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Storing and charging lithium-ion batteries safely

– With helpful tips and checklists

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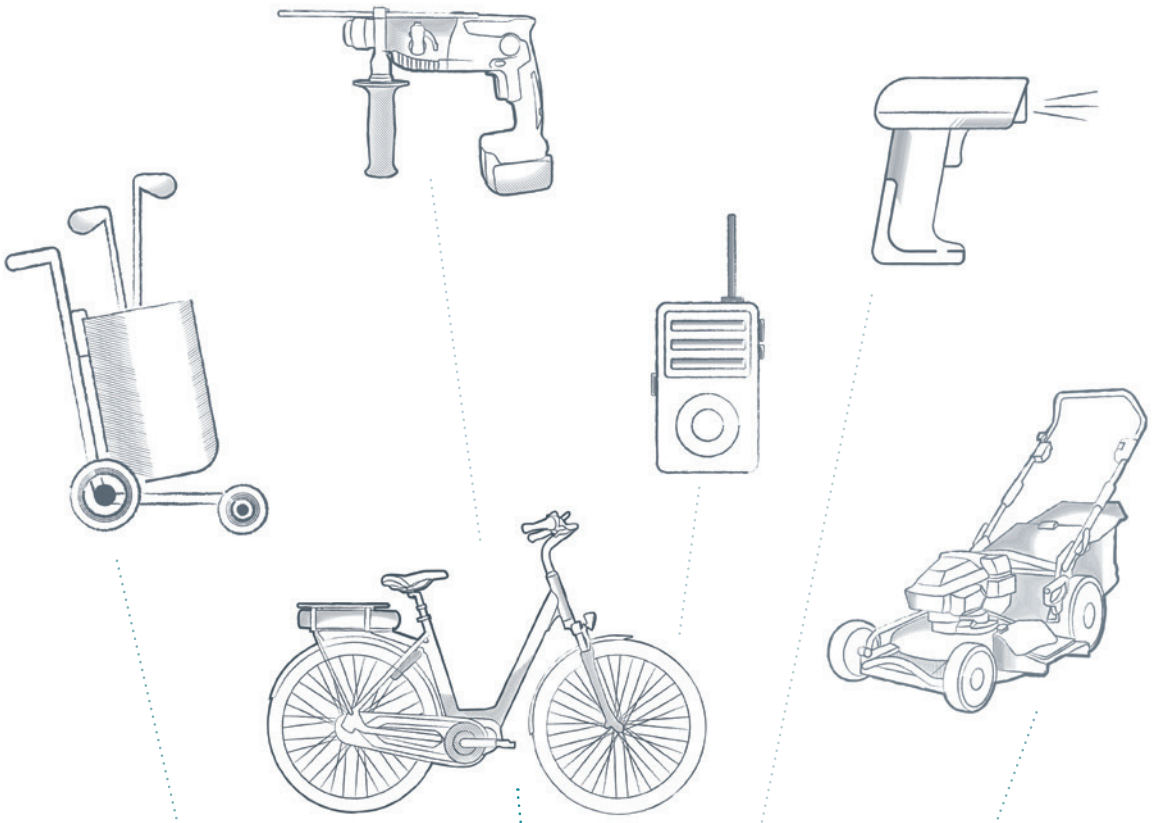

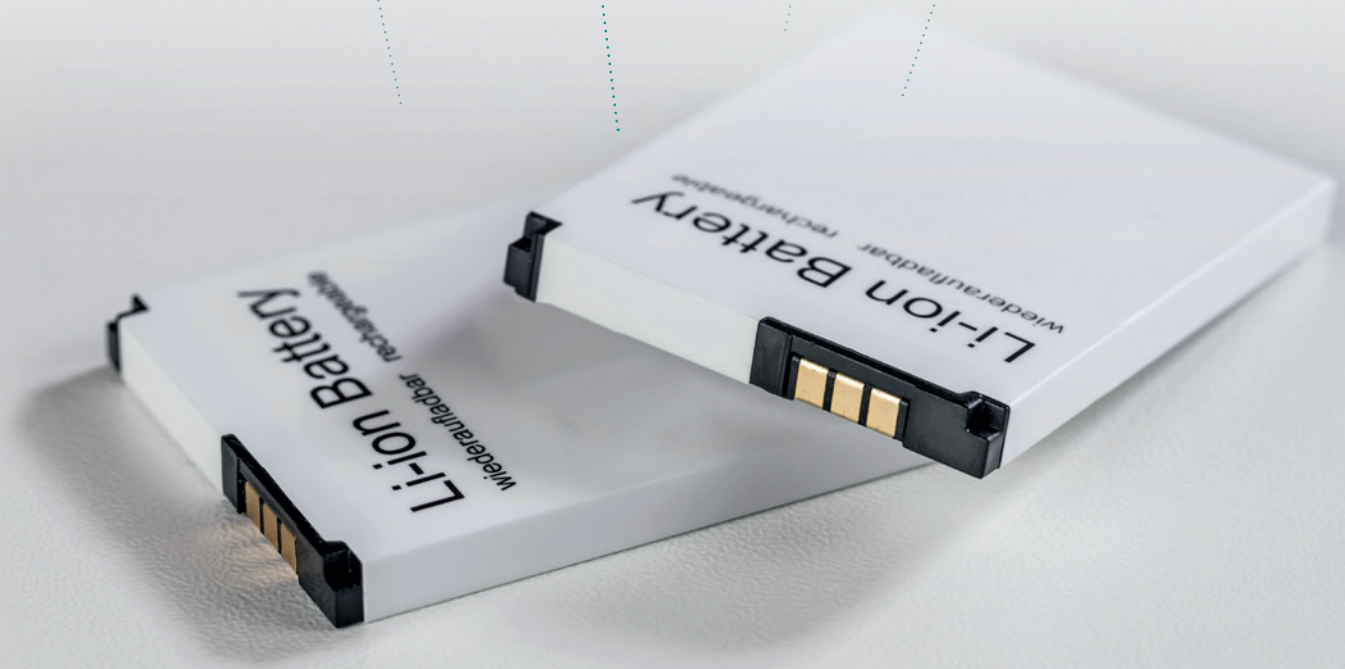
Li-ion Battery
wiederaufladbar rechargeable
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CONTENT

1. Increasing popularity, underestimated risks

There are very few technology trends that have become so firmly established in recent years than the development of ever more powerful energy storage systems based on lithium (Li).
For about 30 years, lithium-ion batteries and accumulators have been conquering the market for energy storage and are used in more and more products and devices. It is no coincidence that the development of the Li-memory technology was awarded with the Nobel Prize for Chemistry in 2019. Whether power tools, garden tools or e-bikes, our private and professional everyday life without lithium batteries is now unimaginable.

But this boom has a flip side. Because these energy storage systems that are so practical and efficient are anything but harmless. They can burst into flames and cause serious fires. Even specially shielded batteries can develop temperatures of over 1,000 °C, as experiments by the BDE have shown.

In recent years, these fire risks have led to frequent recalls of products from a wide range of types and sources of lithium-ion batteries. As more and more batteries are manufactured, the need to transport, store and preserve them has led to an increase in fires with **high damages** as a direct result of lithium-ion batteries. In 2019 alone, around 12,700 tonnes of new lithium-ion batteries came into circulation. Reliable concepts are essential to safely control these risks.

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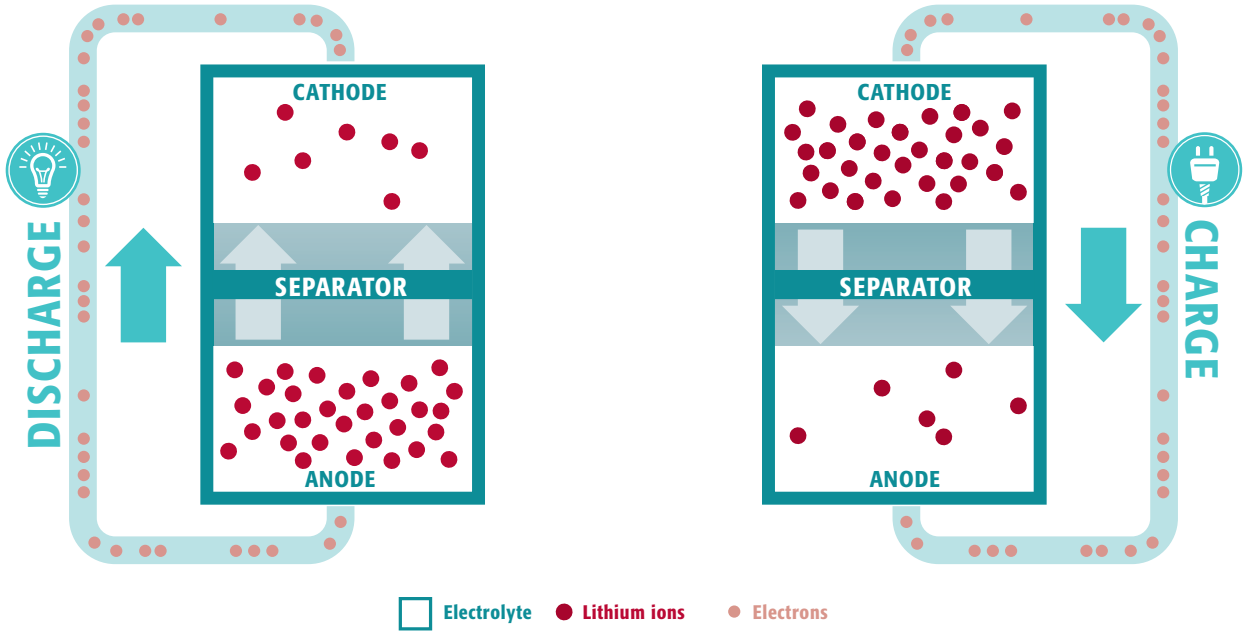
1.1 How lithium-ion batteries work

Like batteries, accumulators are electrochemical energy storage devices. They consist of two metal electrodes, a separator and a liquid electrolyte. When ions migrate from one electrode to the other, an electrical voltage is generated which can be used as an energy source. When charging, the ions are forced by an externally applied voltage to migrate back to the anode, so that the battery regenerates.



The chemical element lithium (Li) has become established for batteries because this alkali metal has particularly favourable electrochemical properties. Lithium is not only the lightest, but also the the most electropositive metal, which means that it releases electrons particularly easily. As a result lithium-ion batteries achieve a **high energy density**. This gives the advantage of a compact and light construction, plus undesirable effects such as self-discharge or memory effect, which are common with other battery types, are kept low. Thus, under suitable conditions, lithium batteries can be stored safely for long periods.

All these advantages make lithium unrivalled and irreplaceable for electrochemical energy storage.
Batteries of the li-Ion type will remain the most frequently used storage technology for energy-intensive applications for the foreseeable future. At the same time, however, lithium is **a very reactive metal** from the chemist's point of view. **This poses a permanent risk of undesirable reactions, which are usually very violent**.

1.2 With higher energy density comes a greater risk of fire

With higher storage capacities and the increasing spread of lithium-ion batteries, the risk of fire has also risen rapidly. The fact that this risk is not only of a theoretical nature has been made clear by a large number of damage events in recent years. The **recall actions** were particularly spectacular with Samsung mobile devices or the **worldwide flight bans** on the Boeing 787 due to burning and exploding batteries.

The list of battery fires is also growing in Germany. Some current examples prove the explosiveness:

- On 28th July 2020, a huge cloud of smoke rose above the site of a **waste disposal site** in Ellwangen. Two warehouses were on fire. The cause of the fire is suspected to be batteries located in yellow bags.
- On 24th July 2020 a container burns on the premises of an **institution for people with disabilities** in Goslar. According to the fire service, lithium batteries had caught fire.
- On 1st June 2020 a lithium-ion battery triggers a fire in the building of a technology service provider in Ehningen. Although the fire can be extinguished quickly, the fire brigade is still on duty for many hours. Due to **highly dangerous hydrofluoric acid** that escaped when the battery decomposed. The danger zone had to be cordoned off over a large area until the battery could be cooled and transported away in a special container.
- 15th November 2019: A fire destroys the roof of the **post distribution centre** in Alsfeld, Hesse. The cause of the fire is a technical defect in a charging station for e-bike batteries.
- On 19th September 2019, flames leap metres high from the window of an **apartment building** in Munich. More than 90 residents flee into the open air. Later, the emergency services find an electric scooter with a burnt-out battery in the flat. The cause of the fire is suspected to be a technical defect in the battery. The battery of the electric scooter ignited “suddenly”, according to the investigating police.
- On 2nd September 2019, the Karlsruhe fire brigade is called to a major fire in a **historic castle complex**. An outbuilding used by a golf club as a caddy hall is discovered in flames. The cause of the fire is a technical defect in the charging station of the electric trolleys. Especially significant: Only two days later the fire brigade has to go to the same place of action again when the battery of a golf trolley explodes during clean-up work.

These and many other fires have one thing in common: the lithium batteries were **stored without any special safety precautions** or **were being charged unattended**.
These are often medium power batteries. The fact that this type of battery is becoming increasingly popular is already reflected in the statistics of property insurers. The cause of loss statistics of the IFS have shown a significant increase in fires caused by batteries for several years.

Fire hazards affect not only private consumers, leisure facilities or bicycle dealers, but also industry and commerce. **For all businesses using Li-based energy storage systems, there is now an additional electrical or electrochemical fire risk.**
It is also particularly critical that the risk of battery fires extends beyond their useful life. Incorrectly disposed lithium batteries have become the main cause of fires in waste treatment plants.

2. Risks and dangers of improper storage

Despite all the risks, it must be noted that lithium-based battery technology is suitable for everyday use. With proper handling and storage, lithium-ion batteries are considered comparatively safe. But the combination of high energy density with flammable electrolytes cannot be avoided by design thus there is always a latent fire risk. If a lithium-ion battery is not handled carefully and handled, stored and charged in accordance with the instructions, uncontrolled discharges, spontaneous ignition bursting of the battery, flash fires and explosive reactions are to be expected.

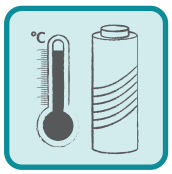
2.1 Causes of battery fires

According to experts, undesired events and damage with batteries can generally be assigned to one of the following initial situations. The following is considered particularly risky if the lithium-ion battery

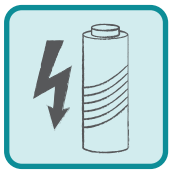
- in combination with the high energy density of the battery is ***mechanically damaged***, e.g. if an electric car or e-bike is involved in a traffic accident.

- is pre-damaged by ***deep discharge***; in this case the cell becomes unstable, internal short circuits occur leading to over-heating.

- by external heat or energy sources ***resulting in thermal overload***, e.g. when a cooling system is switched off in strong sunlight, which leads to an internal short circuit.



- is ***electrically overloaded*** during charging and discharging, e.g. due to a defect in the protective electronics.



In all these situations a fire can occur.
Its consequences depend largely on,

- where the battery is located or where and how it is stored
- which fire protection facilities this storage location has and
- how quickly overheating or a fire is noticed, so that immediate countermeasures can be taken.

The actual cause of burning, bursting and exploding lithium-ion batteries is the so-called **thermal runaway**. This technical term refers to a self-reinforcing chemical process which, once started, is very difficult to stop. The risk of such a thermal runaway is due to the construction of the batteries and the substances that are necessarily used.

The electrolyte liquids consist of organic solvents, i.e. they are flammable and their flammability is almost equal to that of petrol. In combination with the high energy densities this results in an extremely dangerous situation. Because **as soon as the temperature in a single cell of a battery rises, all neighbouring cells also heat up in cascades**. If the temperature reaches a limit range which, depending on the solvents used, starts at around 60°C and becomes extremely critical from 100°C a **chain reaction occurs which can no longer be controlled**. Within fractions of a second the temperature rises up to 800 °C , the gases produced break the cover of the battery cell and **the battery burns explosively**.

Such a situation is unpredictable. Not only are there flames to contend with, but burning battery material is hurled through the air like fireworks. This not only endangers people, but can also start secondary fires, In particular, if a fire **spreads domino-like to neighbouring batteries**, it spreads very quickly. Such a fire with lithium-ion batteries is feared among firefighters, as it is difficult to control. Even immediate cooling cannot stop the process, as the water only reaches the outer shell of the battery.

2.2 Secondary consequences: toxic decomposition, environmental hazards

In addition to the fire itself, the Thermal Runaway poses other risks to the surrounding area and people living nearby. This is because a lithium-ion cell begins to chemically decompose at around 80°C.
In the event of overheating and at the latest during a fire, **toxic substances** are released such as electrolyte and solvent vapours as well as hydrogen chloride from PVC lines.

It is not just flue gases (carbon monoxide, carbon dioxide) that are emitted, but also other substances that are hazardous to health and water, such as **hydrogen fluoride** or the skin-caustic **phosphoric acid**. As these substances are distributed in the environment by the fire-fighting water, the clean-up and decontamination alone can shut down affected areas of the company for several days.

3. What do the experts say?

Assessments and recommendations by experts from fire brigades, statutory accident insurance companies or property insurers illustrate the importance of the correct handling of lithium-ion batteries.

> ***„A lithium-ion battery fire can have many causes and may occur in the complete life cycle of an energy storage system."*** *(DGUV)*

> ***„In terms of the numbers and severity of battery fires it seems like a miracle that nobody was killed so far."***
> *(BDE)*

> ***„Burning lithium-ion batteries represent a large and incalculable danger"*** *(bvfa)*

In particular, the need for safe storage of lithium-ion batteries is repeatedly stressed by all experts:

> ***„The batteries can be dangerous in a warehouse - once they catch fire, the fire is very difficult to control."***
> *(GDV after evaluation of fire tests)*

> ***„Even if relatively small quantities of the lithium-ion batteries stored catch fire, a fast fire spread is very likely. Partially explosive burning may cause the burning parts to be thrown around the area."***
> *(AGBF)*

Not without reason does the IFS recommend that lithium batteries should always be charged in a room with a smoke detector. However, a smoke detector neither prevents a fire nor spontaneous ignition and is not an effective alternative to preventive fire protection measures.

> ***„Defective or damaged batteries pose a particular fire hazard - for example, an ebike may be handed over by a customer to a service depot following a bicycle crash. It is critical that these are placed in protective containers or stored in outside buildings."***
> *(Provinzial Rheinland, Loss Prevention, Risk Advice Department*

> ***„Lithium batteries are the biggest challenge of the industry over the last 40 years. We know about waste management companies, in which they are responsible for 95% of the occuring incidents. There are injured employees and the damage to property is enormous. This cannot continue."***
> *(VOEB)*

With the **growing number of damage claims** and the assessments of many experts, it is becoming increasingly clear that companies and businesses that handle batteries without a comprehensive safety concept and without consistent implementation are faced with occupational safety, insurance and health risks liability in a highly risky situation.

4. Legal basis for handling lithium-ion batteries in use

According to the **Health and Safety at Work Act 1974 (HSWA)**, it is the duty of every employer to ensure, as far as is reasonably practicable, the health, safety and welfare at work of all its employees. This includes arrangements for ensuring, so far as is reasonably practicable, safety and absence of health risks in connection with the use, handling, storage and transport of articles and substances. **The Control of Substances Hazardous to Health** (**COSHH**), which recognises that using hazardous substances at work can put people's heath at risk, supports this. However, in accordance with regulation 5(1), COSHH only applies to substances that are hazardous to health. It is the **Dangerous Substances and Explosive Atmosphere Regulations 2002 (DSEAR)** which covers substances that are capable of producing effects on health because of their explosive or flammable properties

Under both COSHH and DSEAR, the employer is obliged to reduce the accident and health risks for its employees and to evaluate them. Regulation 5 of DSEAR requires employers and the self-employed to assess risk associated with the **use or presence of dangerous substances at work**. DSEAR is specifically written to assist companies in protecting persons **from the risk of fire, the risk of explosion and the risk of energetic energy release** – all potential hazards of lithium-ion batteries.
To adhere to this, it is important that:

- ***risk assessments*** are carried out, which thoroughly evaluate all fire and explosion risks.
- on the basis of the risk assessments, **suitable protective measures and rules of conduct** for the employees are defined.
- ***operating instructions*** for handling lithium-ion batteries are prepared and displayed.
- the employees are instructed on the risks, the safety measures and the ***established rules of conduct***.
- the ***effectiveness of the protective measures taken is regularly reviewed*** and corrected or extended as necessary.

According to DSEAR, a competent person must carry out the risk assessment. Only an expert can decide within the scope of an on-site inspection where and which measures become necessary. The DSEAR guidelines clearly state that **technological measures** are generally preferable over organisational or personal protection measures.
Further recommendations for the storage, handling and use of batteries in commercial and industrial premises are contained in the **RC61** document, produced by the **RISCAuthority** in 2014. RC61 6.7 clearly advocates that storage areas should provide at least 60 minutes fire resistance between the stored batteries and any other part of the premises. Furthermore, RC61 8.12 states, "Where batteries are stored in a relatively small environment consideration may be given to **installing a proprietary in-cabinet system to automatically detect and suppress a fire in the incipient stages**. Where such a system is installed it should be monitored to allow the fire and rescue service to be alerted without delay".

RC61 3.3 also states that ***any battery that has been damaged, dented or pierced should be taken out of service immediately, segregated from other batteries and stored safely (Section 7) while awaiting safe disposal.***

The relevant legislation for the mode of transport should be adhered to when transporting lithium batteries. For example, by Road – ADR; by Rail – RID; by Air – ICAO and IATA; by Sea – IMDG etc.
In addition to the legislation and guidance, the many cases of fire and the assessments of experts (cf. the above quotations) provide sufficient reason for effective preventive measures in order to guarantee insurance cover. From the perspective of the insurance industry, RC61 clearly states Lithium batteries are particularly hazardous if not stored, charged and used correctly.

5. General safety rules

Every employer must ensure that all employees who handle lithium-ion batteries at their work-places or who use equipment and machinery with batteries know the basic rules:

- Never short-circuit batteries, protect battery terminals from short-circuiting (use pole caps or tape them off).
- Inspect batteries regularly and check for physical damage such as cracks.
- Do not use deformed, inflated, corroded, defective, damaged or hot batteries, they must be quarantined immediately and kept at a safe distance or stored separately until disposal
- Never make your own battery packs or use batteries in any other way than specified by the manufacturer.
- No hot work or open flames near batteries.

5.1 Storing lithium-ion batteries safely

If Li-accumulators are provided at production sites, the quantities should be based on the daily or weekly quantities or shift requirements. All other supplies require suitable storage.

If rechargeable batteries are not used for a longer period of time, e.g. removed over the winter, they can and should be stored professionally. In unsuitable storage conditions, the electrolyte may decompose and flammable gases may develop. The next time you try to recharge, an internal short circuit occurs and the cell can catch fire.

Fire and explosion risks can be significantly reduced with the following principles:

- Store dust-free and dry, protect from moisture
- Store in a temperature protected area, i.e. between 10 °C and 25 °C
- Protect from frost, but also from temperatures > 60 °C, never store in the sun or near hot surfaces, motors, etc.
- Store in fireproof separated areas
- Monitor storage areas by means of a suitable fire alarm system
- Do not store together with other fire accelerating products
- Maintain safety distances (up to 5 m from flammable materials, depending on battery type)

In workplaces with fire extinguishing systems, the extinguishing agent instructions in the safety data sheets must be observed.

5.2 Safe charging of lithium-ion batteries

The following rules apply to safety when charging lithium-ion batteries:

- Only use with the chargers approved and intended by the manufacturer
- Only on non-combustible surfaces
- Not in the vicinity of flammable materials and fire loads
- Never cover the batteries during the charging process
- Do not charge when cold (< 0 °C)
- Never deep discharge

Although protective electronics built into the battery should prevent overcharging, such a battery management system (BMS) can fail - for example if the charger is not suitable. **Thus unattended charging is always a source of danger.**

5.3 From risk assessment to safety concept - with convenient checklist

Even if all the above safety rules are implemented in a company, the business owners and employers are not yet automatically legally on the safe side. The decisive factor is that not only individual measures are derived from the risk assessment, but that the business developed and implemented a comprehensive safety and fire protection concept for handling lithium-ion batteries. Such an approach should answer the following 10 questions.

10 critical points of a fire protection concept for lithium-ion batteries

☐ yes ☐ no Are suitable locations and state-of-the-art technical facilities available in the workplace for the safe storage and charging of lithium batteries?

☐ yes ☐ no Do these storage locations or facilities comply with the current state of the art, e.g. with regard to fire resistance, as well as the requirements for separate storage in safe distance to fire loads etc.?

☐ yes ☐ no Is it ensured that the heating or burning of a battery is immediately registered (temperature sensors, smoke detectors) and indicated visually and acoustically by suitable alarm systems?

☐ yes ☐ no Is the power supply to batteries in charging mode immediately and automatically interrupted in the event of increased temperatures or other safety critical situations?

☐ yes ☐ no Is it guaranteed that every safety-critical condition is reliably reported to a control room, building management system or qualified personnel so that the necessary measures can be initiated immediately?

☐ yes ☐ no Are both the alarm and its transmission to the intended recipients secured even outside working and operating hours, e.g. at night, at weekends or in the company holidays?

☐ yes ☐ no Is it possible to remove the existing batteries quickly and safely from the building in a safety-critical situation, e.g. by using storage equipment that can be picked up by industrial trucks?

☐ yes ☐ no Are the technical facilities for charging and storing batteries regularly checked for safety?

☐ yes ☐ no Is the maintenance performed by qualified and competent personnel, e.g. by the manufacturer or persons certified by the manufacturer?

☐ yes ☐ no Are the results of these tests documented and are the test reports kept for an appropriate period?

5.4 Insurance cover and limitation of liability are at risk

Temporary solutions that are not based on the current state of the art can even increase the risks if employees rely on a supposed but de facto inadequate protection against fire and explosion. Only a safety concept that ensures **permanent and reliable monitoring** and alarming and includes a **qualified technical inspection** at regular intervals, offers a sufficient degree of legal certainty.

If safety equipment such as hazardous material cabinets or fire alarm systems are not properly checked, the responsible employer and business owner not only loses insurance cover in the event of damage, but also risks the loss of the business owner liability limitation.

5.5 Reacting confidently in the event of damage

If, despite all precautions, a battery fire occurs, it is necessary to act calmly. Depending on the specific situation and the hazard, the following steps are crucial to limit the consequences of fire:

- Raise the alarm and set the rescue chain in motion
- Use protective equipment according to the safety data sheet of the battery
- If possible, immediately remove the battery from circulation
- Evacuate persons from the danger zone
- Provide first aid to injured persons
- Ensure the ventilation of the room
- Prevent access to the evacuation zone until the batteries have cooled down and are properly removed
- Spilled electrolytes should be bound with suitable materials, e.g. with the non-reactive absorbents clay or vermiculite.

Extreme caution is always required during and after all operations to extinguish battery fires. Even if the batteries appear to be extinguished, there is a **risk of backfire** causing the fire to break-out again, even after hours or days of inactivity.

6. Safety cabinets as the basis of an operational fire protection concept

Thoroughly instructed employees are undoubtedly a gain in safety. But what applies to accidents at work also applies to fire prevention: people make mistakes and individual behavioral mistakes become the cause of accidents far more often than technical failure. If you want to rule out major damage from battery fires from the start, there is no getting around technical solutions.

6.1 Safety storage cabinets for storing lithium-ion batteries

Safety cabinets according to the European standard **EN 14470-1** are considered to be the state of the art for storing flammable liquids. The standard **EN 1363-1** is decisive for the protection from the inside to the outside. It serves as a standard for determining the fire resistance duration of components that are used while being exposed to fire under certain conditions. Safety cabinets that meet these two technical standards and also have suitable warning and reporting devices, meet the above-mentioned technical requirements for the safe storage of lithium batteries.

A safety storage cabinet cannot prevent the fire of a defective battery, but it protects the environment and all persons in the vicinity. Neither flames nor toxic gases can spread to the surroundings. The damage always remains strictly limited. ***An accessible cabinet base enables an evacuation which prevents further damage. In case of danger such a cabinet - by the fire department or own personnel - can be quickly removed from the endangered buildings.***

The decisive safety and quality features of a hazardous materials cabinet intended for the storage of lithium-ion batteries are

- a reliable ***technical ventilation***, where excess heat may be created as a result of battery charging
- a suitable ***sensor technology for smoke and temperature***
- a ***fire resistance of 90 minutes*** according to DIN EN 14470-1 (fire from outside) and EN 1363-1 (fire from inside)
- a ***charge*** and ***message monitoring system*** with suitable warning functions that give visual and acoustic alarms
- ***Devices for fire suppression***
- a ***protection against unauthorised use***

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There is no universally applicable fire protection guidance of what a company-specific fire protection concept should look like. There are too many different company buildings and work areas as well as types and quantities of batteries. **However, storing lithium-ion batteries in an F90 safety storage cabinet is a safe solution for prevention with regard to the risk of battery fires.**

6.2 Alternatives to safety storage cabinets?

For the safe storage and charging of li-ion batteries there are very few real alternatives to the F90 cabinet. Simple battery cabinets or sheet metal shelves or so-called battery charging cabinets do not offer the same protection level as a safety storage cabinet certified to EN 14470-1 and EN 1363-1. Locating lithium-Ion batteries in a separate fire protection storage may also be an option. However, this must be done in accordance with the relevant regulations (GefStoffV, TRGS 510, VDI 3975 sheet 3 and others), so that further protective measures become necessary.

At a first glance, the desire to save on the technical facilities for storing batteries may seem to have a cost-effective effect. But knowing that battery fires can have devastating consequences and in the worst case, endangering human lives, the lack of a high-quality security solution will be very expensive.

7. Glossary / Abbreviations

Battery:	Accumulator
BDE:	Federal Association of the German Waste Management Industry
BMS:	Battery management system
COSHH:	The Control of Substances Hazardous to Health
DGUV:	German statutory accident insurance
DSEAR:	Dangerous Substances and Explosive Atmosphere Regulations 2002
F90:	Fire resistance of 90 minutes
HSWA:	Health and Safety at Work Act 1974
IFS:	Institute for Loss Prevention and Loss Research of Public Insurers
RISCAuthority:	Risk, Insight, Strategy and Control Authority, research and representation on behalf of a group of UK Insurers into risk mitigation measures from fire and security risks
Vermiculite:	a mineral absorbent granulate, which is used by gardeners, but also in fire prevention/ protection dangerous goods transport is used
H3PO4:	phosphoric acid, an inorganic acid with caustic effect
HF:	hydrogen fluoride, a colourless, pungent smelling and very toxic gas
Li:	the chemical element lithium, a light metal
Li2O	lithium oxide
LiOh:	lithium hydroxide

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