Nederlandse Voedsel- en Warenautoriteit
*Ministerie van Landbouw, Visserij, Voedselzekerheid en Natuur*

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**To the State Secretary for Youth, Prevention and Sport and the Inspector General of the Netherlands Food and Consumer Product Safety Authority**

**Advice from the Director of the Office for Risk Assessment and Research**

**Regarding the safety risks of refurbished lithium-ion batteries in consumer products**

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## Introduction

The use of lithium-ion batteries (LIB) has increased significantly in recent years. Driven by the energy transition, products are increasingly supplied with electricity provided by batteries. LIB can deliver a high voltage compared to other types of batteries, they have a large capacity and are relatively cheap. But LIB also have a downside: they contain a solution containing lithium ions which is highly flammable. There is a growing number of reports of incidents with LIB, with sometimes serious consequences. Due to the growth in the number of LIB, the number of incidents is also expected to increase.

There is also an increase in LIB that have been refurbished. Refurbishment means that parts are repaired or replaced so that the LIB can be used again for the same purpose. The increase in refurbished LIB is driven by the pursuit of circularity and sustainability and the right to repair.

The problem of the safety of LIB is complex and affects many stakeholders. The Office for Risk Assessment and Research (BuRO) of The Netherlands Food and Consumer Product Safety Authority (NVWA) organised a meeting in January 2023 with various ministries, inspection services and universities, among others. The aim of this meeting was to explore with the attendees the outlines of a joint approach, focusing in particular on the safety of consumer products with LIB.

Following the meeting in 2023 and based on two studies contracted by BuRO on the safety of refurbished LIB, BuRO is now issuing this advice.

Refurbishment of LIB is a relatively new development. Little is known about the effect of refurbishment on the safety of the LIB. BuRO would therefore like to answer the following question with this research:

*What is the risk to public health of using refurbished LIB in consumer products?*

This question is divided into four sub-questions:

- *What factors can cause a hazard of LIB in consumer products?*
- *Which regulations and oversight are aimed at the safety of consumer products with LIB?*
- *What is the impact of LIB refurbishment on the hazard?*
- *Which regulations and oversight are aimed at the market of refurbishment of LIB for consumer products?*

Within the scope of consumer products, this risk assessment focuses on electric bicycles. The growth in the use of LIB certainly applies to electric bicycles: According to the RAI Association, the number of electric bicycles in the Netherlands increased from 1.5 million in 2017 to 4.3 million in 2023. Compared to the total of newly sold bicycles in a year, the share of electric rose from 31% in 2017 to 56% in 2023.

And refurbishment of LIB for consumer products is nowadays predominantly taking place for LIB for electric bicycles. In 2021, between 34 thousand and 40 thousand LIB for electric bicycles were refurbished and traded in the Netherlands. These LIB have a limited lifespan, shorter than that of the bicycle. The LIB for an electric bicycle is relatively large compared to LIB for other consumer products such as a laptop. Due to the high new price of an LIB for an electric bicycle, it is rewarding to have it refurbished.

## Approach

BuRO has worked according to the four steps of the risk assessment, as described in BuRO's Physical Hazards Methodology: hazard identification, hazard characterisation, exposure assessment and risk characterisation.

The hazard identification describes the danger of an LIB. The hazard characterisation describes the effects that the hazard can cause. For this purpose, scientific literature has been searched using search engines Scopus and Google Scholar and reports from research institutes have been consulted.

Prior to the exposure assessment, the laws and regulations relating to LIB in consumer products are described. Legislation and regulations are seen as organisational control measures that affect the exposure.

For the purpose of the exposure estimate, specifically to gain insight into the probability of the hazard occurring in refurbished LIB, BuRO has had two studies carried out. The first study, conducted by DNV, focuses on the construction and protection systems of new and refurbished LIB, intended for electric bicycles (DNV, 2023). The second study, conducted by Royal HaskoningDHV (Royal HaskoningDHV, 2022), provides insight into the market for the refurbishment of LIB for bicycles and the associated safety risks for private consumers.

The risk characterisation brings together the effects of the hazard and the probability of exposure to characterise the risk.

The findings from these steps are summarised below. A more detailed description is included in the underlying substantiation.

The content of this advice has been subject to an external peer review.

## Findings

### Hazard identification

- An LIB consists of multiple battery cells and a Battery Management System (BMS).
- An LIB cell can be used safely as long as the voltage and temperature of the cell remain within safe limits. The working area within the safe limits is called the 'Safe Operating Area' (SOA). The BMS must monitor that the voltage and temperature of the cells remain within the SOA.
- The danger of an LIB is that the voltage or temperature of a cell exceed the SOA boundaries. If that happens, the cell does not return to the safe state but a self-reinforcing process arises with possible negative effects. This process is called a thermal runaway.
- Exceeding the SOA boundaries can be caused by overloading the LIB cell. Three types of overload can be distinguished: mechanical, electrical and thermal overload.

**Hazard characterisation**

If a thermal runaway occurs in an LIB, a number of effects may occur:

- There may be a fire,
- The gas mixture may cause an explosion, and/or
- Toxic gases are released.

The fire or explosion that occurs can cause direct injury to persons near the burning LIB or can cause or strengthen a house fire.

The gas mixture consists of, among other things, carbon monoxide and hydrogen fluoride. Of these gases, the amounts released by a burning LIB have been published in literature. Based on this data, Annex 1 concludes that the concentrations of these gases in the event of a fire of an LIB for an electric bicycle in a home situation may pose a health risk to the consumer, even leading to fatal injuries.

**Laws and regulations**

- Consumer products are generally covered by the General Product Safety Regulation (EU) 2023/988 . It does not impose any specific requirements on consumer products with an LIB.
- Electric bicycles are covered by the Machinery Directive 2006/42/EC. In the Netherlands, this Directive has been implemented in the 'Warenwetbesluit machines'. The Implementing Decision (EU) 2019/436 of the Machinery Directive refers to a harmonised standard for electric bicycles that refers to a standard for the battery pack: EN 50604-1:2016 and amendment EN 50604-1:2016/A1:2021.
- The Battery Regulation (EU) 2023/1542 is in force since 2023. It aims to reduce the environmental and social impacts of batteries throughout their life cycle and in particular imposes requirements on battery durability. The Battery Regulation (EU) 2023/1542 covers all batteries, including those used in electric bicycles.
- The Battery Regulation (EU) 2023/1542 uses several terms related to refurbishment: 'preparing for re-use' and 'remanufacturing', as well as 'repair'. The definition for remanufacturing is very specific: the battery capacity shall be restored to at least 90% of the original battery capacity, and the condition of all individual battery cells shall not differ by more than 3%.
- The Battery Regulation (EU) 2023/1542 designates an economic operator preparing batteries for re-use or remanufacturing batteries as a manufacturer. And a battery that has been prepared for re-use or remanufactured is equated to a newly manufactured battery for the purposes of the Regulation. This economic operator must also comply with other related Union law. The economic operator revising should therefore also draw up a declaration of conformity and a technical file and apply for a CE marking.
- The Battery Regulation (EU) 2023/1542 does not explicitly specify requirements for the safety of (refurbished) LIB for Light Electric Vehicles (LEV) such as an electric bicycle. Specific safety parameters are included for the category of stationary battery energy storage systems, which includes a home battery.
- At the request of the European Commission, CEN and Cenelec are developing a standard for LIB for LEV, paying attention to refurbishment, focusing on the performance and sustainability of the LIB but not explicitly focusing on safety.
- Due to the different terms and definitions in the Battery Regulation that are related to refurbishment and the absence of explicit safety requirements for (refurbished) LIB for LEV, it may not be clear to economic operators who want

to revise LIB for electric bicycles which requirements they have to meet, or how they can meet them.

**Exposure assessment**

It is expected that exposure to a thermal runaway will increase for refurbished LIB. This is based on the following aspects:

- The number of refurbished LIB will increase:
  - The number of electric bicycles with an LIB is increasing: figures from the RAI Association show that the number of new electric bicycles sold in the Netherlands varies between about 250,000 and 500,000 per year.
  - Research commissioned by BuRO shows that between 34,000 and 40,000 LIB for electric bicycles were refurbished and traded in the Netherlands in 2021. And the research predicts that if the market for refurbishment continues to grow along with the number of electric bicycles sold, it is conceivable that the number of refurbished LIB will exceed one hundred thousand per year in a few years.
- It is likely that the risk of a thermal runaway is greater with a refurbished LIB than with an original LIB.
  - This appears from the studies commissioned by BuRO. Incorrect or incomplete diagnosis, careless or incomplete work, insufficient quality tests, or unsafe transport are points that can affect this.
  - The probability of the occurrence of a thermal runaway cannot be quantified, neither for an original LIB nor for a refurbished LIB, due to a lack of sufficient data.
- There are signs in the media and on the basis of data on the probable cause of home fires that the number of LIB incidents in electric bicycles is increasing:
  - The NIPV has made an analysis of fires with LEV, including electric bicycles, based on media reports. Between 2020 and 2022, there were 327 fires. In about 1/3 of the fires, the LIB of the LEV was the suspected cause. In 6 of the 327 fires, victims were transferred to the hospital as a result of the fire.
  - Stichting Salvage, a foundation that provides first aid to victims in the event of damage caused by fire, among other things, reports that in 2023 2% of approximately 4,200 house fires, i.e. approximately 84 fires, were probably caused by the batteries of electric bicycles, scooters and mopeds. This is a doubling compared to 2022.

**Risk characterisation**

The use of LIB poses a risk to users and bystanders. This risk exists for all (new and refurbished) LIB. Due to overloading of an LIB, a thermal runaway can occur, resulting in a fire, explosion and/or toxic gases that are released, causing users and bystanders to be injured or poisoned.

Based on the studies commissioned by BuRO, it is conceivable that the probability of a thermal runaway is greater for refurbished LIB. Refurbished LIB appear to have a higher chance of abnormalities or an incorrectly tuned BMS. The complexity of the legal framework and uncertainty about or lack of specific standards for the safety of refurbished LIB contribute to this.

The risk cannot be quantified at the moment, partly due to the lack of detailed information about incidents with (refurbished) LIB.

It is the expectation of BuRO that – without further measures – the risk to public health will increase as the chance of incidents with refurbished LIB in an electric bicycle will increase. This chance will increase as the number of electric bicycles continues to increase and also due to the expected increase in the share of refurbished LIB.

## Uncertainties and developments

The market for refurbishment of LIB is developing. The studies commissioned by BuRO are based on information from the years up to 2022. On the one hand, it can be expected that the companies in this market will continue to develop with higher quality as a result. On the other hand, new companies will start, driven by the pursuit of circularity and sustainability, where there may be uncertainty about which laws and regulations they have to comply with to ensure the safety of refurbished LIB.

Where new LIB from some bicycle manufacturers can now be deliberately designed in such a way that refurbishment is not possible, the Right to Repair Directive and the Battery Regulation (EU) 2023/1542 require that each LIB can be refurbished. This is expected to contribute to the growth of the refurbished LIB share.

The safety level of a refurbished LIB for LEV may vary from one to another in the current context. This is because the level of safety will depend on the specific state of the LIB as it is offered for refurbishment, the non-standardised refurbishment process and possible ambiguity about safety standards that refurbished LIB should meet.

The risk to public health cannot be quantified at the moment. This is due to the fact that there is insufficient information to estimate the chance of a thermal runaway of a (refurbished) LIB. There is also limited information on the toxicity of and exposure to the gases released during a thermal runaway. In addition, detailed information on incidents with (refurbished) LIB is missing.

Since 2020, the Dutch battery strategy has been implemented. This is coordinated by the Ministry of Infrastructure and Water Management (I&W). Within the framework of the safety pillar of this strategy, the Working Group on Fire Safety of Light Electric Vehicles was established. The working group states in its action plan that there are too few laws and regulations in the field of refurbishment and repair. The working group therefore wants to investigate how the fire safety of refurbished LIB for LEV can be guaranteed.

In 2025, the working group will also discuss the need and possibility to draw up a Dutch Technical Agreement (*Nederlandse Technische Afspraak*, NTA). With an NTA, minimum requirements can be set for refurbishment and the refurbished LIB. As noted in the context of the legal framework, in 2021 the European Commission made a request to the European standardisation organisations to draw up such standards. An NTA can be realised faster and can serve as a precursor to a European standard.

## Answers to the questions

Before answering the main question, the sub-questions are first considered.

› *What factors can cause a hazard of LIB in consumer products?*

A hazard of an LIB is that a thermal runaway can occur. If a consumer product with an LIB is used, a thermal runaway can be caused by mechanical, thermal and electrical overloading of the LIB.

› *Which regulations and oversight apply to the safety of consumer products with LIB?*

Consumer products are generally covered by the Product Safety Regulation (EU) 2023/988. For electric bicycles, there is specific EU legislation, namely the Machinery Directive 2006/42/EC. For the LIB itself, the Battery Regulation (EU) 2023/1542 is in force since 2023, which also pays attention to refurbishment. The NVWA supervises the Product Safety Regulation and the Machinery Directive, sometimes together with other government inspections such as the Human Environment and Transport Inspectorate (IL&T). Monitoring of the Battery Regulation remains to be worked out. The NVWA is one of the possible supervisors that could play a role in this.

› *What is the impact of LIB refurbishment on the hazard?*

It is important that the LIB, with the battery cells and BMS as components, is configured in such a way that the probability of the hazard to occur is controlled. By refurbishment, the internal structure and configuration of the LIB can be disrupted, which increases the probability of the hazard. Incorrect or incomplete diagnosis, careless or incomplete work, insufficient quality tests, or unsafe transport are factors that can affect this.

› *Which regulations and oversight are aimed at the market of refurbishment of LIB for consumer products?*

The market for refurbishment is relatively new and is developing. Within the scope of consumer products, refurbishment is nowadays predominantly applied to LIB for electric bicycles. The Battery Regulation uses different terms and definitions related to refurbishment, such as 'preparing for re-use' and 'remanufacturing'. An economic operator preparing batteries for re-use or remanufacturing batteries is considered a manufacturer. And a battery that has been prepared for re-use or remanufactured is equated to a newly manufactured battery for the purposes of the Regulation. This economic operator must also comply with other related Union law. The economic operator revising batteries should therefore also draw up a declaration of conformity and a technical file and apply for a CE marking. There are no specific safety requirements for (refurbished) LIB for LEV in the Battery Regulation. Due to the complexity of the regulations, there may be uncertainty among economic operators wishing to revise LIB for electric bicycles as to what requirements they have to meet, or how they can meet them. The NVWA is the responsible regulator on the market for electric bicycles with (refurbished) LIB. As the organization of the oversight on the Battery Regulation remains to be elaborated, it is currently not clear who is supervising the economic operators revising LIB for electric bicycles.

Based on this, the main question can be answered:

*What is the risk to public health of using refurbished LIB in consumer products?*

In this advice, this risk was specifically examined for refurbished LIB for electric bicycles. The risk assessment shows that there is a risk to public health because the LIB can ignite, which can also lead to release of toxic gases. And that this risk is greater if it concerns a refurbished LIB. This risk is currently not quantifiable, but is expected to increase in the coming years. This is mainly due to the growth in the number of electric bicycles, the growth in the market for refurbished LIB, and the higher probability of the hazard to occur with a refurbished LIB. The complexity of and limited attention to safety in laws and regulations for refurbished LIB play a role in this.

Where this has now been investigated for refurbished LIB in electric bicycles, it is to be expected that a similar effect may occur if refurbishment is applied to LIB used in other consumer products. Or if, for example, car battery packs are converted into home batteries. With this advice, BuRO also wants to draw attention to such developments in order to pay timely and balanced attention to both sustainability and safety risks in the preparation of laws and regulations and their oversight.

## Advice from BuRO

To the State Secretary for Youth, Prevention and Sport

- In order to facilitate the refurbishment and circularity of LIB in a safe way, in consultation with the Ministry of Infrastructure and Water Management, provide information on which laws and regulations apply to companies that revise LIB and to the LIB that they have refurbished, with attention to the various definitions in the Batteries Regulation such as for 'preparing for reuse' and 'remanufacturing', not necessarily limited to LIB in electric bicycles.
- Emphasize in the sector the need for and support where possible, the implementation of technical standards for refurbishment and refurbished LIB, in line with ongoing initiatives such as from the Working Group on Fire Safety LEV.
- Explore opportunities and support ongoing initiatives to better investigate and record in more detail incidents with LIB in consumer products.

To the Inspector General of the NVWA

- Where possible, continue and strengthen cooperation with other inspection services in order to gain a better understanding of the companies that offer LIB refurbishment and/or trade refurbished LIB and to organise the oversight of these companies.

Yours sincerely,

*Prof. dr. Dick T.H.M. Sijm*
*Director Office for Risk Assessment and Research*

# Substantiation

## Introduction

The use of lithium-ion batteries (LIB) has increased significantly in recent years. In addition to ease of use, the energy transition is an important driver to provide products with electricity by using an LIB. LIB can deliver a high voltage compared to other types of batteries, they have a large capacity and they are relatively cheap. That makes LIB very popular.

But LIB also have a downside: they contain a solution containing lithium ions which is highly flammable. Reliable figures on incidents involving products with LIB are not available. However, there is a growing number of signals in the media and reports about incidents with LIB, with sometimes serious consequences. For example, the NIPV has made an analysis of fires with LEV, including electric bicycles, based on media reports. In the period 2020 to 2022, 327 fires were counted, with a technical defect being the suspected cause in about 1/3 of the fires. In 6 of the 327 fires, victims were transferred to the hospital as a result of the fire. And Stichting Salvage, a foundation that provides first aid to victims in the event of damage caused by fire, among other things, reports in a news item that in 2023 2% of approximately 4,200 home fires, i.e. approximately 84 fires, were probably caused by the batteries of electric bicycles, scooters and mopeds. This is a doubling compared to 2022. Given the expected increase in the number of LIB, it is to be expected that the number of incidents will continue to increase.

The issue of the safety of LIB used in consumer products is complex and affects many stakeholders. That is why the Office for Risk Assessment and Research (BuRO) of The Netherlands Food and Consumer Product Safety Authority (NVWA) organised a meeting in January 2023 with various ministries, inspection services and universities, among others. The aim of this meeting was to explore the outlines of a joint approach with the attendees.

A core task of BuRO is to analyse available data and information on (new) risks. Following the meeting in 2023 and on the basis of two studies commissioned by BuRO on the safety of refurbished LIB, BuRO is now issuing this advice. Parallel developments have been taken into account as much as possible.

For example, in 2020, the Ministry of Infrastructure and Water Management (I&W) initiated a national strategic approach in the Netherlands, the 'battery strategy', to ensure that the increase in the use of batteries in society is carried out safely, responsibly and sustainably. One of the pillars of this strategy is safety with actions aimed at improving knowledge about safety and stimulating sustainable-and-safe-by-design. A Working Group on Fire Safety Light Electric Vehicles (LEV) has also been established.

There is also an expected increase in LIB that has been refurbished. During refurbishment, battery cells and / or other parts are replaced so that the LIB can be used again for the same purpose. The increase in refurbished LIB is driven by the pursuit of circularity and sustainability and the right to repair. At European level, rules have been drawn up for this purpose in the European Battery Regulation (EU) No 2023/1542[1], which is in force from July 2023. In addition, there is the 'right to repair' Directive (EU) 2024/1799[2]. This Directive was

[1] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC OJ L 191, 28.7.2023, p. 1–117

[2] Directive (EU) 2024/1799 of the European Parliament and of the Council of 13 June 2024 on common rules promoting the repair of goods and amending Regulation (EU) 2017/2394 and Directives (EU) 2019/771 and (EU) 2020/1828. PB L, 2024/1799, 10.7.2024

published in July 2024 and is to be implemented by The Netherlands in Dutch legislation by July 2026. The Battery Regulation (EU) 2023/1542 does not use the term refurbishment, but uses the terms 'preparing for re-use' and 'remanufacturing'. This is discussed in more detail in the description of the legal framework. In this report, we use the more general term refurbishment, which may include both 'preparing for re-use' and 'remanufacturing'.

Refurbishment is a relatively new development. Little is known about the effect of refurbishment on the safety of the LIB. In this risk assessment, BuRO therefore focuses on the risk to public health of the use of refurbished LIB in consumer products.

Within the scope of consumer products, the risk assessment focuses on electric bicycles. The growth in the use of LIB certainly applies to electric bicycles: According to the RAI Association, the number of electric bicycles in the Netherlands increased from 1.5 million in 2017 to 4.3 million in 2023. Compared to the total of newly sold bicycles in a year, the share of electric rose from 31% in 2017 to 56% in 2023.

Refurbishment of LIB is nowadays mainly applied to electric bicycles. The LIB have a limited lifespan, shorter than that of the bicycle. The LIB for an electric bicycle is relatively large compared to LIB for other consumer products such as a laptop. Due to the high new price of an LIB for an electric bicycle, it is rewarding to have it refurbished.

## Approach

To put the risk assessment into perspective, a description of the chain for LIB and the delimitation of the scope of this study follows. For the risk assessment, BuRO has worked according to the four steps described in the BuRO Physical Hazards Methodology: hazard identification, hazard characterisation, exposure assessment and risk characterisation.

For the hazard identification and characterisation, scientific literature has been searched using search engine Scopus, see Annex 2. The laws and regulations that relate to LIB have been reviewed and developments in the field of LIB and the refurbishment of LIB have been looked at in order to gain insight into the extent to which safety is guaranteed.

This risk assessment specifically focuses on the impact of a refurbished LIB on the risk. It is assumed that the character of the hazard of a refurbished LIB is the same as that of an original LIB. Therefore, the hazard characterisation in this risk assessment has been developed to a limited extent.

The exposure assessment looks at the influence of a refurbished LIB on the probability of the hazard to occur and at the development of the number of refurbished LIB. That is why BuRO has had two studies carried out. The first study, conducted by DNV, focuses on the construction and protection systems of new and refurbished LIB, intended for electric bicycles (DNV, 2023).

The second study, conducted by Royal HaskoningDHV (Royal HaskoningDHV, 2022), provides insight into the market for the refurbishment of LIB for bicycles and the associated safety risks for private consumers.

The risk characterisation brings together the effects of the hazard and the probability of exposure to characterise the risk.

## Description of the chain

The chain of an LIB in a consumer product starts with the production of the individual battery cells and ends with the waste treatment, as shown in Figure 1.

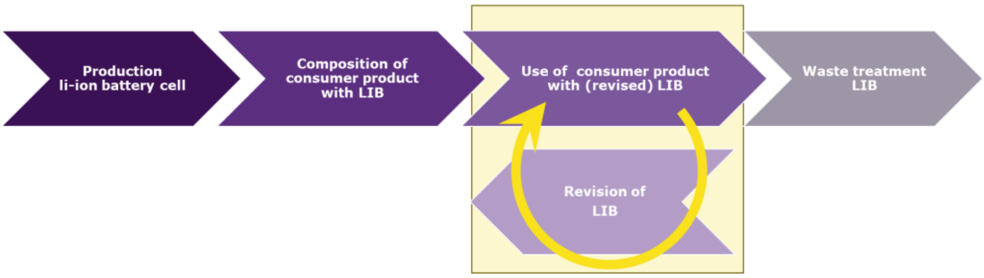



*Figure 1: Illustration of the chain of an LIB in a consumer product*

An LIB cell contains multiple raw materials such as lithium and graphite. These raw materials are mainly sourced outside Europe. It is already being investigated, with the support of the European Investment Bank, whether lithium can also be sourced in Europe with innovative techniques in the future. The production of individual battery cells and battery packs is already taking place in Europe, where the European Commission and the European Investment Bank also play a driving role. In the Netherlands, it is estimated that several hundred companies are now active in making parts or in merging battery cells into battery packs. The integration of a battery pack into a consumer product, such as an LIB in an electric bicycle, is also happening in the Netherlands. When a battery (pack) no longer functions properly, it ends up as waste. Or it may be considered to be refurbished, for which the attention is growing.

Batteries, also other than LIB, are divided into five categories, which are defined by weight and/or application in the Battery Regulation (EU) 2023/1542. One category is that of portable batteries. This includes batteries that are lighter than 5 kg and are used in a multitude of consumer products. Think of watches (smartwatches), electric toothbrushes, hearing aids, headphones, phones, drones, lights, tools and power banks. LIB for electric bicycles fall into the category of batteries for light means of transport. An upper weight limit of 25 kg has been set for this category. In addition, there is a category of electric vehicle batteries (EV), a category of starter batteries (lead batteries) and a category of industrial batteries including stationary energy storage systems (EOS) such as home batteries.

Factors that influence the safety risk to the consumer can be introduced in different chain links. First of all, in the production of a single LIB cell and the configuration of the LIB consisting of a number of LIB cells and a BMS. And if an LIB is then integrated into a consumer product, such as an electric bicycle, the way the product is composed or used are factors that can influence the risk.

## Scope

This advice focuses on the refurbished LIB used in a consumer product as shown in Figure 1. The production of an LIB per se, the composition of a consumer product with LIB, and the waste operation of LIB therefore fall outside the scope of this study.

As indicated in the introduction, the focus of the risk assessment has been on electric bicycles. No specific target groups were considered.

## Hazard identification

An LIB consists of several lithium-ion battery cells and a battery management system (BMS). In a lithium-ion battery cell, different materials can be used, depending on desired storage density, stability, or charging speed (Vos et al., 2024). A single battery cell can be used safely as long as the voltage and temperature of the cell remain within safe limits. The safe operating area is referred to as the 'Safe Operating Area' (SOA) (Kamboj et al., 2024) as shown in Figure 2. The BMS shall monitor that the voltage and temperature of the cells remain within the SOA.



The danger of an LIB is that the voltage or temperature of a cell gets outside the SOA (Sarkar et al., 2024). An LIB cell is not inherently safe: when a cell exceeds the boundaries of the SOA, it does not return to the safe state but a self-reinforcing process arises. This process is called a thermal runaway, see Figure 2.

Exceeding the boundaries of the SOA can be caused by overloading the battery cell. Three types of overload can be distinguished: mechanical, electrical and thermal overload (Sarkar et al., 2024).

Mechanical overload involves deformation (bending, nodding, compression) or puncture of the battery cell. Also, the battery cell can be overloaded when it is subject to collision, fall or vibrations. Electrical overloading of a battery cell occurs by overcharging or over discharging. Thermal overload is caused in case of too high or too low temperature of the battery.

## Hazard characterisation

As described, among others, by Chen and colleagues (Chen et al., 2021), thermal runaway is a process of undesired chemical reactions resulting in release of heat (exotherm). This heat again feeds the chemical reactions. In addition, toxic gases are also released, causing the LIB to swell and at some point it may burst or explode (Huang et al., 2025). When the gases are released, the gases can ignite. Due to the heat that is released, nearby battery cells can also get into thermal runaway. This is called thermal propagation by the battery pack, see Figure 2.

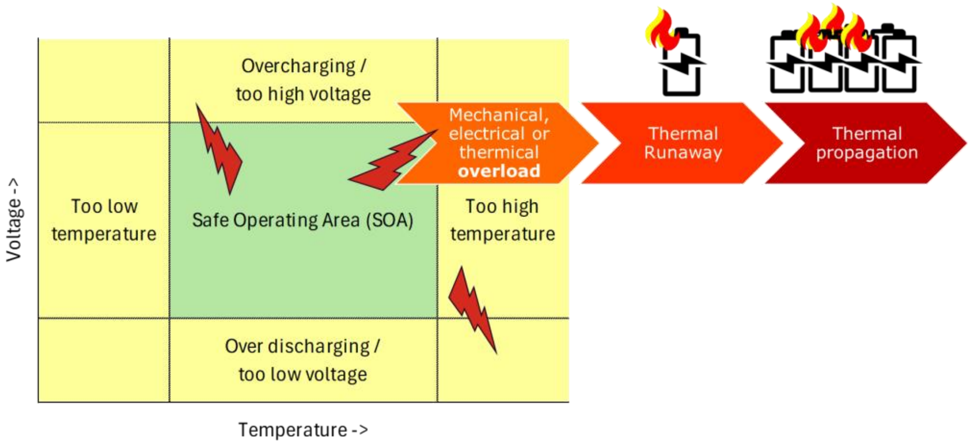



*Figure 2: Illustration of the Safe Operating Area of an LIB depending on voltage and temperature and the hazardous thermal runaway*

If a thermal runaway occurs in an LIB, a number of effects may occur:

- There may be a fire,
- The gas mixture may cause an explosion, and/or
- Toxic gases are released.

The course of an LIB fire has been described by the Netherlands Institute for Public Safety (Nederlands Instituut voor Publieke Veiligheid (NIPV)). Characteristics of an LIB fire are that a torch can arise, that there can be shooting parts, that there can be strong heat radiation and that the fire can last relatively long. The fire that occurs can cause direct injury to persons near the burning LIB or also cause or strengthen a house fire. The effects of a thermal runaway are similar for lithium-ion battery cells of different composition. Because the thermal propagation is almost unstoppable, fighting an LIB fire is difficult (Vos et al., 2024).

The gas mixture released consists of the solvent in the electrolyte that evaporates, combustion gases carbon dioxide and carbon monoxide, and toxic gases including hydrogen fluoride formed from the lithium salt in the electrolyte (Huang et al., 2025). In the gas mixture, soot particles of the metals in the LIB cell can also occur.

This advice focuses specifically on the influence of a refurbished LIB on the risk. It is assumed that the characteristics of the hazard of a refurbished LIB are the same as that of an original LIB. In other words, that a thermal runaway of a refurbished LIB can have the same consequences as an original LIB. Therefore, the hazard characterisation is not elaborated in more detail here. Annex 1 discusses the toxicity and quantities of gases released by a burning LIB. The exposure estimate looks at the influence of a refurbished LIB on the probability of exposure to the hazard (the thermal runaway and its effects) and at the development of the number of refurbished LIB.

## Legal framework

Consumer products are generally covered by the General Product Safety Regulation (EU) 2023/988 in force since December 2024. It does not impose any specific requirements on consumer products with an LIB. NVWA is the oversight authority of this regulation.

For some types of consumer products there are specific regulations. For example, electric bicycles are covered by the Machinery Directive 2006/42/EC. In the Netherlands, this Directive has been implemented in het *Warenwetbesluit machines*[3]. The Ministry of Health, Welfare and Sport (Ministerie van Volksgezondheid, Welzijn en Sport, VWS) is responsible for this.

The Battery Regulation (EU) 2023/1542 has been in force since 2023 for all types of batteries, including LIB used in consumer products.

The coherence of the most relevant laws, regulations and standards is summarised and schematically presented in Figure 3. These are explained below. There is a distinction in laws and regulations that apply to the consumer product with LIB, such as an electric bicycle, and laws and regulations that apply to the LIB itself.

[3] Warenwetbesluit machines, Stb. 1992, 379

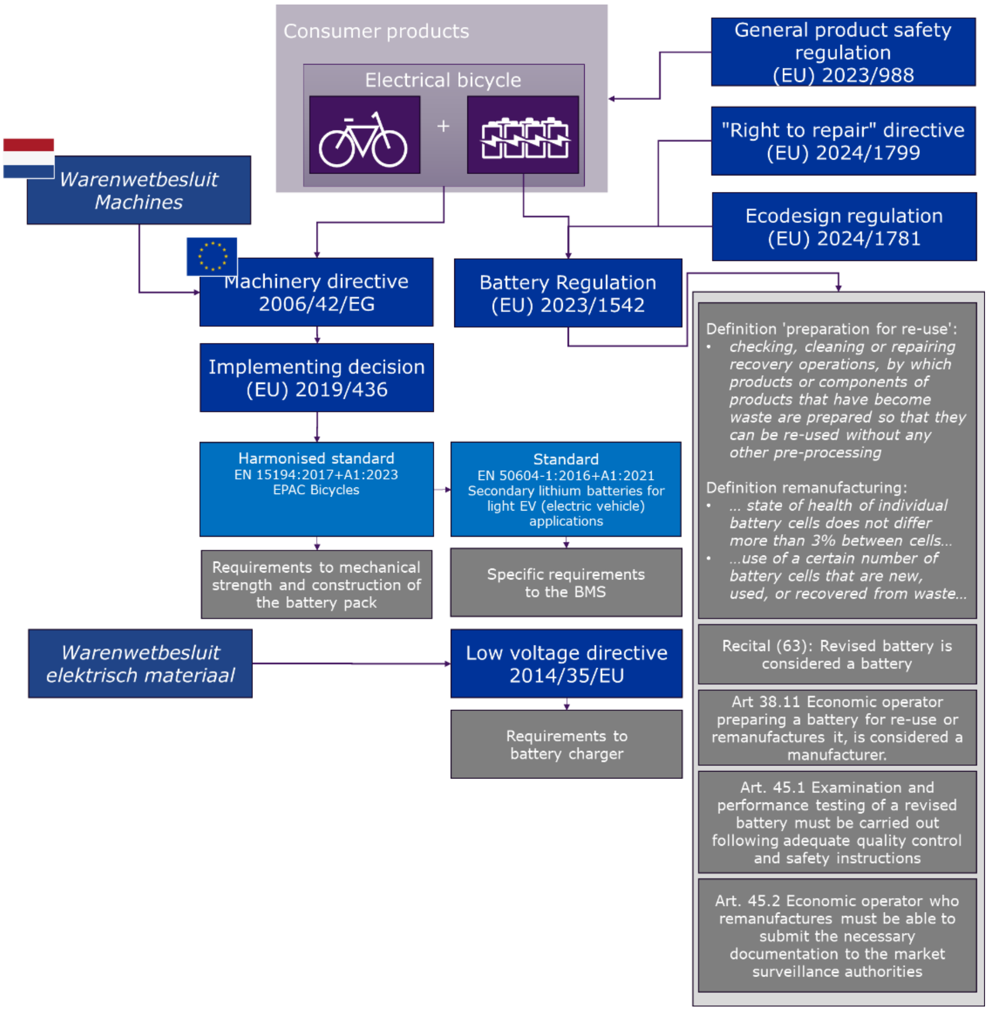



*Figure 3: Illustration of the coherence of relevant laws and regulations (not exhaustive)*

***Machinery Directive and Dutch 'Warenwetbesluit machines'***

These regulations require the party putting a product to market, such as an electric bicycle, to carry out a risk assessment and to create a technical file showing that the product is safe. The manufacturer must check which hazardous situations can be caused by the bicycle and which hazardous situations are associated with it. He must assess the risks taking into account the severity of the potential injury or damage to health and the probability of its occurrence. And he must then determine whether risk reduction is required given the objective of the Machinery Directive and, if necessary, take measures to eliminate the hazard or reduce the risk. This should take into account 'reasonably foreseeable use'. The product must also have a CE marking. A CE marking indicates that, according to the manufacturer, a product meets all EU requirements in terms of safety, health and environmental protection. NVWA supervises the *Warenwetbesluit machines*.

***Low Voltage Directive and Dutch 'Warenwetbesluit elektrisch materiaal'***

For battery chargers of electric bicycles, the rules are set out in the Low Voltage Directive (2014/35/EU). In the Netherlands, this Directive is included in the *Warenwetbesluit elektrisch materiaal*[4], also supervised by NVWA.

***Implementing Decision on the Machinery Directive and standards***
Implementing Decision (EU) 2019/436[5] of the Machinery Directive initially designated harmonised standard EN 15194:2017[6] for electric bicycles. A harmonised standard defines technical specifications that are considered suitable or sufficient to meet the technical requirements of EU legislation. EN 15194 sets requirements for the mechanical strength and construction of the electrical components of the bicycle, including the battery pack.

This standard has been amended to EN 15194:2017+A1:2023. The European Commission (EC) harmonised this amended standard under the Machinery Directive in May 2024. The amendment was made (partly) as a result of a formal objection by the Netherlands against the requirements of the LIB in the original standard EN 15194:2017. Two standards were mentioned to demonstrate the safety of the LIB: EN 62133-2[7] and EN 50604-1. The amended standard refers only to EN 50604-1:2016 and amendment EN 50604-1:2016/ A1:2021[8]. A transitional period has been established until 23 August 2025, after which the old standard EN 62133 no longer counts as an accepted standard.

It should be noted that the use of the standard is not a legal requirement; the safety of the LIB may also be demonstrated by other means.

EN 50604-1 sets requirements for (parts of) the battery package, including specific requirements for the BMS. The scope of EN 50604-1 notes that this standard is not intended for the evaluation of the safety of repair and maintenance services of battery packs. It is not clear whether this includes refurbishment.

***Battery Regulation***
The Battery Regulation (EU) 2023/1542 has been in force since 2023. It aims to reduce the environmental and social impacts of batteries throughout their life cycle and in particular imposes requirements on battery durability. The Battery Regulation (EU) 2023/1542 applies to all batteries, including the LIB used in electric bicycles.

***Refurbishment in the Battery Regulation***
The term 'refurbishment' is not used in the Battery Regulation (EU) 2023/1542. Terms that are used and that are related to refurbishment are: 'preparing for re-use' and 'remanufacturing'.

[4] , Stb. 2016, 244

[5] Commission Implementing Decision (EU) 2019/436 of 18 March 2019 on the harmonised standards for machinery drafted in support of Directive 2006/42/EC of the European Parliament and of the Council C/2019/1932 OJ L 75, 19.3.2019, p. 108–119.

[6] EN 15194:2017 Cycles - Electrically power assisted cycles – EPAC Bicycles

[7] EN 62133-2 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

[8] EN 50604-1 Secondary lithium batteries for light EV (electric vehicle) applications – Part 1: General safety requirements and test methods

For the definition of 'preparing for re-use', reference is made to Directive 2008/98[9]. The definition reads as follows: 'checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing'.

Remanufacturing is seen as an extreme case of preparation for re-use. Recital (17) states: '*As regards used batteries, remanufacturing has the objective of restoring the original performance of a battery. In that sense remanufacturing can be seen as an extreme case of re-use entailing the disassembly and evaluation of the cells and modules of the battery and the replacement of a certain amount of these cells and modules. In order to differentiate remanufacturing from mere re-use, the restoration of the battery capacity to at least 90% of the original rated battery capacity should be considered to be remanufacturing and necessitates the application of a specific regime*'. What is meant by a specific regime is not clear.

Remanufacturing is then defined as '*any technical operation on a used battery that includes the disassembly and evaluation of all its battery cells and modules and the use of a certain number of battery cells and modules that are new, used or recovered from waste, or other battery components, to restore the battery capacity to at least 90% of the original rated capacity, and where the state of health of all individual battery cells does not differ more than 3% between cells, and results in the battery being used for the same purpose or application as the one for which the battery was originally designed*'.

***The economic operator that revises batteries is a manufacturer; Same requirements for a refurbished battery as new battery***

An economic operator preparing a battery for re-use or remanufacturing and placing it on the market is considered a manufacturer in the Battery Regulation. This is stated in Article 38.11 of the Battery Regulation (EU) 2023/1542.

According to recital (63), for the purposes of the Battery Regulation, 'batteries' should also include batteries that have been prepared for re-use or remanufactured.

In addition, Article 45.1 states that the examination and performance testing of a refurbished battery must be carried out following adequate quality control and safety instructions.

Article 45.2 further states that an economic operator preparing a battery for re-use or remanufacturing and placing it on the market shall ensure that the battery complies with the requirements of the Battery Regulation and with all applicable protection requirements relating to the product, the environment and human health and with the safety requirements for its transport as laid down in other Union law. And specifically for the economic operator who remanufactures, it states that he must be able to submit the necessary documentation to the market surveillance authorities to demonstrate that the remanufacturing complies with the Regulation.

This implies that an economic operator revising and placing batteries on the market must comply with the same requirements in the Regulation as an economic operator placing new batteries on the market. The reference to other Union law implies that the requirements for batteries in other European legislation shall also be met. The economic operator who revises must therefore also draw up a declaration of conformity and a technical file, and apply for a CE marking.

[9] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EER relevance). OJ L 312, 22.11.2008, p. 3–30

***No explicit requirements for the safety of (refurbished) LIB for LEV***
The Battery Regulation (EU) 2023/1542 does not contain any explicit text on the safety of LEV batteries.

Recital (20) states that for EVs requiring type approval, a battery that has been repaired must continue to comply with the applicable safety requirements. For LEV, such as an electric bicycle that does not require type approval, this is not specified. However, Recital (40) states that "*for repaired batteries for light means of transport, the Commission will prepare rules on the safety of micromobility devices, building on experience at national and local levels of safety requirements, as announced in the communication of the Commission of 14 December 2021 on 'The new EU Urban Mobility Framework'.*"

The status of these regulations is not known. And the definition of 'repair' ('one or more operations whereby a defective product or waste is returned to a state in which it is fit for its intended use', for which reference is made to the Ecodesign Regulation (EU) 2024/1781[10], differs from the definitions of 'preparation for re-use' and 'remanufacturing'. The question is therefore whether the rules still to be drawn up will also apply to refurbished batteries.

Annex V of the Battery Regulation (EU) 2023/1542 sets out safety parameters, such as protection against overcharging and overdischarging. However, these only apply to stationary battery systems for energy storage, such as a home batteries. This is not the case for (refurbished) LIB in LEV.

In 2021, the European Commission made a request[11] to the European standardisation organisations CEN and Cenelec to draw up standards for the safety, durability and performance of batteries. Following the introduction of the Battery Regulation, this request was amended[12] to include a standard for the refurbishment of certain categories of batteries. The deadline for this standard is June 2027. According to the CEN and Cenelec websites, such a standard[13] focuses on sustainability and performance in development. That the standard will also focus on safety is not mentioned.

***Right to Repair Directive and Ecodesign Regulation***
In addition to the Battery Regulation, the more general 'right to repair' Directive (EU) 2024/1799 and the Ecodesign Regulation (EU) 2024/1781 have been published.

Directive (EU) 2024/1799 was published in July 2024 and is to be implemented by the Netherlands in Dutch legislation by July 2026. Recital (1) of this Directive sets the objective of promoting more sustainable consumption. For electric bicycles

[10] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC. OJ L, 2024/1781 28.06.2024

[11] C(2021) 8614 COMMISSION IMPLEMENTING DECISION of 7.12.2021 on a standardisation request to the European standardisation organisations as regards performance, safety and sustainability requirements for batteries

[12] C(2024) 8343 COMMISSION IMPLEMENTING DECISION of 29.11.2024 amending Implementing Decision C(2021) 8614 as regards harmonised standards in support of Regulation (EU) 2023/1542 of the European Parliament and of the Council and European standards, the deadlines for the adoption of those standards and the duration of the validity of the standardisation request

[13] prEN 50762 Secondary lithium-ion batteries for light means of transport — Part 1: Test specifications for performance and durability aspects

and batteries, this means that they must be repairable. For repairability requirements, this Directive refers to the Battery Regulation (EU) 2023/1542.

The Ecodesign Regulation (EU) 2024/1781 refers to the Battery Regulation in relation to the digital passport that products, e.g., a battery pack, must have, in which the consumer receives relevant information about the product.

***Findings regarding the legal framework***
The main findings with regard to the legal framework are:

- From the Implementing Decision (EU) 2019/436 of the Machinery Directive, there is a harmonised standard for electric bicycles that refers to a standard for the battery pack: EN 50604-1:2016 and amendment EN 50604-1:2016/A1:2021.
- The Battery Regulation (EU) 2023/1542 uses several terms related to refurbishment: 'preparing for re-use' and 'remanufacturing', as well as 'repair'. The definition for remanufacturing is very specific: the battery capacity shall be restored to at least 90% of the original rated battery capacity, and the condition of all individual battery cells shall not differ by more than 3%.
- The Battery Regulation (EU) 2023/1542 designates an economic operator preparing batteries for re-use or remanufacturing as a manufacturer. And a battery that has been prepared for re-use or remanufactured is considered similar to a newly manufactured battery for the purposes of the Regulation. This economic operator must also comply with other related Union law. The economic operator revising should therefore also draw up a declaration of conformity and a technical file and apply for a CE marking.
- The Battery Regulation (EU) 2023/1542 does not explicitly specify safety requirements for (refurbished) LIB for LEV.
- At the request of the European Commission, CEN and Cenelec are developing a standard for LIB for LEV, including refurbishment, focusing on the performance and sustainability of the LIB but not explicitly focusing on safety.

Due to the different terms and definitions in the Battery Regulation that have a relationship with refurbishment and the lack of explicit specification of safety requirements for (refurbished) LIB for LEV, there may be ambiguity among economic operators who want to revise LIB for electric bicycles about which requirements they have to comply with, or how they can comply with them. The investigation carried out by DNV shows that LIB offered as refurbished may have a capacity of more or less than 90%. So they would or would not fall within the definition of remanufacturing. It should be noted, however, that the DNV study was carried out in 2022 and the Battery Regulation was published in 2023.

## Exposure assessment

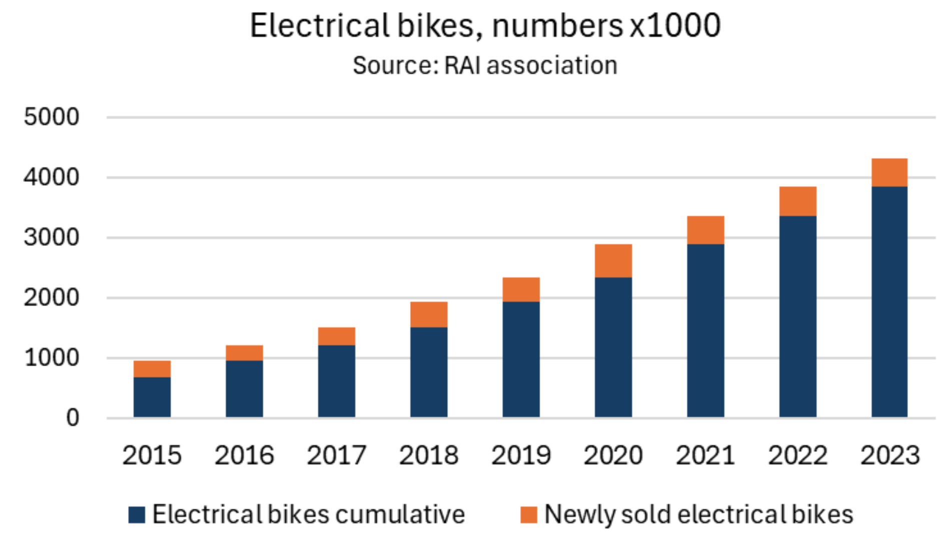
To make an estimate of the exposure to the hazard of a refurbished LIB in an electric bicycle, 4 aspects are important:

- The number of electric bicycles with an LIB
- The number of incidents with LIB in electric bicycles
- The number of refurbished LIB in electric bicycles
- The probability of the hazard (a thermal runaway) of a refurbished LIB compared to an original LIB

These 4 aspects are explained below.

***The number of electric bikes with an LIB***
According to the RAI Association, the number of electric bicycles in the Netherlands increased from 1.5 million in 2017 to 4.3 million in 2023. Statistics Netherlands (CBS) reports that there are 8.4 million households in the

Netherlands at the beginning of 2024. In other words, in about half of the households there is an electric bicycle with LIB. In the period 2015 to 2023, the number of newly sold electric bicycles in the Netherlands ranges between about 250,000 and 500,000 thousand per year (RAI Association), as shown in Figure 4.




*Figuur 4: Estimated numbers of (newly sold) electric bicycles; Source: RAI Association*

***The number of incidents with LIB in electric bicycles***
There is no complete overview of the number of incidents with LIB in electric bicycles, or more generally consumer products with LIB.

Based on media reports, NIPV analysed fires with LEV, including electric bicycles, in the period 2020 – 2022 (NIPV, 2023). There were 327 fires involving a total of 696 LEVs, of which 114 were electric bicycles. More than three quarters of the LEVs concerned a scooter. In about 1/3 of the fires, the likely cause was arson. This is especially the case with (shared) scooters. In about 1/3 of the fires, the LIB of the LEV was the suspected cause. In 6 of the 327 fires, victims, a total of 10, were transferred to the hospital as a result of the fire. Information about the state of the LIB at the time of these incidents, for example whether it has been refurbished, is not available.

Stichting Salvage, a foundation that provides first aid to victims in the event of damage caused by fire, among other things, reports in a news item that in 2023 2% of approximately 4,200 house fires, i.e. approximately 84 fires, were probably caused by the batteries of electric bicycles, scooters and mopeds. This is a doubling compared to 2022. In total, batteries are the suspected cause in almost 5% of cases (3% in 2022). In addition to batteries for electric means of transport, these include batteries for e.g., tools, toys, laptop, tablet and mobile phone.

In 2024, there are several reports in the media about incidents with LIB in electric bicycles, such as in May in Oegstgeest where six people were injured who had inhaled smoke. A similar incident occurred in July in Malmö, Sweden, in which 7 people had to go to the hospital because of the inhaled smoke. An incident involving a fatality occurred in the United Kingdom in August 2024. The battery of an e-scooter was the probable cause.

***The number of refurbished LIB in electric bicycles***
The lifespan of an LIB for an electric bike is about 5 to 8 years. The LIB can then be disposed of as waste or refurbished. In 2023, for example, LIB made in 2015 to 2018 need to be replaced. This means that the number of LIB for electric

bicycles that need to be replaced in the Netherlands in 2023 is in the same order of magnitude as the 250,000 to 500,000 newly sold electric bicycles.

In 2021, between 34 thousand and 40 thousand LIB for electric bicycles were refurbished and traded in the Netherlands. Royal HaskoningDHV (RHDHV) makes this estimate in a study commissioned by BuRO (Royal HaskoningDHV, 2022). In the study, RHDHV predicts that if the market for refurbishment continues to grow with the number of electric bicycles sold, it is conceivable that the number of refurbished LIB will exceed one hundred thousand per year in a few years. In case of strong growth, a number of 120,000 can be expected in 2026, as shown in Figure 5 below from the RHDHV report.

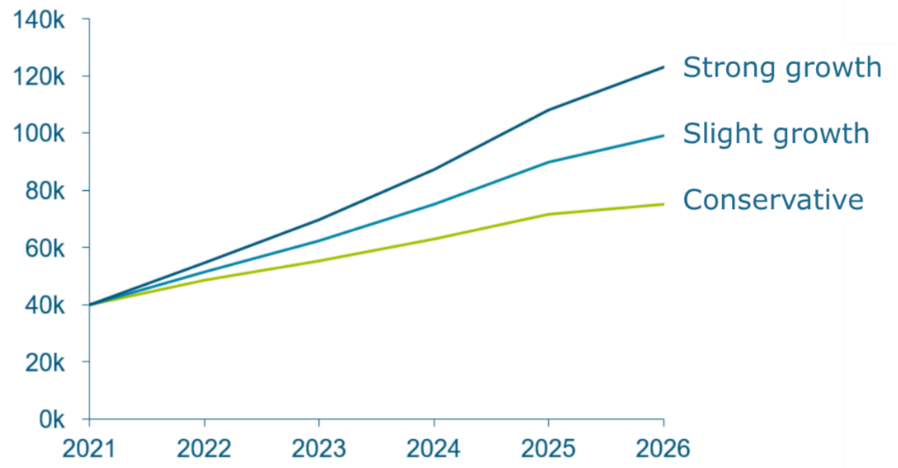



*Figure 5: Forecast market for refurbishment of battery packs for bicycles; Source: RHDHV, 2022*

***The thermal runaway probability of a refurbished LIB compared to an original LIB***

In order to estimate the thermal runaway probability of a refurbished LIB compared to an original LIB, DNV has investigated 17 LIB for electric bicycles on behalf of BuRO (DNV, 2023). Of the 17 LIB, 12 had been refurbished. The 5 original LIB served as reference material. In its research, DNV distinguishes between revision and refurbishment. 'Revised' means that the LIB is offered by a customer for refurbishment. 'Refurbishment' means that a company collects batteries, revises them, and sells them to random customers. This distinction is not relevant for this risk assessment.

DNV notes:

- When revising an LIB, a higher capacity than the capacity of the original can be chosen. This means that a larger number of battery cells will be placed in the package. This makes the internal structure and configuration unpredictable. For example, shock absorption material may have been removed.
- Sometimes the BMS needs to be replaced during refurbishment. But making the choice for a particular BMS is not standardized. DNV also found a non-CE-certified BMS.
- The location of the temperature sensor may have changed, so that the temperature measured by the BMS is not the actual temperature of an LIB cell.
- The refurbished LIB may differ from the original in such a way that the data on the housing no longer corresponds to the interior.

On the basis of the LIB examined, DNV concludes that the original LIB are better structured and more robust than the refurbished LIB. One refurbished LIB turned out to have a similar quality to the original. The changes in the refurbished LIB can cause electrical, mechanical or thermal overload to occur earlier or more easily, or to be detected by the BMS too late or not at all. In addition, DNV notes that the consumer does not receive sufficient information about the quality and changes of the LIB after refurbishment.

In its research for BuRO, RHDHV also looked at the market for the refurbishment of LIB for electric bicycles and the processes used in it. RHDHV identifies the following points in the refurbishment of LIB:

- Incorrect or incomplete diagnoses at the start of the refurbishment process, for example by diagnosing the LIB cells but not the software of the BMS;
- Careless and incomplete work, such as (partial) replacement with lower quality LIB cells, insufficient repair of the BMS or faults in repairing the structure;
- The refurbished LIB is not sufficiently tested for, for example, charging and discharging the LIB or there is no check on the charger;
- Unsafe transport, where an LIB is exposed to temperature fluctuations, shocks and/or humidity.

RHDHV also points out that there is insufficient knowledge about the risks of (refurbished) LIB for electric bicycles. This holds for the bicycle sellers, the refurbishment companies and the consumer.

Organisations like RAI, BOVAG and fire brigade do pay attention to increasing consumer awareness, for example on the website iklaadaccuraat.nl. For example, the consumer is informed about the need for maintenance after the LIB has fallen or has been damaged and about the environment in which the LIB can best be charged. There is no information about to what extent specific attention is given to refurbished LIB. It is therefore unlikely that a consumer is extra aware of any vulnerabilities of a refurbished LIB compared to an original LIB.

Based on the results of the studies of DNV and RHDHV, BuRO considers it plausible that the probability of the hazard, a thermal runaway, is higher for a refurbished LIB than for an original LIB.

In summary, for the 4 aspects introduced at the beginning of this section as relevant to the exposure, the estimation is as follows:

- The number of electric bicycles with an LIB is increasing;
- There are signs in the media and on the basis of data on the probable cause of house fires that the number of incidents with LIB in electric bicycles is increasing;
- It is expected that the share and thus the number of refurbished LIB in electric bicycles will increase;
- It is plausible that the probability of a thermal runaway of a refurbished LIB is greater than of an original LIB.

It is therefore to be expected that the exposure to a thermal runaway will increase with refurbished LIB.

## Risk characterisation

The use of LIB poses a risk to users and bystanders. This risk exists for all (new and refurbished) LIB. Due to overloading of an LIB, a thermal runaway can occur, resulting in a fire, explosion and/or toxic gases that are released, causing users and bystanders to be injured or poisoned. In Annex 1, for the gases hydrogen fluoride and carbon monoxide, it is derived that the concentrations of these gases in the event of an LIB fire for an electric bicycle in a home situation can pose a health risk to the consumer, even with fatal consequences. The estimated concentrations of these gases in an average living room exceed the limits known for these substances.

Based on the studies carried out on behalf of BuRO, it is plausible that the probability of a thermal runaway is greater for refurbished LIB. Refurbished LIB appear to have a higher chance of abnormalities or an incorrectly tuned BMS. The complexity of the legal framework and the lack of clarity about or specific standards for refurbished LIB contribute to this.

The risk to public health from the use of (refurbished) LIB is currently not quantifiable. This is due to the fact that there is insufficient information to estimate the probability of a thermal runaway of a (refurbished) LIB. There is also limited information on the toxicity of and exposure to the gases released during a thermal runaway. In addition, detailed information on incidents with (refurbished) LIB is missing.

BuRO expects that – without further measures – the risk to public health will increase as the chance of incidents with refurbished LIB in electric bicycles will increase. This chance will increase as the number of electric bicycles continues to increase and also due to the expected increase in the share of refurbished LIB.

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## Abbreviations

| Abbreviation | Description |
|---|---|
| **BMS** | Battery Management System |
| **BuRO** | Office for Risk Assessment and Research ("Bureau Risicobeoordeling & onderzoek") |
| **CAS** | Chemical Abstract |
| **CBS** | Centraal Bureau voor de Statistiek |
| **CLP** | Classification, Labelling and Packaging |
| **CO** | Carbon monoxide |
| **DNEL** | Derived No Effect Level |
| **EC** | Europese Commissie |
| **ECHA** | Eurpean Chemicals Agency |
| **EFSA** | European Food Safety Authority |
| **EV** | Electric Vehicle |
| **$H_3PO_4$** | Phosphoric acid |
| **HF** | Hydrogen fluoride |
| **I&W** | Ministry of Infrastructure and Water Management |
| **ILT** | Human Environment and Transport inspectorate |
| **LEV** | Light Electric Vehicle |
| **$Li_2O$** | Dilithium oxide |
| **LIB** | Lithium-ion battery |
| **LiF** | Lithium fluoride |
| **LiOH** | Lithium hydroxide |
| **$LiPF_6$** | Lithium hexafluorophosphate |
| **NIPV** | Netherlands Institute for Public Safety |
| **NTA** | Dutch Technical Agreement |
| **NVIC** | Dutch Poisons and Information Centre |
| **NVWA** | The Netherlands Food and Consumer Product Safety Authority |
| **OECD** | Organisation for Economic Co-operation and Development |
| **$PF_5$** | Phosfor pentafluoride |
| **$POF_3$** | Phosphoryl fluoride |
| **RIVM** | National Institute for Public Health and the Environment |
| **SCOEL** | Scientific Expert Group on Occupational Exposure Limits |
| **SOA** | Safe Operating Area |
| **VWS** | Ministry of Health, Welfare and Sport |

## Annex 1 Health risks of substances formed during lithium ion fire



In case of a thermal runaway in a lithium-ion battery (LIB), the temperature rises and an LIB can ignite. This can result in smoke and gases, which in case of inhalation can potentially lead to health risks. A number of incidents have been described in the media, in which people have inhaled these smokes and gases. In Oegstgeest, six people, including two children, were taken to the hospital in May 2024 after inhaling the smoke from an LIB fire. In Sweden, an incident was reported in which an LIB for an electric bicycle exploded in an apartment, after which seven people were hospitalized due to possible inhalation of hydrogen fluoride.

According to the National Institute for Public Health and the Environment in The Netherlands (RIVM), a fire with LIB releases a cocktail of (hazardous) substances (van Veen et al., 2019), including hydrogen fluoride, lithium hydroxide and dilithium oxide. In addition, substances/gases can be generated by combustion of other parts of the LIB, for example a plastic casing, which may contain flame retardants. However, the focus for this advice is on the substances that can arise from substances present in the electrolyte. This risk assessment assesses the health risks that can arise from an LIB fire in a home situation.

For this risk assessment, the four steps of the risk assessment have been followed, as described in the BuRO methodology for risk assessment of chemicals in consumer products: hazard identification, hazard characterisation, exposure assessment and risk characterisation.

### Hazard identification

The electrolyte used in an LIB is a lithium salt dissolved in a mixture of organic solvents (Li et al., 2016). Typically, this electrolyte consists of lithium hexafluorophosphate (LiPF6) and a mixture of non-aqueous organic alkyl carbonate solvents (ethylene carbonate, dimethyl carbonate, diethyl carbonate and ethyl methyl carbonate), which are highly flammable (Larsson et al., 2017; Qiao et al., 2020). In case of a thermal runaway, the electrolyte will evaporate and eventually be released from the battery cells. The gases can then ignite. Carbon monoxide and carbon dioxide are released, among other things by combustion of the organic solvents.

In the case of a thermal runaway, the temperature rises and, at this temperature increase, Larsson and colleagues observed the release of fluorinated gases (Larsson et al., 2017). At these higher temperatures, the lithium hexafluorophosphate in the electrolyte may form fluorinated gases, such as hydrogen fluoride (HF), phosphorus pentafluoride (PF5) and phosphoryl fluoride ($POF_3$), see Figure 6 (Guéguen et al., 2016; Bertilsson et al., 2017; Larsson et al., 2017; Qiao et al., 2020). The formed phosphorus pentafluoride and phosphoryl fluoride can react even further to hydrogen fluoride. Phosphoric acid ($H_3PO_4$) and lithium fluoride (LiF) are also formed. The formed flue gas may also contain lithium, which can form lithium hydroxide and dilithium oxide during extinguishing.

$$LiPF_6 \rightarrow LiF + PF_5$$

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$

$$POF_3 + 3\ H_2O \rightarrow H_3\ PO_4 + 3\ HF$$

*Figure 6: Reactions of $LiPF_6$ into Fluorine-containing gases (Bertilsson et al., 2017)*

### Hazard characterisation

Information on the toxicity of these substances can be found on the website of ECHA, EFSA, RIVM, NVIC and OECD. It has been investigated whether a Dutch intervention value for incident control has been derived by RIVM for inhalatory exposure to these gases (Mahieu et al., 2025). Furthermore, PubMed has been used to seek for additional scientific information about these substances and emissions of these substances from LIB.



*Hydrogen fluoride (HF)*

Hydrogen fluoride (Chemical Abstract (CAS) No 7664-39-3) is a corrosive and toxic gas according to Annex VI of the CLP (Classification, Labelling and Packaging) Regulation (EC) No 1272/2008[14]. In contact with the skin or eyes or mucous membranes, hydrogen fluoride primarily acts as a corrosive substance. As a secondary effect, tissue necrosis can then occur, caused by the free fluoride ion in the tissues (SCOEL, 1998). According to information on the website of the Dutch Poisons Information Centre (NVIC), hydrogen fluoride is an acid that, unlike many other acids, can penetrate deeper into tissues and therefore also affect deeper tissue. Health problems experienced from inhaling hydrogen fluoride-containing smoke include stimulant cough, irritation of the skin and mucous membranes of eyes, nose, throat and airways with redness, tearing, and sore throat. In more severe cases, retrosternal pain, tachypnosis, dyspnoea, bronchospasm, stridor, asphyxia due to glottis and larynx edema, and chemical pneumonitis may occur.

In 2012, a company accident in South Korea exposed a number of workers and a large number of local residents to hydrogen fluoride (Shin et al., 2021). This resulted in the death of five people and at least 18 injured on site. In addition, a large number of local residents were also admitted to the hospital. Burns and respiratory damage were the main injuries.

In the REACH registration dossier, the applicant indicated that for acute (60-minute) inhalation toxicity, a Derived No Effect Level (DNEL) of 0.03 mg/m$^3$ has been derived based on studies in rats. DNEL is the level of exposure at which a substance does not harm human health. It should be noted that the information from the registration was provided by the registrant and that these dossiers were not checked for accuracy by the European Chemicals Agency (ECHA).

For hydrogen fluoride, RIVM has established a life-threatening intervention value at 10 minutes of exposure of 150 mg/m$^3$ (Mahieu et al., 2025).

*Phosphorus pentafluoride ($PF_5$)*

Phosphorus pentafluoride (CAS No 7647-19-0) is a pre-registered substance according to REACH Regulation (EC) No 1907/2006[15]. The notified classification according to the CLP Regulation (EC) No 1272/2008 is that phosphorus pentafluoride is a corrosive and toxic gas. No further toxicological data have been registered with ECHA. No toxicological data was found at EFSA, RIVM, NVIC and OECD.

According to Maken and Saini, exposure to phosphorus pentafluoride causes dizziness, coughing, shortness of breath, nausea, bluish skin color, lung congestion, kidney damage, and mucous membrane damage (Maken & Saini,

[14] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006. OJ L 353, 31.12.2008, p. 1–1355.

[15] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. OJ L 396, 30.12.2006, p. 1–849.

2021). Higher exposure can cause fluid accumulation in the lungs and displace oxygen, which can lead to suffocation. No standards or health-related limit values have been found for this substance.

*Phosphoryl fluoride ($POF_3$)*

Phosphoryl fluoride (CAS No 13478-20-1) is a pre-registered substance under REACH. No further information on this substance is available on ECHA's website. According to Guénguen and colleagues, phosphoryl fluoride is a reactive intermediate that can react to generate hydrogen fluoride (Guéguen et al., 2016). A health-based guidance value for acute exposure has not been found.

*Carbon monoxide (CO)*

Carbon monoxide (CAS No 630-08-0) is classified in accordance with Annex VI of CLP Regulation (EC) No 1272/2008 as toxic by inhalation and reprotoxic (may impair fertility or the unborn child). Carbon monoxide reversibly binds to hemoglobin in which HbCO is formed, leading to a reduced binding capacity of hemoglobin for oxygen. As a result, oxygen transport in the blood and the release of oxygen into the tissues decreases. Hypoxia can lead to local tissue damage. In organs with a high oxygen demand, such as the heart and brain, the first effects occur.

For short-term acute exposure (15 minutes), workers are subject to a limit value of 117 mg/m$^3$ according to Directive 2004/37/ EG[16]. This value is based on the advice of the Scientific Expert Group on Occupational Exposure Limits (SCOEL) on carbon monoxide (SCOEL, 1995). For incidents, RIVM has established a life-threatening value of 2000 mg/m$^3$ at exposure up to 10 minutes, above which mortality or life-threatening conditions may occur (Mahieu et al., 2025).

*Lithium hydroxide (LiOH) and dilithium oxide (Li2O)*

Lithium hydroxide (CAS No 1310-65-2) is a strong base and a corrosive substance. This substance is registered under REACH Regulation (EC) No 1907/2006. The notified classification of lithium hydroxide is corrosive to the skin and eyes, harmful to ingestion and skin contact. According to the registration dossier, an $LC_{50}$ value of 3400 mg/m$^3$ for inhalation exposure was derived from an acute inhalation study in rats exposed for 4 hours. After 14 days, the following clinical signs were observed: Abdominogenital discoloration, head/neck alopecia, ataxia, chromodacryorrhoea, chromorhinorrhoea, reduced stool, reduced propulsion, diarrhoea, dyspnoea, tear production, necrotic muzzle, oral discharge, rhonchi, squinting eyes, swollen muzzle and lethargy. Only a DNEL for long-term inhalation exposure is indicated in the registration dossier: 6.21 mg/m$^3$.

Dilithium oxide (CAS No 12057-24-8) is registered under REACH Regulation (EC) No 1907/2006. According to the notified classification, this substance is classified as corrosive to the skin and eyes and toxic by inhalation. The REACH registration dossier contains an LC50 value of 940 mg/m$^3$, derived from an animal study in rats. These rats were exposed to an aerosol with a concentration of dilithium oxide ranging from 500 to 1500 mg/m$^3$ for 4 hours. The following clinical effects were observed 14 days after this exposure: Excessive salivation and nasal mucus secretion, coughing and choking, breathing difficulties, including audible mouth breathing, crusting of blood and mucus around the eyes and nose, slowing of the erecting reflex and general lethargy. A DNEL is not derived.

[16] Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC) (codified version). OJ L 158, 30.4.2004, p. 50–76.

According to the information from NVIC, lithium hydroxide and dilithium oxide are strong bases and the local effects after inhalation of lithium hydroxide-containing aerosols (extinguishing) water are similar to the effects of hydrogen fluoride. No studies were found on the amount of lithium hydroxide and/or dilithium oxide released during an LIB fire.

*Lithium fluoride (LiF)*

Lithium fluoride (CAS No 7789-24-4) is a pre-registered substance according to REACH Regulation (EC) No 1907/2006. The notified classification according to CLP Regulation (EC) No 1272/2008 is that lithium fluoride is an irritant to skin, eyes and respiratory tract. No further toxicological data have been registered with ECHA. No toxicological data were found for EFSA, RIVM, NVIC and OECD.

*Phosphoric acid ($H_3PO_4$)*

Phosphoric acid (CAS No 7664-38-2) has a harmonised classification according to CLP Regulation (EC) No 1272/2008 as corrosive to skin and eyes. This substance is registered under REACH Regulation (EC) No 1907/2006. In this registration dossier, long-term exposure is a DNEL of 4.57 mg/m$^3$. It is based on a NOAEC 457.42 mg/m$^3$, from an animal study in rats with a critical endpoint of renal calcification.

For acute exposure (15 minutes), a limit value of 2 mg/m$^3$ applies to workers. This is based on a SCOEL opinion (SCOEL, 1991).

For phosphoric acid, RIVM published a life-threatening value of 300 mg/m3 at a 10-minute exposure (Mahieu et al., 2025).

**Exposure assessment**

For hydrogen fluoride, phosphoryl fluoride and carbon monoxide, emission values for LIB fires have been found in literature. An exposure estimate can be made for these substances. Not for the other formed substances.

According to the Consumentenbond, LIB normally has a capacity of 300 to 600 Wh for an electric bicycle, but there are also batteries of 720 Wh. According to the General Fact Sheet, the volume of an average living room in the Netherlands is 74 m$^3$ (Te Biesebeek et al., 2014). This is, on average, the largest space in a Dutch house. The LIB may be charged in another room in the house, such as the (utility) kitchen or the garage. The living room has been chosen, because this is a space where people are often present.

With these parameters (capacity of 720 Wh and a space of 74 m$^3$), the exposure estimate is calculated for the substances for which emission values have been found.

*Hydrogen fluoride (HF)*

Larsson and colleagues measured that large amounts of hydrogen fluoride are released during the fire of an LIB, ranging from 20 to 200 mg/Wh nominal battery energy capacity (Larsson et al., 2017). Claassen and colleagues measured a hydrogen fluoride emission of 10–81 mg/Wh (Claassen et al., 2024). This is in the same order of magnitude. Bugryniec and colleagues provided an overview of reported emissions of various gases resulting from an LIB fire (Bugryniec et al., 2024). A distinction is made between different types of anodes in the LIB. The highest hydrogen fluoride emission was found for LIB with an anode of lithium iron phosphate (LFP), up to 150 mg/Wh.

In a worst-case scenario (720 Wh LIB, emission of 200 mg/Wh), a fire of an LIB results in a total hydrogen fluoride emission of 144 g (720*200=144,000 mg). This results in a concentration of 1945 mg/m$^3$ of hydrogen fluoride.

*Phosphoryl fluoride ($POF_3$)*

Larsson and colleagues measured 15-22 mg/Wh phosphoryl fluoride in fire tests with an LIB (Larsson et al., 2017). The calculated amount of released phosphoryl fluoride (15.8 g) results in a concentration in an average living room of 214 $mg/m^3$.

*Carbon monoxide (CO)*

Bugryniec and colleagues provided an overview of reported carbon monoxide emissions resulting from an LIB fire (Bugryniec et al., 2024). For LIB with an LFP anode, emissions up to 90 mg/Wh were found. For LIB with an NMC anode, much higher emissions were reported: depending on the state of charge up to almost 400 mg/Wh.

The highest estimated amount of carbon monoxide released from an LIB by fire (emission 400 mg/Wh; capacity 720 Wh) is then 288 g. This results in a carbon monoxide concentration of 3900 $mg/m^3$.

**Risk characterisation**

Quantitative risk characterisation can only be carried out for substances where an exposure estimate and a health-based limit value for acute inhalation exposure are known.

For hydrogen fluoride, the worst-case exposure estimate is 1945 $mg/m^3$. This is well above the DNEL for acute exposure of 0.03 $mg/m^3$, which can create an acute health risk in the event of an LIB fire. And well above the life-threatening intervention value of 150 $mg/m^3$.

The worst-case exposure to carbon monoxide is estimated at 3900 $mg/m^3$. This is well above the acute (15-minute) short-term exposure limit for workers (117 $mg/m^3$), and also almost a factor of two higher than the life-threatening value of 2000 $mg/m^3$ applicable to incidents. This means that a fire from an LIB in a living room (or smaller space) can potentially cause death or life-threatening conditions due to the release of carbon monoxide.

The risk of the other substances that can be formed during a thermal runaway of an LIB can only be qualitatively outlined. Most of these substances are classified in the CLP hazard category corrosive and toxic by inhalation. When these substances are present in a smoke, a potential health risk may arise from inhalation and skin contact.

**Conclusions**

In the case of ignition/thermal runaway of an LIB in a home situation, the combustion gases can form carbon dioxide and carbon monoxide. In addition, the lithium salt in the electrolyte can form toxic gases, including hydrogen fluoride. For a bicycle battery (capacity 720Wh) in a living room (74 $m^3$), the amounts of hydrogen fluoride and carbon monoxide released can pose a health risk to consumers, even leading to fatalities.

Phosphorus pentafluoride, phosphoryl fluoride, lithium hydroxide, lithium oxide, lithium fluoride and phosphoric acid can also be formed. For these substances, there are too few data in terms of toxicology of the substances and/or exposure to carry out a quantitative risk assessment. Based on the hazard properties of these substances, a health risk cannot be excluded.

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## Annex 2 Literature research

Office for Risk Assessment & Research

**Date**
16 June 2025

**Our reference**
2025-010042486

In December 2024, Scopus and Google Scholar have been searched for the following search terms in the title, summary and keywords. It has been delimited to publications from 2020 onwards in order to limit the search result to the most recent publications.

Given the search results, it has been assessed based on the summaries of publications, which publications are relevant for this research.

Results for search terms such as 'remanufacturing' or 'refurbish' usually refer to *how* refurbishment can be done and not to the risk of using refurbished batteries.

In addition, for the health risks of substances formed during lithium-ion fire as described in Annex 1, specific relevant literature has been sought.

| **Search terms** | **Number of search results** | **Included as reference** |
|---|---|---|
| "lithium ion battery" AND "safety" | **Scopus: > 10.000**<br>**Scholar: > 10.000** | **(Chen et al., 2021)** |
| "battery management system" AND "safe operati* area" | **Scopus: 14**<br>**Scholar: 60** | **(Kamboj et al., 2024)** |
| "safe operati* area" AND "lithium ion" | **Scopus: 15**<br>**Scholar: 94** | **(Sarkar et al., 2024)** |
| "thermal runaway" AND "lithium ion" AND "fire" AND "gas" AND "explosion" | **Scopus: 110**<br>**Scholar: > 5.000** | **(Huang et al., 2025)** |
| "thermal runaway" AND "lithium ion" AND ("risk" OR "hazard") AND "vehicle" | **Scopus: 270**<br>**Scholar: >10.000** | |
| "thermal runaway" AND "lithium ion" AND ("risk" OR "hazard") AND ("light electric vehicle" OR "bicycle" OR "bike") | **Scopus: 6**<br>**Scholar: 375** | |
| "lithium ion" AND ("refurbish*" OR "remanufacture*") AND ("safety" OR "risk" OR "hazard") AND ("light electric vehicle" OR "bicycle" OR "bike") | **Scopus: 0**<br>**Scholar: 799** | |