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Safety and Security Certification of Electric Bus Fleets – Industry Best Practices

PREPARED BY

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Center for Urban Transportation Research
University of South Florida

U.S. Department of Transportation
Federal Transit Administration

AUGUST 2023

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Recently, bus transit agencies nationwide have slowly shifted from reducing their carbon footprints through alternative fuel vehicles to eliminating their carbon emissions by adopting battery electric fleets. This push is supported by FTA's commitment to reducing carbon emissions from transit vehicles, infrastructure, and construction through their Low or No Emissions Grant Program funding. In harmony with the battery electric bus (BEB) market's expansion, bus transit systems are also presented with the emergence of new technologies not commonly found in U.S. transit systems, specifically with BEBs. The progression of such technology has exemplified the need to expand current safety and security certification (SSC) capabilities to ensure agencies can maintain their overall safety performance. Therefore, the primary objective of this research initiative is to develop minimum SSC program practices and protocols for transit agencies to verify that BEBs and their associated facilities, systems, and equipment are safe for revenue operations.

This report has been developed based on the information available and provided to the research team at the time the research was conducted, and at the time this report was compiled and drafted. In addition, the representations, worksheets, work products, and information are provided as samples and examples only. This information is not and cannot be considered complete as every battery electric bus, component, infrastructure, and other related assemblies procured are unique to each individual agency and procurement. The included and referenced analyses provided as part of this document, either included or referenced, have been provided as samples and examples to serve as general guidance. This document, including references, samples, and examples are not all-inclusive. Safety and security certification activities will need to be completed for each battery electric bus (BEB) procurement, based on the buses and components being procured and considering the respective circumstances of the agency and its procurement activities. Although this industry practices document strives to address safety and security certification activities of battery electric buses, BEB technology is relatively new and unique, and must be adapted accordingly based on the circumstances of each agency.

Foreword

The Federal Transit Administration (FTA) entered into a cooperative agreement with the University of South Florida (USF) and its Center for Urban Transportation Research (CUTR) to develop a safety standards research report to identify areas of transit safety risk within the industry. The purpose of the research initiative is to inventory existing transit safety standards or those within other transportation industries that could be modified to address safety-related risks and establish focus areas for further research to support FTA's Standards Development Program (SDP). Through the SDP, research and background studies are being performed on safety-critical and other emphasis areas to collect the information necessary to (1) identify and support the voluntary adoption of transit standards in cooperation and coordination with standard development organizations (SDOs), and (2) provide best practices to the industry on measures and processes that may be instituted to improve public transit safety.

Executive Summary

Recently, bus transit has seen a rise in interest among agencies converting their fleets from conventional fossil fuels and compressed natural gas (CNG) to battery electric fleets. Large bus transit providers have begun committing to complete fleet transitions to zero-emissions vehicles, including battery electric buses (BEB).[1] Transitioning to new service delivery systems, especially when it involves an emerging technology, inadvertently introduces unique risks to transit system safety and security performance, thus requiring verification through a well-established safety and security certification (SSC) program.

The Federal Transit Administration (FTA) commissioned the development of the National Safety Program to assist agencies receiving federal financial assistance from FTA, and with significant capital projects meeting the applicability criteria defined in *49 CFR 633: Project Management Oversight*, to prepare and carry out safety and security management plan (SSMP) activities for safety certification. Safety and security certification is how recipients verify that the project outputs are safe for passengers, employees, public safety personnel, and the general public. This process improves safety and supports analysis that reduces the need for expensive retrofitting to correct hazards or vulnerabilities after the system is placed in revenue service. While FTA published the *Handbook for Transit Safety and Security Certification* in 2002, the Handbook does not comprehensively specify methodologies for certifying complex systems and new technology, including those associated with the push for BEBs.

To advance a comprehensive approach to safety decision-making and advance modern safety principles, FTA adopted a safety management system (SMS) model to develop and implement the National Safety Program, initially established by the Moving Ahead for Progress in the 21st Century Act (MAP-21). FTA's adoption of the SMS framework elevated the approach to transit safety, shifting from a reactive method to a proactive approach focused on preventing events. SMS builds a safety culture in public transit dedicated to controlling and reducing risk, detecting and correcting safety hazards early, and sharing and analyzing safety data more effectively to deploy strategic solutions to systemic problems and measure their effectiveness. Critical to this process is applying programs that will ensure the implementation and effectiveness of safety risk mitigation, partly through change management programs, which include methods for SSC.

In support of this report's development, a research study was performed to investigate gaps in certifying BEB sub-systems as part of the overall SSC process. The research findings included identifying safety-critical sub-systems, including but not limited to batteries, charging systems, emergency response

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[1] Transit agencies operating more than 100 non-rail fixed vehicles in peak revenue service

considerations, and serviceability. This was completed using a comprehensive research and review of industry best practices and current programs. More specifically, the research involved the nationwide distribution of a web-based survey, followed by a review of industry standards, practices, and research. The summary research findings included notable gaps in:

- **Safety and security certification utilization:** Just over half of bus agencies used only portions of the 10-Step SSC program while procuring existing BEBs and supporting systems. No agency implemented the complete SSC process.
- **Safety and security design criteria:** The lack of pre-established design criteria may be attributed to the lack of state and local regulations or to gaps in codes and standards.
- **Interagency coordination:** Safety and security departments were only consulted an average of 45 percent under each scenario. Similarly, on average, only 36 percent of first responders were part of both past and active procurements.
- **Codes and standards:** As with many emerging technologies, specific codes and standards may not exist, resulting in unidentified or miscategorized safety risks and security vulnerabilities being improperly mitigated. The lack of codes and standards and a developing program's absence of documented knowledge from the industry often leads to gaps in design criteria, technical specifications, or Contract Data Requirements Lists (CDRLs) not based on minimum acceptable standards.

As more transit agencies begin to purchase BEBs, including those funded through FTA's competitive Low- or No-Emission (Low-No) Grant Program, the need for an expanded SSC best practices document becomes more prudent. When incorporating BEBs and associated systems and infrastructure into their operations, bus transit agencies must undergo more rigorous verification to ensure all risks and vulnerabilities are minimized.

Section 1 Introduction

In November 2021, the White House signed the Bipartisan Infrastructure Law, codifying improvements to the Federal Transit Administration's (FTA's) Grants for Buses and Bus Facilities Program (49 USC 5339). The Grants for Buses and Bus Facilities Program makes federal resources available to states and designated recipients to replace, rehabilitate, and purchase buses and related equipment, and to construct bus-related facilities, including technological changes or innovations to modify low or no-emission vehicles or facilities. Under the Bipartisan Infrastructure Law, additional funding was allocated through 2026 in the estimated amount of $5.63 billion for agencies operating fixed-route bus services to convert to low- or no-emission vehicles and supporting facilities, including BEBs.

Table 1-1 *Bipartisan Infrastructure Law: Grants for Buses and Bus Facilities*

Fiscal Year	2022 (In millions)	2023 (In millions)	2024 (In millions)	2025 (In millions)	2026 (In millions)
Grants for Buses and Bus Facilities (Formula)	$604	$617	$633	$646	$662
Grants for Buses and Bus Facilities (Competitive)	$376	$384	$394	$402	$412
Low- or No-Emissions Grants (Competitive)	**$1,122**	**$1,123**	**$1,125**	**$1,127**	**$1,128**

As funding opportunities increase, so will the industry's adoption of battery-electric systems. Recent studies show that the nation's BEB market has experienced substantial growth, with numerous agencies either actively procuring or planning to procure these zero-emission vehicles, including Boston, Los Angeles, Seattle, San Francisco, Austin, and New York.

With greater financial incentives, BEBs are also considered more sustainable alternatives to their diesel, diesel-hybrid, or compressed natural gas (CNG) counterparts, making them more appealing for both large and small transit providers. A 2018 study conducted by the U.S. National Renewable Energy Laboratory (NREL) determined that the fuel economy of BEBs is 3.8 times greater than that of a diesel bus operated on the same route.[2] Similar studies and lessons learned from early adopters of BEB systems have fostered a greater interest in zero-emission bus operations, culminating in the rapid growth in research and development opportunities of new technologies to improve this efficiency even more. While technological advancements have led to improvements in

[2] https://www.nrel.gov/docs/fy19osti/72864.pdf

operational efficiencies, they have also presented new safety risks, security vulnerabilities, and challenges to the industry.

A battery electric vehicle replaces a combustion engine with a traction-power motor powered by multiple battery packs, typically Lithium-Ion (Li-Ion), and managed through a power electronics controller, which supplies power to auxiliary equipment. Figure 1-1 illustrates the typical components of a BEB designed by Proterra for King County Metro. Note that this is not representative of all configurations but rather one arrangement from one manufacturer. For example, some configurations place the batteries on the vehicle's roof, as shown in Figure 1-2.

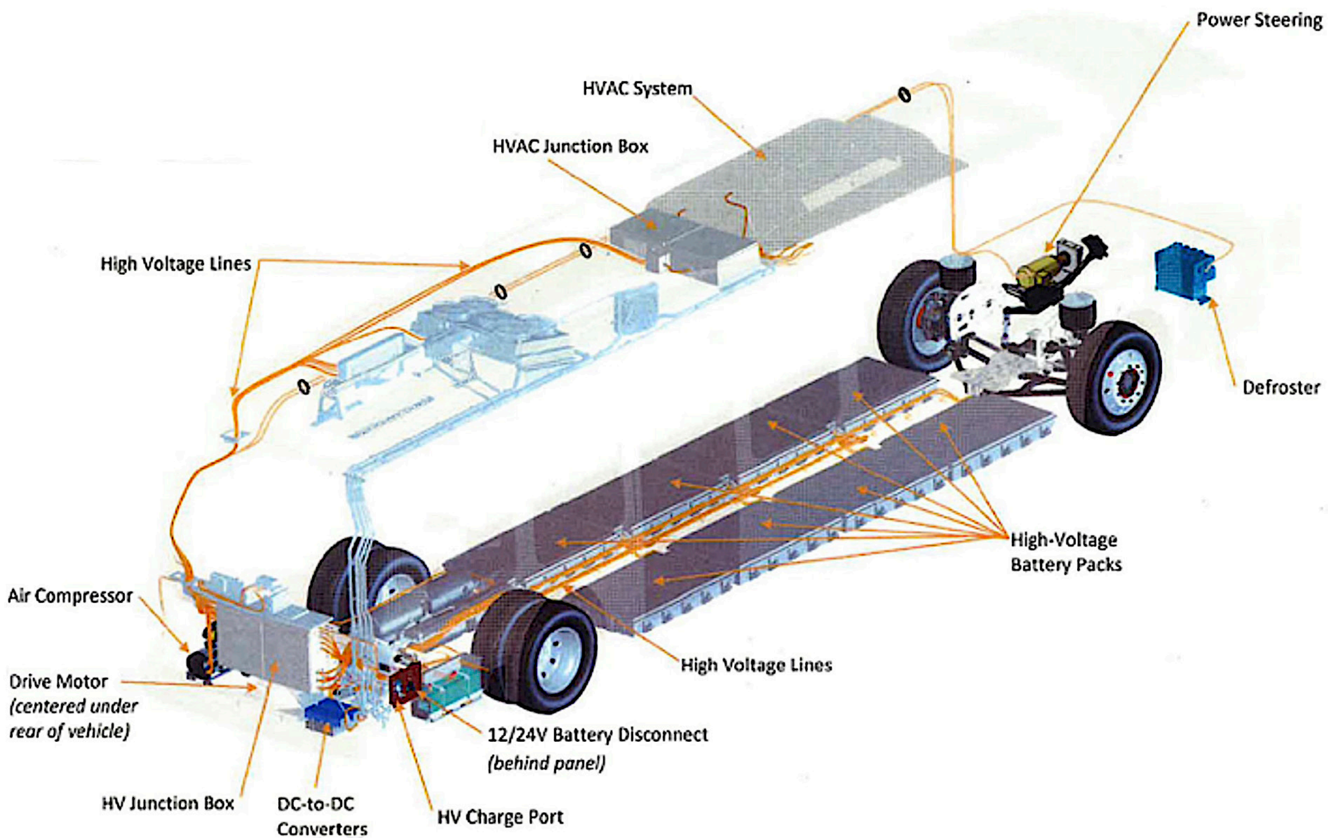

Figure 1-1 *Battery Electric Bus Configuration, Floor Mounted Batteries*

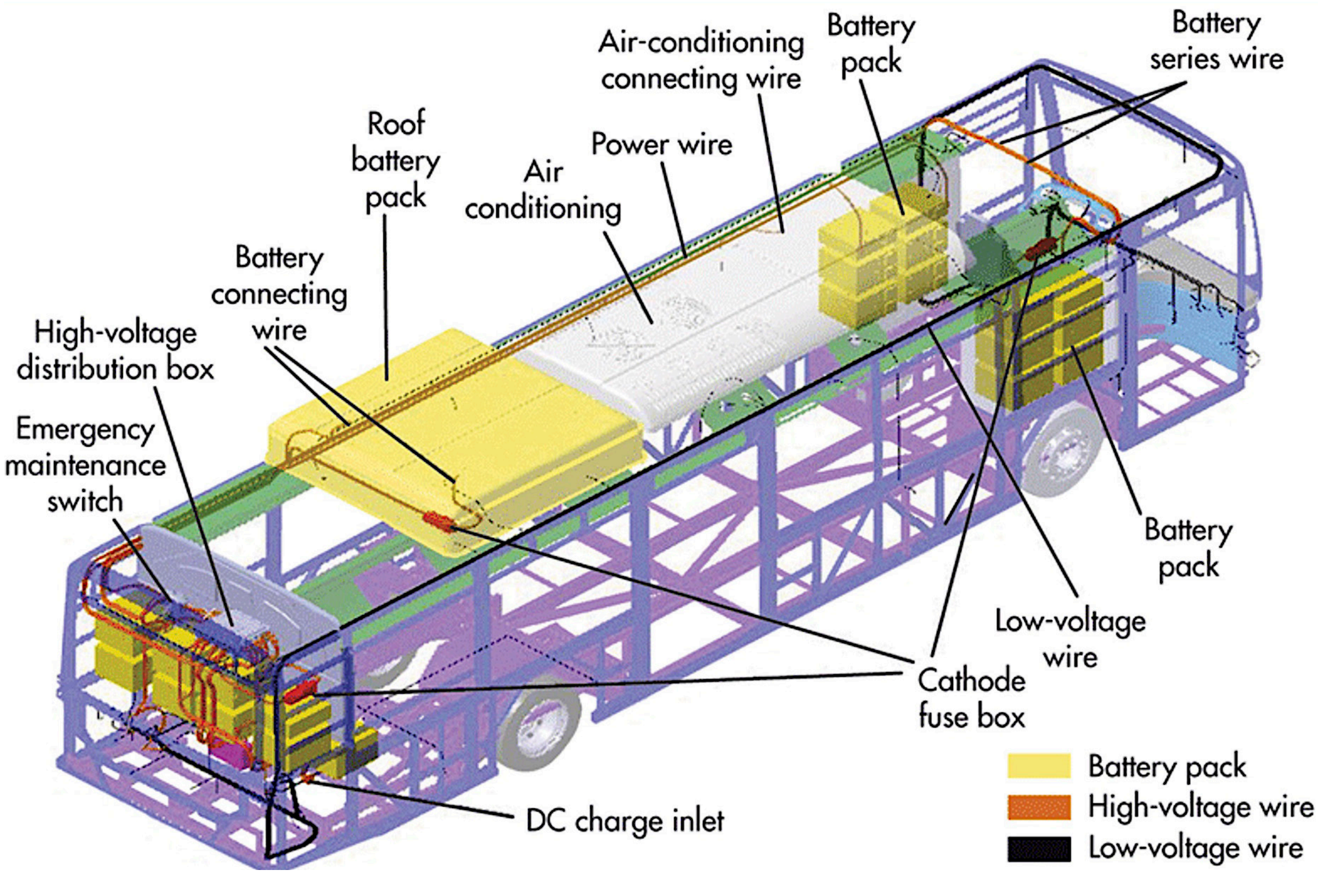

Figure 1-2 *Battery Electric Bus Configuration, Roof Mounted Batteries*

Applying new, unproven systems into the transit arena also presents additional challenges for agencies of all sizes to effectively manage operational as well as fire and life-safety risks. With the nation's transit industry slow to adopt battery electric vehicles, actionable data is not yet available to conceptualize the actual risk of battery electric systems. Using data from the automotive industry provided by the NTSB, the risk of a fire in high-capacity Li-Ion systems is less than that of a combustion engine. However, the disproportionate number of battery electric vehicles to combustion also does not accurately represent the system's risks.

Additionally, advancements in remote monitoring capabilities for vehicle performance and communications necessitate any agency to focus on new potential cyber vulnerabilities. While national and international organizations continue to issue regulations and standards for battery electric systems and high-voltage Li-Ion, the codes and standards development process cannot advise the industry at the same pace as new technology is introduced. This also leads to additional operational challenges for transit systems and emergency response organizations.

Scope

This report expands on areas where standards, practices, or other guidance are necessary, including testing and commissioning BEB fleets and associated equipment and infrastructure. Specifically, this report focuses on industry best practices for the SSC of a BEB system's sub-systems, components, or elements. The information in this report expands on FTA's 10-Step SSC process by documenting identified best practices and additional standards, practices, or other applicable guidance from the industry. More specifically, it identifies the following critical items of the battery sub-system within the safety certification:

- **Design specifications**: Critical aspects of safety and security specification development, and the need for agencies to incorporate national, state, and local regulatory requirements into the design specifications as dictated by the SSC's safety and security analyses.
- **Environmental considerations**: Safety and security procurement considerations are based on the operating environment.
- **Systems testing:** Methods for ensuring the system's functionality with regard to ecological concerns and safety-related systems.
- **Commissioning:** The need to address operational considerations and ensure that all parts of the BEB system (BEB vehicle, charging infrastructure, facility interfaces) interoperate as intended.

Purpose

The purpose of this industry best practices report is to provide transit agencies actively procuring or planning to procure BEBs or associated charging infrastructure with recommended minimum SSC program practices and protocols to verify more effectively that BEBs and their associated facilities, systems, and equipment are safe for revenue operations.

This report does not apply to fuel cells or alternative fuel methods such as hydrogen cells or CNG. Similarly, federal requirements necessitate the development of several project-specific documents such as a project management plan (PMP), safety and security management plan (SSMP), and safety and security certification plan (SSCP). These documents will not be discussed in this report; however, agencies must know their requirements and importance in the certification process.

Section 2

Guidelines for Performing Safety Certification

This report is designed to improve a bus transit agency's ability to recognize the unique hazards, vulnerabilities, and associated infrastructure of a BEB fleet. The guidelines in the report are based on industry literature review and the identification and review of best practices for BEB SSC processes covering sub-systems, components, and elements. The research was performed, and documentation gathered during the project period of performance July 2021 – June 2022. As noted previously, although this guidance strives to address safety and security certification activities of battery-electric buses, BEB technology is relatively new and unique, and must be adapted accordingly based on the circumstances of each agency. In addition, it is important to note that agencies are still required to abide by all local and state codes affecting their certification process and any federal requirements set forth by FTA or other regulators.

Requirements for Safety Certification

Figure 2-1 illustrates the regulatory framework affecting the safety and security verification of BEBs. Identified regulations were used to direct the many recommendations presented in this report. However, agencies must be aware of other local and state requirements applicable to their procurement efforts.

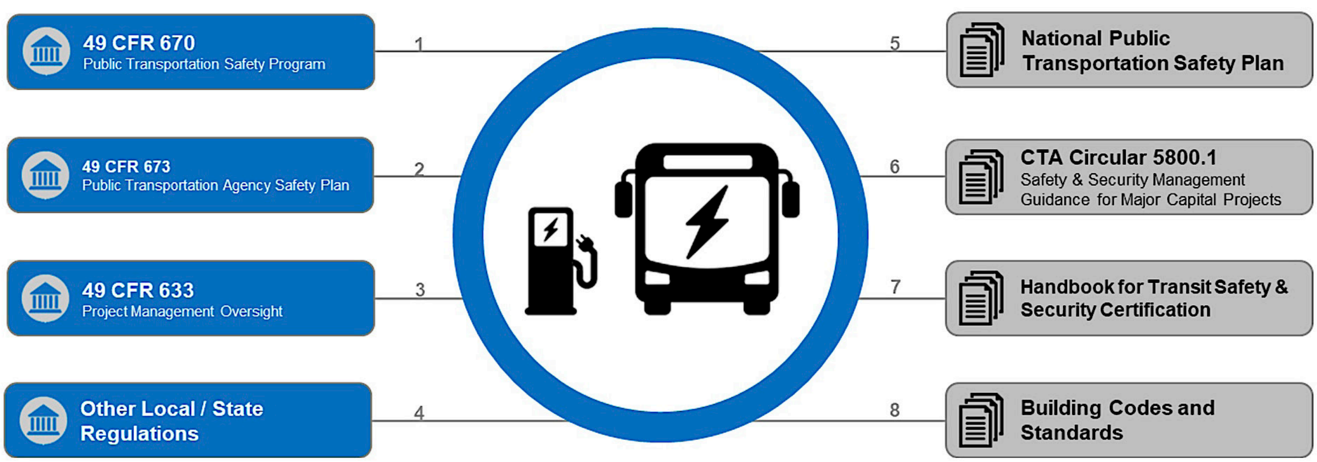

Figure 2-1 *Safety and Security Requirements for Bus Transit Agencies*

Recipients of federal financial assistance from FTA that have significant capital projects meeting the applicability criteria defined *49 CFR 633: Project Management Oversight* are required to prepare and carry out SSMP activities for safety certification. SSC is how recipients verify that the project outputs are safe for passengers, employees, public safety personnel, and the general public.

Additional guidance in Circular 5800.1 Safety and Security Management Guidance for Major Capital Projects is supplemental to this requirement. The Circular identifies safety and security management activities to be performed by grant recipients and provides evaluation criteria to FTA for reviewing SSMP and assessing implementation. Furthermore, the Circular provides a process and outline for preparing an SSMP, including developing an SSC program. While FTA also published the *Handbook for Transit Safety and Security Certification* in 2002, the Handbook does not comprehensively specify methodologies for certifying complex systems and new technology, including those associated with the push for BEBs. Recipients of federal funding covered under 49 CFR Part 633 are also required to address safety and security in the PMP and develop an SSMP and SSCP.

Section 3 SMS and BEB Procurements

Initially established in the Moving Ahead for Progress in the 21st Century Act (MAP-21), FTA adopted the safety management system (SMS) model to develop and implement the National Safety Program. Built on four (4) interconnected components, SMS is intended to advance a comprehensive approach to safety decision-making and to advance modern safety principles. FTA's adoption of the SMS framework elevated the national strategy for safety in transit, shifting from a reactive method to a proactive tactic focused on preventing events. SMS builds a safety culture in public transit, dedicated to controlling and reducing safety risks through the early detection and correction of hazards.

Figure 3-1 *Safety Management System (SMS) Components*

The principles of SMS must be incorporated early into an agency's BEB procurement process. While each of the components is interrelated, the following two (2) of the components should be well-engrained in procurement processes:

1. Safety risk management (SRM)
2. Safety assurance (SA)

Successful implementation of SRM and SA processes in an agency's BEB program can only be achieved through a well-defined safety management policy (SMP) specified in a compliant and organizationally accepted public transportation agency safety plan (PTASP) or agency safety plan (ASP) and supporting program plans, including an SSCP. Concurrently, the ability of an agency to uphold its safety policies is based on the organization's ability to demonstrate competencies in individual roles and responsibilities in the SRM and SA processes, which is accomplished through effective safety promotion.

The following sub-sections provide additional guidance on both SRM and SA processes.

Safety Risk Management

49 CFR Part 673 requires transit agencies to develop and implement an SRM process for all elements of their public transportation system. SRM is defined as:

> *Safety risk management is a process within a transit agency's Public Transportation Agency Safety Plan for identifying hazards and analyzing, assessing, and mitigating safety risk.*

SRM is the careful examination of real or potential conditions that could cause harm if left uncontrolled. In coordination with SA, the process is also used to determine whether sufficient defenses have been implemented or if additional actions are required to prevent harm. Mainly used as a planning activity, SRM provides a perspective into the future to better understand how system interfaces may negatively impact safety performance. SRM supports more efficient resource allocation based on calculated safety risks when appropriately implemented.

SRM is a systematic process built on three (3) sub-components:

1. Hazard identification
2. Risk assessment
3. Risk mitigation

Figure 3-2 *Safety Risk Management Subcomponents*

The SRM process will form the foundation for a BEB procurement's safety and security verification process, assisting in determining necessary mitigations to control risk to the lowest practical level.

Hazard Identification

49 CFR Parts 633 and 673 both require recipients to establish methods or processes to identify hazards and the consequences of hazards associated with system modifications or changes. A hazard is defined as:

> *Any real or potential condition that can cause injury, illness, or death; damage to or loss of the facilities, equipment, rolling stock, or infrastructure of a public transportation system; damage to the environment.*

The hazard identification process informs agencies of what could go wrong with BEB systems. As with any emerging technology, BEB systems may present hazards that an agency has not encountered which need additional mitigations. When hazards are properly identified and clearly defined, agencies can more easily identify potential consequences to better inform decision making and allocate resources to correct safety risks more effectively. The technical aspects associated with a BEB system may necessitate an agency to hire expertise specific to the new technology. Experienced subject matter experts (SMEs) can extrapolate legacy knowledge necessary for identifying potential hazards and associated mitigations.

Hazard identification is supported by access to multiple data sources. Agencies should consider outputs of SA activities, as well as information provided by oversight authorities and FTA, as sources for information on hazards and consequences. Sources for BEB hazard identification may include:

- Safety bulletins
- General directives
- Safety notices
- Industry research
- Agency research
- Employee safety reporting programs (ESRPs)
- Investigations
- Monitoring of operations and maintenance procedures
- System changes
- Internal safety audits
- Rules compliance programs
- Safety trend analyses
- Training and evaluation records

Agencies should consolidate hazards in one location for easier sorting and analysis to inform the BEB procurement process.

Hazard Assessment

The SRM process also necessitates agencies to establish methods or processes to assess the most probable likelihood and severity of the consequences of hazards and prioritize the hazards based on the safety risk. Agencies will select a safety risk index (SRI) based on their assessment of how often they may experience a potential consequence (likelihood) and the consequence's degree of harm or damage (severity), including any existing mitigations. One method of assessing an SRI is using the MIL-STD-882-E risk matrix, but agencies may follow their established and approved processes identified in their PTASPs. Tables 3-1 and 3-2 provide the severity and likelihood ratings, respectively, and Table 3-3 presents the MIL-STD-882E risk matrix that incorporates these ratings.

Table 3-1 *Severity Rating*

Description	Score	Criteria
Catastrophic	1	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10 million.
Critical	2	Could result in one or more of the following: permanent partial disability, injuries, or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1 million but less than $10 million.
Marginal	3	Could result in one or more of the following: injury or occupational illness resulting in one or more lost workday(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $500,000 but less than $1 million.
Negligible	4	Could result in one or more of the following: injury or occupational illness not resulting in a lost workday, minimal environmental impact, or monetary loss less than $500,000.

Table 3-2 *Likelihood Ratings*

Description	Score	Specific Individual Item	Fleet or Inventory
Frequent	**A**	Likely to occur often in the life of an item.	Continuously experienced.
Probable	**B**	Will occur several times in the life of an item.	Will occur frequently.
Occasional	**C**	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	**D**	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.
Improbable	**E**	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.
Eliminated	**F**	Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.	Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.

Table 3-3 *MIL-STD-882E Risk Matrix*

Severity / Probability	Catastrophic 1	Critical 2	Marginal 3	Negligible 4
A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E
F - Eliminated	Eliminated			

1A, 1B, 1C, 2A, 2B	**High**	**Unacceptable**
1D, 2C, 3A, 3B	**Serious**	**Undesirable, executive decision is required**
1E, 2D, 2E, 3C, 3D, 3E, 4A, 4B	**Medium**	**Acceptable, with review**
4C, 4D, 4E	**Low**	**Acceptable, without review**
F	**Eliminated**	**Eliminated**

Assessing likelihood ratings for a new BEB system may require extrapolation of limited data. Often, emerging technology hazards are not identified in a timely manner since the implementation of the new technology is always significantly more rapid than the recognition of a potential problem and the subsequent data capture and analysis.

Agencies may use tools like a safety risk matrix to facilitate risk-based prioritization. This approach combines assessed likelihood and severity into one visual, which can help decision-makers understand when actions are necessary to reduce or mitigate safety risks. These tables are most valuable when customized to an agency's unique operating realities and leadership guidance.

Safety Risk Mitigation

Risk mitigation aims to reduce the assessed risk rating to a level acceptable to the agency. While the mitigation process may not eliminate the safety risk, SME input emphasizing the mitigation will further reduce the hazard to the lowest acceptable level. Agencies may consider obtaining input from SMEs from different departments or outside agencies to ensure that the selected safety risk mitigation is appropriate. Information from multiple sources can help prevent unintended secondary effects, creating new hazards as a result of the mitigation.

Safety risk mitigation can be accomplished using one (1) or any combination of the following:

- Elimination
- Reducing the likelihood of occurrence of the potential consequence(s) of the hazard
- Reducing the severity of the potential consequence(s) of the hazard

Agencies should consider following the National Institute for Occupational Safety and Health (NIOSH) hierarchy of controls (Figure 3-3) when identifying the best methods for mitigating hazards.

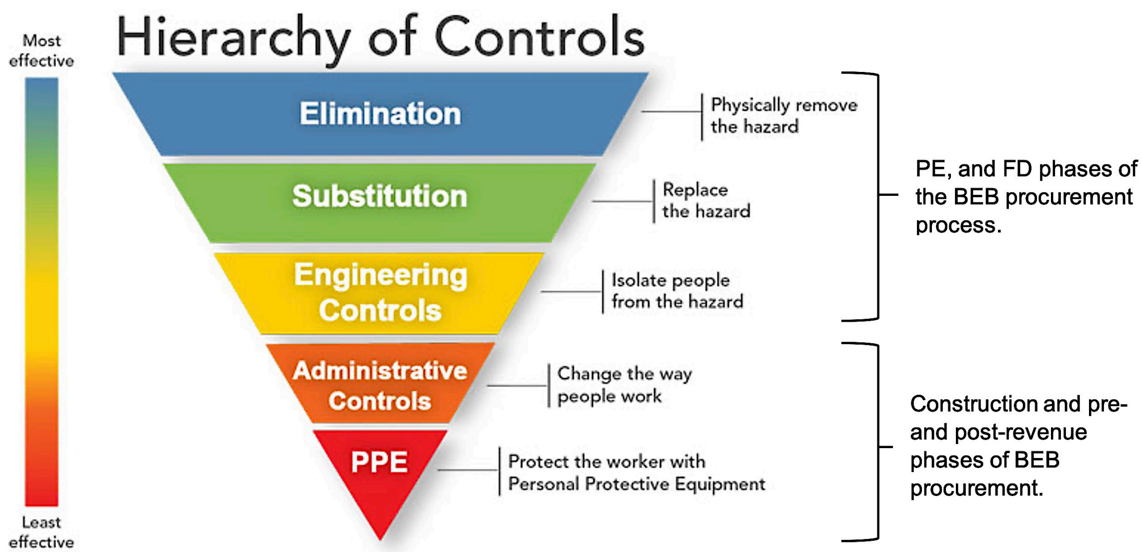

Figure 3-3 *NIOSH Hierarchy of Controls*

Safety Assurance

Safety assurance (SA) is defined as:

> *The processes within a transit agency's SMS that functions to ensure the implementation and effectiveness of safety risk mitigation and to ensure that the transit agency meets or exceeds its safety objectives through the collection, analysis, and assessment of information.*

The SA function helps ensure that mitigations manage safety risks and work as intended. Agencies can use their SA processes in the BEBs procurement process to ensure systematic actions are taken to provide the confidence level required that the system delivers as planned and achieves an acceptable level of safety consistently.

Management of Change

Large bus transit providers must establish a formal, documented change management process to identify changes that may introduce new hazards or impact the agency's safety performance.[3] Management of change, or change management, is an agency-wide process to evaluate proposed or future non-safety changes to system elements. The process assists bus agencies in making more informed decisions about and preparing for the potential introduction of new hazards from the proposed changes. Figure 3-4 illustrates the change management process.

[3] Small transit providers are not required by rule to identify a management of change process in their PTASP.

Figure 3-4 *Change Management Process*

Applicable bus transit agencies must also establish a process for assessing whether the proposed changes could introduce new hazards or impact the bus system's safety performance. If it is determined that a change might affect safety, the change will need to be evaluated using the agency's SRM activities. Bus agencies may use their general SRM process identified in the ASP to assess the proposed changes or may choose to establish an independent SRM process for evaluating hazards specific to the modification through their SSCP. Figure 3-5 provides a flow chart for bus agencies to use when assessing the need for implementing the SRM process.

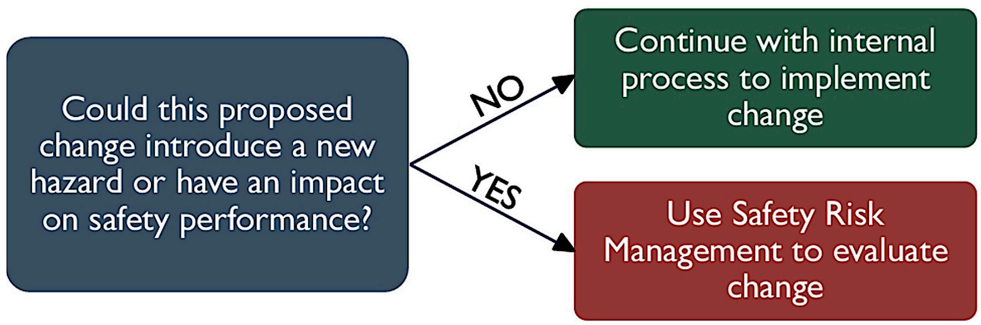

Figure 3-5 *Evaluating Proposed Changes Flow Chart*

FTA provides additional resources to assist affected bus transit agencies with developing and implementing a change management program:

- Joint SSO and RTA PTASP Workshop Participant Guide https://www.transit.dot.gov/regulations-and-guidance/safety/public-transportation-agency-safety-program/2019-fta-joint-sso-and
- PTASP Bus Workshop Participant Guide, v5 https://www.transit.dot.gov/regulations-and-guidance/safety/public-transportation-agency-safety-program/ptasp-bus-workshop
- Safety Assurance Webinar, July 2019 https://www.transit.dot.gov/regulations-and-guidance/safety/ptasp-safety-assurance-july-11-2019
- Management of Change Webinar, August 2020 https://www.transit.dot.gov/safety/public-transportation-agency-safety-program/management-change-august-27-2020

Management of Change for BEBs

BEBs and associated systems must be evaluated using a change management process to identify potential conflicts, hazards, or safety risks to other affected systems. Examples of potential conflicts include, but are not limited to:

1. **Operating rules and procedures**

   Standard operating procedures (SOPs) and procedures that apply to conventionally fueled buses will not necessarily apply to BEBs. For example:

   - Charging procedures for BEBs will need to be developed specifically for the agency's charging methodology.
   - Emergency procedures specific to the hazards associated with BEBs will need to be developed. Procedures will also include on-site training with transit personnel and first responders.

2. **Inspections, testing, and maintenance**

   Maintenance programs specific to BEBs will need to be developed. The primary objective of the inspection, testing, and maintenance (ITM) program is to keep BEBs operating at maximum efficiency while providing a mechanism for early recognition of possible issues. When properly developed, a robust ITM program can assist in the early identification of potential catastrophic battery-related failures. The ITM procedures will need to be established in coordination with the BEB manufacturers.

3. **Training**

   New training programs will likely need to be introduced for operators and maintenance personnel. At a minimum, training should include:

   - Hazard recognition associated with BEBs
   - Working with and around high-voltage batteries and propulsion systems
   - Different driving characteristics of BEBs compared to conventionally fueled buses

4. **Emergency preparedness**

   Ongoing dialog and training with local fire departments will be necessary, given the difficulty in extinguishing BEB-related fires. Particular consideration should be made towards:

Facilities

Charging infrastructure and storage configuration considerations specific to BEBs should be taken. As noted in this document, a qualified fire hazard analysis is the only way to mitigate the associated hazards with BEBs current due to the lack of prescriptive code. Additionally, agencies must consider secure, separate areas to isolate damaged or spent battery modules.

Service and operations

The introduction of BEBs into a conventional bus fleet has many safety implications agencies must consider. For example, BEBs have a limited range in comparison to conventional fuels. Therefore, bus agencies should consider developing operational plans for BEBs that lose their charge and become non-operational when the vehicle is idling in traffic for extended periods.

Additionally, keeping BEB fleets charged requires significant energy. Agencies may consider revising their continuity of operations plan (COOP) to include provisions to provide alternative bus services in the event of an extended blackout.[4] To ensure utility service blackouts minimally affect the BEB network, en-route charging stations must be considered in the SSCP, as described in this report.

Provisions for the eventual disposal of battery modules at the end of their service life should, at a minimum, also be considered by agencies.

These areas must be assessed as part of the SSCP, discussed in greater detail in the preceding section, through the SRM process.

[4] The amount of electricity required to charge BEBs likely does not make fuel-powered generator charging realistic.

Section 4

Safety and Security Certification

FTA's *Handbook for Transit Safety and Security Certification* (FTA-MA-90-5006-02-01) provides the guidance for establishing a certification program to address safety hazards and security vulnerabilities. An established certification program will perform the four key functions, as illustrated in Figure 4-1:

Figure 4-1 *Safety and Security Certification Process*

Safety and security certification is defined as:

> *The series of processes that collectively verify a project's safety and security readiness for public use.*

Several critical activities need to be performed as part of the certification process. Table 4-1 illustrates typical activities performed during the certification process. The table organizes critical activities for each phase of the project's life cycle into the following categories:

- PLN: planning
- PE: preliminary engineering
- FD: final design
- CON: construction
- INT-TEST: integrated testing
- PRE-REV: pre-revenue (interim) operations
- OPS: operations

Checks marks (✓) indicate the initiation of the activity, whereas shaded arrows (▶) represent ongoing performance.

Table 4-1 *Project Development Safety and Security Activities*

TASK	PLN	PE	FD	CON	INT-TEST	PRE-REV	OPS
Develop safety and security policy	✓	▶	▶	▶	▶	▶	▶
Assign SSC responsibilities	✓	▶	▶	▶	▶	▶	▶
Establish safety and security committees	✓	▶	▶	▶	▶	▶	▶
Identify existing safety and security requirements for acquisition process	✓	▶	▶	▶	▶	▶	▶
Develop safety and security certification plan		✓	▶	▶	▶	▶	▶
Identify safety and security certifiable elements and items		✓	▶	▶	▶	▶	▶
Initiate project documentation system		✓	▶	▶	▶	▶	▶
Perform preliminary hazard and vulnerability analysis		✓	▶	▶	▶	▶	▶
Prepare safety and security design criteria		✓	▶	▶	▶	▶	▶
Integrate operations and maintenance requirements into design		✓	▶	▶	▶	▶	▶
Develop design criteria conformance checklists		✓	▶	▶	▶	▶	▶
Perform safety and security design reviews			✓	▶	▶	▶	▶
Perform additional hazard and vulnerability analyses (as applicable)			✓	▶	▶	▶	▶
Implement hazard and vulnerability resolution and tracking			✓	▶	▶	▶	▶
Verify design criteria conformance checklists			✓	▶	▶	▶	▶
Identify safety and security requirements for test program plans, integrated testing, and operational readiness			✓	▶	▶	▶	▶
Develop specification conformance checklists (construction)			✓	▶	▶	▶	▶
Complete specification conformance checklists				✓	▶	▶	▶
Issue permits and certificates (as applicable)				✓	▶	▶	▶
Complete integrated tests					✓	▶	▶
Safety and security review of engineering change orders & waivers						✓	▶
Complete operations & maintenance plans, procedures, and training						✓	▶
Complete operational readiness review (including workarounds)						✓	▶
Issue final safety and security certification						✓	▶
Issue final safety and security verification report						✓	▶

10-Step Safety and Security Certification Process

FTA's recognized SSC process is made of ten (10) individual steps as described in Table 4-2. Also included are the timeline phase(s) within which each step occurs and associated critical SCC outputs. Figure 4-2 depicts where each of the 10 steps integrates into the BEB Procurement process.

Table 4-2 *SCC Certification Process Steps*

Step #	Description	Timeline Phase	Critical SCC Outputs
Step 1	Identify Certifiable Elements	Engineering / Design	▪ Certifiable Elements List ▪ Preliminary Hazard Analysis ▪ Threat and Vulnerability Assessment ▪ Certifiable Items List
Step 2	Develop Safety and Security Design Criteria	Engineering / Design	▪ None
Step 3	Develop and Complete Design Criteria Conformance Checklists	Engineering / Design Construction / Installation / Testing	▪ Design Criteria Conformance Checklist (DCCC)
Step 4	Perform Construction Specification Conformance	Construction / Installation / Testing	▪ Construction / Installation Specification Conformance Checklist ▪ Operational Hazard Analysis
Step 5	Identify Additional Safety and Security Test Requirements	Construction / Installation / Testing.	▪ Testing Specification Conformance Checklist (TSCC)
Step 6	Perform Testing and Validation in Support of the SSC Program	Construction / Installation / Testing	▪ None
Step 7	Manage Integrated Tests for the SSC Program	Construction / Installation / Testing	▪ None
Step 8	Manage "Open Items" in the SSC Program	Construction / Installation / Testing	▪ Hazard Tracking Log
Step 9	Verify Operational Readiness	Start-up / Pre-revenue Service	▪ Operational Readiness Conformance Checklist ▪ Temporary Use Permits
Step 10	Conduct Final Determination of Project Readiness and Issue SSC	Start-up / Pre-revenue Service	▪ Final Certificates ▪ Safety and Security Certification Verification Report (SSCVR)

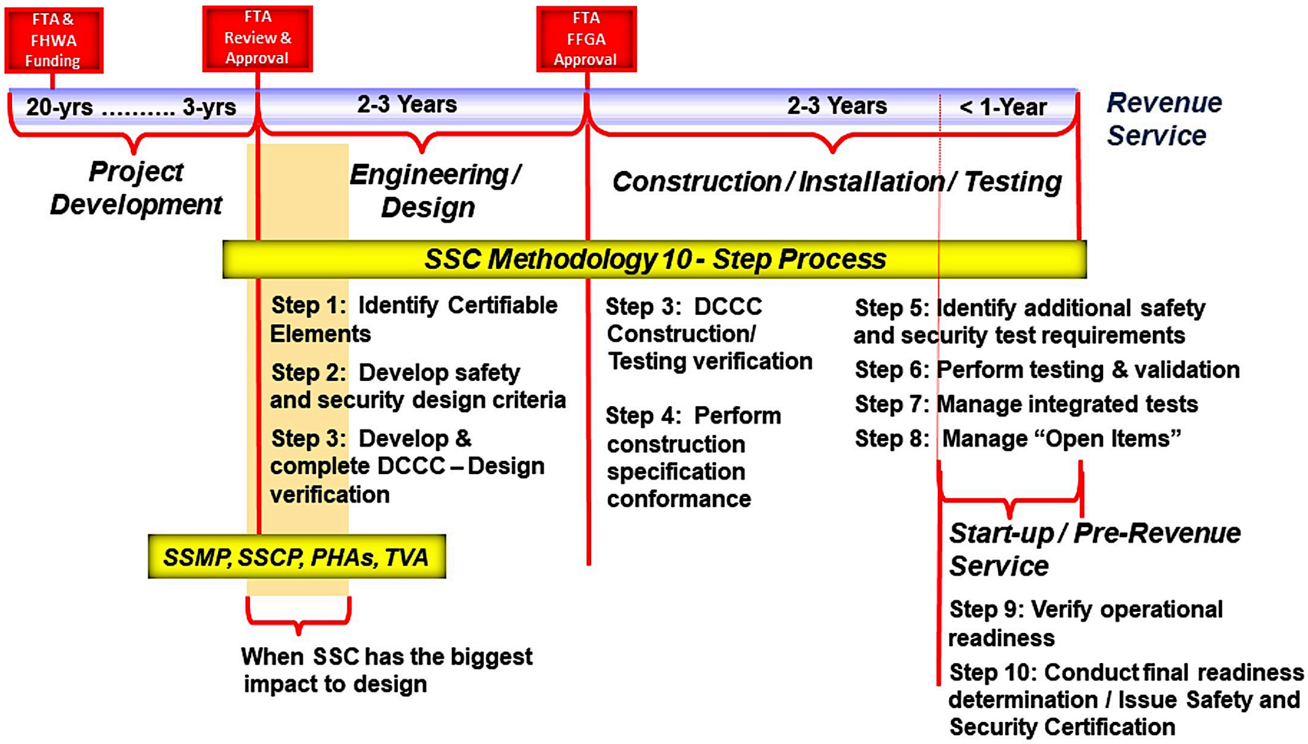

Figure 4-2 *FTA Safety and Security Certification Project Life Cycle*

The following guidelines are excerpts from the 2002 FTA *Handbook for Transit Safety and Security Certification*.

Step 1: Identify Certifiable Elements

Critical SSC Outputs:	- *Certifiable Elements List* - *Preliminary Hazard Analysis* - *Threat and Vulnerability Assessment* - *Certifiable Items List*

The first step in the SSC methodology is to identify the system elements that must be certified for the project. Safety and security certifiable elements include all elements and their individual items that can affect the safety and security of transit agency passengers, employees, contractors, emergency responders, or the general public.

During the procurement process, bus agencies will be exposed to several overlapping activities in the SSC process. However, agencies must be aware of the difference between pre-acceptance inspections and the SSC process. Certifiable elements are specific to safety- and security-critical systems that may reference for verification inspections and tests used in the acceptance process. Inspections and testing programs such as Altoona testing, production inspections, and acceptance testing associated with the manufacturing and receiving processes are not the same as the certification process. Instead, the certification process recognizes that, in some cases, existing tests and inspections may verify certifiable elements. For example:

- Production inspection for sharp edges and protrusions is a quality control inspection during the production of the BEB but also mitigates the hazards to patrons or employees injuring themselves on sharp edges or protrusions.
- Altoona testing of BEBs provides an agency with the required Federal Motor Vehicle Safety Standard (FMVSS) testing of the structural integrity of the BEBs but also mitigates the hazard of patrons or employees getting injured if the BEBs were to be in a crash.

Certifiable elements help focus the certification efforts on safety- and security-critical systems. To develop a comprehensive certifiable elements list (CEL) and certifiable items list (CIL), transit systems must also conduct a preliminary hazard analysis (PHA) and, as necessary, a threat and vulnerability assessment (TVA). Figure 4-3 illustrates the relationship between the safety risk and the security vulnerability assessment processes.

Figure 4-3 *SSC Step 1 Sequence of Events*

Preliminary Hazard Analysis

The PHA provides an early assessment of the hazards associated with a design or concept. The PHA identifies critical areas, hazards, and criteria and considers hazardous components, interfaces, environmental constraints, operating, maintenance, and emergency procedures. The PHA will provide for verification that corrective or preventive measures or strategies are taken in safety reviews and modification of specifications. Additionally, the PHA will ensure the generation of methods and procedures to eliminate, minimize, or control hazards and provide inputs to the operating hazard analysis (OHA).

Documents such as the failure mode effects analysis (FMEA) can be used to assign likelihood factors on the PHA.

Threat and Vulnerability Analysis

A TVA provides an analytical process to consider the likelihood that a specific threat will endanger the new system. A TVA is performed late in the development phase and early in the engineering/design phase to introduce security requirements when the safety and security design criteria are developed for a project. This process is a critical component of the certification process.

Identification of Certifiable Elements and Items

The first step in the SSC methodology is to identify the elements that must be certified for the project. Safety and security certifiable elements include all elements that can affect the safety and security of transit agency passengers, employees, contractors, emergency responders, or the general public.

Certifiable elements that should be explicitly considered for BEBs are listed in Table 4-3.

Table 4-3 *Certifiable Elements List*

Element	Sub-Elements	Items
Charging system	▪ Chargers ▪ Transformers	▪ Fail-safe design ▪ Impact protection ▪ Training and maintenance ▪ Security considerations ▪ Codes and standards ▪ BEB and facility interfaces
BEB vehicles	▪ Battery modules ▪ Electrical ▪ Traction power motors ▪ High voltage electrical ▪ Low voltage electrical ▪ Controllers ▪ Emergency evacuation	▪ Fail-safe design ▪ Codes and standards ▪ Facility and charging interfaces ▪ Emergency releases ▪ Escape hatches
Yards	▪ Parking/charging layout ▪ Physical security ▪ Fire life safety ▪ Drainage ▪ Signage ▪ Damaged vehicles/batteries	▪ Bus separation distance ▪ Security considerations ▪ Fire suppression ▪ Slope considerations ▪ Applicable signage ▪ Isolation area & procedures
Facilities	▪ Parking/charging layout ▪ Physical security ▪ Fire life safety ▪ Signage	▪ Bus separation distance ▪ Security considerations ▪ Fire suppression ▪ Applicable signage ▪ Charging infrastructure interfaces
Cybersecurity	▪ Network security	▪ Firmware updates
Communications	▪ Vehicle – charger ▪ Battery management	▪ Vital hazard management
Testing/integration	▪ Charging ▪ Electrical	▪ Interoperability ▪ Commissioning tests
Operational readiness	▪ BEB towing ▪ Maintenance ▪ Training ▪ Staffing ▪ Routes ▪ Spare parts ▪ Public outreach ▪ First responders ▪ Emergency exercise program[5] ▪ Battery/bus disposal ▪ Service contracts	▪ Training ▪ Procedures ▪ Operators and maintenance ▪ Training and certification ▪ Recharging considerations ▪ Availability and delivery time ▪ Fleet safety tips for the public ▪ Awareness of unique hazards ▪ Exercise AARs ▪ Procedures ▪ Warranty and maintenance

[5] See Section 7.1.3 First Responder Training, Section 8.2 Emergency Training and Exercises, and Section 8.3 Risks to First Responders

Certifiable elements are composed of numerous certifiable items. These items comprise the whole of the major element and require individual safety and security verification before the major element is verified as safe and secure for use. Each item must be documented on a CIL. As projects or programs evolve, the related certifiable elements may also change.

Step 2: Develop Safety and Security Design Criteria

Critical SSC Outputs:	- *None*

The safety and security requirements of BEBs and associated systems are addressed during the project design phase by identifying safety and security design criteria for each certifiable element. Safety and security design criteria are intended to guide the design team to support the definition of systems, sub-systems, and components; the development of performance requirements; and the final specifications for the system. It is a best practice to include the design criteria and the specifications in the procurement package.

Safety and security design criteria can be generated from any of the following:

- Technical specifications from a previous project
- Existing agency design criteria
- Agency lessons learned
- Bus manufacturer's FMEAs
- BEB and charging system operations and maintenance manuals
- Hazard (PHA/OHA) and vulnerability (TVA) analyses
- Industry best practices and reports
- Safety and security codes, standards, and regulations defined by federal, state, and local agency standards boards and organizations

Step 3: Develop and Complete Design Criteria Conformance Checklist

Critical SSC Outputs:	- *Design Criteria Conformance Checklist (DCCC)*

During the design of BEB systems, the project team should begin identifying criteria requirements for certifiable elements and items. This process involves the creation of a checklist, referred to as the design criteria conformance checklist (DCCC), for each certifiable element to record the requirements of the individual items incorporated from safety and security design criteria. In the certification process, contract specifications, design criteria, applicable codes, and industry standards may constitute design conformance for certification verification. For example, some contract specifications requirements may be used as verification, such as maintenance manuals, sub-system hazard analyses, and factory test reports.

While developing the DCCC, safety and security requirements should be identified to assist the project team in performing design reviews, inspections, and testing results. Additionally, during this step, the team will need to determine the process for resolving any "open items" that cannot be verified as compliant with the design requirements, specifications, or safety- or security-specific items identified in the PHA and TVA.

Step 4: Perform Construction / Installation Specification Conformance

Critical SSC Outputs:	- *Construction / Installation Specification Conformance Checklist* - *Operational Hazard Analysis*

The installation specification conformance process verifies that the as-built facilities and systems incorporate the safety- and security-related requirements identified in the specifications and other contract documents, including approved changes since the final design. A construction/installation specification conformance checklist (CSCC) should be developed to assist agencies in verifying conformance to installation specifications for BEBs and their associated systems.

The CSCC should be viewed as a component of the DCCC, as it identifies the tests and verification methods necessary to ensure that the as-built configuration contains the safety-related requirements specified in the applicable specifications and other contract documents. The checklist also provides documented verification that the delivered project meets these requirements of the certification process. Ultimately, the CSCC becomes the guiding document of the SSC process.

To further assure safety compliance for the system, an OHA should be conducted to identify hazardous conditions during operation and maintenance due to human error. This analysis also provides protective recommendations.

As mentioned in Step 3, the management or resolution of most open items should be resolved upon completing the CSCC. Safety and security requirements that have not been verified by available documentation or demonstration should continue to be tracked to resolution.

Step 5: Identify Additional Safety and Security Test Requirements

Critical SSC Outputs:	- *Testing Specification Conformance Checklist (TSCC)*

Contractor and integrated testing requirements should be reviewed for safety and security considerations. Like the DCCC and CSCC, these requirements should be documented on a testing specification conformance checklist (TSCC). There are two (2) types of tests to consider:

1. **Contract testing**: Contractor testing verifies the functionality of the involved system or equipment as required by the contract specifications.
2. **Integrated testing:** Integrated testing verifies the functional interface between different equipment or systems.

Each component of a BEB system (i.e., BEB vehicles, charging equipment, facilities, etc.) should be tested individually while ensuring that subcomponents interface as designed. Both contractor and integrated testing are subject to certification. As previously mentioned, certification of contractor testing may be verified in the TSCC or combined with integrated testing in a test program certification or by other acceptable means.

Step 6: Perform Testing and Validation in Support of the SSC Program

Critical SSC Outputs:	*- None*

From the initial stages of the construction development phase, test reports and other documentation will be submitted to the agency to document the results of:

- Design qualification tests (factory)
- Production verification tests (factory)
- Construction inspection tests
- Installation verification tests (QA/QC)

Safety- and security-related test results should be documented, as appropriate, in the TSCC.

Step 7: Manage Integrated Tests for the SSC Program

Critical SSC Outputs:	*- None*

Integrated tests are any tests or series of tests that require the interface of more than one element and are designed to verify the integration and compatibility between system elements. Pre-operations tests require acceptance of all systems and are intended to demonstrate the functional capability and readiness of the system. These tests are not necessarily required by contract specifications but are required as part of the test program plan to ensure that all systems function safely before being placed into operation. Test result reports form the basis for meeting the safety requirements.

Step 8: Manage "Open Items" in the SSC Program

Critical SSC Outputs:	- *Hazard Tracking Log*

As the certification proceeds, open items will be identified and managed according to the process developed during Step 3. During pre-revenue testing and start-up activities, requests for risk-reduction alternatives and temporary use or occupancy permits or notices will be made. The SSC program must have the tools available to ensure that the safety and security designed into the system are realized in the delivered, tested, and validated project.

All open hazards or vulnerabilities separate from the PHA, TVA, or OHA can be tracked using a hazard tracking log (HTL).

Step 9: Verify Operational Readiness

Critical SSC Outputs:	- *Operational Readiness Conformance Checklist* - *Temporary Use Permits*

During the pre-operations phase of the system, procedures and plans are tested for effectiveness under simulated operating conditions for normal, abnormal, and emergencies. Verifying these activities often includes signatures by the appropriate officials or employees on all procedures, rulebooks, and training necessary to support the operation and maintenance of the system. All operating and maintenance procedures and plans are assessed to determine if they meet the requirements of the agency's operations or if further modifications are required.

Operational readiness also depends on the agency's ability to effectively control hazards before introducing the BEB system into revenue service.

Step 10: Determine Project Readiness and Issue Safety and Security Certification

Critical SSC Outputs:	- *Final Certificates* - *Safety and Security Certification Verification Report (SSCVR)*

Before revenue service begins and formal certification is completed, the project team and supporting committees should review all safety and security certification documentation to determine if any outstanding items remain.

Approval of certifiable elements occurs when work has been completed in conformance with criteria and hazards have been reduced to an acceptable level. Any temporary risk-reduction alternatives affecting a certifiable element require a hazard management plan to be initiated to analyze the hazard and control the risk to an acceptable level for a defined period. The hazard management plan must include any category I (unacceptable) and II (undesirable) hazards to ensure that they have been resolved or controlled to an acceptable level before entering revenue service.

Once a certifiable element is ready for final certification, the safety and security review committee (SSRC), or equivalent, will evaluate the CEL and the accompanying verification documentation, along with recommendations and restrictions, and prepare a certificate of conformance for that element. Upon issuance of all project certifiable element certificates of conformance, a final project safety and security certificate will be drafted for signature by the executive management team for formal approval.

Before or shortly after revenue service begins, the project team will develop an safety and security certification verification report (SSCVR) that summarizes the activities performed to assure the project's readiness to enter revenue service. Suggested items for inclusion in this report can be found in the FTA’s 2002 *Handbook for Transit Safety and Security Certification.*

Section 5

Safety and Security Risk Management

Introducing BEB fleets and related charging infrastructure into an existing transit agency's conventionally fueled fleet may present hazards many transit agencies have not yet considered. This is particularly true for agencies first introducing a BEB fleet into their existing operation. Inadequate safety risk and security vulnerability management may also result from the unfamiliarity with FTA's SSC process, primarily adopted by rail transit when introducing new rail cars and infrastructure into the agency.

Considerations for Effective Hazard Identification

Effective risk and vulnerability management depend on developing a robust preliminary hazard list (PHL), a precursor to the PHA. Nonetheless, even with the availability of PHAs based on conventionally fueled buses, BEB fleets and the associated charging equipment and infrastructure present unique hazards that are more analogous to the hazards associated with battery storage systems than vehicles. *For a sample PHL, refer to Appendix A*.

Consideration must be given to identifying the following unique BEB hazards that would not typically be considered for conventionally fueled buses:

- The lack of code basis for the design of sprinkler systems to protect BEB fleets:
  - Conventional sprinkler systems are largely ineffective in suppressing internal battery pack fires.
  - There are no provisions for managing the contamination of suppression water when used to suppress Lithium-Ion battery fires.
- Thermal runaway. *Refer to Appendix B for more information about these events.*
- Battery packs damaged in an accident. Studies show that battery modules that have caught fire are susceptible to reignition up to 22 hours after the initial event.[6]
  - Battery compartments and configurations must be considered in the overall design of BEBs. Roof-mounted versus floor-mounted battery modules have both advantages and disadvantages concerning operability or hazards.
  - The battery module containment needs to be robust enough to survive impact related to crashes. In addition, the modules need the ability to vent gases in case of a battery failure.

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[6] NTSB Safety Report SR 20/01.202

   - Encapsulation of battery modules can also mitigate fire conditions by containing a fire to an individual battery module. This encapsulation can be enhanced with intumescent coatings or suppression systems, both of which are being developed by BEB manufacturers when producing this document.
- Malfunctioning or damaged battery modules sparking or off-gassing of toxic vapor clouds can pose a respiratory system exposure or explosion risk.
- Susceptibility to radio-frequency interference (RFI) and electromagnetic interference (EMI) can affect BEB functions as well as other transit agency systems.[7]
- Storage provisions of damaged, spent, or malfunctioning battery packs or BEBs.[8]
- Storage configuration considerations:
   - Li-Ion battery fires tend to propagate quickly and may not be controlled with a conventional fire sprinkler design.
   - The peak heat release of EV fires is more intense than fires from conventionally fueled vehicles. The potential impacts on the parking structures from the additional heat loads will need to be considered.
   - Lack of industry consensus of fire suppression extinguishment of a battery fire. *Refer to Appendix C for more information about extinguishing agents.*

Systematic Hazard Identification

Separating the safety certification of a BEB fleet from the BEB charging equipment and infrastructure will likely create safety certification challenges due to the numerous interfaces between the BEBs and the related charging infrastructure. As such, it is best to systematically verify all BEB components during the certification process, especially during the PHA development process. By approaching the PHA in this manner, all hazards associated with BEB interfaces and safety interlocks directly connected to the integrated system can be identified and specific mitigations implemented.

PHAs developed for vehicles independent of charging infrastructure or in reverse will likely result in missed hazards and uncontrolled safety risks. As such, the following interfaces need to be considered by agencies:

- Vehicle fire sensors interfaced with charging equipment and other fire life safety (FLS) systems

[7] NFPA 855 Standard for The Installation of Stationary Energy Storage Systems requires RFI/EMI assessments

[8] NFPA, SAE, and most BEB manufacturers recommend that fire damaged buses and battery modules be isolated with a 50-foot radius or a surrounding physical barrier for separation

- BEB battery thermal detectors interfaced with building fire alarm systems and battery management systems
- Charging system emergency stops interfaced with BEBs and buildings fire and life safety systems
- Commissioning and testing of battery and charging safety interlocks on board the BEB and as part of the charging equipment
- Onboard fire suppression (directly applying extinguishment to the BEB battery modules) systems and thermal management systems to ensure battery modules remain cool

Threat and Vulnerability Assessments

While incorporating numerous BEB charging stations throughout a service area will benefit operations, agencies inadvertently introduce new security vulnerabilities not otherwise seen in conventional fueling systems. In this age of cyberattacks and security breaches, bus transit providers must protect the BEB internet-connected infrastructure from cyber intrusions. New, unproven technology may incorporate unintentional vulnerabilities in a cyber system, which allow adversaries to exploit specific software vulnerabilities. In the case of one (1) manufacturer, a software system analysis (SSA) identified a potential vulnerability in the vehicle's software that could allow hackers to control some of the vehicle functions, such as:

- Preventing the vehicle from charging
- Unlocking doors and windows
- Starting the vehicle
- Disabling the security system

Agencies must insist that BEB manufacturers subject their internet-accessible systems and software to the same rigorous cybersecurity testing as other industries to mitigate these vulnerabilities and protect against potential threats and attacks. These security vulnerabilities can be assessed through a comprehensive TVA and an SSA.

Before purchasing BEBs, each agency should ensure that vendors will provide a list of the internet-accessible systems and software that comprise the total system to assist with meeting their Safety and Security Certification requirements. Ask questions of the vendor such as:

- What safeguards and standards are implemented in the BEB system to reduce the potential for cyber-attacks?
- Have their buses been involved in a cyber incident? If yes, what was learned, and what was done to prevent it in the future?

Currently, the transit industry has been limited in the availability of this information from manufacturers, with most requests being fulfilled weeks after the delivery of vehicles. In the interim, an agency's safety and security staff should work collaboratively with their bus operations and maintenance, information technology, and consultants to evaluate the cybersecurity risks associated with equipment and software until the vendor provides more specific information.

Resources are available for transit agencies to use when drafting cybersecurity vulnerability assessments. APTA SS-CCS-WP-005-19 standard for "Securing Control and Communications Systems in Transit Bus Vehicles and Supporting Infrastructure" offers an initial starting point for evaluating these vulnerabilities and risks.[9] Additionally, the Transportation Security Administration (TSA) Cybersecurity Toolkit provides best practice cybersecurity resources.[10]

With the rapid push for converting fleets to electric power, the cybersecurity attack surface is growing exponentially. Developing a national standard to secure these fleets is not progressing at the same pace. More emphasis should be placed on the need to ensure safety than on the need to be first.

Operational Hazard Analysis

Hazard mitigation through design and engineering is always preferential compared to hazard mitigation via procedures and protocols. Developing an OHA is crucial to providing necessary mitigations to hazards that cannot be fully mitigated through design or engineering.

Caution: An OHA should not be used to forego hazard mitigation through design. Relying exclusively on operational procedures or PPE to mitigate hazards often burdens the agency, and such reliance on the mitigation will likely diminish over time.

If specific hazard analyses are not feasible, such as a fire hazard analysis described in the preceding section, or proposed engineering mitigations are not practical, consideration of the following types of operational mitigations should be made:

1. Fire watch during charging operations, mainly where BEB charging is intended to occur within a building or structure

[9] APTA Standard for Securing Control and Communications Systems in Transit Bus Vehicles and Supporting Infrastructure https://www.apta.com/wp-content/uploads/APTA-SS-CCS-WP-005-19.pdf
[10] TSA Cybersecurity Toolkit: https://www.tsa.gov/for-industry/surface-transportation-cybersecurity-toolkit

2. Fleet storage segregation of the BEB fleet from conventionally fueled buses
3. Enhanced training for operator and maintenance personnel to recognize possible conditions that might lead to a thermal runaway event or BEB fires
4. Subjecting BEBs to inspections, testing, and maintenance programs identified in the National Fire Protection Association (NFPA) 855: Standard for the Installation of Stationary Energy Systems[11]
5. Other nationally recognized standards from institutions, including, but not limited to, the following, may provide further “best practice” guidelines to apply to BEBs and the associated battery packs
    a. Institute of Electrical and Electronics Engineers (IEEE)
    b. National Fire Protection Association (NFPA)
    c. Society of Automotive Engineers (SAE)
    d. Underwriters Laboratories (UL)
    e. American Society for Testing and Materials (ATSM)
    f. FM Global

[11] The scope of NFPA 855 would dictate that it does not apply to BEBs; however, application of this standard as it relates to the maintenance of Li-Ion cells would represent a “best-practice”.

Section 6

Design Management

As with many emerging technologies, specific codes and standards may not yet exist, resulting in unidentified or miscategorized safety risks and security vulnerabilities being improperly mitigated. BEBs and their infrastructure have associated hazards that need to be recognized and mitigated before these systems are implemented. The lack of specific codes providing prescriptive guidance on effectively mitigating hazards represents a challenge to transit agencies wishing to implement BEBs quickly into service. Coupled with the lack of substantial design criteria, transit agencies must often rely on the BEB provider as the SME in determining hazards and mitigations associated with BEBs and the related charging infrastructure.

This identified gap in codes and standards makes the safety certification of a BEB fleet and the associated charging and storage a challenge.

Prescriptive Code Analysis

Designing a system or facility usually commences with a design and the subsequent verification of code compliance to ensure the design meets the minimum safety standards established by the code. This is commonly referred to as prescriptive code analysis (PCA).

A PCA is a process of using recognized codes and standards to design a project. Specifically, project elements are addressed within the code or standard, and the application of the code ensures that the project is producing a compliant product, which infers a safe product. PCA works well enough on many common systems and facilities; however, the challenge arises if existing recognized codes and standards do not offer specific prescriptive code solutions. This is the case concerning BEB storage and charging infrastructure. Additionally, agencies should recognize that adherence to prescriptive code will only mitigate hazards to minimum requirements, not necessarily the lowest acceptable level.

Agencies have two (2) options if a PCA cannot offer relevant design parameters:

1. Reliance on best practices or experience, or
2. Conducting a performance-based analysis

Option 1: Reliance on Best Practices

When prescriptive code is unavailable, agencies must rely on proven alternatives or best practices to control a recognized hazard effectively. Best practices or industry standards not supported through comprehensive data analysis should be used only as a last resort during the BEB certification process. The use of best practices will not necessarily provide a code-compliant result, but may be used as effective mitigation to satisfy safety certification requirements. Agencies must be aware of the potential presumption in a basis of design (BOD) that the past practice is code compliant. To verify compliance with code, the designer of record (DOR) should be encouraged to provide a detailed code analysis supporting the claim that details all applicable code sections. Similarly, agencies must ensure the DOR does not apply certain areas of codes or standards without consideration to other sections with downstream implications. This issue is often experienced when designing processes or infrastructure for emerging technologies.

Option 2: Performance-Based Analysis

This option provides a code-recognized alternative to a PCA. Except for a few, all codes allow for performance-based design as an acceptable equivalent to a prescriptive design.

Performance-Based Design

Performance-based fire protection methods have effectively managed identified hazards in the BEB system, further bolstering the SRM process. The Society of Fire Protection Engineers (SFPE) and the NFPA have the following guides to assist these processes:

- *SFPE Guide to Performance-Based Fire Protection*
- *NFPA 551: Guide for the Evaluation of Fire Risk Assessments*

Both documents provide transit agencies the basic framework for establishing guidelines for a fire hazard analysis that, through modeling, can provide data-based solutions to fire protection and hazard management. Additionally, nearly all existing standards identify the need to conduct a fire hazard analysis for unquantified hazards, including those related to BEBs and supporting infrastructure.

A performance-based design considers specific parameters of any system and subjects them to well-established computer modeling programs. In many cases, codes or standards will provide scenarios to consider when designing a fire and life safety system. As this relates to fire protection, a performance-based design is based upon these provided fire scenarios. An authority having jurisdiction (AHJ) is allowed by code to establish specific scenarios as a basis of the performance-based assessment.

Performance-based designs are founded on computational programs that allow fire protection engineers to alter different parameters to find the safest solution for the best value. Often, performance-based design recommends a system that may cost less than a prescriptively designed system with very high safety factors to compensate for design assumptions.

The basis for conducting performance-based design is provided in most codes, such as:

- NFPA 13: The Standard for Sprinkler System Design
- NFPA 101: Life Safety Code
- NFPA 550: Guide to the Fire Safety Concept Tree
- SFPE Performance-Based Fire Protection

When using performance-based design parameters, agencies must ensure that the AHJ approves all decisions to ensure that the eventual report will provide the required information to design FLS systems that will protect a building or systems as intended and subsequently mitigate associated hazards.

General Requirements of Performance-Based Assessments

The general requirement for all performance-based assessments (PBA) is consistent in most codes. As such, agencies should follow these criteria:

1. Goals and objectives need to be established and approved.
2. The assessment can only be conducted by a registered design professional.[12]
3. The AHJ must approve baseline data used for the assessment.
4. This designer must provide all assumptions that were made to the AHJ for their determination of whether the final report adequately addresses the agreed-upon objectives.

Agencies should be aware that the AHJ can require an independent review of the evaluation. This would be necessary when AHJ personnel lack the qualifications to understand assessments of a highly technical nature. Additionally, designers must provide maintenance provisions to ensure the proposed FLS systems remain operable over the life of the asset.

Examples of PBA for Fire Protection System

As noted, prescriptive codes are not presently available to address storage and the related charging of BEBs. Transit agencies can best mitigate FLS hazards by commissioning a performance-based design to determine how to best store a BEB fleet and what protective systems would best mitigate the recognized risk.

A transit agency might ask an FPE to base a fire hazard analysis on the elements described below. This task is best driven by establishing a PHA that identifies all potential hazards associated with BEB fleet storage and charging. Additionally, a fire hazards analysis is best undertaken very early in the conceptual phases of any BEB system implementation.

[12] The AHJ has the right to refuse qualifications.

1. **Establish a purpose for the performance-based fire hazard analysis (FHA).**

   BEBs pose a higher fire hazard than fueled buses due to the sizeable Li-Ion battery packs. The potential for thermal runaway events or other fire events involving the battery packs presents a hazard that needs design consideration for protecting personnel, bus fleet, and infrastructure. The primary purpose of this task is to provide fire mitigations specific to the charging and storage of a battery electric bus fleet stored in an open parking structure or a parking lot.

2. **Conduct an FHA.**

   The agency needs to determine specific tasks of the FHA to ensure the end report provides the relevant information the agency needs to mitigate BEB hazards and related infrastructure. The FHA should be based on the methodologies established in *NFPA 551: Guide for the Evaluation of Fire Risk Assessments* and the *Society of Fire Protection Engineers (SFPE): Performance-Based Fire Protection*. Furthermore, agencies must ensure that an FHA is signed and sealed by a registered fire protection engineer (FPE).

   The FHA should focus on the vehicle types and configurations used at the agency. The FHA should include, as a minimum: [13]

   a) An examination of the peak heat release rate for BEB combustible elements
   b) Total heat released
   c) Ignition temperatures
   d) Radiant heating view factors
   e) The behavior of BEB components during internal or external fire scenarios

   Computer modeling and material fire testing should assess performance under the potential scenarios. Fire scenarios must consider how Li-Ion batteries contribute to the identified scenario using a typical bus configuration. Fire modeling should include the following fire scenarios, at a minimum:

   a) BEB starts on fire during charging. All battery systems are the most susceptible to a fire event during charging. It is essential that charging equipment manufacturers and BEB vehicle providers provide an FMEA to assist in fire modeling.

[13] If possible, the FHA should use all heat release rate data provided by the NFPA or the designated bus manufacturer for this determination.

b) BEB starts on fire while stored among other buses with different considerations to indoor and outdoor storage scenarios. This should determine the extent and speed a fire might spread, including the spread between a fleet of buses stored in a dense packing arrangement typical of most agency fleet storage arrangements.

c) BEB fire scenarios should be based on BEB fleet storage in an unenclosed parking garage and an open parking lot.

d) A fire starts in the parking garage or parking lot due to an outside event such as arson, lightning strike, or facility malfunction that then involves a vehicle igniting.

While computer simulations modeled around these scenarios are effective in most cases, some conditions may require agencies to complete a full-scale fire test. Agencies should be aware that such tests are often costly and can be avoided with computer-generated modules which will provide data nearly identical to a full-scale test.

Lastly, the FHA should provide anticipated flammability and smoke emissions typical to buses within the agency's fleet. According to ASTM E84, flammability and emissions data should be provided for smoke development and fire spread. Data identifying gases that are a byproduct of fires associated with BEBs should also be available from the FHA. This analysis should include types of gases, expected concentrations as a function of time, and the effects these gases have on humans.

3. **Mitigate hazards identified in the FHA.**

All risks calculated in the FHA must be reduced to the lowest practical level. Doing so will reduce the severity of BEB fires and the potential impacts to personnel, buses, and infrastructure. Mitigations may include, but are not limited to:

a) Determining a sprinkler design that would adequately control a fire based on the results of the FHA. The sprinkler design should consider all factors contributing to determining an adequate sprinkler design basis.

b) Providing alternative extinguishment systems such as a clean agent or foam-based system.

c) Incorporating mechanical separation either in terms of firewalls or fire areas where a BEB fire would be contained for a minimum duration of one hour.[14]

d) Reconsidering fleet storage configurations to mitigate the spread of fire.

[14] Agencies must be aware of all potential thermal events and explosions

e) Identifying fire alarm interfaces that can mitigate fire risks through quicker detection of fires and earlier fire department response.

f) Methodologies for managing spent and damaged BEBs and batteries.

Agencies may also consider combinations of systems or mitigations that would best control the identified fire hazards.

Hazard-Based Design Criteria

Another approach to mitigation associated with BEBs and the related charging infrastructure is the development of design and installation design criteria (DC) specific to the agency. A performance-based fire analysis will provide mitigations to fire hazards associated with BEBs. The agency's DC can be based on the information gathered from this FHA. An agency's DC should consider, at a minimum:

- Sprinkler design
- Alternative suppression protection
- Fleet storage configuration with either physical or mechanical separation
- Safety interfaces, including emergency stop capabilities

If a performance-based FHA is not feasible and DC cannot be based on identified hazards, it may still be possible to mitigate hazards associated with BEBs. However, hazard mitigation will not be as effective as an FHA-based approach to the extent and accuracy of the information a performance-based FHA provides. Possible approaches to non-FHA DC development include:

1. **Over-designed sprinkler system approach to fire mitigation**

   A sprinkler design can be set as an extra hazard group one (1) or two (2), the highest identified prescriptively in NFPA 13. The challenge to this approach is installing a sprinkler system that may be over-designed for the hazard at a significant cost to the agency. Most facilities would not have been designed to this level of sprinkler protection, necessitating significant changes to existing sprinkler systems.

2. **Onboard fire suppression systems**

   Onboard BEB suppression systems that can directly apply extinguishment to the battery modules can be assessed as mitigation to the current lack of code to address facility fire protection.

3. **Onboard battery cooling systems and thermal management systems**

   Keeping battery modules cool can reduce the risk of possible thermal runaways. Onboard cooling and thermal management systems can be assessed as mitigation to reduce the possibility of thermal runaway events.

4. **Extreme physical separation approach to fire mitigation**

   Institute fleet storage guidelines with extreme storage distances between BEBs or groups of BEBs to minimize the spread of fire in the event of a fire. Physical separation is a simple and effective way to mitigate the potential spread of fire. Challenges with this approach include the extra space necessary for physical separation. For example, if BEB storage typically calls for buses to be stored with a three-foot separation between each bus, calling for an eight-foot separation requires a significant amount of unutilized open space. It is also not possible to accurately identify how much physical separation is adequate. While, for example, an eight-foot separation may seem sufficient, this determination cannot be made without an FHA to confirm an adequate distance. Mitigating the associated hazard of fire spread can only be based upon a best-practices approach.

5. **Creation of fire area approach to fire mitigation**

   Agencies can also create distinct fire areas with a limited amount of BEBs in each fire area to limit the spread of fire to a lesser number of BEBs. Similar to physical separation, challenges arise when attempting to implement this type of mitigation. Primarily, each fire area will be damaged or destroyed if a fire occurs. Nonetheless, this is a code-recognized way to limit fire loss by containment within a fire area. Fire areas have higher costs since rated walls and associated openings must be designed to code. These areas still require a suppression system; however, a more typical ordinary hazard (OH) design basis likely can be used since the fire area would contain the potential losses.

Fleet and Charging Infrastructure Design Mitigations

The following design elements may enhance the operational mitigations discussed in this document and exceed current code requirements. However, the recommendations alone do not fully mitigate the associated hazard to the lowest practical levels, and further engineering solutions will likely be required.

1. **Emergency stops**: Emergency stop capabilities added near the charging BEB, and remote so first responders can cease charging operations immediately and limit the potential for additional fire spread.
2. **FLS systems integration**: Temperature monitors and fire detection systems on BEBs may be interfaced with existing sprinkler and fire alarm systems to alert fire departments and activate suppression.
3. **Automatic disconnect switches**: Although no standard exists for this, BEBs should be equipped with an automatic disconnect switch for battery packs before they reach critical temperatures. This can be supplemented with a battery thermal maintenance or cooling system to prevent battery packs from approaching critical temperatures.
4. **Manual disconnect switches on the exterior of BEBs**: Providing multiple battery manual disconnect switches on the exterior of the BEB can provide first responders the ability to stop the flow of energy from the battery packs without entering compartments.

Cybersecurity

Systems, including chargers and buses, could be affected by a successful cyberattack, further illustrating the need for information technology (IT) departments to assist with the design, specifications, and manual reviews provided by the manufacturer(s). The most likely vulnerabilities occur while updating the equipment firmware. During this time, agencies expose themselves to the potential of a network breach simply by using the standard methods of utilizing a Wi-Fi or 3G/4G/5G internet connection to perform a firmware update. Should an attacker gain access and introduce an alternate firmware package to make the bus or charger perform abnormally, the consequences could be severe if the attacker affects the bus's operation or allows the charger to rapidly charge the bus batteries leading to a collision or a battery fire. Conversely, an update could render the charger(s) incompatible with some or all buses, preventing them from returning to revenue service. As with other cybersecurity measures, default passwords provided by the manufacturer should be changed immediately and replaced with complex passwords to prevent tampering.

Section 7

Operations and Maintenance Considerations

Operational and maintenance considerations are a significant component of the SSC process. When assessing BEBs and their associated systems for potential hazards and vulnerabilities, transit agencies must consider operational and maintenance needs when systems are introduced into service. Operational and maintenance requirements are identified in the OHA discussed in Section 2 of this report.

Operational considerations can be reviewed as stopgap measures to mitigate fire risk while establishing a reasonable basis for fire and life safety design. Operational mitigations for consideration include, but are not limited to:

1. **Fire watch**: During the charging of BEBs, a qualified firewatch can provide faster initiation of emergency-stop procedures, quicker fire department notification, and perhaps extinguishment with a portable fire extinguisher.
2. **Standard operating procedures (SOPs)**: Developing SOPs specific to BEBs and the related charging infrastructure would determine what operators and maintenance personnel are required to do in a fire involving a vehicle or related BEB system.
3. **Outside storage**: Storage adequacy is based on the presumption that fire protection designs of either new or existing facilities are sufficient to protect the infrastructure from the enhanced fire loads of BEBs. Conditions permitting, agencies can consider moving charging and storage operations to an outdoor location at appropriate setbacks from buildings and other vehicles. Doing so is one of the more cost-efficient and most effective operational mitigations if fire protection systems are inadequate to manage recognized FLS hazards.
4. **Storage separation**: Supplemental to item number three above, agencies should consider storage separation of at least ten (10) feet from adjacent buses.

Training

Consistent operator and mechanic training will increase safety and facilitate an agency's transition to BEBs, helping minimize the inevitable learning curve for BEB maintenance and operation. Similarly, the staff involved in bus planning, scheduling, and run cutting should be provided with BEB training, as block scheduling and dispatching may be impacted by the range limitations of certain BEB technologies and other factors that influence bus scheduling and planning. BEB training can also influence operational and economic considerations for an agency, as suboptimal operation of BEBs can affect the bus range and charging efficiency. Beyond training, additional key practices for ensuring safety include bus tests, charging infrastructure inspection, and emergency preparedness plans. The bus original equipment manufacturer (OEM) provides most operations and maintenance training for the bus and charging infrastructure.

Existing operator and maintenance training associated with BEB systems will need to be revised from the typical training provided with conventionally fueled buses. For example, a diesel mechanic may not be well-suited to repair or work on electric vehicles, resulting in the need to hire different skill sets to maintain a BEB properly. This consideration may require bus agencies to consider including OEM requirements for basic skills, allowing for more comprehensive training to be provided. Providing specific training to both operational and maintenance staff will supplement other FLS and electrical hazard mitigations.

Training provided by the OEM should be clearly outlined in the bus procurement documents and should occur shortly after bus delivery to limit delays in revenue service deployment. Contract specifications should include requirements for training hours, aids, materials, tools, and diagnostic equipment. In advance of the buses arriving at the property, confirm what direct staff training or "train-the-trainer" training will be provided by the OEM and ensure that the transit agency has access to the needed tools and materials.

Operations Training

The introduction of BEBs will require additional training and retraining of current bus operations personnel. For training programs, agencies must consider education for individuals beyond operators, including, but not limited to:

- Supervisory staff
- Training personnel
- Bus planning, scheduling, and run cutting teams

Consistent training will increase safety, enhance organizational transitions to BEBs operations, and help minimize service disruptions, especially if supporting departments such as planning and scheduling are informed of current BEB-fleet limitations. This will lead to increases in greater efficiencies and service reliability.

Operator training on the differences between BEB operation and conventionally fueled vehicles is essential for safety and efficiency. Training for BEB operators is vital to address the concerns of proper docking during charging, energy-efficient driving, braking, and shutdown. However, it is also essential for a general understanding of BEB operation. Operators need to know how the battery state of charge (SOC) relates to the range and how environmental factors affect the range so that sufficient charge can be maintained according to the planned route. Additionally, operators must be familiar with emergency safety protocols.

Training topics agencies should consider include, but are not limited to:

- BEB hazards
- On-route charging procedures
- Hazards related to battery chargers
- Regenerative braking
- Noise level
- Emergency procedures

Maintenance Training

Routine BEB maintenance is dissimilar from more common diesel or hybrid vehicles. While diesel vehicles require knowledge of electrical systems, greater understanding and awareness are required amongst maintenance staff on the more complex BEBs electric systems. Electrical systems knowledge will also be required for supporting systems such as charging stations, charging monitoring systems, and communication systems.

Agencies must train maintenance personnel at all levels to ensure knowledge and ability with all electrical propulsion and auxiliary systems. Training should also include instruction on onboard diagnostic systems and safe maintenance operations with or around high-voltage systems, including handling, storage, and disposal of batteries. Additionally, an agency should ensure its preventative maintenance inspection (PMI) processes are revised and incorporated into the training curriculum. Training topics might include information regarding hazards associated with:

- Battery chargers
- High-voltage cables
- Potential thermal events
- Hazards related to battery chargers
- Safe handling and deactivation of high-voltage components, including required personal protective equipment (PPE) for different tasks and capacitor discharge timing
- OSHA-compliant lockout and tagout (LOTO) procedures for working on energized components and systems, as specified in *The Control of Hazardous Energy*
- Battery-specific safety hazards include electrocution, arcing, and fires from short circuits
- Locations of emergency cut-off switches and fire response equipment

Transit agencies may consider hiring additional staff with the proper training and accreditations to maximize maintenance efficiencies and manage potential gaps in training proficiencies. Bus OEMs may also support this necessity, especially for maintaining advanced systems relating to the electric propulsion system or charging systems.

The maintenance training program must include scheduled training and retraining for tow truck operators and contractors moving BEBs.

Community Awareness

As BEBs are introduced into the fleet, communication with the public regarding the positive impact BEBs have on the environment should be supplemented with a safety community awareness language. Such programs should inform the community of the inherent risks of BEBs. More specifically, emphasis should be placed on the vehicle's lack of noise while requesting additional vigilance at or around bus stops for approaching BEBs.

First Responder Training

During the procurement process, agencies should coordinate first responder training with the OEM in advance of revenue service deployment of BEBs. Doing so should ensure proper emergency response procedures will be followed if an incident does occur. Similarly, incident response procedures should be revised and included as part of the training program to discuss assessing high-voltage systems and risks and procedures for isolating risks and preventing further damage and exposure.

At a minimum, agencies should consider the following within their training program:

- How to distinguish electric buses from conventional buses
- How to best approach BEB vehicle fires
- How a BEB fire differs from a conventional internal combustion vehicle fire
- Properties of Li-Ion and Lithium-metal batteries and the distinct fires each produces
- How to isolate high-voltage systems
- Overview of the location of essential components on a BEB
- Location of emergency cut-off switches
- Proper procedures for disconnecting batteries and isolating them from the bus
- How to treat chemical burns and neutralize battery fluid
- Understand all hazardous fluids being used and proper storage methods
- Information on any potential explosive or toxic gas hazards that batteries may pose

Training should be followed up with the deployment of a drill or exercise following the Homeland Security Exercise and Evaluation Program (HSEEP) methodology. A drills and exercise program could begin with a seminar incorporating the content previously discussed, followed up with a table-top exercise (TTX) to establish adequate SOP, which can lead to a full-scale exercise (FSX).

Maintenance

Most maintenance procedures will be developed through the manufacturer's operations and maintenance (O&M) manuals. As part of the overall certification process, specifically OHA verification and operational readiness conformance (ORC), agencies may ensure copies of O&M manuals include the following information, at a minimum:

- Preventative maintenance procedures and schedules
- Diagnostic procedures
- A list of spare parts
- A list of final parts
- Component repair processes
- Operator instructions
- Bus schematics
- Training materials
- BEB operations and maintenance hazards
- High voltage safety procedures
- Safety precautions to minimize risks to passengers, drivers, and maintenance personnel
- Emergency procedures

Agencies must ensure adequate OEM-provided operations, maintenance, and safety training is included in the contract language. Training will depend on the agency’s knowledge of the technology. Subsequent deployments of the same or similar technology may require less training. While many OEMs have a standard training plan, most offer the option to purchase additional training hours as needed.

Specific Maintenance Considerations

In addition to the typical inspections and maintenance items for a conventionally fueled bus fleet, a BEB fleet will need additional inspections, testing, and maintenance programs developed in coordination with the BEB system providers.

- **Controlling thermal runaway:** Battery management systems cannot fully mitigate the conditions leading to a thermal runaway. Operator training, agency preventative maintenance, and data analysis of the battery management systems (BMS) can be considered an operational mitigation against a thermal runaway event.
- **Battery management systems:** BMS data should be analyzed per the manufacturer's recommendations. Identifying when the battery system may trend towards conditions that could lead to an incident is possible. Additionally, BMS can notify if batteries are overheating or overcharging. Working with software engineers and architects, such monitoring capabilities could be interfaced with supervisory control and data acquisition (SCADA) systems to prompt further attention. Procedures should be developed to address such SCADA alerts.
- **Testing:** Periodic testing procedures should be performed to ensure batteries operate as intended and within design parameters to avoid malfunctioning events.
- **Software management and cybersecurity:** BEBs and charging infrastructure are likely software dependent. Protocols and procedures identifying updates should be established.
- **Charging system management:** Pantographs, plug-in chargers, and inductive charging have unique operating characteristics. As such, procedures should be developed and implemented to assure safe operation. Bus systems can consult with rail transit agencies that use pantographs to establish baseline maintenance protocols for similar electric systems.

Section 8 Emergency Management Considerations

Current regulations require bus transit agencies to identify emergency preparedness and response plans or procedures. Additionally, SSC processes necessitate the validation of operational readiness to be completed, partly through methods for verifying emergency personnel readiness for emergencies involving battery electric systems in transit systems. There are two (2) considerations that agencies need to make as they relate to emergency management:

1. Up-to-date emergency response procedures and guidelines
2. Recurrent training for internal staff and emergency response organizations

Both considerations need to be assessed around two (2) primary hazards posed by Li-Ion batteries and electric systems:

1. Risk of electric shock from exposure to high-voltage connections in a damaged battery.
2. Risk of thermal runaway from damaged cells in the battery. *Refer to Appendix B for detailed information about thermal runaway.*

When reviewing SOPs, training material, and other emergency guidance documents for personnel, agencies must ensure these unique hazards of BEB fleets and associated equipment are incorporated into revised procedures. An agency's emergency response plan to a BEB emergency should also be designed around manufacturer recommendations and industry best practices. In support of this effort, NFPA maintains a collection of emergency response guides for alternative-fuel vehicle manufacturers and first responders, including:[15]

- Gillig
- Nova Bus
- Proterra

Standard Operating Procedures

The OHA process will help transit agencies identify which emergency procedures require revision to account for BEB fleets and their associated systems. Transit agencies and emergency response organizations must consider operational hazards when establishing pre-planning and incident response plans. Considerations include:

[15] https://www.nfpa.org/Training-and-Events/By-topic/Alternative-Fuel-Vehicle-Safety-Training/Emergency-Response-Guides

- **Existing fire suppression systems**: It is conceivable that sprinklers may be unable to control a BEB fire from propagating and spreading to the remaining fleet. Suppose the sprinkler system has not been designed specifically to the hazard level that a BEB fleet might present. In that case, fire suppression response should be modified to protect fire personnel.
- **Li-Ion battery off-gassing:** Facility evacuations must be the top priority of any agency's SOP. Transit personnel are not trained or equipped to populate areas where Li-Ion batteries are on fire. Therefore, standard portable fire extinguisher (PFE) training and SOPs should emphasize evacuation over suppression. Similarly, interagency SOPs with external responders must underscore the proper use of PPE, specifically self-contained breathing apparatus (SCBA) during interior firefighting operations. Pre-plans and emergency response strategies can be further supported through wind direction indicators so first responders can ascertain the direction of vapor cloud travel.
- **Hazardous materials considerations**: If enough of a BEB fleet is involved in a fire, a significant vapor cloud could propagate, necessitating an appropriate hazardous material release response. As such, an agency’s emergency spill response plan should be reviewed and revised to address hazardous materials released into the environment.

Additional procedures should be requested from manufacturers based on the individual characteristics of the fleets being procured.

Emergency Training and Exercises

BEB maintenance personnel and BEB Operators should be provided specialized training to recognize potential BEB hazards and what actions should be taken. Training and SOP considerations for internal personnel may include:

- Use of a PFE in the event of a BEB fire
- Managing over-temperature conditions or fire
- Isolating damaged or malfunctioning BEBs or battery modules
- Initiating emergency charging stops
- Recognition when charging is not proceeding correctly and possible corrective actions

As part of an agency's emergency planning process, agencies must consider joint training with local responding fire departments. With the introduction of a BEB fleet and the related charging infrastructure, emergency responders should be aware of the new hazards encountered upon fire suppression response. For transit agency personnel, emergency response training is guided by manufacturer recommendations and industry best practices. As part of the procurement process, agencies should request that manufacturers provide guidance and user interfaces of critical emergency systems. Additional guidance can be obtained from NFPA using their previously mentioned manufacturer SOPs database.

Similarly, the agency can assist fire departments by providing tactical guidance to responders based on system expertise. *Specific tactical considerations that can be provided to the fire departments can be found in Appendix E*.

Risks to First Responders

Suppression activities related to electric vehicle fires expose responding fire crews to unique hazards not typically found with conventionally fueled vehicles. Agencies must ensure that first responders are made aware of the following hazards associated with BEB fires. Specific considerations include, but are not limited to:

- The high-energy battery modules and associated conductors feeding the propulsion motors on the BEBs pose an electrocution risk that does not exist on conventionally fueled buses.
- The Lithium component of batteries may add to the intensity of a vehicle fire once water is applied.
- Battery fire reignition is common. Fire suppression crews should remain alert to rekindling BEB fires for significant periods of times until the battery cells have sufficiently cooled.
- Off-gassing associated with ruptured battery cells can be toxic and explosive.

The NFPA, NTSB, and BEB manufacturers provide response field guides and best practice guides that can be invaluable for responding fire departments. Agencies should consider having these documents available and current to provide to their local jurisdiction as part of ongoing training endeavors related to BEBs. Below is a short list of possible resources for first responders:[16]

Guides and Standards

- Delphi Corporation. (2012). *Hybrid Electric Vehicles for First Responders*, Troy, MI
- NFPA. (2012). *Electric Vehicle Emergency Field Guide*, Quincy, MA.
- National Highway Traffic Safety Administration. (2012). *Interim Guidance for Electric Vehicle and Hybrid-Electric Vehicles Equipped with High Voltage Batteries*, Washington, DC.
- NTSB Safety Report SR20/01. (2020). *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles*.

[16] Due to the fast-evolving technology associated with BEB's, a list of resources such of this should be continually reviewed and updated.

Publications

- Grant, C. (2010). *Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid-drive Vehicles*, Quincy, MA.
- Long, Thomas R., Jr. (2013). *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results*. Fire Project Research Foundation.
- Moore, R. (2022). “University of Extrication: Electric Vehicle Fire Suppression,” Fire House Magazine.
- Ruiz, Vanesa A.P. (2018). J*RC Exploratory Research: Safer Li-Ion Batteries by Preventing Thermal Propagation*, EUR 29384 EN.

Section 9

Impact Analysis

SSC is an iterative and deliberate process designed to minimize safety risks. Often, agency project teams are unaware of the SSC process and its proven benefits to the project and the system as a whole. When properly implemented, a well-established SSC program can help reduce procurement costs through reductions in additional project costs, including change orders. However, cost control through SSC can only be accomplished through the early incorporation of the SSC process into the project's life cycle. Doing so will allow for early identification of appropriate mitigations based on no recognized safety hazards and security vulnerabilities from the PHA and TVA. Doing so will enable the SSC to influence design and construction costs positively. Figure 9-1 illustrates the diminished capabilities of certification to affect change as the project progresses through the later stages of PE into FD, construction, and ultimately, revenue service.

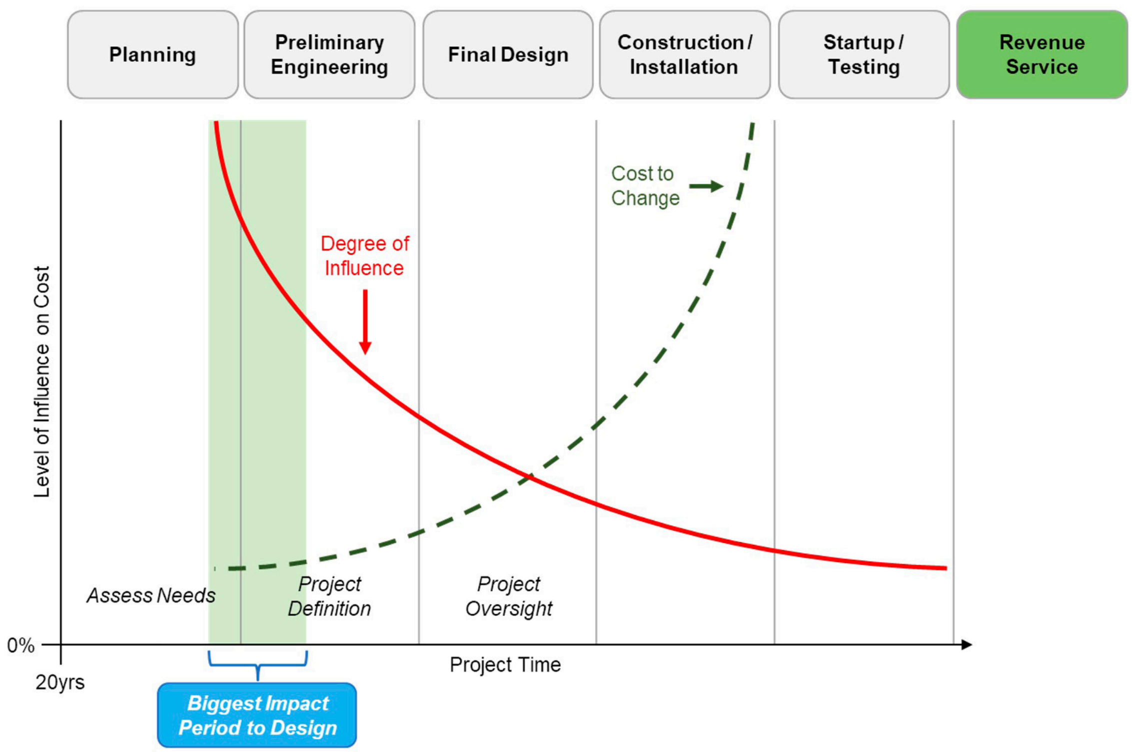

Figure 9-1 *Safety and Security Certification Project Influence Model*

Better project management and the coordination of engineering departments and SSC staff to ensure timely integration will be necessary for agencies to control calculated safety risks and security vulnerabilities adequately. The hazard and vulnerability analysis process can then be used to evaluate the impact of project decisions and potential deviations not otherwise thought to have safety or security implications. The business impact review is illustrated in Table 9-1.

Agencies have five (5) options or a combination of each to complete the SSC process.

1. Self-certification with internal resources
2. Self-certification with a certification consultant representing the agency
3. Project team, certification consultant
4. Designer of record (DOR) consultant
5. Manufacturer's consultants

Table 9-1 *Business Impact Review*

	Method of Certification	Description	Considerations	Resource Requirements		
				Human	Financial	Agency Level of Effort
1.	**Self-certification with internal resources**	An agency chooses to perform all safety certification activities using internal capabilities.	a. Training and qualifications to perform SSC b. Personnel availability	High	Low	High
2.	**Self-certification with a certification consultant representing the agency**	A 3rd party contract is solicited to work on behalf of the agency's safety and/or security department(s) to perform SSC efforts. This can be to self-certify or provide 3rd party verification.	a. Delays caused by the procurement process b. Additional operational or capital cost c. Experience in battery electric systems d. Contractor qualifications	Low	Moderate	High
3.	**Project team, certification consultant**	Safety and security certification is completed independently of the agency's safety and security functions	a. Training and qualifications to perform SSC b. Integration with Safety and Security functions c. Project team availability	Low	Moderate	High
4.	**Designer of record (DOR) consultant**	The DOR completes certification for design with oversight by the transit agency.	a. Training and qualifications of the selected subconsultant b. Conflicts of interest with contract requirements c. 3rd party verification by the agency	Moderate	High	High
5.	**Manufacturer's consultants**	The selected manufacturer completes certification for installation based on designs and technical specifications.	a. Training and qualifications of the chosen subconsultant b. Conflicts of interest with contract requirements c. 3rd party verification by the agency	Moderate	High	High

Section 10 Conclusion

FTA prepared this industry practices document to support transit agencies' SMS implementation processes. As part of FTA's effort to promote the management of change in the public transit industry, *Safety and Security Certification of Electric Bus Fleets – Industry Best Practices* was developed to provide bus transit agencies with leading industry practices for verifying the safety-critical BEB items and associated infrastructure. The industry best practices presented in this report, and emphasized through the background research, are not intended to be prescriptive. All public transit agencies should develop comprehensive SSC programs based on the FTA *Handbook for Transit Safety and Security Certification* and tailored to their unique operating environments, the complexity of their operation, and the transit modes they provide.

SSC is a risk-based process paralleling the project's life cycle and schedule. While the process is often misunderstood, SSC acts in the best interest of the bus agency to ensure all hazards and vulnerabilities are appropriately mitigated and that any calculated risk is reduced to the lowest practical level. As such, the rapidly evolving dynamics of the battery electric market demand that agencies implement a robust verification process through SSC to identify and mitigate BEB-specific hazards. While most BEB components are similar to conventional fuel alternatives, new considerations must be made for those unique items and hazards inherent to BEBs and the associated infrastructure procurement processes.

To effectively implement FTA's 10-step SSC process described in Section 4 for BEBs, agencies should, at a minimum, develop or update the following:

- Manual of design criteria
- Agency specifications
- Standard operations procedures
- BEB and charger preliminary hazard lists
- Define committee and working group membership

Managing the recognized gaps in the SRM processes of SSC requires agencies to employ several operational strategies to mitigate unwanted risks. Notable gaps or issues in the certification process for BEBs include:

- Late coordination with the electric company
- Absence of specific codes and standards
- Some BEB certifiable items may change during assembly
- Parts availability issues hamper BEB operation
- Specific BEB fleet fire protection code requirements

- Most agencies do not utilize a complete safety certification process for BEBs
- Many agencies have not developed safety and security DC
- Missing input/coordination from all agency departments and local first responders
- No coordination with other agencies to identify issues and lessons learned
- Acquisition of any new PPE and tools

Appendix A Preliminary Hazard List

Sub-system / Elements	Potential Hazard
Design Criteria	Specific design criteria are not established before procurement of BEBs, leading to the purchase of BEBs with unknown or incomplete mitigation of hazards.
Gross Vehicle Weight - GVW	GVW exceeds tire factor limits causing tire failure/accidents.
Engineering Staff Training	Engineering/design staff are not knowledgeable of the hazards with the BEB, leading to potential injuries or damages.
Maintenance Managers Training	The maintenance staff is not knowledgeable in the maintenance aspects of the BEBs, leading to potential injury or damage.
Driving Instructors Training	Training staff is not knowledgeable in the operational aspects of the BEBs, leading to potential injuries or damages.
Technical Instructors Training	Technical training staff are not knowledgeable of the hazards with the BEB, resulting in injury or damage.
Instructor Guides	Instructor guides are not developed. Trainers are not able to provide consistent training to every student specific to the hazards of BEBs.
Student Manual/Guides	Student guides are not developed. Students are not able to review training information at a later date as reference material.
Environmental Issues	BEB is unable to operate efficiently within the local temperature and humidity ranges.
Operator Compartment / Noise exposure	Operators are subjected to noise levels greater than 75 dBA.
Exterior Operating Noise	Patrons and the public are subjected to noise levels greater than 83 dBA while the bus pulls away.
Exterior Operating Noise	BEBs operate with hardly any sound and can create a hazard for riders waiting at a stop. Signage should be placed at BEB stops to advise riders to “be alert for arriving buses."
Fire Safety	The bus does not meet the applicable fire and smoke emission regulations. FST results should be requested from the manufacturer(s).
Material Fire Safety	Materials used in the construction of the passenger compartment do not meet the FMVSS 302 requirements.
Fire Safety	The BEB is not equipped with a 5-pound multi-purpose Type A-B-C rated fire extinguisher and a portable extinguisher capable of extinguishing a battery fire.
Battery/Propulsion Fire Protection	The BEB is not equipped with a fire detection system integrated into the propulsion battery system.
Fire Suppression	The BEB is not equipped with a fire suppression system in the battery pack or the drivetrain areas.

Sub-system / Elements	Potential Hazard
Fire Detection / Battery Overheating Condition	The BEB is not equipped with sensors in proximity of propulsion system components that can detect over-temperature in critical areas, alert the operator through warning lights and alarms on the dashboard, and provide mitigation to prevent thermal runaway.
Bus Width	BEB is wider than 102 inches creating maneuverability issues that lead to accidents.
Bus Height	BEB is taller than 135 inches, creating potential overhead clearance and charging issues.
Propulsion System / High-Voltage Conductors	High-voltage wires are not easily identifiable/ located on the BEB per NFPA recommendations. First responder electrocution potential.
Propulsion System / High-Voltage Conductors	Wiring does not have indelibly and conspicuously labeled identification.
Exposed Propulsion Cabling	Exposed wiring is not tolerant of bus washer soap and degrades over time.
High-Voltage Connections	Connections are not formed within a safety interlocked dedicated junction box.
High-Voltage Cables	High-voltage cables are not orange in color to provide a visual warning of high voltage.
Wiring Connectors	Wiring connectors are located in areas where water can immerse the cables and create physical damage.
Wiring Connectors	Wiring connectors do not comply with the jacketing coloring requirements leading to potential electrocution.
Propulsion Cabling	Cabling is not arranged to eliminate vibratory fatigue, chafing, environmental or other forms of degradation.
Compatibility of BEB Batteries with Charging Systems	BEB batteries are not designed or sized to assure compatibility with charging devices.
Energy Storage System (ESS) / BEB Batteries	The BEB batteries are not equipped with a thermal management system to maintain the battery within the manufacturer's recommended temperature range during operation.
Energy Storage System (ESS) / BEB Batteries	The BEB batteries are not properly load distributed to reduce rollover or the bus "pulling" to one side.
Energy Storage System (ESS) / BEB Batteries	The BEB design does not prevent gassing or fumes from the ESS from entering the interior of the bus passenger/driver areas.
Bus Body and Interior	The design of the bus does not minimize the potential exposure to hazardous electrical current in the event of a vehicle accident.
Battery Disconnects	Batteries are not equipped with both automatic and easily accessible manual disconnect devices.
Electrical Isolation Fault	The HV System and ESS are not isolated from the bus chassis system.
Electrical Isolation Fault	The BEB is not equipped with a detection and alerting system to alert the operator and maintenance of any isolation faults.

Sub-system / Elements	Potential Hazard
Electrical Disconnect Devices	The BEB is not equipped with redundant 1 inside / 1 outside electrical disconnect switches for quickly shutting down the bus in the event of an accident.
Electrical Disconnect Devices	The electrical disconnect switches are not clearly marked and labeled.
HVDC Junction Box	The junction box is not fully isolated from the LVDC controls, controllers, and interlockings.
Battery Management System (BMS)	The BMS cannot monitor the voltage of cells within each battery pack.
Battery Management System (BMS)	The BMS cannot monitor the voltage at a frequency sufficient to ensure reliable and safe operation.
Battery Management System (BMS)	The BMS is not able to monitor battery temperatures.
Battery Management System (BMS)	The BMS is not able to mitigate damage to the battery and surroundings.
Battery Management System (BMS)	The BMS cannot alert when a battery fault has occurred and identify its location.
Battery Management System (BMS)	The BMS cannot employ safety interlocks when an unsafe battery condition is detected.
Battery Management System (BMS)	The BMS cannot monitor the battery state of charge and provide information to the rest of the vehicle.
Batteries / Cooling Systems	Battery temperatures exceed the manufacturer's recommended range during operation due to a lack of cooling systems.
BEB Charging System	The bus does not support plug-in and overhead conductive charging to allow for redundant charging opportunities.
BEB Charging System	Charging systems do not comply with the battery manufacturer's electrical and thermal limits.
BEB Charging System	The BEB can drive away while the charger is actively charging the BEB.
Propulsion System	The BEB does not have an auto-neutral feature to ensure the bus shifts to neutral when the propulsion system is selected and the parking brake is applied.
Propulsion System	The BEB is not equipped with a control mechanism to temporarily disable regenerative braking to prevent skids on low traction coefficient surfaces.
Propulsion System	A brake pedal application of 6 to 10 psi is not required to select forward or reverse from the neutral position.
Fluid Lines	The BEB is not equipped with a fireproof bulkhead and fittings to prevent fire propagation.
Traction Motor Cooling Lines	The BEB is not equipped with non-rigid cooling line piping except when vibrational frequencies prohibit or make rigid piping unreliable.

Sub-system / Elements	Potential Hazard
Thermal Management System	The BEB is not equipped with a system that will automatically shut down the charging system and provide a visual alert.
Thermal Management System	The BEB is not equipped with a system that will notify the operator of a failure with the battery thermal management system with an audible and visual alert that must be reset by maintenance personnel.
Thermal Management System	The thermal management alert can be reset without the action of maintenance personnel to ensure recognition of the fault by qualified personnel.
Thermal Management System	The thermal management fans are not designed to turn off in a fire automatically.
Hydraulic Systems	Hydraulic lines are not capable of withstanding maximum system pressures and temperatures.
Altoona Testing	The BEB did not satisfactorily complete FTA-required Altoona testing.
BEB Structural	The BEB, loaded to GVWR under static conditions, exhibits deflection and/or deformation that impairs the operation of the steering mechanism, doors, windows, and passenger escape mechanisms or service doors.
BEB Fire Separation	The BEB is not equipped with a fire-resistant bulkhead that separates passengers from battery and propulsion system compartments.
BEB Structural	The BEB body and roof cannot withstand a static load equal to 150 percent of the curb weight evenly distributed on the roof with no more than a 6-inch reduction in any interior dimension.
Towing Procedure	The towing device cannot withstand tension loads up to 1.2 times the curb weight of the bus within 20 degrees of the longitudinal axis of the bus.
Towing Procedure	The BEB towing procedure was not delivered with the vehicle to ensure proper and safe towing.
Towing Procedure	The rear towing device(s) shall not provide a toehold for unauthorized riders.
Passenger Door Interlocks	The BEB is not equipped with an interlock that locks the accelerator in a closed position.
Passenger Door Interlocks	The BEB is not equipped with a brake interlock that engages the service brake system to prevent the vehicle's movement with the operator's door control in the enable or open position.
Circuit Protection	The BEB is not equipped with manual reset circuit breakers, fuses, or multiplex over-current protection at all circuits and circuit branches.
Circuit Protection	Critical manual reset circuit breakers are not mounted with a visible indication of open circuits.
Battery Cables	The battery cables are not arranged in a harness, making it possible to connect the wrong connection points.

Sub-system / Elements	Potential Hazard
Battery Cables	The cables are not color-coded (red for positive 12V, black for ground, and blue or yellow for any 12V cables).
Master Battery Disconnect	The BEB is not equipped with a single disconnect switch that will isolate the batteries from the rest of the vehicle systems.
Master Battery Disconnect	The BEB disconnect switch is not connected directly to the battery posts.
Batteries	The batteries are located on the street side of the bus.
Batteries and Compartment	Exposed wiring is on the batteries or within the battery compartment.
Master Battery Switch	Turning the master battery switch off with the propulsion system operating fails to disconnect high voltage from the traction motor and other propulsion system components and isolate the high voltage to the ESS.
Master Battery Switch	The master battery switch does not interrupt the total circuit load.
Grounding	The battery is not grounded to the vehicle chassis/frame at one location only.
Grounding	The battery is not grounded to the vehicle frame as close as possible to the batteries.
Low/High Voltage Wiring and Terminals	The BEB is not constructed such that high-voltage systems and cabling do not interfere with the operation of the low-voltage control systems.
Low/High Voltage Wiring and Terminals	High-voltage cabling and low-voltage wiring are not separated as far apart as practicable.
Wiring Harnesses	Wiring harnesses contain wires of different voltage classes and are not insulated appropriately.
Wiring	Wire runs on the interior of the BEB are exposed.
Software Updates	The multiplex system does not provide security to protect its software from unwanted changes.
Electromagnetic Interference (EMI) Radio Frequency Interference (RFI)	Electrical and electronic subsystems on the bus emit EME or RFI that interferes with the onboard systems, components, or equipment.
Electromagnetic Interference (EMI) Radio Frequency Interference (RFI)	Electrical and electronic subsystems on the BEB are affected by external RFI/EMI.
Electromagnetic Interference (EMI) Radio Frequency Interference (RFI)	Patrons are subjected to RFI/EMI levels that may affect implanted healthcare devices.
Monitoring Software	The monitoring software for the bus does not meet the minimum requirements of Open Charge Point Protocol (OCCP) version 1.6 or higher.

Sub-system / Elements	Potential Hazard
Operator Area - Glare	The area is not designed to minimize glare.
Sunshade(s)/Visors	The use of the sunshade/visor restricts or blocks the view of the cameras.
Driver Protection System	Driver protection system not designed to minimize glare.
Driver Protection System	Driver protection system door lock impedes operator entry/exit from the operator area.
Window Glazing	BEB is not equipped with anti-vandalism glazing material.
Roof-mounted equipment	The roof of the BEB is not equipped with a nonslip surface and a clearly marked walkway for accessing and servicing the equipment.
Door Open/Close	Rear doors unlock/open at speeds greater than two mph.
Emergency Alarm System	The BEB is not equipped with an emergency (silent) alarm accessible to the operator but hidden from view.
Alarm Interface	The BEB is not equipped with an alarm interface that triggers CCTV recording.
Cyber Security	The BEB is not equipped with a system to detect and prevent software-based systems from malware and cyber-attacks (Malicious code injections, DDoS, etc.).
Cyber Security	Before being placed into revenue service, the BEB did not undergo vulnerability testing for SANS/CWE Top 25 and OWASP Top 10 issues.
Cyber Security	The BEB software is not equipped with a vulnerability and patch management system.
Brake System	The braking system installed is not the heaviest duty available for the GVWR of the bus.
Brake System	The BEB is not equipped with a regenerative braking system.
Brake System	Activation of the Anti-lock Braking System and/or Automatic Traction Control does not override the operation of the regenerative brake.
Brake System	Service brakes do not meet the requirements of FMVSS 121.
Brake System	The amount of force to achieve maximum braking exceeds 70 lbs.
Brake System	The total braking effort is not distributed among all wheels equally.
Brake System	Brake system materials do not absorb and dissipate heat quickly.
Brake System	Upon release of the emergency brake, the brakes do not engage to hold the bus in place.
Brake System	The bus does not sound an alarm if the ignition is turned off and the parking brake is not applied.
Emergency Egress/Exits	The bus is not equipped with emergency exits that meet the applicable emergency exit requirements of FMVSS No. 217 (S5.2.2 or S5.2.3).

Appendix B

Preliminary Hazard Analysis Template

PRELIMINARY HAZARD ANALYSIS (PHA) Battery Electric Bus Charging System and Infrastructure Program															
PHA No.	Hazard Description				Initial Hazard Rating *(Pre-resolution)*			Proposed Mitigation Against Potential Causes	Initial Hazard Rating *(Post-resolution)*			Implemented Mitigation	Final Hazard Status		
	Element/ Sub-element	Potential Hazard	Potential Causes	Effects	Initial Severity (1,2,3,4)	Initial Probability (A,B,C,D,E)	Initial Safety Risk Index		Final Severity (1,2,3,4)	Final Probability (A,B,C,D,E)	Final Safety Risk Index		Status	Date Closed	Notes
Certifiable Element:															
Certifiable Element:															
Certifiable Element:															
Certifiable Element:															

Appendix C

Thermal Runaway

The following is an excerpt from Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles NTSB Safety Report NTSB/SR-20/01, PB2020-101011, Adopted November 13, 2020.

> **Thermal Runaway.** Thermal runaway is a chemical process that produces heat (an *exothermic reaction*); the heat increases the reaction's rate, further increasing the temperature and escalating the process. Thermal runaway can spread from one battery cell to many cells in a domino effect. The originating cause of thermal runaway is generally short-circuiting inside a battery cell and a resulting increase in the cell's internal temperature. A short circuit in a Lithium-Ion battery cell can result from defects introduced during manufacturing, such as contamination, or from damage to the cell caused by crushing or puncturing—precisely the kind of damage produced by high-impact, high-severity car crashes. An external fire might heat a battery cell enough to initiate a thermal runaway. Fire and explosion can result when cells go into thermal runaway. The flammable solvent in the electrolyte can ignite if exposed to high temperatures or electrostatic sparks.

In basic terms, a Lithium-Ion battery cell produces electricity when Lithium ions, stripped of an electron, travel from one pole to another inside a cell. While this occurs, electrons that have been separated from a Lithium atom travel through vehicle or component circuity. If the Lithium-Ion cell is working correctly, the Lithium ions reunite with the electrons at the opposite pole, creating current. The separator/electrolyte is present in all Lithium-Ion cells and controls the flow of Lithium ions. This is illustrated in Figure C-1.

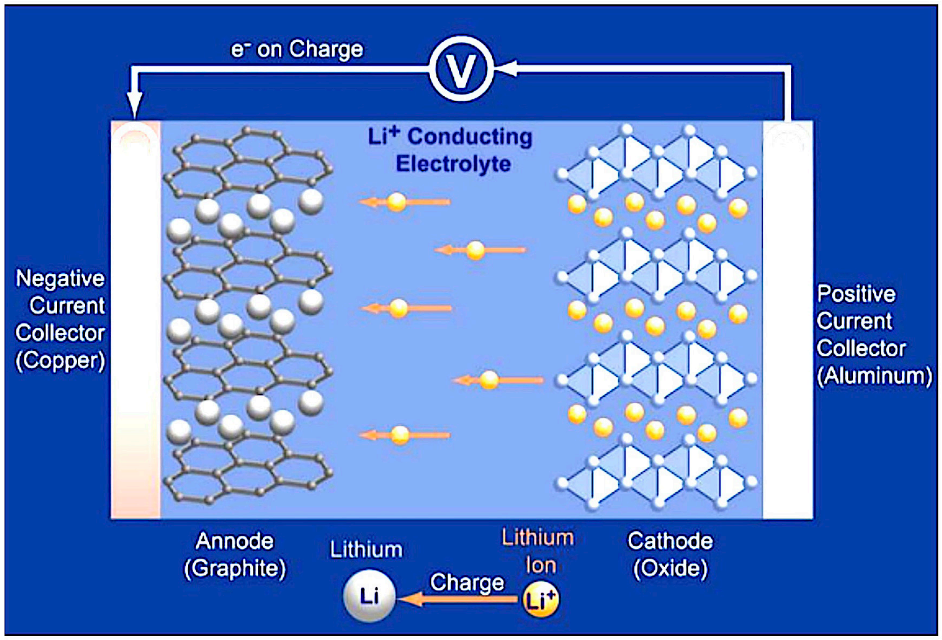

Figure C-1 *Thermal Runaway Illustration* [17]

Certain conditions, such as hot ambient temperatures, aged batteries, fast charging, overcharging, or a filled primary electrode, can affect the electron migration described above. This may result in Lithium plating on the electrode. If this plating process continues, dendrites (filaments that cause internal short circuits) are formed, generating heat. The excess heat generates more off-gas leading to a self-sustaining cycle. The described self-sustaining process is called a thermal runaway and can occur very rapidly, leading to the vaporous release of explosive clouds.

Factors that can lead to thermal runaway include:

- ***High Ambient Temperatures****:* Ambient temperatures above 75 degrees Fahrenheit (F) reduce a battery's ability to shed excess heat to the surroundings.
- ***Age of Batteries:*** Older batteries may require longer charge times being subject or higher currents, generating additional heat.
- ***Overcharging:*** Continuous overcharging can lead to internal battery damage.

The conditions leading to a thermal runaway cannot be fully mitigated by battery management systems (BMS). Rather operator and agency maintenance and data analysis of the BMS are the best defenses against a possible thermal runaway event.

[17] Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full Scale Testing Results, 2013, Fire Protection Research Foundation

Figure C-2 *Thermal Runaway Images*

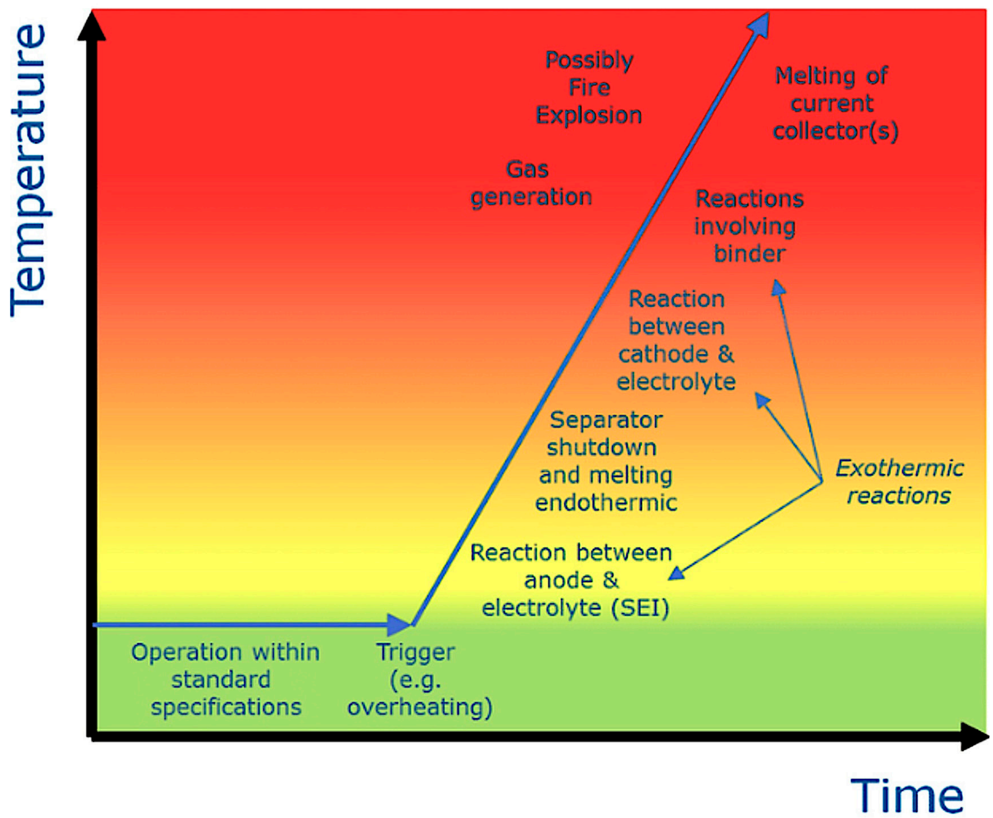

Figure C-3 *Onset of a Thermal Runaway Event Leading to a Fire* [18]

[18] Image Source: JRC exploratory research: Safer Li-Ion batteries by preventing thermal propagation, October 2018, EUR 29384 EN. Venesa Ruiz and Andreas Pfrang

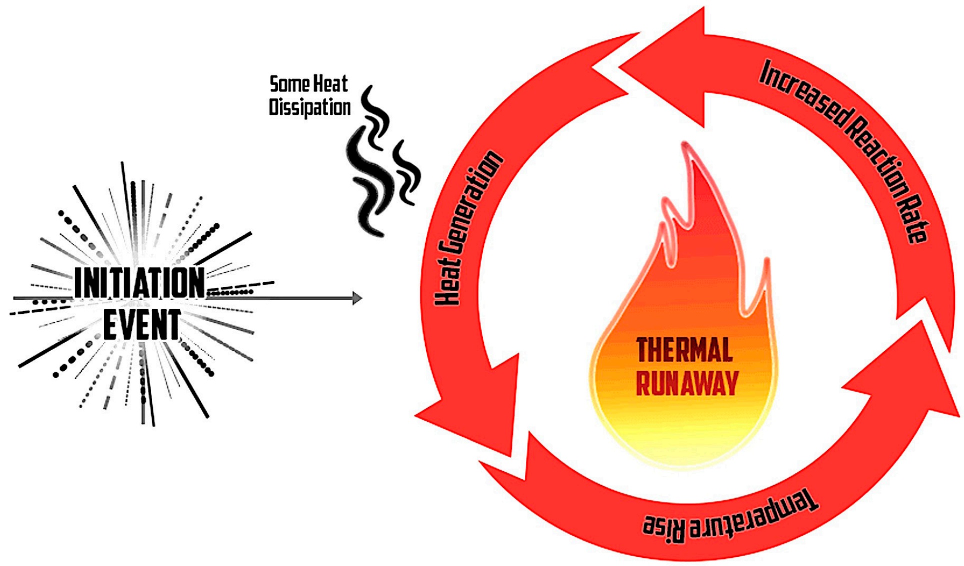

Figure C-4 *Onset of a Thermal Runaway Event Leading to a Fire from Initiation Event* [19]

[19] Image Source: 2022 Mitsubishi Electrical Power Products Website

Appendix D

Lack of Consensus on Extinguishment for Battery Electric Buses

Fire suppression tactics are typically developed from past experiences and Fire Science studies. The intention is to ensure fire suppression is completed efficiently to protect life, minimize property loss and reduce potential environmental impacts. With emerging technologies associated with BEBs, tried and true suppression tactics may not prove effective and may result in worsened fire scenarios. At the time of development of this document, major fire standards associations, safety organizations, and manufacturers all provide slightly different recommendations for the extinguishment of an electric vehicle, further exemplifying fire suppression tactics. With standard fire suppression tactics not well defined for battery electric vehicles, firefighting crews are faced with additional challenges as the industry expands the availability of BEBs.

NFPA Electric Vehicle Field Guide

NFPA's Electric Vehicle Emergency Field Guide states the following:[20]

> *Using water or other standard agents does not present an electrical hazard to firefighting personnel. If a Hybrid Vehicle (HV) battery catches fire, it will require a large, sustained volume of water. If the Li-ion HV battery is involved in fire, there is a possibility that it could reignite after extinguishment. If available, use thermal imaging to monitor the battery. Do not store a vehicle containing a damaged or burned Li-Ion HV battery in or within 50ft. of a structure or other vehicle until the battery can be discharged.*

Fire Protection Research Foundation Report

The Fire Protection Research Foundation report, Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid-Electric Vehicles states:[21]

> *Dry chemicals, CO2, and foam are often the preferred methods for extinguishing a fire involving batteries, and water is often not the first extinguishing agent of choice. Another important consideration with an EV or Hybrid-Electric vehicle (HEV) fire is that the automatic built-in protection measures may be compromised to prevent electrocution from a high voltage system. For example, the normally open relays for the high voltage system could possibly fail in a closed position if exposed to heat and if they sustain damage. Further, short circuits to the chassis/body may*

[20] National Fire Protection Association. Electric Vehicle Emergency Field Guide. Quincy, MA. 2012.

[21] Grant, C. Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles. Quincy, MA. 2010.

become possible with the energy still contained in the high voltage battery or any of the high voltage wiring still connected to the battery.

Hybrid Electric Vehicles for First Responders

Delphi Corporation's Hybrid Electric Vehicles for First Responders states:[22]

> *Firefighting techniques for vehicles using Li-ion battery packs should be treated like any electrical fire by using a Class C extinguishing agent. The initial attack on hybrid HEV battery pack fires: perform a fast, aggressive attack. Should a fire occur in the Nickle-Metal Hybrid (NiMH) high voltage battery, attack crews should utilize a water stream or fog pattern to extinguish any fire within the trunk.*

NHTSA Guidance for Electric and Hybrid Vehicles

The National Highway Traffic Safety Administration's publication, Interim Guidance for Electric and Hybrid Electric Vehicles Equipped with High Voltage Batteries, states:[23]

> *If the fire involves the Lithium-Ion battery, it will require significant, sustained volumes of water for extinguishment. If there is no immediate threat to life or property, consider defensive tactics, and allow the fire to burn out.*

[22] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.

[23] National Highway Traffic Safety Administration. Interim Guidance for Electric Vehicle and Hybrid-Electric Vehicles Equipped with High Voltage Batteries. Washington, DC 2012.

Appendix E

Tactical Considerations for Fire Departments

The following information provides tactical considerations for fire departments responding to a BEB fire. Transit agencies may choose to incorporate this material into training for the first responders. However, tactical considerations should be finalized by each fire department. As such, this material can be provided to local jurisdictions to assist them in developing specialized training programs.

The following recommended tactics were taken from Firehouse Magazine, March 14, 2022, "University of Extrication: Electric Vehicle Fire Suppression," by Ron Moore.[24]

1. **Thermal Imaging**

   Using Thermal Imaging Cameras (TIC) to identify possible hot spots in battery modules.

2. **Hot-Sticks**

   Lithium-Ion batteries will present high-voltage DC, which voltage awareness devices do not usually detect..

3. **Resource Requirements**

   Extended suppression times may require additional logistics and staffing. Additionally, fire suppression apparatus will likely be taken out of service for extended periods.

4. **Fire Suppression**

   Access to the underside of buses for battery modules to support fire suppression may require shoring equipment to tilt vehicles. Additionally, tilting the BEB up can allow cooling of the battery packs and may be another tactical consideration. Suppression will also require copious amounts of water to suppress Li-Ion battery fires. During an NFPA full-scale Li-Ion battery test fire, researchers found that more than 2,600 gallons of water were needed to extinguish the fire in anapproximately 600-lb. Li-Ion battery.[25] Unlike most vehicle fires, fire suppression will not likely be successful utilizing available pumper engines alone, and securing a hydrant is a necessary tactic. Additionally, jurisdictions may need to consider water tenders in areas with poor water supply.

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[24] Moore, R. (2022) University of Extrication: Electric Vehicle Fire Suppression. Fire House Magazine.

[25] Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results Final Report Prepared by: R. Thomas Long Jr., P.E., CFEI Andrew F. Blum, P.E., CFEI Thomas J. Bress, Ph.D., P.E., CRE Benjamin R.T. Cotts, Ph.D. Exponent, Inc. 17000 Science Drive, Suite 200 Bowie, MD 20715 © June 2013 Fire Protection Research Foundation

Products are available, allowing fire suppression crews to pierce a battery module to inject extinguishment directly. However, most BEB manufacturers do not recommend utilizing such a technique at the time of this presentation. Complete submergence of a BEB could be a consideration; however, the improbability of a tank of sufficient size negates this discussion.

5. **Electrical Safety**

   SAE J2990 recommends three methods for disabling high-voltage systems.

   a) Automatic shutdown capability. This function should be part of the best-practice design for a BEB.
   b) Switching the ignition switch to OFF. Confirm that this disconnects the high-voltage system from the high-voltage sources.
   c) Cut or disconnect battery cables to discharge the 12-volt system and cut or disconnect the 12-volt output cable.

   Refer to Appendix F for more information.

Appendix F

SAE J29990 Post Incident Inspection Process

	ACTION	NOTES
1	Inspect for signs of fire or smoldering.	Use a thermal camera or infrared temperature probe if possible.
2	Listen for gurgling, bubbling, crackling, hissing, or popping noises from the battery.	Sounds can indicate the venting of overheated cells or arcing in a high-voltage system.
3	If groups of battery cells have separated from the battery enclosure, alert responders of potential exposure to high voltage or fire reignition.	Contact equipment manufacturer for depowering recommendations, packaging instructions, and disposal recommendations. If sufficient information is not available, consult the latest version of the US Department of Transportation (US DOT) / Transport Canada *Emergency Response Guidebook* for Lithium-Ion batteries (guide 147) or NiMH (guide 171).
4	If the vehicle is submerged, do not remove the submerged service disconnect, but turn off the ignition if possible. Disable the vehicle by chocking wheels, placing it in park, removing the ignition key, or disconnecting the 12-volt battery.	Understand that electric vehicles are designed to be safe in the water. Small bubbles emanating from the vehicle do not create a shock hazard. Water damage to electrical components could lead to reignition. Do not store a vehicle that has been submerged indoors until high-voltage energy is depowered.
5	Ensure that the high-voltage system is disabled.	Refer to the manufacturer's emergency response guide or emergency field guide to verify. At a minimum, disable the 12-volt system.
6	Examine the mechanical integrity of the battery system.	Is the enclosure ruptured, cracked, punctured, or dented?
7	Inspect for evidence of fire or heat damage.	Signs include smoke residue or heat damage around the battery system and burnt odor from the battery system.
8	Inspect for evidence of arcing in a high-voltage system. Notify tow truck drivers of potential hazards and recommendations for isolation.	Carbon traces indicate that the isolation of the high-voltage system has been lost.
9	Inspect for evidence of external battery leaks. Notify tow truck drivers of potential hazards and isolation requirements.	The Lithium-ion battery electrolyte has a sweet odor, like ether, that could indicate a battery leak. Leaking electrolytes normally creates drops, not puddles.

Appendix G Referenced Codes and Standards

American Society for Testing and Materials (ATSM)
FM Global
Institute of Electrical and Electronics Engineers (IEEE)
International Building Code
International Building Code (IFC)
NFPA 13: Standard for the Installation of Sprinkler Systems
NFPA 70: The National Electric Code (NEC)
NFPA 70E: Standard for Electrical Safety in the Workplace
NFPA 72: The National Fire Alarm Code
NFPA 88A: Standard for Parking Structures
NFPA 551: Guide for the Evaluation of Fire Risk Assessments
NFPA 855: Standard for the Installation of Stationary Energy Storage Systems
Society for Automotive Engineers (SAE)
SFPE Guide to Performance-Based Fire Protection
Underwriters Laboratories (UL)

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Acronyms and Abbreviations

AAR	After Action Report
AHJ	Authority Having Jurisdiction
APTA	American Public Transportation Association
ASP	Agency Safety Plan
ASTM	American Society for Testing and Materials
BEB	Battery Electric Bus
BMS	Battery Management System
BOD	Basis of Design
CCTV	Closed-Circuit Television
CDRL	Contract Data Requirements List
CEL	Certifiable Elements List
CFR	Code of Federal Regulations
CIL	Certifiable Items List
CNG	Compressed Natural Gas
CO	Change Order
CON	Construction
COOP	Continuity of Operations
CSCC	Construction Specification Conformance Checklist
CUTR	Center for Urban Transportation
CWE	Common Weakness Enumeration
dBA	A-Weighted Decibels
DC	Design Criteria
DCCC	Design Criteria Conformance Checklist
DDoS	Distribute Denial-of-Service (attack)
DOR	Designer of Record
DOT	Department of Transportation
EES	Energy Storage System
EMI	Electromagnetic Interference
EN	Engineering
ESRP	Employee Safety Reporting Programs
EV	Electric Vehicle
FD	Fire Department
FDS	Fire Dynamic Stimulator
FFGA	Full Funded Grant Agreement
FHA	Fire Hazard Analysis
FLS	Fire Life Safety
FMEA	Failure Modes and Effects Analysis
FMVSS	Federal Motor Vehicle Safety Standards
FPE	Fire Protection Engineer
FST	Fire Safety Test
FSX	Full Scale Exercise
FTA	Federal Transit Administration

GVW	Gross Vehicle Weight
HA	Hazard Analysis
HEV	Hybrid Electric Vehicle
HSEEP	Homeland Security Exercise and Evaluation Program
HTL	Hazard Tracking Log
HV	Hybrid Vehicle
HV	High Voltage
HVDC	High Voltage Disconnect
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
INT-TEST	Integrated Testing
IT	Information Technology
ITM	Inspection, Testing, and Maintenance
lbs	Pounds
Li-Ion	Lithium-Ion
LOTO	Lockout Tagout
LVDC	Low Voltage Disconnect
MAP	Moving Ahead for Progress [in the 21st Century]
MIL-STD	Military Standard
NEC	National Electric Code
NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration
NiMH	Nickel Metal Hydride (battery)
NIOSH	National Institute for Occupational Safety and Health
NREL	National Renewable Energy Laboratory
NTSB	National Transportation Safety Board
OCCP	Open Charge Point Protocol
OEM	Office of Emergency Management
OHA	Operational Hazards Analysis
OPS	Operations
ORC	Operational Readiness Conformance
OSHA	Occupational Safety and Health Administration
OWASP	The Open Web Application Security Project
PBA	Performance-Based Assessments
PCA	Prescriptive Code Analysis
PE	Preliminary Engineering
PFE	Portable Fire Extinguisher
PHA	Preliminary Hazard Analysis
PHL	Preliminary Hazard List
PLN	Planning
PMI	Preventive Maintenance Inspection
PMP	Project Management Plan
PPE	Personal Protective Equipment
PRE	Pre-revenue

PSI	Pounds per Square Inch
PTASP	Public Transportation Agency Safety Plan
QA	Quality Assurance
QC	Quality Control
RFI	Radio-Frequency Interface
SA	Safety Assurance
SAE	Society of Automotive Engineers
SANS	SysAdmin, Audit, Network, and Security (Institute)
SCADA	Supervisory Control and Data Acquisition
SCBA	Self-Contained Breath Apparatus
SDO	Standards Development Organizations
SDP	Standards Development Program
SFPE	Society of Fire Protection Engineers
SME	Subject Matter Expert
SMP	Safety Management Policy
SMS	Safety Management System
SOC	State of Charge
SOP	Standard Operating Procedure
SRI	Safety Risk Index
SRM	Safety Risk Management
SSA	Software System Analysis
SSC	Safety and Security Certification
SSCP	Safety and Security Certification Plan
SSCVR	Safety and Security Certification Verification Report
SSMP	Safety and Security Management Plan
SSRC	Safety and Security Review Committee
TA	Transit Agency
TIC	Thermal Imaging Camera
TSA	Transportation Security Administration
TSCC	Testing Specification Conformance Checklist
TTX	Tabletop Exercise
TVA	Threat and Vulnerability Assessment
UL	Underwriters Laboratory
US	United States
USC	United States Code
USDOT	U.S. Department of Transportation
USF	University of South Florida
V	Volt

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