Photo by Michael Dziedzic

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Fire safety in e-bus depots – Risk, prevention and handling

eBussed
Interreg Europe

European Union
European Regional Development Fund

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Fire safety in e-bus depots – Risk, prevention and handling

Batteries play a vital role in the transition to electric mobility, including e-bus public transport services. However, a series of fire-related accidents in electric buses have lately occurred in Germany[1], China and some other countries. Initially identified causes were attributed to overheating of the lithium-ion (Li-ion) batteries inside the bus. These batteries do have fire risks when damaged, and damage can be caused by overcharging, mechanical failure, physical impact, or overvoltage. This has raised a series of technical investigations as well as the search for preventive measures to reduce similar accidents in the future.

Introduction

This article describes the way of bringing fire risk management to a higher level. First, we have to consider that fire-risk and safety management related to e-buses is a very actual subject, although detailed knowledge of controlling a huge bus fire is rather limited. What we do know, is that the risk of e-bus catching fire is similarly high while driving and while charging. In case they catch on fire, e-buses (like e-cars) burn with more heat and longer as the battery can reignite after having been extinguished. The fire can suddenly flare up again because of the enormous heat released. With electric vehicles, there is a danger of the emission of various toxic gases, among which hydrogen fluoride that can cause severe damage to both the skin and the respiratory tract[2]. Therefore, firefighters need to keep a distance.

In an online article[3] fire protection expert Matthias Bohnert explains the domino effect of a so-called thermal runaway when the fire runs from one cell of the battery to

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[1] A news about a fire in Stuttgart, published on 8 October 2021: https://marketresearchtelecast.com/charging-electric-bus-could-have-triggered-a-major-fire-in-stuttgart-bus-depot/174355/ Accessed 26 January 2022. Earlier, fires have broken out at bus depots in Hanover and Düsseldorf.
[2] "Depotbrände verunsichern Verkehrsbetriebe", an article published 21October 2021 https://www.tagesschau.de/wirtschaft/technologie/elektrobusse-depotbrand-101.html. Accessed 26 January 2022.
[3] "Wenn E-Fahrzeuge in Flammen stehen", an article published on 1 October 2021 https://www.swr.de/swraktuell/baden-wuerttemberg/brandgefahr-e-autos-100.html. Accessed 26 January 2022.

another. This is the reason why battery fires are more difficult to handle. It takes five to ten minutes for a combustion engine car fire to develop to its full extent. With an electric car, the fire spreads more rapidly and it takes seconds for a fully developed fire which releases carbon monoxide, other toxic gas emissions, and in some cases can produce large explosions[4]. What is more, vehicles whose batteries have caught fire need to be monitored after the fire has been put out for possible reignition and taken to a place where the burning battery causes no danger. In some cases, electric cars are being put into a water tank, but e-buses are too big for such tanks.

According to battery expert Maximilian Fichtner CEO of Helmholtz Institute in Ulm (Germany), battery electric vehicles statistically get twenty times less on fire than combustion engines. You can never fully preclude a fire, but he trusts the technology. This view is shared by the German Insurance Federation (GDV). Fichtner says that especially the solid-state batteries like the ones in the e-Citaro of Evobus (which started the fire in Stuttgart) can be considered very safe. They have been used for 20 million fleet kilometres in the French e-cars “Blue Cars”. By the way, very similar batteries can be found in iPhones. In classical batteries, the storage material of the positive and negative poles is separated by a liquid. In solid-state batteries, there is a plastic foil. This is per se safer. As a possible cause for a battery fire, Fichtner sees a charging fault, e.g. overcharging which can theoretically lead to a critical state[2].

The present article summarises a series of innovative initiatives to contain/reduce fire risks and proposed improvements to fire detection/delay, based on various information obtained from the consultation of the documents listed in the footnotes and at the end of this article. Any interested reader is invited to refer to them for more and better details.

This article presents case-by-case e-bus depots’ building structures and charging infrastructure then proceeding to fire safety and incident prevention. The examples are four European cities: Stuttgart in Germany, Pécs in Hungary, Turku in Finland and Utrecht in the Netherlands.

Case Stuttgart – Learning from the accident

The reason for this article lies in the serious accident that took place in Germany. A major fire occurred in a bus depot of Stuttgarter Straßenbahnen AG (SSB) on 30 September 2021. We, the Technical requirements working group, interviewed Markus Wiedemann (SSB) in November 2021 to learn more. What is clear is that the fire broke out in a small explosion of the solid-state battery on the roof of an e-bus (Evobus e-Citaro, Mercedes Benz). Everything is well documented, so SBB and their experts know WHAT happened, but they do not know WHY it happened. The first explosion was followed by a larger one and within two minutes and 30 seconds, three buses were on fire. The bus in question had been on tour before and had been charging for the past 20 minutes when the incident occurred. No anomalies during charging (neither the vehicle nor the infrastructure) have been reported.

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[4] TheBigRedGuide “Electric Buses Spark New Fire Safety Requirements” in: https://www.thebigredguide.com/insights/electric-buses-spark-fire-safety-requirements.1635855016.html?ref=pdf Accessed 26 January 2022.

The fire brigade arrived five minutes after the alarm was sent. 38 vehicles could be evacuated by bus drivers present at the depot at the time. Fortunately, the depot has three entrances, so two were used by the fire brigade (for rolling out their fire hoses) and through the third one, bus drivers continued to evacuate buses. Normally, evacuation can only take place before the fire brigade begins with the extinguishing of the fire. The fire broke out at about 8 pm and was under control by 10 pm. However, the fire needed cooling to keep the heat low, and supervision in case the battery reignited. Two million litres of water were needed for extinguishing and cooling the fire. The fact that chemical analyses did not find any lithium in high concentration (from the battery) implies that it burnt. This means that temperatures must have reached up to 3000°C. They used snow cannons for cooling the battery. The concrete floor under the battery was destroyed to a depth of 20 cm. Altogether 25 buses completely burned, one of which was an e-bus.

The lessons learnt from this incident are numerous. The thermal load created is very high. Hence, Markus Wiedemann replied, when he was told about the plans in Westraven (Utrecht, NL), that 40 buses in a potential fire are already quite a high number. Another issue is related to data storage: Data collected from control systems need to be stored in a different location than where it is collected. At the time of the fire, SSB had four e-buses with plug-in charging. Near to where the fire broke out, another e-bus in the depot kept on charging undisturbed until 9 o'clock in the morning and then announced that it was fully charged! Lesson learnt: Supplies of electricity and compressed air need to be cut off automatically in such incidences.

Stuttgart e-bus depot's building structure and charging infrastructure

The bus depot in Stuttgart was a 15,000 square meter carport with a solid roof (steel and concrete), open on three sides with a sound-insulating wall on one side. Due to this, heat and smoke could not escape upwards. The new bus depot that will be built will definitely be an open structure only with some weather protection.

For building new e-bus depots (and the same applies for private underground garages under apartment houses) there are no specific requirements with regard to electric vehicles. According to Markus Wiedemann, if you have an existing depot with an approved and valid building permit, you do not need any new building permission when this depot is being changed to host electrical infrastructure. To gain new practical insights and change legislation, a lot of research on this relatively new topic needs to be done.

Experience from a fire in a depot in Hanover (ÜSTRA) has shown that to save a bus depot, one has to sacrifice an affected fire compartment.

Fire safety and incident prevention in Stuttgart

In Stuttgart, there is a regular collaboration between the transport operator and the local fire brigade through 1-2 false alarms per year. That facilitated communication during the accident on 30 September 2021. Afterwards, SSB invited the department responsible for preventive fire protection to present their concept for a new depot to be built; they would only get insurance after consulting the fire brigade.

Sprinklers are not a viable solution for a fire in an electric bus depot, as much more water is needed to extinguish and cool the fire than in a fire without batteries (three to twelve times more water is needed). Such a large amount of water retention is not realistic. Research is underway to examine to what extent high-pressure water mist can support cooling and controlling the fire.

Firefighter Jan Voß from Fire Brigade Hamburg said that, as more water is being needed, in case of a fire of an electric bus on an open road with no hydrant near, the fire brigade would have to bring a water tank vehicle for water supplies. Due to the extreme heat development, other extinguishing agents (sand, powder etc.) are not recommendable. Gas can be an option to protect separate rooms for transformer stations, switchboards and other infrastructure in order to keep damage through extinguishing agents low.

For the Fire Brigade in Hamburg, Jan Voß expects specific training for firefighters only if new findings from practical experience or research will become available. The transition to e-buses is already in full swing. It is likely that the Stuttgart incident and insights gained from it (and shared with other stakeholders) will be translated into training for Hamburg's firefighters.

Accident prevention in Pécs

The e-bus project in Pécs started in November 2018 with the construction of the garage for the electric buses, equipped with the necessary charging infrastructure. A light steel skeleton structure with insulated sandwich panel cladding of 600 m2 space was built. The hall can accommodate 10 electric buses and provides four twin-charging devices required for depot charging of the buses. The BYD K9 BU buses are charged with alternating current (AC) – a unique feature of the Chinese manu-

Hall building at Pécs (Source: B Build & Trade Ltd)

facturer. These alternate current chargers are manufactured in the Netherlands by Floading and are only suitable for indoor charging of 348 kWh lithium-ferrite batteries. There is one additional Floading twin-charger installed outdoors. The existing electrical network (connections, pedestal, etc.) has been extended to provide the necessary capacity of at least 600 kW for simultaneous charging.

Fire safety and incident prevention in Pécs

At Tüke Busz Plc., the Pécs public transport operator, there are several employees entrusted with the management of fire protection and occupational safety. This includes the occupational safety office, dispatcher, workshop manager and shift manager. Tüke Busz Plc. also issued a document about fire safety regulations.
The construction of the bus depot was ordered by the Municipality of the City of Pécs via Pécs Urban Development Plc. Before construction started, the territorial government administration approved the construction of the depot from a fire prevention point of view. However, at Tüke Busz, the interviewed employees were not aware of how the fire brigade was involved in the construction process.
During recent years there were several diesel-engine related fires at Tüke Busz Plc. but none of those happened at the bus depot. In each case, the local fire brigade acted as per protocol. The 10 electric buses have not been involved in any fire emergencies. However, interviewed employees replied that during charging, the interaction between the e-bus and the external high-performance charger can cause damage and fire due to communication errors or short circuits. Employees also replied that electric bus fires raise a number of unexplained questions, including the source of the flames. It should be considered that even prevention and protection should be provided throughout the “high voltage chain” beginning with the transformer, switch units, cables and charging devices before arriving at the batteries.

Turku – Foreseeing and training

The buses of the operator company Turun Kaupunkiliikenne (“Turku City Traffic Ltd”) are parked in an open-air depot with an asphalted terrain. There are six 50 kW depot chargers for overnight charging. Additionally, at both ends of the e-bus line, there are 300 kW fast chargers with so-called inverted pantographs, i.e. coming down to the rooftop for charging.
There is no uniform contingency plan for the depot itself in place. Safety regulations for the depot can be found in the risk analysis documents, occupational safety and health documents as well as in the preparedness plan of the company.

Fire safety and incident prevention in Turku

In Turku, at the launch of the e-bus service, the fire brigade was involved and got familiar with the electric buses. However, fire-rescue personnel were not involved in the planning of the depot. Turku City Traffic Ltd. has not had any depot fires in recent years. However, in Turku in September 2015, there was a quite extensive depot fire at another bus company’s depot, burning down 23 buses. All the buses involved were diesel-powered, and arson was determined to be the cause of the fire. Turku City

Traffic Ltd contributed to helping the company affected by the accident by loaning buses.

To date, Turku City Traffic Ltd has not had any fire-related e-bus incidents. However, a few threatening diesel bus fires have happened while on the road. This shows that if the buses are old and poorly maintained, they create a fire risk regardless of the energy source.

When the bus is in use, the fire risk increases. For example, in a situation where the bus brakes get stuck and get overheated. Another cause of a fire is, of course, collision. Nevertheless, in these situations, the driver can react rapidly to minimize the consequences. When a bus is recharged unattended at a depot, a possible fire breakout may go undetected.

Safety measures at the new Utrecht Westraven e-bus depot

On the south side of the city of Utrecht, a new bus depot, Westraven, is being built. It is planned that the depot will have a maximum capacity of 160 e-buses and facilities for overnight charging. The charging infrastructure enables all the buses' simultaneous charging. Due to the considerable power capacity required, it was necessary to install an extra network cable.

At Westraven, fuel storage is located next to the planned bus depot (see figure below). At the storage, liquid fuel is pumped from tankers to fuel trucks and stored. The

Situation bus depots and fuel storage at the Utrecht Westraven depot
Source/data: Google Earth

combination of a large bus depot with charging facilities next to a fuel depot proved to be a safety risk. It should be mentioned that in general, electric buses include a fire risk that needs specific measures.

The most important issue is, however, the presence of a high-risk fuel depot. It should be necessary to reduce the fire risk in general, independent of the local situation. In fact: awareness of safety risks is inherent to the location or surrounding of a bus depot. Thereby, this article is useful to any authority or bus company intending to build a bus depot.

There has been innovating, state of the art safety measures taken at the new, not yet fully operational Westraven bus depot. The charging facility at the bus depot is scheduled to come into full operation on the date of the new concession: December 2025. The current concession was extended by 2 years due to the corona pandemic. However, it is already possible to park buses at the depot.

Fire safety and incident prevention in Utrecht

The following parts describe the measurements taken at Westraven.

Selected parking and charging lots at the bus depot

As with electric passenger cars, the progression of an e-bus fire is slower and longer than with a conventional similar vehicle. As with the extinguishing of electric vehicle fires in general, the extinguishing fires on the ZE-bus requires additional extinguishing methods, due to its battery pack. In battery fires, e-buses cannot be submerged in water containers. The extinguishing agents existing on buses are insufficient to stop a 'thermal runaway' but only extinguish the flames of a normal fire. It is therefore important to have a clear idea of where the conventional and electric buses are parked at the bus depot.

Although a large bus fire leads relatively quickly to the conclusion that the fire should be extinguished in a controlled manner but on its own, extinguishing a diesel bus fire requires a different approach than an e-bus fire. So, at a bus depot, different types of buses should not be mixed up, but separated and arranged according to their engine type.

Compartments for electric buses

At the Westraven bus depot, the e-bus charging area is divided into compartments. A maximum of 40 e-buses is grouped in each compartment while the compartments are segregated by concrete firewalls.

The walls divide the site into compartments. In addition, between 2 compartments, there is also at least 4 meters wide space. The space can be used as a roadway for fire trucks. To make a virtue of necessity, the walls also function as support walls for portals to which the charging points are attached. A fire truck

Bus depot 'Westraven' with the charging facility and the fuel depot on the left.
Photo by Van der Ven, Brakel

must be able to drive around the burning buses. So, multiple compartments with the capacity of up to 40 buses, are separated by a retaining wall and a fire-break.

The number, 40 buses, is specific for this bus depot and should be customized to meet other local circumstances. In Utrecht, the number is based on the fact that such a number of demolished buses can be replaced in a relatively short time without unduly endangering the operation of public transport. Instead of the needed safety measures, it was time to get back to regular operation after a big fire, that concluded the number.

Innovative radar-based fire warning system

In addition to the compartmentalization, an innovative fire detection system has been installed at the bus depot. This is a system based on radar images, reacting to heat. The system was developed by the US Army. In Utrecht, there is not yet practical experience with the system, and it still needs to be fully configured to respond adequately and exclude false alarms as much as possible.

Safety region (contact and instruction)

It is important to have good contact with the safety region or the local fire brigade. They must be aware of the possibilities in terms of access, methods to extinguish the fire, location and type of buses and other important things ac-

cording to the local situation. The fire brigade should have a local plan and a complete situational overview.

It is not often that a bus depot is made directly suitable for 160 buses. In many depots, the number of electric buses will gradually increase over time. The safety risk, therefore, increases more slowly and is less clear. However, there is a need to be aware of the risks. Although a lot of effort is needed to avoid a fire, it is also necessary to consider how to reduce the risks in the event of a fire.

Concrete walls and a fire lane divide the charging compartments.
Photo by Van der Ven, Brakel

Conclusions

After examining the cases described above, the information gathered from the various interviews and the documentation referenced, several countermeasures to prevent battery-fires are outlined hereunder, together with some cautions and recommendations stemming from investigations of past incidents or tests carried out:

- Overnight charging should be monitored

- Distance among e-buses should be increased when charging the batteries, to prevent fire spread. Moreover, buses of different engine types (combustion or electric) should be separated when parked. Thus, in the case of a fire, identification of the type of fire is easy and required measures for extinction can be taken quickly.

- Suppression solution: Solutions to prevent a thermal runaway are worth being introduced. A suppression solution offers an early warning system aided by spot cooling, to prevent thermal runaway from occurring while containing and suppressing fire[5]. The system is comprised of heat and aspirating smoke detectors and a fire extinguishing system for the batteries' compartment in electric busses, separately controlled by an intelligent response system embedded in the vehicle CAN-bus control system (from: Li-Ion Fire project).

- Division into protective zones: Dafo Brand AB, a leading fire protection system provider, also involved in the Li-Ion Fire project, has provided for dividing the EV or HEV-bus into four protection zones which are protected in various ways with robust detection and fire suppression systems, applied on both liquid and gas-based solutions.

The four protection zones are:

Zone 1
Auxiliary heater and AC – protection for potential fires due to leakage of flammable fuels sprayed on hot surfaces

Zone 2
Battery compartment – protection of batteries from outside fire, fire containment at battery fire/thermal runaway.

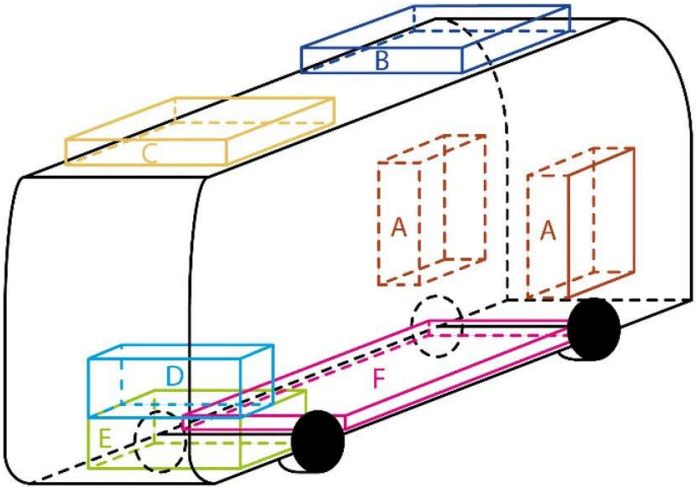
Zone 3
Electrical cabinet – protection for electrical-related fires due to short circuits, arcs etc.

Zone 4
Engine compartment – protection installed for combustion engine (HEVs) and a compartment with electrical components (EVs) for potential fires due to leakage of flammable fuels sprayed on hot surfaces etc.

- Battery location: Some manufacturers opted to locate the batteries on the vehicle top, instead of underneath (solution B in the fig ure on the next page displaying also other solutions for battery location and those bus models which have been adopting them).

  Advantages of such a solution are exposure to external air; thus, improving the battery cooling, easier access for recharging and increased space for passengers. The main disadvantage is a higher centre of gravity.

[5] Dafo Vehicle Fire Protection and RISE (Research Institute of Sweden), as part of an EU-funded initiative, have developed a new suppression solution that directly addresses the unique fire risks associated with electric vehicles. For more details, see DAFO's For a safer environment of electric and hybrid vehicles https://dafo-vehicle.com/segments/electrical-vehicles/. Accessed 26 January 2022.



BYD K9	A+C+E [14]
Volvo 7900	C[15]
VDL Citea	B [16]
Solaris Urbino	B [17]
Optare Versa	D+E [18]
Proterra Catalyst	F [19, 20]

Battery packs in e-buses[6]

- Battery handling: Due precaution is required when handling damaged electric vehicles, as a Li-ion battery can cause burning or electric shock.

- Battery storage: A study to investigate the performance of packaged small-format batteries in storage has indicated that a practical sprinkler protection solution, similar to that used for other common stored commodities, can be effective[7].

  Isolation is required for damaged EV and LI battery storage. This can be in the form of a designated location. Such location should be kept away at least 15 m from structures, vehicles and combustible materials in case of re-ignition or delayed ignition. Moreover, damaged EVs or LI batteries should never be stored in under-ventilated enclosed spaces. Another step in securing the vehicle is to ensure that the LI battery is completely isolated from the vehicle[8].

- Training systems and requirements on the qualifications of the personnel performing critical tasks such as LI battery handling and removal constitutes one way to control and reduce risks connected with such activities[9].

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[6] The diagram on page 5 in the technical paper by Roeland Bisschop, Ola Willstrand and Max Rosengren Handling Lithium-Ion Batteries in Electric Vehicles: Preventing and Recovering from Hazardous Events https://doi.org/10.1007/s10694-020-01038-1 It is reproduced with thanks here, without changes and as per requested link to Creative Common license http://creativecommons.org/licenses/by/4.0/. Accessed 26 January 2022.

[7] For more details, see the report by R. Thomas Long Jr and Andrew Blum "Lithium ion batteries hazard and use assessment", Fire Protection Research Foundation, November 2016 https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFLithiumIonBatteriesPhaseIII.ashx.
Accessed 26 January 2022.

[8] For a link to the article and National Fire Protection Association recommendations, see the German article: "Wenn E-Fahrzeuge in Flammen stehen", published on 1 October 2021 https://www.swr.de/swraktuell/baden-wuerttemberg/brandgefahr-e-autos-100.html.
Accessed 26 January 2022.

[9] Mr. Dannis 't Hart, interviewed 20 November 2021, is working for the Veiligheidsregio Utrecht / Utrecht regional fire dept. and is specialised in chemical and explosive substances.

We would like to conclude with the final consideration of Sun, Bisschop, Niu and Huang in their article reviewing battery fires in electric vehicles[10], which we fully share, also because of further research and testing of new devices needed:

> "EV fire is harder to suppress because of the potential re-ignition of battery and the difficulty in cooling the battery pack inside. For the suppression of EV fire, water is still considered as most effective, and a significant amount of water is required to extinguish and cool the battery. However, less suppressant can be used if it is directly applied to the battery pack. Moreover, there is very little knowledge of the fire risk of the disposed EVs and wasted battery packs. In the future, fire-protection systems with a better design should also be required for buildings and parking spaces that contain a greater number of EVs and charging stations. This review aims to aid researchers and industries working with batteries, EVs and/or fire safety engineering, to encourage active research collaborations, and attract future research and development on improving the overall safety of future EVs. Only then will society achieve the same comfort level for EVs as they have for conventional vehicles."

We trust that some of the comments, observations and recommendations provided in the partner interviews summarized above could prove a somehow useful contribution in that respect.

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[10] Peiyi Sun, Roeland Bisschop, Huichang Niu, Xinyan Huang "Review of Battery Fires in Electric Vehicles" January 2020. https://www.researchgate.net/publication/338542510_A_Review_of_Battery_Fires_in_Electric_Vehicles. Accessed 26 January 2022.

Further readings

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