March 4, 2024 HIR-24/03

Fire on Battery Electric Transit Bus

Hamden, Connecticut
July 23, 2022

On Saturday, July 23, 2022, at about 3:39 a.m. eastern daylight time, a battery electric transit bus, owned by the Connecticut Department of Transportation and operated by public transit system CTtransit, began emitting smoke while parked inside a CTtransit maintenance facility in Hamden, New Haven County, Connecticut.[1] The bus had been placed out of service 2 days earlier due to an error in the bus charging system. Responding fire department personnel did not observe any visible flames, and the bus was pushed to an outdoor, isolated parking area. In the process, two CTtransit maintenance workers suffered smoke inhalation and were treated at an area hospital. Later that same morning, the bus was again emitting smoke, and fire was observed coming from the rear of the vehicle. Fire personnel returned to the site and the incident commander decided to let the bus burn in the controlled environment. The fire remained active for several hours and fully consumed the vehicle. Following the departure of fire personnel, the bus continued to smolder while remaining isolated in the parking lot. On Monday, July 25, 2022, smoke and an orange glow were observed emanating from the right rear wheel well of the burned bus. Fire department personnel responded for a third time and applied water to the smoking battery compartment. No additional injuries were reported.

[1] (a) In this report, all times are eastern daylight time. (b) Visit ntsb.gov to find additional information in the public docket for this National Transportation Safety Board investigation (case no. HWY22FH011). Use the CAROL Query to search safety recommendations and investigations.

Location	CTtransit maintenance facility, Hamden, Connecticut
Date	July 23, 2022
Time	3:39 a.m. eastern daylight time
Involved vehicles	1
Involved people	2
Injuries	2 minor
Weather	Night, dry, and clear
Roadway information	Not on a roadway

Figure 1. Image of an exemplar CTtransit bus, viewed from the left rear.

1. Factual Information

1.1 Background

The National Transportation Safety Board (NTSB) conducted a focused investigation of the fire with the goal of examining potential safety risks to emergency responders and other personnel responding to similar fires on battery electric transit

buses (also referred to as BETBs), as well as to learn about potential risk mitigation strategies.

Fires in electric vehicles powered by high-voltage lithium-ion batteries pose the risk of electric shock to emergency responders from exposure to the high-voltage components of damaged lithium-ion batteries. Another risk is that damaged cells in the battery can experience thermal runaway—uncontrolled increases in temperature and pressure—which can lead to battery fire reignition. The risk of electric shock and battery reignition/fire arises from the "stranded" energy that remains in a damaged battery. In our report *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles*, we issued several safety recommendations to address the identified issues (NTSB 2020).

In this report, we built on the knowledge gained from our investigations of fires in high-voltage lithium-ion batteries in electric vehicles. In the investigation of a non-crash BETB fire in Hamden, Connecticut, we examined:

- The event sequence and cause of the fire;
- Safety training and protocols of the municipal operators and first responders; and
- Operating procedures for maintaining, charging, and storing the bus.

The report also documents information gathered from two other non-crash BETB fires we investigated, one that occurred at an IndyGo (Indianapolis Public Transit Corporation) facility in Indianapolis, Indiana, and another that occurred at a SEPTA (Southeastern Pennsylvania Transportation Authority) facility in Philadelphia, Pennsylvania. Additional factual information for each related investigation can be found in the public docket for each case.[2]

1.2 Event Sequence

On Saturday, July 23, 2022, about 3:39 a.m. eastern daylight time, a 2021 New Flyer Xcelsior 40-foot BETB, operated by CTtransit, began emitting smoke from the rear compartment while parked inside a maintenance facility in Hamden, New Haven County, Connecticut. An exemplar bus is shown in figure 1. The bus was powered by high-voltage lithium-ion batteries. The energy storage system (ESS) for the batteries consists of six enclosures, four mounted on the roof and two in the rear of the bus.[3] Each

[2] The docket for the Indianapolis investigation is located at https://data.ntsb.gov/Docket/?NTSBNumber=HWY22FH012, and the docket for the Philadelphia investigation is located at https://data.ntsb.gov/Docket/?NTSBNumber=HWY23IH002.

[3] The vehicle battery system was manufactured by XALT Energy. The ESS enclosure is a sealed fiber-reinforced composite enclosure, containing seven high-voltage battery packs. Each pack has 24 cells of 3.7 volts.

ESS also contains components used to control and monitor the batteries' voltage, conduct thermal management, and eliminate moisture. A diagram of components from the emergency response guide (ERG), including ESS locations, is shown in figure 2.

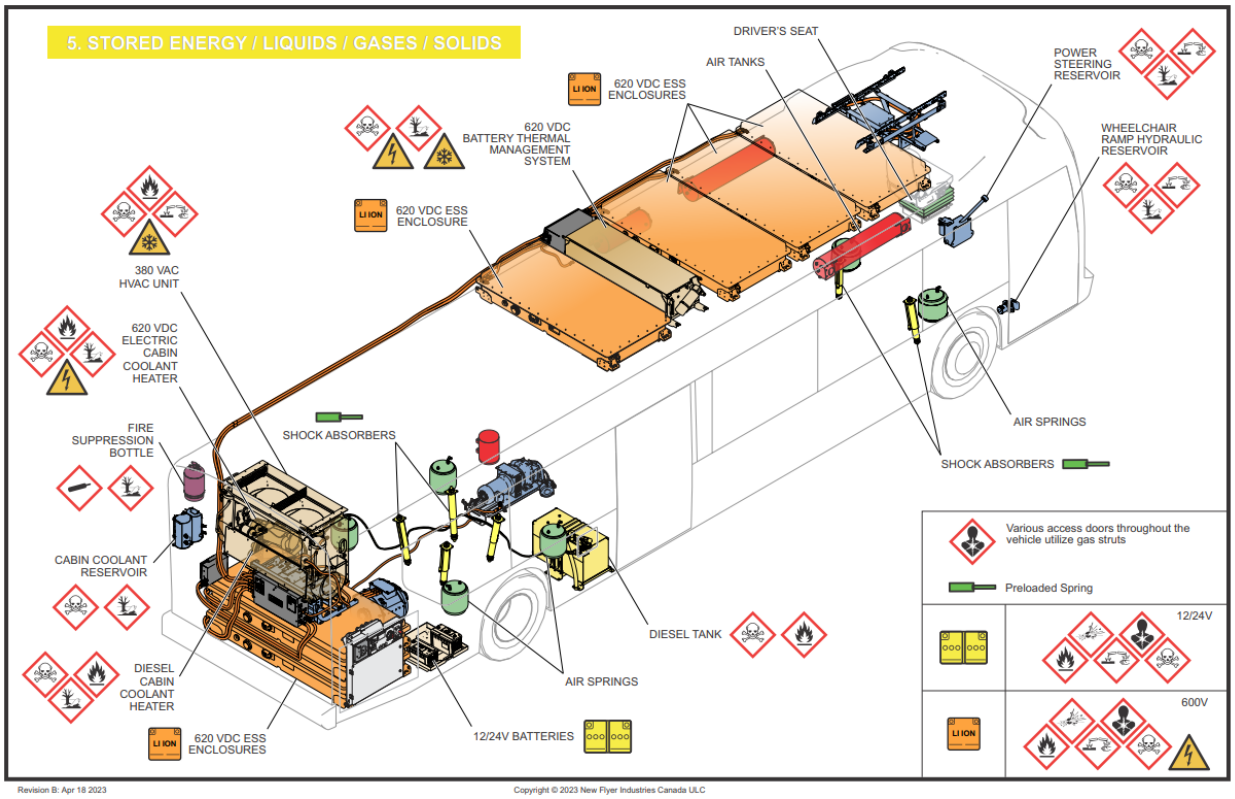

Figure 2. Diagram of component locations, including ESS enclosures, from the New Flyer ERG.

The bus had been charged on July 20 and failed to power up the next day when the ignition was turned. As a result, the bus was taken out of service, taken off the charging station, and parked inside the maintenance facility to await inspection from a New Flyer technician. The thermal event started 2 days later, on July 23, when CTtransit maintenance personnel observed smoke and heard crackling and hissing coming from the rear of the bus. Due to the volume of smoke coming from the ESS, maintenance personnel could not access the emergency battery disconnect located in the engine compartment at the rear of the bus. Between 3:40 a.m. and 3:43 a.m., the CTtransit facility evacuated, and personnel notified the Hamden Fire Department (HFD), who received the alarm at 3:44 a.m. HFD arrived on scene at 3:49 a.m.

Upon arrival, HFD recommended removing the bus from the building. Between 3:50 a.m. and 4:08 a.m., CTtransit personnel prepared by moving the buses surrounding the incident-involved bus. At 4:09 a.m., at the direction of the HFD, CTtransit maintenance personnel moved the incident bus from the building, using a service truck to push it to an isolated parking area about 100 feet from the building. The HFD monitored the bus until 4:35 a.m., and after observing no further smoke or fire, HFD left

the scene. HFD was again notified to return to the scene at 4:45 a.m. to evaluate the two CTtransit maintenance workers who suffered smoke inhalation while moving the bus. The two workers were transported to the hospital for further evaluation, where they were treated for smoke inhalation and later released.

At 7:32 a.m., CTtransit notified HFD that the bus had become fully engulfed in fire. HFD dispatched two fire engines and arrived on scene at 7:34 a.m. Once on scene, HFD determined that battery cells were burning. The incident commander had previously received training from CTtransit and New Flyer for first responders to BETB fires. Because the bus was already outside and there was no further danger to structures or personnel, the incident commander allowed the bus to burn. After most of the bus had burned, HFD attempted to extinguish the remaining fire using water to cool the battery cells.[4] At the rear of the bus, two of the six ESS continued to flare up for several hours. Once the remaining fire was stabilized, HFD cleared the scene at 3:30 p.m., leaving a small crew to monitor the bus until 8:30 p.m.

On July 25, 2022, at 3:31 a.m., CTtransit personnel noticed smoke again emitting from the rear of the bus near an ESS enclosure, and they notified HFD. At 3:37 a.m., HFD arrived and applied water to the ESS and cooled the battery compartment. HFD departed the scene at 3:57 a.m.

1.3 Vehicle and Battery Damage

As shown in figures 3 and 4, all areas of the bus sustained severe fire damage. All windows were missing and the fiberglass cladding was consumed, exposing the steel frame of the bus. All tires were consumed, leaving only the wheels. At the rear of the bus, the upper fiberglass door covering the heating, ventilation, and air-conditioning (HVAC) system and the lower door covering the rear high-voltage lithium-ion battery storage area were consumed, exposing the remnants of both the HVAC system and the batteries. Examination of the rear ESS enclosures showed evidence of water or coolant damage to the batteries in one of the ESS enclosures.[5]

[4] Insufficient cooling of the batteries can lead to delayed thermal runaway due to stranded energy.

[5] A third party examined the battery cells on October 25–27, and New Flyer provided the results to NTSB investigators.

Figure 3. View from the front driver's side of the battery electric transit bus after the fire.

Figure 4. View of the burned transit bus from the left rear corner of the bus.

1.4 Transit Agency, Fleet, and Electric Bus Infrastructure

CTtransit is the Connecticut Department of Transportation (CTDOT)-owned bus service and New England's second largest public transit system, with a total fleet of almost 600 buses. Eleven BETBs are currently in operation as of the date of this report, with the rest being diesel or diesel hybrid-powered.[6] Several companies were under contract with CTDOT to provide transit service in metropolitan areas throughout Connecticut. HNS Management, a subsidiary of First Transit, was the company under contract to manage CTtransit for CTDOT in the Hartford, New Haven, and Stamford divisions. HNS employs more than 1,500 bus operators, maintenance employees, and administrative personnel and serves more than 27 million riders.

Buses were serviced, fueled, charged, and stored at the Hamden maintenance facility in addition to housing administrative offices for HNS Management. The facility was the first CTtransit location to establish an electric vehicle-charging infrastructure. Vehicle-charging infrastructure included new electrical equipment to accommodate increased electrical loads and upgrades to existing fire suppression systems to handle larger volumes of water. At the time of the fire, the Hamden facility had 10 charging stations for BETBs. CTtransit personnel told NTSB investigators that only five charging stations could be used at one time due to electrical grid constraints.

1.5 Safety Risk Management

1.5.1 Onboard Fire Suppression Systems

The FTA does not require buses purchased with FTA funding to have onboard fire suppression systems; however, all buses purchased with FTA financial assistance are required to comply with NHTSA's federal motor vehicle safety standards (FMVSS). Although no FMVSSs require fire suppression systems, a transit agency may consider installing onboard fire suppression systems on its vehicles as part of its Safety Risk Management process.

The incident-involved bus had a Fogmaker fire suppression system installed, which CTDOT includes on all transit buses, whether BETB or internal combustion. The system included a fire detection mechanism and multiple fire suppressant discharge nozzles in the rear ESS compartment. An extinguisher cylinder located in the interior bulkhead supplied the discharge nozzles. When activated, the cylinder will discharge an extinguishing agent to the area of the fire via the nozzles. The spray nozzles for this

[6] See https://portal.ct.gov/DOT/Publictrans/Bureau-of-Public-Transportation/Battery-Electric-Bus-Projects-and-Partners.

system are pointed toward the rear enclosures as well as forward toward the rear seats of the bus. The system was designed to cool the enclosures, protect auxiliary systems such as the HVAC system, and increase the amount of time available to passengers to evacuate in the event of a fire. The solution contained within the cylinder was a mixture of water, a foaming agent, and nitrogen gas propellant. Due to the fire damage sustained by the bus, investigators could not determine if the system activated during the fire.

1.5.2 Emergency Response Guide

New Flyer provided CTtransit with the ERGs, and a copy was stored behind the driver's seat on every BETB.[7] This ERG included information on the location of each battery enclosure, and the location of all battery disconnects and high-voltage interlock switches. The ERG contains additional information regarding battery fires, fire detection, exposure hazards, battery spills, first aid measures, the fire suppression system, and a summary of how to fight lithium-ion battery fires. A list of the hazards associated with high-voltage systems is also in the ERG.

1.5.3 Maintenance Personnel Training

Maintenance personnel are provided a 30-minute class on BETBs and what to do in an emergency. Only designated and trained maintenance personnel are permitted to charge the BETBs. Each day, a battery electric bus charge sheet is completed. Data on the sheet includes the number of the bus being charged, which charger it was connected to, the time at which the bus was connected, and the current state of charge. The mileage of the bus is documented and so is the employee who plugged the bus into the charger. There is space to record any defects noted or make comments.

The New Flyer BETBs in the CTtransit fleet are currently under warranty. CTtransit personnel conduct preventive maintenance and limited-service procedures on the buses, such as tire replacement. New Flyer field service technicians perform all repairs involving the electrical system of the bus at the CTtransit facility.

1.5.4 First Responder Training

CTtransit and New Flyer developed a training program to familiarize Connecticut first responders with BETBs. The first three training sessions were held in Hartford, New Haven, and Stamford during January and February 2022, and included a significant

[7] See https://www.nfpa.org/downloadable-resources/guides-and-manuals/new-flyer-xcelsior-charge-ng-electric-35-40-ft-transit-bus.

number of local police and fire personnel.[8] In addition to the fire department personnel, first responders from several police departments attended. This training was intended to be a "train the trainer" program, and the attendees were expected to disseminate the information to others in their organization. As noted above, the incident commander for the second fire response on July 23 at 7:32 a.m. had received this in-person training.

1.6 Other NTSB Investigations

In this section, we document information gathered from two other BETB fires we investigated, one that occurred at an IndyGo facility in Indianapolis, and another at a SEPTA facility in Philadelphia.

1.6.1 Indianapolis, Indiana

On Wednesday, June 15, 2022, about 11:58 p.m. eastern daylight time, a BETB was reported to be on fire while charging inside the IndyGo facility in Indianapolis.[9] The bus, a 2015 Complete Coach Works Zero Emission Propulsion System, was unoccupied and not in service at the time. Facility personnel had not observed or reported any fault codes or other prior indications of battery failure.

Facility personnel noted that the fire and smoke were coming from the rear of the bus. They activated the fire alarm and began evacuating the facility. They then moved several other buses away from the smoking bus. The Indianapolis Fire Department (IFD) arrived at 12:02 a.m. One of the fire trucks entered the building under conditions of heavy smoke and limited visibility, and the responders extinguished the fire.

About 12:53 a.m. on June 16, 2022, approximately 55 minutes after the fire was initially reported to the IFD, IndyGo personnel used a service vehicle to tow the extinguished BETB to the outside of the building, and the IFD applied additional water to cool the vehicle's battery packs, with the understanding that large amounts of water were needed to cool the batteries.[10] The IFD then monitored the vehicle for about an hour to ensure that it did not reignite. At the request of the IFD, IndyGo personnel moved the bus a second time, to an isolated area away from structures and near a fire hydrant. IndyGo has since designated this area as the location where buses will be parked in case of another thermal event.

[8] Fire departments represented included Stamford Fire, Stony Hill Fire, Glenbrook Fire, Norwalk Fire, Wilton Fire, Hamden Fire, East Haven Fire, North Haven Fire, Cheshire Fire, Woodbridge Fire, Wallingford Fire, and Hartford Fire.

[9] IndyGo is a public transit agency and municipal corporation of the City of Indianapolis.

[10] IndyGo had previously conducted training with IFD on procedures for BETB fires.

1.6.2 Philadelphia, Pennsylvania

On Wednesday, November 9, 2022, at 8:43 a.m. eastern standard time, a BETB caught fire while charging inside Bay 4 at the SEPTA Southern Bus Depot in Philadelphia. The bus, a 2018 Proterra E2 Catalyst BEB40, was not in service and was unoccupied during the event.[11] Facility personnel had not observed or reported any fault codes or other prior indications of battery failure. About 3 minutes after the fire ignited, the SEPTA facility's sprinkler system was activated.

The first Philadelphia Fire Department (PFD) units arrived on scene at 8:51 a.m. and controlled the fire by continuously applying water to the high-voltage lithium-ion battery pack, which was located behind the front axle.[12] The incident commander reported that they did not consult the Proterra ERG and had not attended any training specific to lithium-ion battery fires.[13] Further, he reported that responders applied water to the underside of the bus as that location appeared to be the source of the fire. After the fire was extinguished, the bus was towed from the building and isolated in a "sandbox" made from jersey barriers, plastic, sand, and water to mitigate reignition.[14] No injuries were reported. The event was confined to a single high-voltage battery pack, and the affected battery did not reignite after the PFD extinguished the first fire.

Proterra representatives found that the bus displayed fault codes for "high relative humidity," "low internal isolation," and "coolant flood" before the thermal event. The "high relative humidity" fault code was also observed in at least one other bus in the SEPTA fleet (#916). Proterra's investigation concluded that the accumulation of liquid inside the battery pack enclosure likely caused the thermal event.[15] Proterra reviewed telemetry data fleet-wide and found 28 battery packs (out of about 4,000) in 19 vehicles with similar fault codes. Proterra issued a recall of the vehicles on November 30, 2022; at the time of this report, the root cause of the fault codes was still under investigation and not determined.

[11] Onboard video views of the interior of the bus were obtained by the NTSB.

[12] Proterra BETBs have a different battery pack configuration than the New Flyer BETB.

[13] See the Proterra ERG at: https://content.nfpa.org/-/media/Project/Storefront/Catalog/Files/Emergency-Response/Emergency-Response-Guides/Proterra/Proterra-Bus-Catalyst-E2-EV-2017-2018-QRG.pdf.

[14] The ERG guidance mentions a 20-foot safety zone but does not specify the isolation method that was utilized. The decision to use sand in the isolation area was made by the Philadelphia Hazmat Administration Unit in coordination with the incident commander.

[15] The full Proterra report is available in the docket for the event; see https://data.ntsb.gov/Docket/?NTSBNumber=HWY23IH002

1.6.3 Incident Comparison

For ease of comparison, table 1 includes a summary of the facility and fire department responses for the three events.

Table 1. Comparison of responder actions in each fire.

Event	Hamden	Indianapolis	Philadelphia
First fire department (FD) action	Moved other buses, then removed the involved bus	Cut power to the chargers and then removed the involved bus	Water on bus
FD BETB training	Yes, not used	Yes, used	No
Time to isolate and location description	30 minutes; bus moved to parking lot	55 minutes; bus moved to grass area away from building	3 hours 25 minutes; isolation area constructed in response to fire
Approach to extinguish	Upon reignition, monitored the fire and let it burn without extinguishment	Applied 750 gallons of water to cool battery	Application of a large amount of water from hoses and sprinkler system, monitored for heat
Monitored after the initial event?	Yes. HFD fire watch for ~5 hours after the main event was extinguished	IFD monitored for ~1 hour after the bus was isolated outdoors and batteries cooled.	Yes. Placed in an isolated sandbox for 24 hours
Reignition	Yes, about 4 hours later and again 2 days later	No	No

1.7 Post-Fire Actions

1.7.1 First Responder and Maintenance Personnel Training

After the Hamden fire, additional training was made available to all local first responders in the Greater New Haven Area. New Flyer provided the training material, and this training will be conducted biannually on an ongoing basis.

Separate from first responder training, an additional 40 hours of training was provided to maintenance personnel at all three CTtransit divisions. These training courses were taught by New Flyer instructors on how to diagnose and respond to problems with the different electric bus configurations, fault codes, and charging issues. A maintenance training curriculum and catalog was also compiled as a minimum standard of required training for all transit agencies in Connecticut. This standard will provide a baseline training minimum, as well as courses and exercises for continued training and development, before deploying BETBs.

Working in collaboration with New Flyer, CTtransit developed a more detailed training program to further educate bus operators on BETB technology, optimum driving techniques, and emergency preparedness. The multimedium training program comprised classroom training, physical demonstrations, employee handouts, and internal media campaigns. Thirty CTtransit instructors participated in New Flyer's trainer program to obtain the necessary material and procedures to implement during relaunch training as well as new hire training for the CTtransit Operator Academy, which is the training facility for CTtransit.

The charger manufacturer ABB provided a 2-day training course for CTDOT and CTtransit staff that covered specific details on the following topics: daily charger operations, charger troubleshooting, personal protective equipment (PPE), and safety procedures for working in and around charger cabinets and power system controls. Specific details were provided about the PPE required to work in the charger cabinets and switchgears.

Through collaboration with other agency partners as well as guidance from the manufacturers, CTDOT developed baseline tooling and PPE for the maintenance technicians working on the BETBs at CTtransit facilities. Diagnostic tools, thermal cameras, arc-flash PPE and insulated rescue hooks designed to remove a person incapacitated by electrical shock from a hazardous location are among the items for fleet maintenance personnel to procure.

1.7.2 Battery Temperature Monitoring

After the fire, the remaining 11 BETBs in the CTtransit fleet were stored outside in the parking lot, away from buildings, with approximately 15 feet of space between each bus. All six ESS enclosures on all buses were checked for signs of liquid contamination and none was found. All wires, cables, electronic equipment, sensors, and connections were also inspected in each ESS enclosure and no issues were discovered.

The New Flyer Connect system software program has been updated so that the buses will send automatic emails to CTtransit personnel when the battery temperature reaches a minimum threshold of 35°C/96°F. This preemptive battery temperature monitoring will occur while the bus is in operation (either driving or idle). This system is designed to rapidly notify personnel of temperature increases in the battery system that could result in a potential safety issue.

1.7.3 New Flyer Recall Notice

New Flyer informed investigators that, similar to the Hamden event, a subsequent incident also involved coolant liquid leaking into the ESS. In January 2023, a bus owned

by another operator had high temperatures inside the ESS but did not catch fire. However, New Flyer found evidence of coolant liquid in the ESS.

On February 15, 2023, New Flyer issued a recall notice (23V-083) for all 2021–2023 XE35, XE40, and XE60 buses.[16] The defect noted that liquid may accumulate in the ESS and not be detected. Although New Flyer was unable to determine the cause of the coolant leak, the company is addressing the issue in the interim by asking purchasers/operators to check the enclosures for liquid by inspecting the desiccant canisters for the presence of moisture if the bus has been parked for more than 3 days.[17] In addition, if maintenance requires adding coolant to the system, the instructions indicate that personnel should check the system for leaks and then diagnose and repair the leaks rather than just topping off the system with additional coolant. On May 3, 2023, owners were notified of a remedy involving adding four ports in each battery enclosure with automatic activating drain valves in each port. When liquid contacts the valve, the valve will open allowing the liquid to drain out. The valves are chemically activated, and the bus does not need to be operating or powered up for the valve to open. If a coolant leak has occurred that is significant enough to activate the valve, the driver will be notified through warning lights on the dash. Valves must be replaced once they are activated, and a service technician will inspect the ESS to determine the cause of the activation when replacing the valve.

In addition to the drain port remedy for specific ESS designs, New Flyer and the battery manufacturer, XALT Energy, have established measures to return the buses to service. One measure is inspecting all existing bus battery packs for moisture, and repairing and replacing the battery packs as needed. Another measure is using a high-voltage isolation warning indicator to detect moisture in the battery enclosures.[18] After the events in Hamden, New Flyer identified 18 buses with either saturated desiccant material or fault codes for excessive moisture.

[16] See https://static.nhtsa.gov/odi/rcl/2023/RIONL-23V083-4775.pdf.

[17] *Desiccants* are drying agents that absorb moisture. The desiccant material in New Flyer buses is contained in canisters with removable caps that allow personnel to inspect the content for the presence of moisture.

[18] For New Flyer BETBs, during operation and charging, the battery temperature in the enclosures is constantly monitored. If the bus is shut down, there is no temperature monitoring. The New Flyer software has been updated to send automated emails to CTtransit personnel when the battery temperature reaches a minimum threshold of 35°C/96°F. This preemptive battery temperature monitoring will occur while the bus is turned on (driving or idle). This system is designed to rapidly notify personnel of temperature irregularities in the battery system that could result in a potential safety issue. This is in addition to the existing battery alert system on the bus that shows alerts when the system temperature exceeds 35˚C, 40˚C, and 45˚C. When the temperature is detected at these levels, the bus automatically reduces power or, at 45˚C, shuts down and no longer operates.

1.7.4 Federal Transit Administration

The FTA's Public Transportation Agency Safety Plans regulation (49 *CFR* 673) requires that an agency's safety risk management process identify hazards and the consequences of hazards, establish methods and processes to assess the safety risks associated with identified safety hazards, and develop and monitor the effectiveness of safety risk mitigations.[19] The FTA requires transit agencies to develop a comprehensive safety training program for all employees and contractors who are directly responsible for safety. Transit agencies such as CTtransit that serve an urbanized area with a population of 200,000 or more are required to include maintenance personnel in their safety training program. At the time of the fire, the FTA did not have specific guidance or requirements addressing BETB-specific safety risk mitigations.

FTA is actively funding research programs and projects to assist transit agencies transitioning to BETB fleets. For example, FTA's Transit Vehicle Innovation Deployment Center program established a resource center for transit agencies to learn about best practices in next-generation vehicle deployment and BETBs. In August 2023, FTA's Standards Development Program published a guidebook for deploying BETBs (FTA 2023).

2. Analysis

The cause of the fire in the Hamden event is attributed to battery cell damage from coolant that had leaked into the battery enclosure. Post-event investigations identified a faulty moisture monitoring system in the ESS enclosures on the New Flyer BETBs. As noted, New Flyer has issued a safety recall for all ESS enclosures with this design. The specific cause of coolant entering the enclosure has not been determined.

2.1 Safety Risk Management Plans

As noted in table 1, CTtransit had a safety plan in place, as required by the FTA. However, at the time of the incident, the plan did not contain any special provisions for BETBs; and it was not required to by the FTA. As described in section 1.7.1, CTtransit has since updated its response plans to incorporate specific needs of BETBs that differ from internal combustion engine transit buses, such as additional physical separation of BETBs and creating an isolation area in the event of a fire. Although these changes occurred before the FTA released updated guidance, they are consistent with the new guidance (FTA 2023). The new guidance includes, in part, hazard-based design criteria

[19] Requirements for facilities, such as sprinkler systems, are established by the local authorities.

of BETBs, physical separation between parked BETBs, outdoor storage of BETBs, and the creation of a fire area to isolate BETBs to limit a fire from spreading.

The topic of best practices for safety risk management of BETBs is also being researched by other stakeholders. A 2023 project (with estimated completion in early 2025) by the Transportation Research Board was awarded to the Fire Protection Research Foundation to document best practices for preventing BETB fires and managing fire risks. According to its description, the project should review the potential root causes of lithium-ion battery fires, including analyzing the potential for such fires to spread to other vehicles or reignite after suppression; evaluate risk mitigation options; identify, evaluate, and summarize effective practices for fire risk mitigation and suppression, focusing on agencies that store and charge their buses in indoor facilities; identify quantitative and qualitative metrics that can be used to evaluate vehicle and battery performance as related to fire and life safety; and address the technical, economic, and institutional barriers to implementing identified solutions (TRB 2023).

Although no fatalities occurred in any of the fires, the facility workers in Hamden were treated for smoke inhalation after they were exposed to smoke while moving the bus outside the facility. Had the updated guidance from FTA been available, CTtransit would likely have already been storing its buses outdoors. CTtransit has since begun storing its BETB fleet outdoors, making the buses easier to isolate in the event of a fire. CTtransit has also increased training for personnel. Further, the agency is providing additional PPE for personnel working with BETB charging stations. Although not explicit to smoke inhalation, use of appropriate PPE should improve the safety of workers interacting with high-voltage electrical systems.

2.2 Emergency Response

The emergency responders arrived promptly in the Hamden, Philadelphia, and Indianapolis cases while the buses were still inside the facilities. The immediate response and firefighting efforts varied between the three cases and depended on the bus location when it caught fire, the size of the fire, the fire department's experience and understanding of high-voltage lithium-ion battery fires, and the ability to isolate the bus outside the facility.[20]

The HFD responders had previously received training on high-voltage electric-battery firefighting approaches, which led them to isolate the bus during their initial response. Because the bus was already isolated when responders arrived the second time, the incident commander allowed the bus to burn until most of the bus had

[20] The approaches were consistent with the information provided in the ERGs.

been consumed by the fire. HFD continued to monitor the bus after it burned, consistent with training.

In the other two cases, firefighters used sufficient water to fully cool the batteries, based on training received from the transit agencies, bus manufacturers, and ERG. This is consistent with NTSB Safety Recommendation H-20-32 that vehicle manufacturers provide information about their specific vehicle systems in order to reduce risks when extinguishing battery electric vehicle fires. The overall status of H-20-32 is Open—Acceptable Response, with the response from Proterra classified Closed—Acceptable Response.[21] Further, NTSB Safety Recommendation H-20-33 asked four fire safety organizations to disseminate guidance to their members concerning fires in high-voltage lithium-ion batteries in electric vehicles, so that their members would have knowledge to efficiently fight these fires. This recommendation is classified Closed—Acceptable Action for two fire organizations and Open—Await Response for the remaining two.[22] In Indianapolis, firefighters also had previous BETB training and extinguished the fire after the bus had been isolated. In Philadelphia, firefighters had not received specific training from SEPTA on its BETB fleets but did use water to extinguish the fire before the bus was isolated, and continued to apply water once it was isolated.

2.3 Fire Suppression Systems

In the Hamden case, due to the fire damage sustained by the bus, it is undetermined if the suppression system engaged during this fire event. As noted above, current best practices for fighting high-voltage electric-battery fires require using large amounts of water to cool the battery packs in a thermal event, which cannot be accomplished with an onboard fire suppression system. Therefore, onboard fire suppression systems are unlikely to extinguish a high-voltage battery fire. However, they may provide valuable time for passengers to exit a bus or may prevent a non-battery fire from spreading to the high-voltage battery systems. In addition to onboard fire suppression, the design of the passenger compartment and location of battery cells can allow for more time to exit a bus. In the Philadelphia fire, for example, video from the system onboard the bus showed that the fire was directed away from the passenger compartment.

[21] Safety Recommendation H-20-32 was not issued to other manufacturers in this report.

[22] Safety Recommendation H-20-33 is classified Closed—Acceptable Action for the National Fire Protection Association and the International Association of Fire Chiefs. The recommendation is classified Open—Await Response for the International Association of Fire Fighters and the National Volunteer Fire Council.

2.4 Additional Battery Recalls

Other manufacturers of electric vehicles have issued recalls for moisture in high-voltage battery packs. In July 2022, Gillig, LLC recalled certain 2019–2022 low-floor vehicles, such as transit buses, equipped with certain battery packs. It was discovered that the battery packs may develop a coolant leak internally, causing the battery pack to short circuit. Gillig's remedy for the issue is to tighten the coolant fittings and replace the coolant.

In April 2023, Nova Bus (US) Inc. recalled certain 2022–2023 electric buses after discovering that the coolant line in the high-voltage battery pack may not be fully seated and locked, which can result in coolant loss and an electrical short circuit. Nova Bus's remedy is to inspect and replace the battery packs as necessary.

3. Conclusions

3.1 Probable Cause

The National Transportation Safety Board determines that the probable cause of the Hamden, Connecticut, fire on a battery electric transit bus was moisture in the high-voltage lithium-ion battery system, which led to battery damage resulting in the fire. Contributing to the injuries to facility personnel was the lack of a safety plan by CTtransit for mitigating risks associated with high-voltage lithium-ion battery fires during emergency response.

3.2 Lessons Learned

High-voltage lithium-ion battery fires require a specific firefighting approach that relies on application of water to cool the high-voltage batteries. Stranded energy in the batteries presents a risk of battery reignition. The NTSB previously issued safety recommendations to manufacturers of electric vehicles equipped with high-voltage lithium-ion batteries to provide vehicle-specific information in their ERGs about safely extinguishing fires, mitigating reignition events, and transporting and storing damaged vehicles. All three manufacturers of the buses mentioned in the report have the recommended information in their training materials and/or ERGs.

After the fire events in Hamden, the FTA published a handbook for deploying BETBs that includes updated guidance for managing risks associated with high-voltage BETB fires consistent with actions CTtransit implemented after the initial bus fire, including outdoor bus storage and providing isolation areas should a BETB fire occur. In addition, best practices for managing risks associated with BETBs are an area of active

research by the Fire Protection Research Foundation, under a project awarded by the Transportation Research Board. As transit agencies continue to electrify their bus fleets, the NTSB will continue to monitor issues related to BETB fires and ongoing research in the area to understand the safety impacts of these alternative-fueled vehicles.

References

FTA (Federal Transit Administration). 2023. *Guidebook for Deploying Battery Electric Buses*. https://www.transit.dot.gov/sites/fta.dot.gov/files/2023-08/FTA-Report-No-0254.pdf. Washington, DC: FTA

TRB (National Academies of Sciences, Engineering, and Medicine, Transportation Research Board). "Lithium-Ion Battery Transit Bus Fire Prevention and Risk Management." Accessed 9/28/2023. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5258

NTSB (National Transportation Safety Board). 2020. *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles*. NTSB/SR-20/01. Washington, DC: NTSB.

NTSB investigators worked with the **Federal Transit Administration** (FTA); the **Connecticut State Police**; the **Connecticut Department of Transportation (CTDOT)**; **New Flyer of America**; and **First Transit** throughout this investigation.