RÄDDNINGSTJÄNSTEN
STORGÖTEBORG

# Accident investigation

*Fire in container for battery energy storage, Gothenburg 2023-04-26*


*Investigator*

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*Date/Version*

*2023-10-10 Final version*

**ACCIDENT INVESTIGATION**

Fire in container for battery energy storage
Sisjön industrial area
Gothenburg
2023-04-26

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| Reference Incident report: | G2023.045651 | |
| SOS Case number: | 19.10663457.2 | |
| Client: | Anders Ekberg | Rescue manager |
| The investigation carried out by: | Carl-Fredrik Lindahl | Accident investigator |
| | Goran Kallin | Accident investigator |
| Reference persons: | Jonas Olsson | Fire engineer |
| | Per-Albin Halldin | Work environment coordinator |
| | Helena Grimm | Environmental strategist |
| | Patrick Sonberger | Fire engineer |

# SUMMARY

A thermal runaway started in a battery cell connected to a large lithium-ion battery energy storage unit housed in a 20-foot container. The rush created a cloud of smoke and then a powerful explosion. When the explosion occurred, rescue personnel were in the immediate vicinity. No one was injured in the explosion.

Energy storage in lithium-ion batteries is a relatively new energy storage system, but one that is expected to increase in the near future. The investigation shows a number of areas of development within fire and rescue that urgently need to be taken care of in order to prevent fires and create safer work in the event of a possible future rescue effort.

The investigator believes that an individual municipal rescue service does not have the opportunity to drive this development on its own, but sees a need for national cooperation between authorities, rescue services, manufacturers and users to achieve national guidelines for preventive fire protection and safety in the event of a rescue operation. Work on the review of national guidelines has already begun and the investigator hopes that results from this work will help the local rescue services to work more clearly and safely going forward.

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# 1 INTRODUCTION

## 1.1 Background

On April 26 at lunchtime, a 112 call is received to SOS Alarm/LC about a fire/smoke development from a larger container that contains lithium-ion batteries and is located indoors at a company in Sisjön's industrial area. When the emergency services arrived at the property, continued fire/smoke development was noted, however, the company's staff managed to move the container out of the building.

## 1.2 Purpose

The aim is to be able to gather experience from rescue efforts in connection with fires in lithium ion batteries. This basis shall then be used for learning and further development of our operational activities and provide the preventive activities with basis for further management in this subject area.

## 1.3 Questions

- Description of the course of events and the execution of the operation
- Describe the implementation of the operation with regard to the choice of tactics and methods linked to the size of the lithium-ion batteries
- The level of knowledge of responding officers/fire personnel with regard to the organization's produced documents/guidelines and completed training sessions?
- Work environment impact with respect to possible contamination by fire smoke and explosion?
- Was the intervention affected by special risks linked to the extinguishing water?
- Describe handling and storage at the operator linked to building technical fire protection and describe possible experiences linked to the same

## 1.4 Limitations

The cause, course of fire with lithium-ion batteries, organization of rescue efforts and VMA management will be described more comprehensively. Parts of the investigation consist of factual evidence that can be processed further within the association to provide knowledge and important lessons learned in this area.

## 1.5 Accounting plan

The work must result in a written report to the client no later than September 30, 2023. The investigation must be partially reported in the FIR group according to add. Investigation is also sent to MSB.

### 1.5.1 Served to

- Current company
- RISE

# 2 METHOD

The following documentation has been studied:

- Event report from current event
- Internal guideline in case of fire in lithium-ion batteries
- Guidance, rescue operation where lithium-ion batteries are present
- International reports from similar events
- National reports on work with guidelines and environmental impact
- Investigations from involved actors
- Legislation and regulations

The following functions have been interviewed:

- Firefighters
- Force leader
- Operation leader
- Regional operations leaders
- Officer in charge
- Emergency manager on duty

Other reference persons:

- Representative from affected organization
- Representative from the supplier of the cutting tool
- Representative from Utkiken.net

# 3 INVOICE

## 3.1 Description of the accident scene

The incident occurred in the Sisjön industrial area located in Västra Frölunda, Gothenburg. An area with many large shophouses and smaller to medium-sized industrial properties. It can be expected that there will be a lot of people in the area for large parts of the day, even people without area or local knowledge. The area is bounded by a traffic route in the north, a golf course in the east and various types of housing developments in the south and west. The location in question was in the eastern part of the area and the wind direction at the time was favorable in relation to the large commercial buildings and residential buildings that were mostly south and west of the accident site. Current building and its nearest neighbors were smaller industrial and office buildings in one or two floors of building class (BR2-3). The buildings were separated by paved areas for staging, loading/unloading and parking. There was a certain difference in level between the different businesses. The building in question was in class BR2 and was a combined warehouse/ manufacturing and office building on two levels where the warehouse part was on one level for the entire height of the building. Next to the warehouse/manufacturing part were two larger gates for ingress and egress. In addition to the normal fire protection in the form of indoor fire hydrants, hand fire extinguishers and smoke hatches, the building also had a burglary and fire alarm with cameras.

*Figure 1 shows an overview of the area. Source Land Survey*

### 3.1.1 Description of the battery energy storage

Inside the warehouse part of the building was, among other things, a 20-foot uninsulated steel container set up on wheels. Half of the container contained a battery energy storage consisting of many battery cells assembled into larger battery strings. There were ten battery strings connected to a large battery unit with an energy content of up to 875 kWh and which weighed approximately 9 tonnes. The other half of the container was empty. The battery energy storage was under construction and not commissioned, i.a. a software for the batteries was not supplied by the battery manufacturer. The batteries were charged to a delivery voltage but were not fully charged.

An air/liquid cooling system with the purpose of cooling the batteries during operation was mounted in the container but not commissioned or connected to mains voltage. The container's doors on one end were open. In the middle of one long side of the container was a water inlet with a coupling that fit the hoses of the rescue service. The pipe then went up inside the container over the battery unit.

**3.2 The course of the accident**

Just before lunch, staff in the warehouse noticed thin white smoke coming from the far side of the container where the battery unit was located. The staff on site raised the alarm internally about the incident and immediately began to move the container out of the premises using the wheels the container was on and a truck. In connection with this, the emergency services were also alerted via SOS alarm. The white smoke increased and began to fill the storage area. The location of the container inside the premises was just inside one of the gates but it had to be turned 90 degrees to get out through the gate. During this part of the move, the container came off the wheels it was set on, making it difficult to move the container out. When the emergency services arrived at the scene, the staff had managed to get more than half the container out through the gate and quite soon after that the whole thing was out and the extinguishing operation began.

### 3.2.1 Accident causes

RSG has received two investigations from the actors involved. One from the company in Sisjön and one from the international battery supplier. Both investigations point to the most likely cause being that when the batteries' cooling system is pressure tested after installation, a leak has occurred inside a battery cell, which in turn caused a short circuit with thermal rush as a result. The conclusions from both investigations can be read in their entirety in the original language (see appendices 1 and 2).

### 3.2.2 Consequences of the accident

Several people from the company inhaled varying amounts of fire smoke during the earliest part of the fire. However, no one needed emergency medical care. The building and its contents suffered minor smoke damage during the early part of the accident. The container in question with its contents was completely destroyed. An unknown amount of contaminated extinguishing water flowed out, the largest part via the stormwater wells that were in the yard. The building's facade was affected by heat, extinguishing water and smoke. The investigation has no information about the economic or psychological consequences of the accident.

## 3.3 Execution of the rescue operation

At 11:37 a "big alarm, fire in battery container" went off at the Frölunda fire station, which was the nearest station in time. They moved out with rescue unit (RE) and height unit (HE), where HE is immediately turned by the command center (LC) to be exchanged for water unit (VE). Mölndal's fire station was alerted at the same time and they also went with RE and VE. During the drive-up, the staff formed the image that it was a container containing smaller batteries, possibly a collection container for used batteries. They were reached by the information that personnel on site are trying to move the container out into the open. The force leader in RE from Mölndal

advised that they used a spare car that did not have a fire extinguisher. The incident leader (IL) from Mölndal was also alerted. Arriving at the site (at 11:44), Frölunda was met and shown behind the building. There they saw that the container was halfway out and the company's staff worked to get it out completely, which they succeeded in doing shortly after. The container was now outside the building and the fire personnel saw that the door on the end of the container was open and white smoke was coming out. Personnel from the company described the contents of the container to the force leader and that there was an entry for extinguishing water on the long side of the container, this to be able to sprinkle and fill the container with water if necessary and thus destroy all the batteries inside the container. This entry was connected but not started.

*Picture 2 shows the container early in the operation. Source RSG*

At the same time, the rescue unit was established at the entrance to the farm. The open door of the container was closed and they prepared to cool and inert the smoke gases inside the container with cutting extinguishers. Cooling/inerting of the smoke gases began and the attack was made centrally on the long side of the container high up so as not to risk also penetrating the batteries.

IL was in the car when he received the alarm (at 11:41). He contacted the command center and asked them to produce the internal guideline concerning Lithium-ion batteries. The information he received from the LC was that inhalation of the fire smoke was seen as the main risk and that any fire that did occur could be very difficult to extinguish. During the approach he also requested Unmanned Aerial System (UAS) from Lindome fire station. IL arrived at the scene of the accident at the same time as RE from Mölndal (at 11:50) and received more information there regarding the size of the batteries, where, among other things, it appeared that the entire battery weighed approximately nine tons. Cooling/inerting of the battery and its surroundings had begun with a cutting extinguisher and with it they shot diagonally upwards towards the roof of the container to avoid hitting the battery. IL continued as rescue manager (RL) and in connection with a short management meeting,

about 4 – 5 minutes after cooling with cutting extinguishers started, a strong explosion occurred which deformed the container and where the doors on one short side of the container flew open.

*Image 3 shows a clip from a film that captured the explosion. Source current company*

No people were injured in the explosion. Everyone was immediately ordered to back away and that the continued work would take place under cover. Favorable winds meant that you could work with the wind at your back.

*Figure 4 shows smoke development and work from a protected position. Source RSG*

Zoning was determined and communicated and where compressed air equipment would be used in the hot zone and a so-called half mask in the hot zone. With the help of the police, the adjacent building was evacuated and the people who were staying in properties further away but still in the direction of the wind were informed to stay indoors.

In connection with the explosion, the development of smoke increased significantly and they could now see open flames from the batteries. The new orientation meant that resources were now also being put into limiting the fire's spread to adjacent buildings. This was carried out by cooling facades and roofs with water from jet pipes and water cannons.

After dialogue between RL and RIL, RIL went to the scene of the accident. IL from Lundby fire station was inside LC and was there helping with staff work. IL contacted i.a. the rescue leader and handed over contact details to a couple of people who could contribute knowledge/information. Among other things, what was conveyed to the scene of the accident was that there was no point in cooling the batteries as long as the temperature stayed below a certain given temperature. Applying water in that situation only created further problems with increased amounts of contaminated extinguishing water.

RIL came out to the scene at about 12:30 and continued as RL and IL became large sector manager. RL decided to request an Important Public Notice (VMA) to warn people about the suspected hazardous smoke. The request came in to the LC and was then handled further by the duty officer (VB) according to instructions. VMA went out at 1:15 p.m.

The work progressed for a couple of hours where, among other things, neighboring properties were checked. A number of gas cylinders were proactively moved and an hour later the container was also moved away from the facade with the help of a truck.

*Picture 5 shows the new location of the container. Source RSG*

The temperature in the batteries was continuously checked and it was found that the conditions were becoming more and more favorable. Well seals were laid to limit extinguishing water from flowing into the stormwater wells. Later, a suction truck was used to dispose of the extinguishing water and transport it to purification or destruction. Relief began and sometime after At 16:00 there was a new RL on site and also a new IL in the role of large sector manager. RL tried here, in cooperation with the business and with a representative from the property owner, to get a container that could be filled with water and lifted down the batteries into. It could not be arranged during the evening, so instead it was decided to cut the fastenings in the container and lift

out the batteries to enable more efficient cooling if needed. The company also stated here that an expert from the battery supplier would arrive during the day tomorrow, approx. one day after the fire started. The temperatures remained low during the evening, approx. 20 degrees, and during the night only one VE and two firefighters were needed on site for surveillance. Throughout the night, the temperature in the batteries was around 14–15 degrees and ongoing IL was tasked with ending the rescue operation, which was done at 09:00 after evaluation of the four criteria for emergency services.

After just over 1.5 hours after the end of the rescue operation, a new 112 call was received, where it emerged that smoke had once again started to come from the batteries. RSG started a new rescue effort where initially a risk distance of 50 m was kept and the plan was once again to get a container that could be filled with water and then submerged in the batteries. They had contact with expertise that meant that in itself is there any additional danger with this type of reboot other than just continuing to cool. A few hours later, the company had produced a container that was coated on the inside with pressing and then filled with water. With the help of a crane truck, the battery was then lowered in its entirety for cooling.

*Picture 6 shows the battery immersed in a water bath. Source RSG*

After that, the rescue service ended and the responsibility was handed over to the business at 14:40 on 27 April 2023.

## 3.4 Legislation

Below is a brief description of the laws that the investigator believes regulate or may affect emergency services in the event of battery energy storage events. Legislation and regulations have not kept up with the rapid development in the area and right now a number of works are underway to quickly bring about an adaptation to societal development regarding "electrification", i.e. solar cells, energy storage, electric vehicles, etc.

Battery energy storage can take place in several different ways. Indoors, it can e.g. be a room integrated into the building or perhaps a container that stands freely on a workshop floor.

Outdoors, it is often a question of storage in a container. Larger facilities or BESS parks (BESS-Battery Energy Storage Systems) can consist of container systems, i.e. a larger number of containers or parks with cabinet-like storage spaces where the batteries are stored.

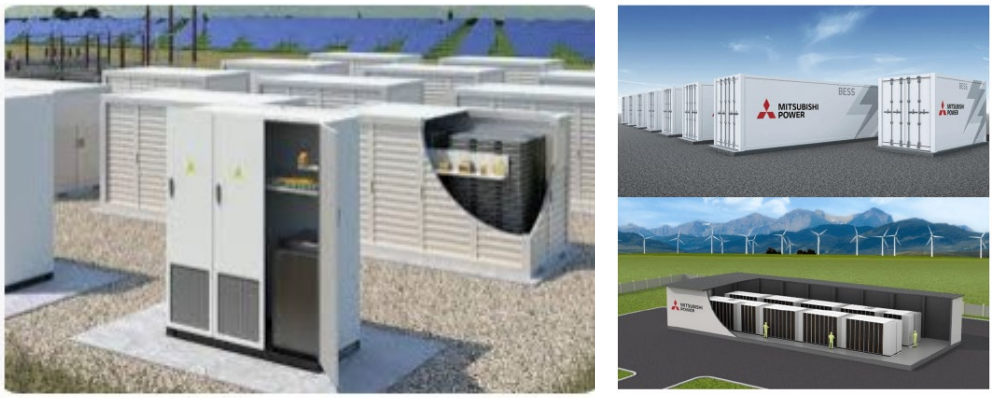


*Figure 7 shows different energy storage methods. Source Bender UK*

As far as upcoming regulations are concerned, there are thus many different cases to take into account.

#### 3.4.1 The Housing Agency's building regulations (BBR)

The last major change to the building regulations came into force in 2012 and the fire protection regulations in BBR were drawn up based on a preliminary study that was done in 2006. Since then, a lot has happened regarding new technology and the current BBR is not designed with regard to knowledge of e.g. solar panels and charging vehicles or energy systems and their possible risks. There is thus no specific regulation in the BBR on energy storage with batteries. There is also no guidance or equivalent from the Housing Agency. In BBR, however, there are some generally formulated regulations that may be applicable. One such regulation is the requirement for fire cell division in buildings in section 5:53 BBR. Even if energy storage or the equivalent is not enumerated in general advice, it can be argued that the regulation may be applicable.

The Housing Authority is currently working on a review of the rules on fire protection, current section 5 of the BBR. It is a sub-project in the building regulations of the possibilities, which shall transfer the current building regulations to a new, simplified model. One area of several that the Swedish Housing Agency is reviewing is new technology such as solar panels, energy storage and charging vehicles. With regard to energy storage, the following proposals from the Housing Authority are to be introduced in BBR. The proposal means that energy storage of the type lithium-ion batteries with a total storage capacity > 20 kWh must be carried out as its own fire cell and with fire sluices to escape routes that serve other businesses. Limiting at 20 kWh aims to limit the consequences in the event of a fire. The Housing Authority also proposes a general requirement that facilities that pose a particular risk to rescue personnel must be marked with signage.

### 3.4.2 Accident Protection Act (LSO)

The act on protection against accidents aims to prevent accidents and learn from accidents and develop/manage rescue efforts.

*LSO 2:2 The owner or usufructuary of buildings or other facilities must, to a reasonable extent, keep equipment for extinguishing fires and for saving lives in the event of a fire or other accident and otherwise take the measures necessary to prevent fire and to prevent or limit damage to consequence of fire.*
Owners and right-of-use holders of buildings/facilities thus have a far-reaching responsibility to prevent fire and limit damage as a result of fire. Here there are opportunities for the rescue service to set requirements also regarding energy storage during inspections. However, it is unclear how far the requirements can go, the future will tell.

Within LSO there are 2 chapters. Section 4 Obligations in case of dangerous activities. The investigator makes the assessment that this activity does not fall within this chapter.

### 3.4.3 The Flammable and Explosive Goods Act (LBE)

Not relevant here, but possibly LBE may be applied for larger facilities.

3.4.4 The Swedish Electrical Safety Authority

Several different regulations can govern the involvement of the Electricity Safety Authority regarding the construction of energy systems/battery storage. If e.g. the battery/batteries are part of an electrical installation, so supervision can take place using the high current regulations Elsäk-FS 2022:1, 2022:2, 2022:3. Furthermore, there are rules for electrical authorization when performing an electrical installation or for performing a permanent connection of a battery to an electrical installation.

### 3.4.5 The Sevesol Act

Not relevant for this event, but larger battery energy facilities may be covered. There are currently no precedents or guidelines regarding how lithium-ion batteries should be assessed.

### 3.4.6 Transport Dangerous goods

When transporting lithium-ion batteries, the rules for the transport of dangerous goods apply. As this was not the case in this incident, the investigation has been limited and not delved into this part.

### 3.4.7 Waste (Naturvårdsverket)

Companies that manufacture, sell or bring batteries into Sweden and resell them are defined as producers and have producer responsibility. Among other things, this means a responsibility to ensure that users can dispose of the batteries and to take care of them when they have become waste.

### 3.4.8 Standards

With regard to fire protection, there are international standards but no national ones that take a comprehensive approach to fire protection for battery energy storage. However, there are both national and international standards for testing batteries, both at cell, module, pack and system level. The investigator does not delve further into this investigation.

# 4 DISCUSSION

## 4.1 Discussion linked to the issues

### 4.1.1 Knowledge level and decision support

The commanders on site requested decision support and what was available was presented to the commanders orally via radio/telephone in a first instance. In this guideline, it can be deduced that it is, among other things, the smoke that must be taken into account, which was also done throughout the operation's implementation. The smoke was considered to be the primary risk when zoning, determining protection levels and further also issuing a VMA at the event.

Furthermore, you can read the internal guideline under the point *3.2.4 larger internal battery storage systems*:

- Information collection from business/property owners. Where are the batteries?
- Ensure that the affected part of the building is evacuated
- Carry out ventilation of a fire-exposed building, the attic/fan in the back when working
- Pressurize adjacent spaces to prevent spread
- If possible, try to extinguish/cool from a distance, if possible from outside
- Explosive environment. If thermal rush occurs in an enclosed space, a combustible mixture may occur. This is particularly important to consider for spaces such as battery storage in containers or similar, i.e. where there is a larger amount of energy collected in a smaller, closed space

The rescue personnel on site also had the risk of explosion based on the text "combustible mixture" in mind and as a method to meet this risk, the cutting extinguisher was the tool they considered best suited to cool and inert the environment inside the container. With hindsight, the investigator can state that rescue personnel initially established themselves too close in view of the explosion that occurred. When reading the internal guideline, it is easy to interpret it as only applying to containers indoors, in this case the container was outdoors. There have also been tests showing successful results when using fire extinguishers against car batteries in the open. This overall may have influenced the staff to the decision to use the cut extinguisher method in this case.

The internal guideline that exists was developed in 2018 and revised in 2021 based on the Swedish Agency for Community Safety and Emergency Preparedness (MSB) guidance Rescue operation where lithium ion batteries are present. It has been presented on the internal command forum Meeting point management and on RSG's internal information channels. However, no central training or exercise in the area has been carried out as reported by the investigator. It is also a relatively new phenomenon with energy storage of larger formats, so there is not much information and educational material available.

The investigator believes that the fire personnel have a basic level of knowledge but with little experience of this type of event. They have searched for information on site, absorbed and valued the information and handled the situation based on their interpretation of this. The investigator believes

however, that the fire personnel are in further need of training and practice in order to more safely deal with a similar situation in the future.

#### 4.1.2 Tactics and method choice

The rescue personnel made the choice to use cutting extinguishers as described above with the aim of cooling and inerting fire gases in a closed space to reduce the risk of explosion. The staff reasoned that it is faster to use the cutting extinguisher than to hook up hose systems to try to cool the batteries and try to fill the container with water. The time factor and the information on the financial value of the battery were two factors that came into play.

RSG's internal guideline Lithium-ion paragraph *3.2.4. Larger internal battery storage system* says "If possible try to extinguish/cool from a distance, if possible from outside" and "Explosive environment. If thermal rush occurs in an enclosed space, a combustible mixture may occur. This is particularly important to consider for spaces such as battery storage in containers or similar, i.e. where there is a larger amount of energy collected in a smaller, closed space".

The investigator has not found anything in RSG's instructions or guidance based on the current incident that directly points to risk with the method of using fire extinguishers. However, they say that there may be a risk of an explosive environment during thermal rush. In external investigations following similar events internationally, it has emerged that in the event of white smoke without visible flame during a reaction in lithium-ion batteries, ventilation of the space is preferable. This is because the white smoke can be an explosive gas in the right mixing ratio. Taken together, the investigator believes that the internal guidelines need to be updated and clarified to reduce the risk of being too close if a similar event occurs again.

#### 4.1.3 Work environment

Question "Work environment impact with regard to possible contamination by fire smoke and explosion that has occurred?" Under this heading, the investigator will discuss the various situations that have arisen from a work environment perspective.

##### 4.1.3.1 The explosion

In the early stages of the operation, an explosion occurred in the battery energy storage container. It occurred in connection with the fact that the rescue personnel from the Frölunda fire station had just started using the cutting extinguisher tool. The work was preceded by the fire personnel containing the smoke evolution from the reaction by closing the open container doors and thus creating a closed environment where they could cool and inert the combustible gases from the battery reaction using the cutting extinguisher. This is the most common and most effective method when using a fire extinguisher in the event of, for example, a room fire. According to an interview with the staff from Frölunda, the explosion occurred approximately 3–5 minutes after the work with the fire extinguisher began. A short film sequence from the incident shows that just after the water with the cutting agent penetrates the container, the explosion occurs. However, it is likely that the fire extinguisher operator has drilled holes before, changed location and then started a new hole when the investigator saw similar holes in the area. The investigator has no reason to doubt the interviewees' observations and the film sequence the investigator saw only shows this short part.

The staff at the Frölunda fire station are well trained in fire extinguishers and their various methods. They are often used within the association as instructors for internal training on this tool. The film is privately owned and the investigator has only seen this short sequence and does not have access to the film either. The film also shows that the explosion was so powerful that both long sides and the roof of the container buckled outwards by about 10 cm and that the steel container's front doors, which were closed, flew open with tremendous force. It is unclear how well these doors were closed, but interviews and the film suggest that they were properly closed. This overall shows how powerful the explosion was. There was no traditional fire smoke on the film in connection with the explosion that can be seen in the case of a fire gas explosion in fibrous fires, but here it was completely "clean". After the explosion, the fire inside the container increased and then a more black, characteristic fire smoke was also seen.

What happened? The investigator tries below to describe some different scenarios that may have occurred, but does not rule out that it could be something else entirely as the uncertainty factors are many and expert knowledge is lacking in the area.

- The batteries can create a flammable gas in the uncontrolled reaction that was going on which then mixed with the oxygen inside the closed container so that the flammability zone was reached. Could the cutting agent of the fire extinguisher create some kind of spark when it penetrated the wall of the steel container which in turn ignited the combustible gas?

- If there is a combustible environment inside the container but pressure conditions inside the closed container mean that ideal mixing does not prevail. Could the forces of the cutting extinguisher then create a stirring effect and ideal mixture occurs which ignites?
- Or, are they just different events that happened to happen at the same time without any connection?

The investigator clarifies that these are just problematizations and there is no evidence that it is as described above. Here, however, there is great uncertainty which, from a work environment perspective, clearly points to the need to exercise caution with this type of reaction/fire until clearer guidelines are drawn up (see also 4.1.2 Tactics and method choice). In order to arrive at clearer guidelines, the investigator believes that national cooperation between authorities, emergency services, research and producers is required as this is a relatively new way of storing energy in large quantities, that development is fast and that it is expected to become more common in the near future future. In the investigator's opinion, a municipal local rescue service does not have the expertise, time or finances to carry out such work on its own. It is of the utmost importance from a work environment point of view for all national rescue personnel that this be investigated and national guidelines drawn up in the near future.

### 4.1.3.2 Fire smoke

In connection with the escalation of the effort, a strong smoke development was created from the fire. The smoke drifted and engulfed buildings and streets in the direction of the wind. Already during the operation leader's approach to the accident site, a request for help with knowledge and guidelines had been made to LC, which they delivered. In these guidelines it emerged that the smoke was a factor to be taken into particular consideration. This is also described under chapter 4.1.1 and the investigator believes

this has been risk managed and taken care of in a good way based on RSG's instructions and guidelines.

#### 4.1.3.3 Application of water for cooling via prepared coupling

The container was equipped with a water inlet which was clearly pointed out by the company's representative when the emergency services arrived. The introduction was equipped with a coupling that fits the rescue service's coarse hoses and a pipe that was mounted at the top on the inside of the container.

*Picture 8 Shows the connection for the introduction of water on the right and emptying on the left. Source RSG*

This inlet was connected with hose from RE early in the operation but water application was not started. The company's representative announced in connection with the information about the introduction that "using this method destroys all batteries". That information together with other assessments led RL to decide at the time to start the operation with the method of containing, inerting and cooling the fire gases using the cutting extinguisher described above. When the explosion resulted in the container being deformed, cooling via introduction was no longer relevant.

If this introduction was used in the early stage, what would have happened? The investigator describes below some reflections on this, in the effort, unproven method.

- A 20-foot container can contain approx. 33 m3load. In this case, the container was approximately 1/3 filled. 11 m3. If the availability of water at the time of the incident is not limiting, it would take an estimated 15–20 minutes to fill from RE with 1000–1500 l/min, which may be normal depending on other water withdrawals from RE.
- The above reasoning is dependent on the container being completely sealed at the bottom, walls and doors and the pipes on the inside of the container being of the same dimension as the coupling. In the current case, it was a new or almost new container and thus we can assume that the tightness was good. However, the pipes were of a smaller dimension.
- The above reasoning also assumes that the container has some form of pressure relief or ventilation in the top of the container. In order to be able to fill it with water, the air needs to be able to escape at the same rate as the filling, otherwise a back pressure occurs inside the container which means that the water only reaches a certain volume, unknown which. IN

in the current case, the investigator was able to find ventilation in the container. However, it is unknown how large a volume of air can pass through this ventilation and at what rate.

*Picture 9 shows two of eight ventilation openings. Source RSG*

It also requires that the water be applied to the top of the container so that rising water pressure does not affect the filling. According to the description, the pipe must have been constructed in this way. The deformation of the container in connection with the explosion suggests that pressure relief hatches for sudden pressure increase were missing.

The reasoning described above suggests that the method of sprinkling/filling the container with water via the pre-assembled insert must have worked on the basis that the water first sprinkled the batteries and at the same time slowly filled the container. The investigator believes that with a properly built container, good water access via fire hydrant systems or water units and the right knowledge of different methods, the sprinkling/filling with water method should have been less risky in the current operation.

#### 4.1.4 Management of extinguishing water

A new research study conducted by RISE, *ETOX 2 – Analysis of extinguishing water from fires in electric vehicles*, have also included a battery energy storage in the study to show what comes out of this in case of fire and extinguishing. The study, which measures both gases, pollutants that accompany soot and pollutants that accompany extinguishing water, gives an indication of what can come out in the event of a fire in a battery energy storage. As lithium-ion batteries can have different components, the study does not function as a conclusion, but it provides some important knowledge.

When it comes to the gases that depart from a battery energy store, they are significantly smaller amounts and usually below the limit values that exist for most gases compared to car fires, regardless of fuel. The soot, on the other hand, contains high levels of aluminum, cobalt, nickel, copper and lithium, but extremely small amounts of the heavy metals that have a negative impact on people and the environment, e.g. lead. The extinguishing water has a high pH, which is good together with the various metals as they do less damage at high than at low pH. The biggest problem with the extinguishing water is that it contains PFAS that are released when the electrical lines between the batteries burn. There are moderate amounts of PFAS, but two of them that come out the most are those that have very low limit values and the third is the same as the one that can occur in firefighting foam. For this reason, it is important to be careful with the handling of extinguishing water in cases where there are private wells or water sources in the area.

After contact with, among other things, an expert from the company, information was obtained which said that there was no risk of thermal rush as long as the temperature stayed below a given temperature. Applying more water in that situation only created increasing amounts of contaminated extinguishing water, which in turn then had to be handled further. Hence, the response personnel, a bit into the response, were restrictive with the application of water when the temperature was estimated to be low. The affected company engaged a clean-up company, which was tasked with pumping up collected extinguishing water from the storm water well that was next to the burning container, then transporting it away and destroying it. An unknown, but estimated large amount of the extinguishing water ended up in the well and could thus be partially taken care of. The problem was the design of the stormwater well, which is similar to a soil bed with macadam and infiltration, which risks an unknown amount of extinguishing water spreading further into the immediate environment without the possibility of handling it.

The investigator considers that the handling of the extinguishing water during the rescue operation based on the prevailing circumstances was good.

### 4.1.5 Handling and storage by operators

The emergency services have no suspicions of deficiencies in the building's built-in fire protection or in the right-of-use holder's systematic fire protection based on the building class and the nature of the business. In the event in question, the container containing battery energy storage was under construction and not commissioned. The container was, when the fire started, indoors in the warehouse part of the building and was located directly inside a large gate out into the open. The container was turned 90 degrees to the right, moved a few meters so as not to block the gate. It stood on swivel wheels so that it could be moved more easily for production technical needs, but also for rescue technical needs. As there is currently no clear law that regulates how such battery energy storage may be placed, it is up to the right-of-use holder together with the property owner and possibly the insurance company to agree on suitable measures for storage and handling which the local rescue service can then evaluate from an authority perspective. As the company's actions during the incident in question show an early detection of the fire, a quick intervention which in turn meant that the rescue operation was carried out outdoors and this in turn shows that the intended rescue plan worked in general, the investigator therefore delimits this question with the final words, what had What if this plan didn't work?

## 4.2 What is going on nationally?

A few different projects in this area are underway in the country. Below, the investigator tries to simply describe what can be expected to come in the near future.

- On March 27, 2023, the Report "Demonstration of extinguishing method for lithium ion batteries" was published. which describes conducted trials and a method for handling propagating lithium-ion batteries in vehicle batteries. The method which has been tested and which has been shown to work is, in short, that by supplying water with low pressure and flow into the battery, an ongoing propagation can be extinguished. MSB points out that it is important to carry out a risk assessment and that the tools used must be intended for the purpose. Although this does not apply to battery energy storage, it is worth it

to mention it because battery energy storage sometimes consists of a container of car batteries with too low a capacity for electric cars.

- RISE has several projects underway regarding batteries and they also have a project dealing with energy storage - "fire protection guidance for battery energy storage". RSG is involved as a partner, one among many others. This is how RISE describes the project: There are currently no rules, advice or standards for how the fire protection should be dimensioned or where battery energy storage can be installed. This creates uncertainty for those who want to install battery energy storage. As there are no national instructions, it will be the individual rescue service in the municipality where the energy storage is installed that determines which requirements must be set. This results in different requirements in different municipalities and leads to more expensive installations, which risks hindering the transition towards a fossil-free society. The project aims to produce a national guideline regarding dimensioning and fire protection requirements for battery energy storage to facilitate and support the transition to a fossil-free society. The guidance will be based on existing research and knowledge regarding battery energy storage with Lithium-ion batteries. The project is carried out in close cooperation with emergency services, installers and retailers of battery energy storage. The preparation of the guidance will be ready by the end of the year.

# 5 RECOMMENDATIONS

## 5.1 National guideline

Energy storage systems in this way are a relatively new phenomenon for rescue services in Sweden, but one that is expected to increase significantly. The investigator states that legislation, knowledge, tactics and methods before or during an operation against these systems need to be clarified and updated to create a safer workplace for the rescue personnel. The investigator believes this applies nationally.

⇒ The investigator recommends RSG to address the need for clearer national guidelines for energy storage systems in the areas of preventive fire protection and rescue operations.

## 5.2 Internal guideline

During the current rescue effort, the internal guidelines and instructions that were available were requested and used. Despite this, an explosion occurred where rescue personnel were in dangerous proximity.

⇒ When the investigator established that the knowledge of tactics and methods within RSG when working against these energy storage systems from a rescue operation perspective was not sufficient, the investigator recommends RSG to update the internal guideline as soon as possible based on new knowledge. Also to continuously update it as new knowledge will be announced by RSG.

⇒ The investigator also recommends RSG to carry out training efforts and exercises based on current events or similar scenarios.

**APPENDICES**

**Appendix 1 Conclusion from an investigation produced by the company in question**

Conclusions

A failure investigation has been conducted for the battery fire at on 26th of April 2023. There is an incomplete set of data that opens for more than one reasonable possibility, but available data indicates a failure that is either due to a cooling system filling error at or due to a weakness in the delivered product.

**Appendix 2 Conclusion from the investigation produced by the battery supplier**

Conclusions

Whilst we continue to engage in data gathering with the third party, it is clear from our evidence and factual assessments that there were a number of process failures during the commissioning of the system that have most likely led to this unfortunate event.

Thankfully there were no serious injuries reported as a result of this incident and property damage appears to have been largely restricted to the actual battery pack itself. Engineers are studying the remains of the battery system as this is the first recorded incidence of a MWhclass thermal runaway.

Overall, the battery packs far surpassed industry standard thermal runaway and passive propagation resistant design guidelines. Based on verbal evidence from XXX, the thermal runaway event took place over a period of around 3 hours before significant smoke generation was observed. This indicates that the passive propagation resistant technology was functioning as intended. Furthermore, it appears that a number of packs were largely mechanically intact and significant remains of the battery were still present after the incident. The design held up to a prolonged thermal runaway fire and a hydrogen gas explosion and gave first responders sufficient time to bring the system under control and make it safe. Forensic photographs also show resistance and significant delays in the spread of thermal runaway through cross-module and cross-pack thermal propagation.

Please note that at the time of writing we are still engaging with the third party integrators and have a call on the 30th of May but do not believe it will change our global findings.