, polyoxybenzylmethylenglycolanhydride (commercially available as Bakelite) and polypropylene which constitute 35% of the battery mass.

After an initial simple breaking, separation permits recovery of the battery paste. The remaining solids, consisting of lead grids, Bakelite and polypropylene, are crushed again to a lower particle size for better separation efficiency. Hydraulic separation sorts the lead grids from the other compounds. Then, in a further stage of hydraulic separation, polypropylene is efficiently separated from hard rubber (commercially available as Ebonite) and Bakelite. The various relative densities of the solids are as follows: Ebonite-Bakelite (d = 1.3), polypropylene (d = 0.9), and lead (d = 11.4).

3) Hydrometallurgical technology

The hydrometallurgy process for spent lead-acid batteries includes leaching or desulphurization, electrowinning, melting and casting. The main advantages of this process are the low operation temperature and the low environmental impact due to minimization of fine dust emission. The hydrometallurgical process involves a leaching method where lead paste reacts with chemical reagents as a spent electrolyte (sulphuric acid), in order to dissolve lead-containing compounds as lead(II) oxide (PbO), lead(IV) oxide (PbO_2) and lead(II) sulphate ($PbSO_4$). Subsequently, electrowinning is applied where the electro-extraction of cathodic lead with a purity of more than 99.9% is obtained, heated in smelting furnaces at 700°C, then cast as lead ingots to be used as raw materials in battery manufacture. The slag, which contains cyanide and traces of lead oxide, is disposed of in special hazardous waste landfills.

7.3.2 Rechargeable nickel-cadmium batteries [b-BAT/BEP Egypt]

Rechargeable nickel-cadmium batteries use metallic cadmium and nickel(II) hydroxide as electrodes. nickel-cadmium batteries are typically contained in a plastic case that must be removed prior to cadmium extraction and nickel-iron recovery through the pyrometallurgy high temperature metal recovery (HTMR) process. They are disposed of via the pyrometallurgical technology. Nickel-cadmium batteries go through the following process stages.

a) First is feed preparation in which batteries are crushed then sent to a pelletizing disk. The positive nickel plates are then shredded and fed into the rotary hearth furnace and subsequently into the electric arc furnace for nickel and iron recovery. The negative cadmium plates are processed in the cadmium recovery facility.

b) Second is reduction where the blended feed materials are transferred to a rotary hearth furnace operating at approximately 683°C. In the rotary hearth furnace, some of the carbon added during the blending stage reacts with the oxygen in the waste to reduce the metal-bearing wastes to their metallic form. Gas produced in the process is discharged to a wet scrubber system. The scrubber water is then treated in a wastewater treatment plant on-site. This water is recycled back to the plant for reuse.

c) Third is a smelting process in which the hot reduced feed is transferred from the rotary hearth furnace to an electric arc furnace where smelting occurs. The electric arc furnace performs a smelting operation to produce nickel, chromium and iron alloy. Lime (calcium oxide, CaO), silica (SiO_2), magnesia (Mg_2O_3) and alumina (Al_2O_3) are separated to form a slag, which is collected and hauled to a cooling area for subsequent use in building roads, carparks and commercial driveways.

d) Fourth is casting, in which molten metal is converted to small pieces known as pigs in a casting machine and then shipped to manufacturers to be used as a re-melting alloy for the production of stainless steels.

7.3.3 Lithium-ion batteries

Recycling has been successfully implemented for WLABs and nickel-metal hydride (Ni-MH) batteries. For example, the recycling rates of lead-acid batteries in both the USA and Europe approach

100%. The collection is ensured via a value-driven model, which does not yet exist for LIB technology. Recycling rates of small-format LIBs (in the consumer electronics industry) have been reported as low, due to low collection rates. As noted, LIB technology faces more recycling-related challenges than its lead-acid or Ni-MH predecessors. First, at least five different cathode chemistries are widely used in commercial LIBs, including those in EVs. The vast research efforts presently directed at cathode materials are certain to produce an even more variable supply chain for recyclers to process. Because the supply chain for recyclers fluctuates significantly and includes LIBs with many different cathode (and other) materials, if a recycler cannot recover pure and consistent material, the recoverable value will be low and inconsistent. Since cathode materials account for 40% of the material value in typical LIBs, their recycling is especially important for optimal economics. Currently there are three major LIB-recycling processes including pyrometallurgy, hydrometallurgy and direct recycling. The three different battery recycling technologies are shown in Figure 12: a) pyrometallurgy; b) hydrometallurgy; and c) direct recycling.

A pyrometallurgical process involves high-temperature smelting, which usually includes burning and subsequent separation. A hydrometallurgical process is achieved using aqueous chemistry, via leaching in acids (or bases) and subsequent concentration and purification. Direct recycling harvests and recovers active materials of LIBs, while retaining their original compound structure. Pyrometallurgy and hydrometallurgy are operated at industrial level, and direct recycling is on the laboratory and pilot scale.

Novel approaches in all three categories are the subject of extensive development in industry and academia [b-Chen].

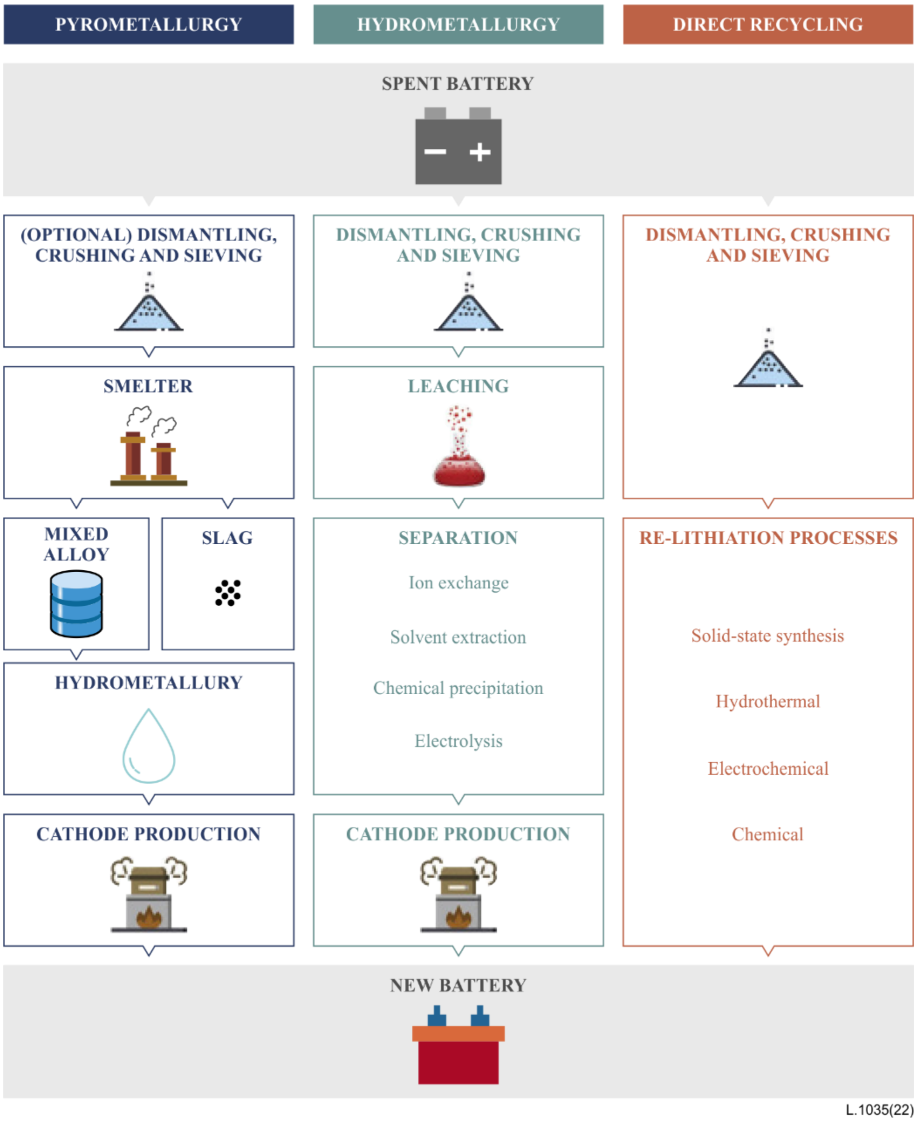


Figure 12 – Three major current recycling technologies for LIB-recycling

During the disposal of LIBs, a pre-treatment step is necessary to render the lithium and by-products inert, this step is optional in some pyrometallurgical processes. Once dismantled, sorting separates copper foil, aluminium foil, separator and coating materials.

There are five methods of disposal as follows.

1) Pyrometallurgical processes

Pyrometallurgical processes prevail widely in industry because of their simplicity and high productivity. In general, slag systems can be designed to optimize recovery efficiencies of metals in LIBs during smelting reduction processes.

CaO-SiO_2-Al_2O_3 and FeO-SiO_2-Al_2O_3 were primarily employed as slag systems in pyrometallurgical processes, whereas the recovery of manganese and lithium was low. Lately, a novel slag system (MnO-SiO_2-Al_2O_3) has recovered manganese and lithium. Co-Ni-Cu-Fe alloy and lithium-containing manganese-rich slag have been produced, and with its further leaching, the recovery rates of manganese and lithium reached 79.86% and 94.85%, respectively. Lithium exists in slag as compound and is hard to recycle by pyrometallurgy, due to its high melting and boiling point. A hydrometallurgical process is necessary to recover lithium. This includes leaching, extraction, crystallization, and precipitation from a liquid solution. Hydrometallurgical treatment is used to recover pure metals, e.g., lithium, gleaned from separated coating materials after mechanical processes or from slag in pyrometallurgical processes [b-BU]. Recently, it has been proposed to recover lithium from slag by evaporation during chlorination roasting, and the best chlorine donor, donor dosage, roasting temperature and time were found by experimenting on the simulated slag, resulting in a lithium recovery efficiency of 97.45% [b-Chen].

2) Hydrometallurgical (wet chemistry) process

In this process, LIBs are recycled through initial chemical separation followed by physical separation. They are then placed in a liquid argon or liquid nitrogen bath to reduce their reactivity, so that the batteries can be close to inert and safely handled regardless of their specific chemistry. The batteries are cooled to between −175°C and −195°C with liquid nitrogen; at these temperatures the reactivity of the battery material is sufficiently low and there is no risk of explosion. Also, the low temperatures make the plastic casing of the battery's brittle, so that they can easily be broken. The cooled batteries go through an automated recycling process, starting with crushing with an enclosed high impact crusher to prevent fugitive lead dust emissions down to yielding lithium carbonate [b-BU].

For LIBs, ions in solution are separated by various technologies (ion exchange, solvent extraction, chemical precipitation, electrolysis, etc.) and precipitated as different compounds. The main advantages of the hydrometallurgical process are: a) that high purity materials can be generated; b) that most LIB constituents can be recovered; c) low temperature operation; and d) lower carbon dioxide emissions than with the pyrometallurgical process. The main disadvantages of the hydrometallurgical processes include: 1) a need for sorting, which requires increased storage space and adds to process cost and complexity; 2) the challenge of separating some elements (Co, Ni, Mn, Fe, Cu, and Al) in the solution, due to their similar properties, which can lead to higher costs; and (3) the expense of waste water treatment and associated costs [b-Chen].

3) Direct recycling

Direct recycling is a recovery method proposed to directly harvest and recover active materials of LIBs, while retaining their original compound structure. In this process, battery constituents are separated, primarily using physical separation methods, magnetic separation and a moderate thermal processing, in order to avoid chemical breakdown of the active materials, which are the main recovery target. The active materials are purified, and both surface and bulk defects are repaired by re-lithiation or hydrothermal processes. However, cathodes may be a mixture of more than one active material and separating them may not be economically or technically feasible. Furthermore, inputs containing multiple chemistries cannot yet be separated and thus present significant sorting challenges. The main advantages of the direct recycling approach include: a) a relatively simple process; b) that active materials could be directly reused after regeneration; and c) significantly lower emissions and less secondary pollution, in comparison with pyrometallurgy and hydrometallurgy.

The main disadvantages of the direct recycling process include: 1) that it requires a rigorous sorting and pre-processing, based on exact active material chemistry; 2) that it is a challenge to guarantee consistent high purity and pristine crystal structure, which may not meet rigorous standards required by the battery industry; 3) an unproven technology that, thus far, exists only on the laboratory scale; 4) significant sensitivity to input stream variations; and 5) an inflexible process: what goes in comes out, and thus the process may not be appropriate to meet the reality of changing cathode chemistry. In the near term, this technology is more likely to be adopted by battery manufacturers for recycling electrode scrap, where the chemistry is known and current [b-Chen].

4) Biometallurgy

Biometallurgy is a hydrometallurgical process in which fungi or bacteria carry out the leaching. Literature reports using such a technique for metals extraction from electronic devices and mining ores or waste.

The process has a very high potential for industrial applications, being eco-friendly as a bonus. Its main drawbacks might be the low kinetic rate, since the biohydrometallurgical process takes days to achieve the same efficiency as acid leaching. Further separation techniques after bioleaching are similar to the hydrometallurgical route [b-Martins].

5) Electrometallurgy

Electrometallurgy is a process for refining (electrorefining) and production (electrowinning, electroplating and electroforming) from a solution containing metals throughout electrolysis. [b-Martins].

Figure 13 shows LIB recycling facilities worldwide.

The locations of LIBs recycling facilities are listed and marked on the world map. With most facilities being concentrated in a few countries or locations within a country, challenges arise in transportation when the quantity of spent LIBs becomes significant [b-Chen].

Figure 13 – Lithium-ion battery recycling facilities worldwide

7.3.4 Alkaline batteries [b-BAT/BEP Egypt]

Rechargeable and non-rechargeable dry cell batteries consist of manganese dioxide and zinc as an electrode. They have an alkaline electrolyte of potassium hydroxide. Alkaline batteries are taken to recycling facilities where they are recycled to make new products. They are disposed of via pyrometallurgical and hydrometallurgical technologies as follows, Table 2 summarizes recycling methodologies for different battery chemistries.

1) Pyrometallurgical recycling process

Used alkaline batteries are recycled through initial physical separation, followed by pyrolysis and a reduction process. Alkaline batteries are sent into an innovative mechanical dismantling process where the battery parts are sorted into three end products including steel, plastic, paper and zinc, as well as manganese concentrates. Each material goes into a different recycling phase as follows:

– plastic: plastic pieces are washed, dried, and sent to a plastic recycler where the pieces are melted together;

– battery components including zinc and manganese concentrates, after being separated are sent to the following processes:

  • pyrolysis: battery components are fed into a shaft furnace, where they are pyrolysed at temperatures up to 700°C while organic compounds are thermally destroyed and emitted as a gas together with water and mercury,

  • reduction: the metallic fraction that remains in the furnace after the pyrolysis is subjected to reduction process at temperatures around 1 500°C.

2) Hydrometallurgical recycling process

The hydrometallurgical process for spent alkaline batteries includes crushing followed by magnetic separation and then leaching. The main advantages of this process are low operation temperature and low environmental impact as there is no dust emission.

This includes the Mechanical treatment: This physical operation facilitates the dissolution of metals in the aqueous phase and the hydrometallurgical reprocessing where the pulverized battery contents are leached in dilute sulphuric acid where zinc sulphate ($ZnSO_4$) and manganese sulphate ($MnSO_4$) are obtained.

7.3.5 Silveroxide batteries [b-BAT/BEP Egypt]

Silver oxide batteries are disposed of using a hydrometallurgical process through the following steps: crushing, distillation, leaching, precipitation and reduction.

7.3.6 Mercury batteries [b-BAT/BEP Egypt]

A mercury battery is a non-rechargeable electrochemical battery, a primary cell in the form of button cells. Mercury batteries are roasted at high temperatures, which causes their mercury to evaporate for subsequent recovery as a condensate. The mercury is then triple distilled to produce pure elemental mercury. The main steps for the recovery of mercury from mercury batteries are as follows:

• roasting (thermal process): mercury button cells are roasted in a retort oven at about 370°C or at multiple hearth furnace at high temperatures ranging from about 600°C to 800°C to vaporize mercury as fumes to be recovered;

• mercury recovery (condensation process): mercury vapours are collected via scrubbing to be cooled and condensed via cooling towers to obtain a condensate comprised of water and mercury;

• mercury purification (triple distillation process): the condensate is fed to distillation towers, then the retorted mercury is distilled three times to remove impurities and obtain high quality mercury.

Table 2 – Summary of recycling methodologies for different battery chemistries

Battery chemistry	Pre-treatment[a]	Separation/Direct recycling	Pyro-metallurgy	Hydro-metallurgy	Biohydro-metallurgy	Electro-metallurgy
	Pretreatment involves discharge, grinding.	The separation after grinding or manual dismantling aims at concentra-ting materials with the same properties to increase the recovery rates.	Pyro-metallurgy is a thermal process in elevated temperatures with fast kinetics that consists of separating the slag from the materials of interest, which are concentra-ted in another phase.	Hydro-metallurgical processing includes the treatment of complex composition, the recovery of metals in low concentration and obtaining highly pure products. The separation and extraction of metals is based on reaction in aqueous medium.	It consists of a hydro-metallur-gical process, in which fungi or bacteria carry out the leaching.	Electro-metallurgy is a process for refining (electro-refining) and production (electro-winning, electro-plating, and electro-forming) from a solution containing metals throughout electrolysis.
1. Lead-acid	✓	✓	✓	✓		
2. Rechargeable nickel/cadmium	✓	✓	✓			
3. Lithium-ion	✓	✓	✓	✓	✓	✓
4. Alkaline	✓	✓	✓	✓		
5. Silver oxide	✓	✓		✓		
6. Mercury	✓	✓	✓			
[a][b-Martins].						

8 Regulations, policies and legislation

8.1 Examples of regulatory frameworks to manage waste batteries

8.1.1 Introduction

The rules and regulations governing the management of used batteries vary depending on the country, continent and other external factors. Not all countries have implemented such regulations. Even in those that do, non-compliance continues to threaten the environment, human health and the world economy.

8.1.2 European Battery Directive

To support increased battery collection, some regulations have been introduced. For example, the European Battery Directive 2006/66/EC ensured a minimum battery collection rate of 45% by 2016 and has forced producers to be responsible for LIB collection and treatment, as well as the Chinese Extended Producer Responsibility (EPR) plan of 2017. In the USA, despite the absence of national regulations, different organizations (e.g., Call2Recycle, Battery Solutions and the Big Green Box programme) operate to properly collect and manage post-use LIBs [b-Mossali].

The main objectives of the 2006/66/EC, Directive, as revised in 2016, are to [b-EU Battery]:

- minimize the negative impact of batteries and waste batteries on the environment by reducing hazardous substances and by improving battery waste management;
- improve the environmental performance of batteries;

- ensure a high level of collection and recycling;
- attain a high level of material recovery: establishing obligations in relation to the efficiencies of the recycling processes to which batteries are subject.

The European Battery Directive was reviewed in 2020. Its revision was in the approval process at the time publication of this Recommendation. The publication of this directive is part of the European Green Deal and related initiatives, including the new circular economy action plan and the new industrial strategy. The circular economy action plan identified batteries among resource-intensive sectors with high potential for circularity to be addressed as a matter of priority.

The proposed regulation concerning batteries and waste batteries would replace the Batteries Directive. It has three interlinked objectives:

- strengthening the functioning of the internal market (including products, processes, waste batteries and recyclates;
- promoting a circular economy;
- reducing environmental and social impacts throughout all stages of the battery lifecycle, establishing requirements for sustainability, safety and labelling to allow the placement on the market and putting into service of batteries, as well as requirements for their end-of-life management.

The main innovations in the proposal include the following.

- Progressive requirements to minimize the carbon footprint of EV batteries and rechargeable industrial batteries: a carbon footprint declaration requirement, applicable as of 2024-07-01, complemented by classification in a carbon footprint performance category and related labelling (as of 2026-01-01); and a requirement to comply with maximum lifecycle carbon footprint thresholds (as of 2027-07-01).
- A recycled content declaration requirement, which would apply from 2027-01-01 to industrial batteries, EV batteries and automotive batteries containing cobalt, lead, lithium or nickel in active materials. Mandatory minimum levels of recycled content would be set for 2030 and 2035 (i.e., 12% cobalt; 85% lead, 4% lithium and 4% nickel as of 2030-01-01, increasing to 20% cobalt, 10% lithium and 12% nickel from 2035-01-01, the share for lead being unchanged).
- Minimum electrochemical performance and durability requirements for portable batteries of general use (applying from 2027-01-01), as well as for rechargeable industrial batteries (from 2026-01-01). The Commission would assess the feasibility of phasing out non-rechargeable portable batteries of general use by the end of 2030.
- A new obligation of battery replaceability for portable batteries.
- Safety requirements for stationary battery energy storage systems.
- Supply chain due diligence obligations for economic operators that place rechargeable industrial batteries and EV batteries on the market. For this requirement on responsible raw material sourcing (as well as for those related to the carbon footprint and the recycled content levels), the Commission proposal envisages mandatory third-party verification through notified bodies.
- Increased collection rate targets for waste portable batteries, excluding waste batteries from light means of transport (65% by the end of 2025, rising to 70% by the end of 2030).
- As regards recycling efficiencies, increased targets for lead-acid batteries (recycling of 75% by average mass of WLABs by 2025, rising to 80% by 2030) and new targets for lithium-based batteries (65% by 2025, 70% by 2030). The proposed regulation also envisages specific material recovery targets, namely 90% for cobalt, copper, lead and nickel, and 35% for lithium, to be achieved by the end of 2025. By 2030, the recovery levels should reach 95% for cobalt, copper, lead, and nickel, and 70% for lithium.

- Labelling and information requirements. From 2027-01-01, batteries should be marked with a label with information necessary for the identification of batteries and of their main characteristics. Various labels on the battery or the battery packaging would also provide information on lifetime, charging capacity, separate collection requirements, the presence of hazardous substances and safety risks. Depending on the type of battery, a quick response (QR) code would give access to the information relevant for the battery in question. Rechargeable industrial batteries and EV batteries should contain a battery management system storing the information and data needed to determine the state of health and expected lifetime of batteries. This system should be accessible to battery owners and independent operators acting on their behalf (e.g., to facilitate the reuse, repurposing or remanufacturing of the battery).
- The setting up, by 2026-01-01, of an electronic exchange system for battery information, with the creation of a battery passport (i.e., electronic record) for each industrial battery and EV battery placed on the market or put into service.

8.1.3 The concept of a battery identity global passport

One challenge for battery recycling is how to efficiently sort batteries of different chemistries to avoid or at least reduce the complicated separation processes. A simple yet effective design principle would be appropriate labelling in many forms, such as labels, QR codes, and radio frequency identification device tags. The Battery Recycling Committee of the Society of Automotive Engineers has developed a label to be placed on EV battery packs to enable separate processing of different battery types.

Another example is that Battery Recycling Prize from United States Department of Energy funded Everledger to trace the lifecycle of LIBs using blockchain technology to ensure optimal management and responsible recovery at end of life. Scanning those labels automatically would facilitate sorting batteries, circumventing the aforementioned challenging separation processes. With relevant information available, recyclers can take less effort to identify the electrode chemistry. A recent report from the World Economic Forum and the Global Battery Alliance suggests that battery diagnostic and shared data systems or battery passports should be established, especially for EV batteries. The development of such a system embedded within batteries or as separate tools could provide key information including battery chemistry, origin, the state of health of the batteries and the chain of custody that can be captured by the battery recyclers at the recycling facilities. A battery identity global passport (BIGP) will help to efficiently unveil the identity of the components in the cells to support quick and automated sorting, and hence could lead to streamlined separations. A second-life application sector could use the BIGP information of a battery to enable effective selection and assessment of suitable batteries for reuse. Also, the BIGP can make information on cathode compositions and electrolyte formulations available to recyclers. This might be challenging because manufacturers may not want to share their proprietary formulations. It is thus important for all stakeholders and policymakers to collaborate and make agreements between battery manufacturers and recyclers [b-Bai].

8.2 Recommendations on legislation, regulations, and management plans for waste batteries

- In least-developed and developing countries, countrywide regulations should be implemented to govern the system for collecting used batteries of all types, with certified operators and shipment to authorized and specialized centres or countries that import wastes to recycle them in an environmentally sound manner.
- Regulations should establish partnerships with collection operators and recycling companies for all countries that have not ratified the Basel Convention and lack the technology for recycling wastes themselves.
- International sanctions should be instituted for practices that contravene:

a) the Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa [b-Bamako];

b) the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal [b-Basel];

c) The Minamata Convention on Mercury. In particular, according to paragraph 1 of Article 4 of [b-Minamata], the Parties (with some exceptions allowed) decided to phase out the manufacture, import and export of mercury-containing batteries by 2020, except for button zinc silver oxide batteries with a mercury content <2% and button zinc air batteries with a mercury content <2%.

- Within individual countries, legislation should be introduced on batteries, in particular waste batteries, taking into account the fact that least developed countries and developing countries lack the appropriate resources for recycling.
- The indiscriminate disposal of primary and secondary batteries, as well as equipment in which such batteries are incorporated, should be banned, as should the disposal into the environment of solid and liquid constituents of such batteries.
- The informal or clandestine recycling of batteries, notably those of the lead-acid type, should be banned.
- The burial of hazardous materials resulting from indiscriminate battery disposal and recycling activities should be banned.
- Objectives should be established for collection and recycling.
- It is recommended that countries develop reliable, official, and comparable e-waste data and statistics. This provides the foundation for the development of responsible domestic e-waste management policies and legislation, including batteries. More than 40 countries now compile comparable national statistics on e-waste [b-ITU media e-waste].

Appendix I

Best practice – The case of Côte d'Ivoire

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

The development of ICTs has not bypassed Côte d'Ivoire: in recent years the country has witnessed a remarkable period of growth in the digital domain.

Thus, between December 2018 and March 2019, the number of mobile telephony subscribers nationwide increased from 33 807 850 to 34 411 807, a growth rate of 1.79%, according to the Autorité de Régulation des Télécommunications/TIC de Côte d'Ivoire [Telecommunication/ICT Regulatory Authority of Côte d'Ivoire] (ARTCI).

The growth of the sector has consequences, including the production of electronic waste.

The question of WEEE has become a major concern for most African countries, and Côte d'Ivoire is no exception.

As a result, practices such as the unregulated burning of wastes in the open air and the dumping of unwanted residues directly into the environment have become widespread, creating a serious threat to the environment and to human health.

Electronic waste includes all components from electrical and electronic equipment, such as batteries, an indispensable element in the proper operation of ICT equipment.

Batteries commonly contain substances or components that are a danger to the environment and for human health, including lead, cadmium and mercury. At the same time, they have high potential in terms of the recycling of certain materials they contain (ferrous and non-ferrous metals, rare metals, glass, plastics, etc.).

However, what actually happens to the batteries in ICT equipment once they are no longer in use?

This, in a nutshell, is the problem of the sustainable management of batteries from ICT equipment in Côte d'Ivoire.

Unfortunately, until recently the country did not have a formal system for handling electrical and electronic equipment arriving at the end of its useful life; it therefore decided to deal with the problem of e-waste in order to protect the population and the environment.

I.2 Description of batteries

An accumulator battery – or more commonly simply a "battery" – is a set of electrical accumulators connected together to create an electrical generator with the desired voltage and capacity. They are sometimes called battery cells. These rechargeable elements are intended for domestic electrical and electronic devices such as household appliances, refrigerators, mobile telephones, computers, game consoles, television sets and remote controls.

There are several types of battery: lead-acid; nickel; and lithium.

I.3 Origins of electrical and electronic waste

Electronic waste, including batteries, comes from sources such as those discussed in clauses I.3.1 and I.3.2.

I.3.1 Local origin

WEEE of local origin includes obsolete equipment gathered from collection boxes and waste bins or by means of door-to-door collection from businesses and households, generally in the Abidjan area, by informal collectors who work for scrap merchants and electronics technicians who repair televisions, mobile telephones, computers, etc., buying up discarded devices for small sums: FCFA 500 for a mobile telephone; or FCFA 2 500 to 5 000 for a television set.

I.3.2 External origin

Most WEEE that is found in Côte d'Ivoire is imported by companies who bring large amounts of so-called second-hand equipment to Abidjan, where they resell the untested goods to wholesale purchasers.

This practice is in violation of international law, e.g., [b-Bamako] and [b-Basel]. The situation is sustained by the activity of illegal export networks.

The legislation is bypassed by certain companies, which for the most part export the waste primarily to West Africa, often declaring it as second-hand equipment.

I.4 Collection, sorting, dismantling and recycling techniques

The Ivorian WEEE trade is entirely in the hands of informal operators, operating under conditions that are far from ideal.

The waste is collected casually by individuals, but is also processed in a sophisticated way. Purchasers sort what can still function and then sell off the rest to scrap merchants. The latter dismantle the equipment and recycle the recovered materials in an ingenious but entirely unregulated fashion, with complete disregard for the International Labour Organization's rules on the health and safety of workers [b-ILO]. See Figure I.1.

Figure I.1 – Informal collection and sorting of ICT waste

I.5 Risks linked to used batteries

Once out of use, most equipment and its various components, including batteries and hardware, end up in open landfills.

The open-air burning technique for recovery of precious metals is not without risk for workers who take no protection measures and thus expose themselves to dangerous substances in the smoke that are harmful to both health and the environment. See Figure I.2.

Electronic waste in Côte d'Ivoire is estimated at 90 000 t according to *Fraternité Matin*, a State-owned Ivorian daily. The unregulated manner in which this waste is processed feeds an opaque casual economy that represents a real loss for Côte d'Ivoire in terms of the benefits that a modern and regulated recycling chain could generate.

Figure I.2 – Burning waste in the open air to extract precious metals

I.6 Reaction of the government of Côte d'Ivoire

I.6.1 Establishment of a national programme for the management of electrical and electronic waste

Faced with this worsening problem, the Government of Côte d'Ivoire reacted in 2017-04, with its Council of Ministers adopting a decree providing for the ecological management of WEEE. According to the decree, the objective is to combat the proliferation of WEEE and promote the reuse and recycling of such waste and alternative ways of recovering it.

This will make it possible to collect greater quantities and manage it in accordance with ecological standards at a more competitive cost for industry and consumers. The decree also establishes requirements regarding the financial and operational aspects, specifying related sanctions for all those involved in the ecological collection and management of electrical and electronic waste.

After 8 months, the Government issued a communication authorizing an operator for the ecological management of WEEE and used tyres based on an offer by the Société Générale de Surveillance/Société Africanaise de Recyclage (SGS/SAR) group (SGS is a multinational corporation offering services such as inspection, control, analysis and certification).

The National Programme for the Management of Waste aims to establish a management system for WEEE based on three major modules.

The first will cover the registration of concerned products imported into Côte d'Ivoire, ensuring that when they are declared as second-hand material, they are not in fact WEEE or waste pneumatic tyres, the export of which is banned under [b-Basel], to which Côte d'Ivoire is a signatory. The purpose of this is to avoid environmental disasters.

The second will comprise collection, for the State of Côte d'Ivoire, the ecological tax charged on relevant products imported into Côte d'Ivoire new or second hand, based on the polluter-pays principle and that of extended producer responsibility. The first two modules will be implemented by SGS, whose service provision contract was signed on 2018-09-20.

Last, the project will enter its practical phase of benefit to the population, as it will entail the creation of over 10 000 direct and indirect green jobs overall.

Thus, module three will establish a system for reliable and professional waste management, with collection centres set up at key locations in the country for the industrial processing and recycling of the objects collected.

Ultimately, two processing units and centres for the collection of WEEE will be created. The advantage of the project will be to make it possible at the environmental level to significantly reduce the harm related to such waste and allow Côte d'Ivoire to advance in the fight against climate change.

The National Programme for the Management of Waste will present this initiative officially to stakeholders – including administrations, importers and exporters, chambers of commerce, diplomatic missions, civil society organizations and the public – in order to keep them informed and raise their awareness of the benefits Côte d'Ivoire will derive from implementing this project.

I.6.2 Creating a legal and institutional framework

I.6.2.1 Legal framework

I.6.2.1.1 National level

For its environmental legislation, Côte d'Ivoire, like most developing countries, for many years relied on its colonial legacy. Some laws were adopted on an *ad hoc* basis following independence. However, now the legal regime for the environment is being strengthened with the adoption of a series of legislative instruments. The first national environment code, Act No. 96-766, in Côte d'Ivoire was enacted on 1996-10-03.

Numerous legal measures have been taken in the form of decrees issued over the years to protect the environment. Examples include:

- Act No. 88-651 of 1988-07 on the protection of public health and the environment against the effects of toxic and nuclear wastes and harmful substances – notable for the regional approach it takes to environmental problems;
- Decree No. 98-42 of 1998-01-28 on the organization of an emergency plan for combatting pollution, regardless of its origin, or the threat of such pollution, involving a large-scale or dangerous discharge into the sea or into the waters of lagoon areas or coastal regions of products or substances that could cause major harm to the aquatic environment or to coastal zones;
- Decree No. 96-894 of 1996-11-08 setting out the rules and procedures applicable to environmental impact studies for development projects;
- Decree No. 2005-03 of 2005-01-06 on environmental auditing;
- Decree No. 2012-1047 of 2012-10-24 setting out the procedures for implementing the "polluter pays" principle;
- Decree No. 2012-988 of 2012-10-10 establishing the Risk Reduction and Disaster Management Platform and setting out its powers, organization, and functioning;
- Decree no. 2013-41 of 2013-01-30 relating to the strategic environmental assessment of policies, plans and programmes;
- Decree No. 2013-327 of 2013-05-22 banning the production, import, sale, possession and utilization of plastic bags.

Numerous other pieces of draft legislation including that on management of chemical products, coastal regions, and climate change are currently being examined with a view to their adoption.

I.6.2.1.2 International and regional level

At the time of publication, Côte d'Ivoire had ratified 39 conventions, with three others in process. It has acceded to several multilateral agreements on the environment, at the regional and international level, including [b-Bamako] and [b-Basel].

I.6.2.2 Institutional framework

I.6.2.2.1 The Ministry of the Environment, Urban Waste Management and Sustainable Development

Pursuant to the 2013-07-25 decree setting out the functions of the Ministry of the Environment, Urban Waste Management and Sustainable Development, the Ministry is responsible for implementing and overseeing government policy on protection of the environment, urban waste management and sustainable development. The Ministry is organized pursuant to Decree No. 2014-507 of 2014-09-15. It consists of:

- 10 directorates and services operating directly under the cabinet, three general directorates, each with three central directorates, and 25 regional directorates;
- five operational entities for the ongoing management of environmental problems: the Agence Nationale de l'Environnement [National Environmental Agency] (ANDE), responsible for environmental evaluation, the anti-pollution centre for Côte d'Ivoire, responsible for monitoring the environmental matrices (water, air and soil), the Fonds de Financement des Programmes de Salubrité Urbaine [Fund for Financing Urban Waste Management Programmes] (FFPSU), responsible for the mechanisms by which financial support is provided for urban waste management programmes, the Agence Nationale de la Salubrité Urbaine [National Urban Waste Management Agency] (ANASUR), responsible for managing household waste and related waste categories, and the Office Ivoirien des Parcs et Réserves [Côte d'Ivoire Parks and Reserves Authority] (OIPR), which manages protected areas;
- five national programmes to coordinate work on the major environmental issues of the day on: climate change; waste management; the management of chemical products; natural resource management; and the management of the coastal environment.

Each thematic programme has the objective of formulating a national strategy and action plan, with the involvement of key stakeholders.

I.6.2.2.2 Other entities

The cross-cutting Ministry of the Environment, Urban Waste Management and Sustainable Development works closely with other ministries to anchor the government's action in the principles of sustainable development.

Côte d'Ivoire maintains a strong partnership with organizations of the United Nations system on major environmental questions, at the international, regional, and national level. Public-private partnership is one of the pillars of environmental action to meet the major environmental challenges. This leads to a synergy of action between the private sector and the Ministry responsible for the environment.

A participative and inclusive approach to managing the environment is another important policy instrument for the Ministry, which involves civil society organizations, local communities, citizens' associations and local government in all its work.

I.7 Private sector involvements in the management of WEEE in Côte d'Ivoire

I.7.1 PARO-CI

Programme Assainissement – Recyclage Ordures – Côte d’Ivoire [Waste Decontamination and Recycling Programme – Côte d'Ivoire] [b-PARO-CI] is an organization that works in the renewable energy sector and in sustainable development. It was created in Côte d'Ivoire on 2010-11-03 and promotes sustainable development in West Africa. With a staff of over 40, it processes some 35 t of e-waste per month.

PARO-CI is active in educating the general public on sustainable development, the recycling of non-biodegradable waste, water hygiene and treatment, promotion of energy saving and renewable energies in Côte d'Ivoire.

Working through ecological initiatives tailored to local needs, PARO-CI contributes to the achievement of the sustainable development goals in Côte d'Ivoire.

WEEE is considered a public health problem in Côte d'Ivoire because most of it is disposed of in an unregulated fashion, creating serious environmental and health hazards. To mitigate this highly undesirable situation, PARO-CI, together with PAGANETTI, its technical partner, has set up a WEEE dismantling and recycling platform in Abidjan.

This facility puts the project on an institutional footing, with a capacity of 10 000 t/year. It is designed not only to facilitate compliance with applicable international rules for WEEE management at the local level, but also to create green jobs, by promoting the circular economy. See Figure I.3

Figure I.3 – Collection and sorting of waste electrical and electronic equipment in PARO-CI workshops

The dismantling and recycling platform of the PARO-CI–PAGANETTI consortium is intended to contribute to the ecologically responsible management of equipment that has reached the end of its useful life in Côte d'Ivoire. This innovative ecological facility makes it possible to reduce considerably the environmental and public-health harm generally associated with poor management of e-waste.

The dismantling and recycling platform for WEEE is the first ecological Ivorian platform that takes care of equipment reaching the end of its useful life locally. In addition to providing for ecologically responsible WEEE management, the platform is effective in promoting the circular economy in the e-waste sector in Côte d'Ivoire. See Figure I.4.

Figure I.4 – WEEE platform technician

I.7.2 MTN Côte d'Ivoire

The mobile telephone operator MTN Côte d'Ivoire, as part of its environmental responsibility mission, and in partnership with municipal governments and a range of companies – PARO-CI–PAGANETTI, BOLLORE, PROSUMA, the European Chamber of Commerce (EuroCham), PACOCI and CASD – periodically conducts large-scale collection and recycling campaigns in the Abidjan area targeting WEEE.

The WEEE collection time-scale covers a year at designated collection sites. During the campaign, members of the public are encouraged to hand in their WEEE (household appliances, refrigerators, telephones, computers, game consoles, television sets, remote controls, used batteries, etc.) – large items in the 20-foot [6.1 m] containers at the collection sites and small items such as telephones, remote controls and used batteries in collection bins that PROSUMA sets up in supermarkets.

Following the success of the first such campaign, which was conducted in 2016 and resulted in the collection and recycling of 72 t of WEEE, MTN Côte d'Ivoire and its partners have set themselves the goal, with their second campaign, which started in 2019-02, of convincing the public in the District of Abidjan to accept the systematic collection and recycling of WEEE as a means of protecting public health and reducing pollution of the environment. See Figure I.5.

Figure I.5 – The e-waste 2.0 campaign: MTN Côte d'Ivoire takes a stand against electronic waste

Efforts initiated by PARO-CI to ensure an ecologically responsible management of equipment that has reached the end of its useful life is now supported by MTN Côte d'Ivoire and several other partners, including the EuroCham, the PROSUMA organization and Common Action for Sustainable Development (CASD-CI).

Through a public awareness promotion entitled "E-waste 2.0 campaign" the different partners in the project task force have undertaken to educate the Ivorian population about the dangers of WEEE, the need to collect that waste and feed it into an institutional, ecologically responsible management system so as to protect human health and the environment.

The project initiators intend to contribute to efforts to reduce the public health and environmental harm caused by such waste through the institutionalization of the sector, for the benefit of all people of Côte d'Ivoire.

I.7.3 Batterie Plus (battery recycling and regeneration company)

[b-Batterie Plus] has more than 15 years of experience manufacturing and selling battery regenerating equipment. The flourishing company, with a network of 15 distributors around the world, has been present in Abidjan since 2012, the economic capital of Côte d'Ivoire, a major metropolis with a booming industry.

It was in this context that Batterie Plus decided to establish its main battery regenerating facility for the region. The aim was to promote the concept and to share the know-how and the numerous benefits that this activity brings with it, particularly in telecommunications.

At the Abidjan facility, a multicultural team of experts in environmentally responsible technology provide battery regenerating services to numerous companies – including mobile operators – that are interested in saving energy and improving profitability, thanks to a concept that combines economic and ecological considerations. See Figure I.6.

Figure I.6 – Batterie Plus Côte d'Ivoire: New regenerator for batteries

Mobile telephony represents a major portion of the market on the African continent, which is why mobile operators from around the world are present here: Orange, MTN, Moov, etc. All companies have centres where they store thousands of backup batteries, which must be regularly exchanged and which are a significant cost factor, as well as producing a colossal amount of waste.

The regenerating equipment made available by Batterie Plus includes regenerators for the batteries that equip UPSs of the type used in mobile telephony. This allows client operators to recharge their batteries, increasing their useful life and thereby reducing their expenditure, as well as the mass production of waste. These companies save a lot of energy and can be justly proud of supporting a process that respects the environment.

This service brings other benefits to telephone operators, too. For example, recharging of batteries in a centre like that in Abidjan is very fast, reducing considerably the costs of maintaining equipment, in terms of labour. A regenerating system also reduces the likelihood of technical downtime or malfunction.

It is for these reasons and many others that the establishment of the battery-regenerating facility in the city of Abidjan is of significant benefit to all telecommunication companies in the region. The services offered by Batterie Plus ensure the best possible outcome for recycling in the energy domain.

The facility is certain to meet the needs of mobile operators, whose work and sales are thriving in West Africa, for participating in the sustainable management of the environment.

This battery-regenerating facility offers many benefits for numerous companies present in Côte d'Ivoire, such as mobile phone operators:

- savings can be made in terms of energy and greater profitability, made possible by this economic and ecological concept;
- batteries can be recharged with a charge time virtually identical to that of a new battery; extending their lifetime and considerably limiting both expenses and the mass production of waste, using a process that respects the environment;
- an optimal result is guaranteed in terms of recycling in the energy domain;
- energy efficiency and productivity are optimized.

I.8 Conclusion

Given the dangers that electronic waste presents when left out in the open unrecycled, non-professional handling and recycling are a real threat to people and the environment.

Considering the various texts and conventions that exist on electronic waste, the different responsibilities must be shared and assumed. Signatory states must ensure that such texts and conventions are applied in order to put an end to the illegal export of WEEE to developing countries.

The sustainable management of batteries from ICTs using modern technologies remains more essential than ever in order to safeguard people's health and the environment.

Appendix II

Current practices for safe management and disposal of batteries in Egypt

(This appendix does not form an integral part of this Recommendation.)

Batteries that are safely managed and disposed of in Egypt include lead-acid, non-rechargeable nickel-cadmium, and lithium-ion. Batteries are end-processed in Egypt according to standards of the Egyptian Environmental Affairs Agency (EEAA) at El-Nasrya hazardous waste landfill. While there is no collection system for all types of used batteries, there is a take back system adopted by Chloride Company for lead-acid batteries on a pilot scale through exchanging the used batteries for discounted new ones.

Batteries at the end of their lifecycle are then transported to recycling facilities or El-Nasrya hazardous waste landfill. El-Nasrya landfill accepts all types of batteries except for the lead-acid type, which are sent to specialized facilities for processing. This appendix explains the disposal process for each type of battery (as noted in Table 1) in Egypt in more detail.

1) Lead-acid batteries

The only applicable technology for lead-acid battery recovery in Egypt is the pyrometallurgical technology and it is also the most commonly used method in international facilities. The disposal of lead-acid batteries in Egypt is done through the following steps.

a) Discharging: The acid is discharged from the batteries and collected for resale and further treatment.

b) Crushing: After reaching the recycling facility, the battery is fragmented into small pieces in a hammer mill.

c) Sorting: The fragmented pieces are sorted by density through a water bath, where heavy metals and lead are separated from the plastic.

d) Sieving: The plastic fragments are scooped out of the water bath leaving behind the lead and other heavy metals. Plastic pieces are washed, then gathered for further manufacturing that might result in new battery casings. They can also be sold to plastic product manufacturers as raw materials.

e) Pyro-metallurgical processes (secondary lead smelting):

- The sorted lead plates and fragments are smelted in rotary furnaces at a temperature of 1 300°C to obtain lead bullion to be cast as lead ingots to be used as raw materials in many industries.
- The rotary furnace is equipped with a pollution control system (bag filters) to clean the air resulting from the secondary smelting process.
- The slag resulting from the secondary smelting is disposed of in hazardous waste landfill due to the nature of the materials.
- The resulting lead is then refined through aqueous chemical treatment and cleaning to eliminate any impurities and to obtain lead alloy of high mechanical properties that could be used in many applications such as reproduction of lead – acid batteries.

The following are lead-acid battery licensed recycling facilities in Egypt:

i) Egyptian Company for Lead Smelting, Refining and Manufacturing;

ii) Chloride Company for Batteries Production;

iii) El Nisr (Varta) Company for Batteries Production;

iv) United Company (El Motaheda) for Batteries Production;

v) Germany Company for Batteries Production;

vi) El Sharq Company for Batteries Production;

vii) Exact Company for Batteries Production;

viii) El-Wahab in Beni-Suef.

These facilities apply the pyrometallurgical technology as described in list entry e).

2) Lithium-ion batteries

LIBs are commonly used in Egypt. The disposal of this type of battery follows the following stages to ensure an environmental sound disposal.

These stages involve: Discharging: The batteries are firstly discharged. The main purpose of discharging the batteries is to reduce the reactivity of the batteries so that it is close to being inert. Afterwards, the discharged batteries are directly landfilled, then transported to El-Nasrya hazardous waste landfill. These batteries should be drilled and punctured before being landfilled.

3) Alkaline batteries

In Egypt, alkaline batteries are commonly removed and disposed of as follows. Batteries are transported to El-Nasrya hazardous waste landfill, they are then solidified in concrete moulds in a solidification unit due to the presence of manganese dioxide, zinc and an alkaline potassium hydroxide electrolyte. The product is then disposed of in special cells at El-Nasrya landfill.

4) Silver oxide batteries

In Egypt, silver oxide batteries are commonly removed and disposed of first by being transported to El-Nasrya hazardous waste landfill, then solidified in concrete moulds in a solidification unit.

5) Mercury batteries

The disposal of this type of battery goes through transportation to El-Nasrya hazardous waste landfill, then solidification in concrete moulds using a solidification unit to avoid leaching of mercury as it is a toxic heavy metal. The product is then disposed of in special cells at El-Nasrya landfill.

II.1 Cost effectiveness analysis for batteries

This clause includes a cost effectiveness analysis for the two options for environmentally sound recycling of batteries. The first option is to export the batteries to foreign facilities, while the second option is to build a dismantling and recycling facility in Egypt. The cost-effective analysis was only conducted for LIBs and not conducted for other types, which are either recycled or landfilled.

A) Exporting lithium-ion batteries to foreign facilities for recycling

End-processing technologies for batteries have been discussed earlier in this appendix and a list of the international facilities that accept used batteries provided. The foreign facilities that accept used LIBs from Egypt are: Belmont, Boliden, Valdi, Batrec and Kinsbursky Brothers and Retriev based on the methodology discussed earlier. The benefit of exporting LIBs is estimated to be USD 5 000/t.

B) Investing in a local dismantling and recycling facility

Recycling LIBs would maximize materials recovery and socio-economic benefits at the local level. There are different recycling processes for LIBs such as pyrometallurgical recycling (smelting) and hydrometallurgical processing (leaching), which have been discussed earlier in this appendix. These processes are able to recover high value materials such as cobalt, nickel, copper and lithium, with cobalt contributing to approximately 70% of the revenues. However, recycling of LIBs is not yet a universally well-established practice due to the following factors:

- technical constraints such as the varying composition of LIBs;

- economic barriers such as high transportation and logistics costs, and weak collection mechanisms;
- regulatory issues such as the absence of specific guidelines for removing, discharging, dismantling, and storing used LIBs;
- the introduction of EVs, which use LIBs, to the international market will create a new demand for recycling that is not yet accounted for.

In addition, there is no consensus over which recycling process is the most efficient and environmentally friendly given that each process has different pros and cons and recover different materials. The most effective way to improve the overall recycling process efficiency would be to consider battery end-of-life (EoL) during the design and manufacturing stage itself. In general, it seems that the LIB-recycling industry is in its early development stages, with a lot of variables involved and possible future developments and changes expected.

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