Developing guidance and best practices for occupational safety during the life cycle of Li-ion batteries

Project	Lithium-ion battery's life cycle: safety risks and risk management at workplaces
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Task	T. 4.1 Developing guidance and best practices for occupational safety during the life cycle of Li-ion batteries
Responsible organisation	FIOH
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Abstract

This task report summarises the results of the 'Lithium-ion battery's life cycle: safety risks and risk management at workplaces' project. The findings of the study interviews and the related literature are presented as guidelines on occupational safety issues for industry and users in the form of good practices.

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1 Methods

In order to compile good practices for managing the safety and risks of lithium-ion batteries’ (LIB) life cycle, we reviewed the selected information sources and summarised the related safety recommendations for the whole value chain. These findings were combined with the results from 22 semi-structured interviews in nine companies (4 in Finland and 2 in Spain) and four interviews in Finland of representatives of the rescue, transport and communications authorities, the safety and chemicals authorities, one occupational health service organisation, and one expert organisation. The interviews were conducted via Microsoft Teams between the autumn of 2021 and spring of 2022 and were recorded and transcribed.

The topic of the interviews was the life cycle of LIBs and the related occupational safety and health issues and concerns. The companies represented different phases of the LIB value chain and operated in the EU. The company interviewees were workers’ representatives and managers responsible for health and safety, quality, and the environment. The subtopics of the company interview questions were safety management practices (5 questions), risk assessment (10 questions), safety responsibilities (3 questions), safety instructions (12 questions), commitment to safety (8 questions), safety hazards and reporting these (12 questions), and safety communication and training (15 questions). Eighteen of the questions were addressed to top management, 54 to safety managers, 38 to safety delegates and 45 to supervisors. The fire, rescue and safety authorities were asked eight questions, and occupational health service 11 questions.

The good practices are the findings from the interviews and the related literature.

2 Scope of the guidelines

The different phases of the LIB value chain involve a wide range of potential risks for workers. These include chemical risks, and when handling LIBs, many risks related to mechanical damage to the battery, which may lead to short circuits or thermal runaway (TR).

Some good risk management practices already exist. For example, the Finnish Safety and Chemicals Agency has identified risks and risk management procedures (Tukes, 2018). The guidelines presented here summarise good risk management practices from the interviews of companies and experts. We have also included good practices from the selected literature. These guidelines take into account safety communication throughout the value chain and focus on identifying good practices to avoid risks when

- assembling the battery
- integrating the battery
- using the product
- recycling the LIB.

Error! Reference source not found. illustrates the LIBs' end of life and the different operators who may be affected by the risks.

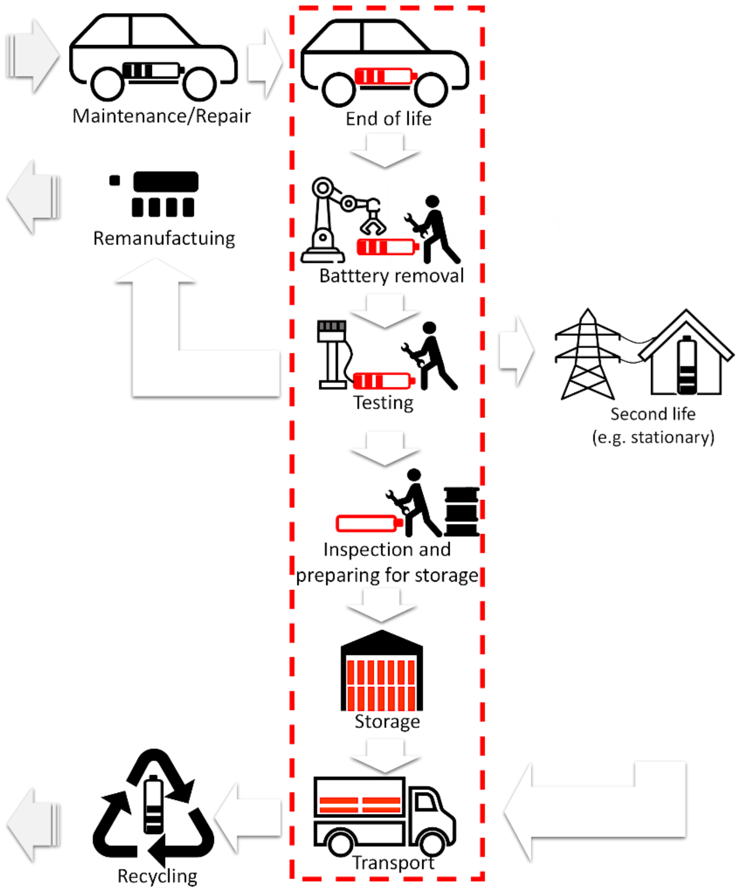

Figure 1. Operations in the end-of-life phase of LIB value chain. The flow presented in the figure is merely an example, the operations may be carried out by different agents, with multiple variations.

The high-energy density and the presence of toxic and flammable substances pose significant safety risks when LBS are handled and transported. One of the most serious hazards is TR, which can be described as a cascade of uncontrolled exothermic reactions, caused by initial overheating of battery cells. It depends on the age of the used cells. (Neumann et al., 2022)

Short circuits can also occur during handling, due to external mechanical stress or incorrect storage. A single short-circuited cell can initiate the TR of many other cells (Neumann et al., 2022). This results in the combustion of flammable electrolyte components and the decomposition of cathode materials, which can lead to fires, explosions and the release of toxic substances (Neumann et al., 2022). Different issues, including abusive handling, can cause risky situations during these operations.

Some of the most relevant aspects that can potentially lead to safety incidents are detailed below:

- Rough/careless handling or excessive shock and vibration
- Failures to detect already existing battery damage (e.g. explosive gas emissions, damaged parts…) that can lead to related incidents
- Electric discharge while handling, inspecting, etc.
- Short circuiting and TR in damaged or normal batteries
- Deficient packing and storage conditions (exposure to water, humidity or high/low temperatures, proximity to combustible materials).

Factsheet 1: Good practices for safety management

A safety management system includes the determination of the processes, procedures and responsibilities related to safety management. If the safety management system is integrated into another management system, it is essential to ensure that

- the management system identifies and considers critical operations,
- the indicators defined for safety monitoring provide a comprehensive overview of the state of safety
- all the necessary information is available, and
- no prioritisation conflicts occur due to the integrated management system (e.g. between safety and production objectives).

Vision zero and safety-first principles guide not only the prevention of occupational accidents but also chemical and environmental safety. Management must be committed to safety and make this visible in how they use their time, set goals, supervise and show a good example. Responsibilities for safety and safety tasks must be clearly identified, defined and communicated to line managers at all levels of the organisation. The role of an environment, health and safety (EHS) organisation is to support safety management, but it is not responsible for it. Safety management is seen as part of everyday management and is actively driven by line management. The line management and personnel must be provided with adequate safety training and resources. Management practices include involving the personnel in safety processes. Effective safety management requires the diversity of leading and lagging safety indicators and focusing on processes that improve/support safety.

The company enforces the quality of safety management in other parts of the value chain by, for example, setting safety-related requirements for suppliers.

Factsheet 2: Good practices for safety communication

Understanding the risks related to LIBs and their chemicals and being prepared for these requires continuous safety communication, both at the workplace level and between value chain partners. Informing other value chain partners of any safety concerns or safety topics helps them in their risk management. Communication should be well-planned, systematic and structured as well as positive and interactive, and safety perspectives should be part of everyday communication. Good practices include the following:

In one's own company

- Ensuring that employees are aware of the risks related to LIBs
- Discussing the risks and risk management procedures at workplaces
- Providing adequate training for managing the risks related to LIBs or battery chemicals
- Communicating with fire services about how to manage possible accidents.

Value chain partners

- Creating a good foundation for communication between value chain partners: designated contact persons and agreed communication channels
- Requesting and providing up-to-date information on the status of LIBs from/to the next partner in the value chain
- Informing the next partner in the value chain of any uncertainty regarding the proper condition of the LIB
- Informing the previous partner in the value chain of possible unproper condition of the LIB.

Factsheet 3: Good practices for risk management

Comprehensive risk assessments are necessary throughout the LIB value chain, and a safe-by-design approach, including maintainability, is the leading principle of risk management, covering the versatile safety perspectives of production, manufacturing and end-of-life processes. Risk assessments are conducted from different perspectives and at different levels (task, work site, process, value chain), using suitable methods, and should cover the perspective of (possibly outsourced) maintenance, cleaning and other services. The responsibility for conducting risk assessments lies with line management, and their commitment and participation must be visible during the process. The employer ensures that line management has adequate know-how concerning risk assessment, and EHS personnel can assist and facilitate during the process. The employees are involved in the risk assessment of their own work. The personnel of occupational health service participate in risk assessments and provide information, especially on occupational hygiene and risks of chemical exposure related to normal situations, and on accidents and fires (including the usage of ready-made batteries). The role of occupational health service personnel is emphasised in the assessment of health effects.

Risk assessment results should be stored in such a format that the personnel have access to at least the assessments related to their own work and work environments. There must be a written plan for communicating the risk assessment process and results to the personnel, as well as a plan for integrating risk information into training. Regarding the prevention of safety risks, the requirements of Directive 89/391/EEC should be applied, which include combating risks at the source and replacing chemicals with less harmful ones, utilising technical solutions to reduce the need for protection, actively looking for technical progress and new solutions (e.g. processes, equipment, personal protective equipment (PPE)), and giving collective protective measures priority over individual protective measures. If needed, chemical exposure risks are monitored, using occupational hygiene measurements and/or biomonitoring, in co-operation with the occupational health service provider.

Factsheet 4: Good practices for handling LIBs

There are particular risks related to handling LIBs and precautions are needed:

- Batteries should be moved carefully because they can be heavy and lifting them can cause injury. Mechanical damage can occur if boxes or pallets of batteries are dropped or damaged in forklift accidents.

- Cells should be transported in plastic trays set on push carts. This can reduce the chances of cells being dropped on the floor and causing shorting or other physical damage. Working on movable elements (such as wheeled working tables) may facilitate transporting batteries (even heavier ones) to a safe location in cases of risk events.

- The personnel who handle cells should remove personal items (such as rings, wristwatches, pendants, exposed metal zips, etc.) that could come into contact with the battery terminals.

- PPE, such as insulating gloves, protective clothing and non-metallic toe cap safety boots with high voltage insulated soles, should be used.

Factsheet 5: Good practices for mechanical disassembly

In order to manage certain risks related to mechanical disassembly, only qualified professionals or service personnel with recognised electrical expertise or training in high-voltage systems or in dealing with large batteries should de-install an energy storage system or remove a battery from an electric vehicle.

Batteries should be classified on the basis of their risks and the requirements for professionals should be defined on the basis of classifications (the riskiest ones having stricter requirements for e.g. qualifications).

Disassembly should be in accordance with the manufacturer's instructions, which should be readily accessible and available to allow professionals to remove used batteries safely. Commercial secrets related to battery manufacturing should not prevent mechanical disassembly providers from obtaining essential information required for safe disassembly.

During the maintenance of LIB forklift trucks, we recommend that high-voltage safety signs are placed on the forklift and cordons and safety notices set up to prevent unauthorised personnel entering the area.

Factsheet 6: Good practices for inspection and preparation for storage

The state of safety should be assessed at various points of the LIB value chain. Cells should be inspected for physical damage, caused by the cell having possibly been dropped. Cells with dented cases or terminal caps should be inspected for electrolyte leakage.

The batteries should be packaged in a way that prevents them from being crushed or damaged (Herreras-Martínez, Anta & Bountis, 2021). It is recommended that the terminal cap, shrink wrap or protective potting not be removed from a battery pack or cell.

Potentially unsafe characteristics of batteries listed by Eunomia (2021):

- Partially disassembled, opened, or casing visibly deformed or miscoloured.
- Leaking fluid.
- Emitting an unusual smell.
- Changing shape, e.g., swelling or bulging.
- Overheating (usually, >30 ºC) and/or smoking.
- Emitting sparks.
- Making a hissing sound.
- Visible crystallisation or white powder formation.
- Signs of water or fire damage (i.e. water stains or char marks).

The LIB must be segregated from other battery chemistry types in separate storage areas because cross-contamination creates risks. Furthermore, LIBs must be kept separate from lead acid batteries because of a risk of fire.

Batteries with physical or mechanical damage should be stored separately from other batteries. Defective batteries must be classified as critical or non-critical (Neumann et al., 2022).

Unsafe batteries should be handled as follows:

1) The battery must be placed in a fireproof container, for example:
    - A container with an in-built smoke detector and automatic fire extinguishing system.
    - Enclosed steel containers filled with non-conductive material, such as sand or vermiculite.

2) The surrounding area should be cleared, for example:
    - Any nearby source of heat and electricity should be removed.
    - The battery should be moved (if possible, unless battery is too heavy to move safely) into a separate room with non-combustible building materials, such as concrete walls, or outside, well away from any structures, on a concrete floor.

After the end of a battery's first life, its state of safety should be assessed.
The scope of the inspection can focus on two aspects:

- Evaluating its usability, for example, in terms of reuse. This assessment should be based on safety criteria produced by the battery manufacturer and carried out by a technical expert such as an electrician, electrical engineer, or a certified high-voltage expert with knowledge of the battery's safety features, or a person trained to assess battery safety.
- Evaluating potential damage in a disposed battery, in order to ensure safety during end-of-life operations. This is the most common inspection after battery collection and requires specific training.

When considering the safety of LIBs in the value chain, it is important to ensure the transparency of the materials and chemicals used, as well as the condition of the LIB. The procedure must include all the safety and risk information concerning the product, as well as the materials and chemicals transferring to the following phases of the value chain. It should also cover the accident history of the LIB (e.g. falls, crashes, shocks). The safety of the transportation and end-of-life handling of the retired LIBs relies on the information provided by the previous phases' actors. Providing adequate information helps inspections in later phases of the value chain.

Factsheet 7: Good practices for storing LIBs

When possible, the battery storage areas at collection points should have all the features of an appropriate storage facility. However, this may not always be practicable, as collection points are not designated, long-term storage spaces. Eunomia (2021) advises that all batteries presented for storage should be treated as though they were fully charged. Manufacturers' recommendations must be followed when storing batteries. Storage should be developed and implemented in accordance with the fire and emergency management plan, which outlines how a battery failure event can be prevented or managed.

At the very least, storage areas must fulfil the following conditions (Eunomia 2021):

- Cool, dry, under cover and out of direct sunlight, and protected from water, humidity, and any water condensation. Temperature close to 25 °C (77 °F), limiting the production of hydrogen.
- Away from any sources of heat or ignition.
- Batteries of different chemistry types must be stored separately.
- Stored batteries should be kept well ventilated, bearing in mind that:
    - Most batteries emit toxic or explosive gases if the electrolyte is released or cells vent, and buildings with ventilation reduce the concentration of hydrogen to a safe level.
    - Ventilation systems also allow heat energy in the room to decrease in cases of fire (Eunomia, 2021).
    - Storage facilities should have forced ventilation or oversized flue gas windows.
    - Ventilation systems should be such that they can be scrubbed and diluted, as gases emitted during a battery failure event can be noxious.

- Closed coverage of storage areas for large, used batteries should be avoided.
- Storage facilities should have fire-resistant walls, floors, and roof sheeting with a passive fire protection of at least two hours (i.e. concrete, not gypsum board). Ideally, when large amounts of batteries are stored in the same building, the building should be of fire-rated construction so that any fire can be contained.
- If the facility is fully enclosed and on the same floor, installing a sacrificial roof in order to disperse air pressure in case of serious fires or explosions from LIBs might be necessary.
- Storage facilities should be bound by impermeable surfaces and weatherproof coverings to retain any contaminated run-off, for example, heavy metals. Measures should be taken to prevent potentially hazardous material entering stormwater drainage.
- Outdoor storage areas must have an escape route that does not run through the storage area; any emergency exit gate or door must not open inwards to the storage area. If an office is inside a storage room, there must be a means of exiting the office that does not run through the storage area.

Factsheet 8: Good practices for transporting battery packs, modules, cells and other elements

According to the regulations, LIBs with energies of >100 Wh are classified as Class 9 Dangerous Goods. LIBs are classified as Dangerous Goods for Transport by Road/Rail, Sea and Air. It is important to conform to the requirements of the UN Regulation on the Transport of Dangerous Goods (UNECE, 2022). Transport quantities of batteries with energies of more than 100 Wh in road transport are limited to 333 kg per transport unit and must have a strong outer packaging that prevents short circuits and unintentional activation. For smaller batteries with energies of ≤100 Wh, no transport quantity limits apply. Furthermore, batteries must be labelled adequately and pass the UN safety tests. Defective batteries must be classified as critical or non-critical. (Neumann et al., 2022).

In the case of large, used batteries, transport by land or sea is recommended. There are many restrictions on transporting LIBs by air, and often it is prohibited. All vehicles used to transport large, used batteries should be fitted with fire extinguishers. The batteries must be placed in non-metallic inner packaging that completely encloses the cell or battery and separates it from contact with electrically conductive materials (e.g., metal) in the packaging. The batteries must be packed to prevent shifting that could cause damage to the cells or batteries within the outer packaging. Before transportation, large batteries should be classified according to the primary danger they present and should be packaged, marked and labelled (U.S. department of transportation, 2021).

Road transport drivers need to be trained to deal with LIB problems. The induction training of new drivers should include guidance on recognising possible problems and how to manage them.

Factsheet 9: Good practices for preparedness and battery accidents

LIB fires do not require oxygen to burn. Burning LIBs are considered a chemical fire. Once extinguished, a high voltage battery can catch fire without early warning. Water and impurities increase a battery's risk behaviour and conductivity. On-site security is particularly important for the prevention of fires.

Some examples of good practices (Herreras-Martínez, 2021):

- safety surveillance on a 24/7 basis, covered by a combination of external services, in-house services and technical supervision.
- regular temperature control and smoke detection during operation and nonoperation times (e.g., security staff is often equipped with portable temperature control equipment such as handheld temperature cameras),
- discharge testing of fire extinguishers and/or hydrostatic tests to make sure the cylinder is still safe to operate. They should also be mounted to the wall so that they are secure, visible, and readily accessible.

LIBs should be segregated according to different criteria:

- LIBs should be kept separated from other chemistries
- Damaged batteries should be separated from non-damaged batteries. Among damaged batteries, critical damage (batteries that overheat, emit fumes/odours, hiss or bulge) and non-critical damage should also be separated.
- Extinguished vehicles should not be stored indoors or less than 15 metres from flammable material.

For the most part, an LIB fire can at best be cooled, contained and suppressed. Extinguishing an LIB fire with 100% certainty is not always possible due to potential TR (Schütz, 2022). The best knowledge available claims that a vehicle's LIB fire is most effectively extinguished by large amounts of water. Small amounts of water tend to accelerate the fire. Only a small portion of the substance used to extinguish the fire goes into the battery. There are special waters for extinguishing an LIB fire, but there is no widespread evidence of their effectiveness. It is worthwhile remembering that LIB fires cannot be suffocated, and powder and CO2 extinguishers are ineffective.

Sinking the vehicle on fire is not necessarily the only option. If possible, the battery should be removed and placed outdoors to burn out in a safe place (Schütz, 2022). A small battery that is on fire can also be immersed in water. Water-based products are most readily available and are appropriate, as lithium-ion contains very little lithium metal that reacts with water. Water also cools the adjacent area and prevents the fire from spreading.

Substances for managing LIB fires are rapidly developing. Be active and interested, but also exercise source criticism.

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