DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Reference herein to any social initiative (including but not limited to Diversity, Equity, and Inclusion (DEI); Community Benefits Plans (CBP); Justice 40; etc.) is made by the Author independent of any current requirement by the United States Government and does not constitute or imply endorsement, recommendation, or support by the United States Government or any agency thereof.

SANDIA REPORT
SAND2025- 11072
Printed Click to enter a date

Sandia National Laboratories

A Review of Regulations, Codes, and Standards for Fuel Cell Electric Bus Use on Airports

Michael C. Devin, Marina Miletic, and Brian D. Ehrhart

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

Issued by Sandia National Laboratories, operated for the United States Department of Energy by National Technology & Engineering Solutions of Sandia, LLC.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@osti.gov
Online ordering: http://www.osti.gov/scitech

Available to the public from

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.gov
Online order: https://classic.ntis.gov/help/order-methods/


DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA
NNSA
National Nuclear Security Administration

ABSTRACT

Transit authorities are exploring integrating hydrogen fuel cell electric buses (FCEBs) into ground transportation fleets, including for potential use on commercial airports. This report reviews regulations, codes, and standards to be considered for FCEB operations on airports governing vehicle safety, hydrogen infrastructure, and airport operations. Documents were reviewed to consider the operation of FCEBs on public roadways, airport aprons, and for emergency power generation. Overall, the review found the existing regulatory framework largely suitable for FCEB operations on airports, with only minor gaps identified pertaining to heavy-duty vehicle fueling, operation and fire safety on airport aprons, and authorization for emergency power use. Airport authorities may need to reassess how codes and standards are implemented in their internal airport planning and training protocols to ensure the unique risks associated with hydrogen fuel cells are properly considered.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Hydrogen and Fuel Cell Technologies Office (HFTO) Safety Codes and Standards sub-program. This work was performed as part of a cooperative research and development agreement (CRADA) with the Pacific Northwest National Laboratory (PNNL) and the Port of Portland/Portland International Airport (PDX). The authors thank Bryan Wofford and Chris LaFleur from Sandia National Laboratories and Arun Veeramany from the Pacific Northwest National Laboratory for their technical reviews of this work.

CONTENTS

Abstract....3

Acknowledgements....4

Acronyms and Terms....8

1. Introduction....9

2. Applicable Regulations, Codes, and Standards....10

3. Application and Gap Analysis of Relevant Documents....12

   3.1. SAE J2601-2 - Fueling Protocols for Gaseous Hydrogen Surface Vehicles - Part 2: Heavy Duty Vehicles....12

   3.2. SAE J2578 - General Fuel Cell Vehicle Safety....12

   3.3. SAE J2579 - Hydrogen Fueling System Component Standards....13

   3.4. SAE AIR8466 - Hydrogen Fueling Standardization Guidelines for Aircraft....13

   3.5. NFPA 2 - Hydrogen Technologies Code....13

   3.6. NFPA 407 - Standard for Aircraft Fuel Servicing....14

   3.7. NFPA 415 - Standard on Airport Terminal Buildings....14

   3.8. ISO 19880-1 - Gaseous hydrogen — Fueling stations — Part 1: General requirements....15

   3.9. 14 CFR Part 139 - Certification of Airports....15

   3.10. AC 150/5230-4C - Aircraft Fuel Storage, Handling, and Dispensing on Airports....16

   3.11. AC 150/5210-20A - Ground Vehicle Operations to Include Taxiing or Towing an Aircraft on Airports....16

   3.12. AC 150/5360-13A - Airport Terminal Planning....16

   3.13. ACRP Report 146 - Commercial Ground Transportation at Airports: Best Practices....17

4. Summary and Conclusions....18

References....20

Distribution....22

LIST OF TABLES

Table 1. The identified regulations, codes, and standards applicable to FCEB use on airports. 10
Table 2. Summary of findings from the regulations, codes, and standards reviewed for applicability to hydrogen fuel cell electric buses. 18

This page left blank

ACRONYMS AND TERMS

Acronym/Term	Definition
AC	Advisory Circular
ACRP	Airport Cooperative Research Program
AOA	aircraft operations area
CHSS	compressed hydrogen storage system
FAA	Federal Aviation Administration
FCEB	fuel cell electric bus
FMVSS	Federal Motor Vehicle Safety Standards
ISO	International Organization for Standardization
LFL	lower flammability limit
LH2	liquid hydrogen
MAQ	maximum allowable quantity
NFPA	National Fire Protection Association
PDX	Portland International Airport

1. INTRODUCTION

Hydrogen is a potential alternative to diesel fuel for bus and mass transit applications, and various municipal transit authorities are exploring the use of hydrogen fuel cell electric buses (FCEBs). Hydrogen fuel cell electric buses combine electric propulsion with the extended range and refueling capabilities of traditional combustion engine vehicles. These buses utilize hydrogen fuel to generate electricity through an electrochemical process, emitting only water vapor as a byproduct [1].

California has seen the greatest adoption of FCEBs in the United States driven by state level goals to convert all its public transit agencies to a fully electric fleet by 2040 [2]. AC Transit, the municipal transit authority for Alameda County, California, were early adopters of FCEBs and now have one of the largest fleets in the United States [3]. SamTrans, the San Mateo County Transit District, placed an order with New Flyer in October 2024 for 108 FCEBs, marking the largest order of its kind in North America [4]. At least 14 other California transit agencies had also placed orders for FCEBs as of October 2022 [5].

Transit agencies elsewhere in the United States are also moving to adopt FCEBs into their bus fleets. King County in Washington (the metro Seattle area) is planning on adding four FCEBs as a pilot project in early 2026 to complement its battery electric bus fleet and improve fleet reliability [6]. The National Renewable Energy Laboratory identified four additional transit agencies currently using FCEBs and seven more planning to do so [7].

Transit agencies implementing hydrogen vehicles also introduces novel settings for the technology that have not been thoroughly explored. In 2024, the Port of Portland completed feasibility studies on converting the shuttle bus fleet for Portland International Airport (PDX) to battery electric and/or fuel cell electric buses [8]. Using FCEBs on airports has not been comprehensively studied, and this use case may impact how existing regulations for transportation, buildings, and fire safety are revised and implemented to account for the unique risks of FCEBs, such as high-

pressure hydrogen releases [9]. As local building codes are regarded as the primary regulations which should be followed, localities (and likewise airports) call on national regulations, codes and standards documents for guidance. Local building codes, including those applied to airports, draw upon and reference national codes and standards, emphasizing their importance across the U.S. and facilitating consistency between municipalities. For these reasons, this report aims to review existing regulations, codes, and standards to inform the Port of Portland and other airport agencies on details pertinent to implementing FCEBs by identifying:

- What relevant regulations, codes, and standards apply to FCEB operation on public airports
- How these regulations, codes, and standards may be implemented in practice by airport authorities, and
- What gaps exist in these regulations, codes, and standards that could be updated to better reflect the use of FCEBs at airports

2. APPLICABLE REGULATIONS, CODES, AND STANDARDS

Based on discussions with the Port of Portland about the current and future potential use for their shuttle bus fleets, this review considers the following applications for FCEB operations on airports:

- Transportation of passengers between terminal buildings and parking areas on publicly accessible roadways
- Transportation of passengers between terminals on roadways closed to the public
- Emergency use of onboard fuel cells to supply backup power generation to airport buildings

Table 1 provides an overview of the regulations, codes, and standards considered in this report and their general purpose. Several of these documents do not directly pertain to transportation vehicles or fueling but have implications for FCEBs on airports if the buses are operating in airport aprons (the private roads owned by the airport connecting the passenger terminals to the airstrip where aircraft are parked, boarded, and refueled[1]). Various authorities responsible for airport regulations have more stringent requirements for operations on airport aprons compared to publicly accessible roadways due to the presence of passenger aircraft and their associated risks. In the case of PDX, passengers arriving on international flights use a shuttle bus to travel directly to the U.S. Customs area, which includes driving on the airport apron [10]. Additionally, the prospects of using FCEBs as emergency backup power in the event of a disaster event explicitly introduces additional fire safety considerations and may require operations on airport aprons to reach certain power modules.

Table 1. The identified regulations, codes, and standards applicable to FCEB use on airports.

[1] The airport apron is sometimes referred to as the “flight line”, “ramp”, “fueling ramp”, or “tarmac”.

Document	Purpose	Citation
SAE J2601-2 – Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	Outlines the requirements for hydrogen dispensing systems used for 35 MPa heavy-duty vehicles, specifying fueling rates, pressure limits, and safety measures.	[11]
SAE J2578 – Recommended Practice for General Fuel Cell Vehicle Safety	Establishes general safety requirements for fuel cell systems, hydrogen fuel storage, and high-voltage electrical systems in fuel cell vehicles, encompassing electrical, mechanical, testing, and operational safety aspects	[12]
SAE J2579 – Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	Establishes requirements for hydrogen and hydrogen handling systems onboard vehicles, specifically addressing the delivery, containment, and storage of hydrogen fuel.	[13]
SAE AIR8466 – Hydrogen Fueling Stations for Airports, in Both Gaseous and Liquid Form	Provides standardization guidelines for hydrogen fueling of aircraft, including fueling rates, pressure limits, and safety measures.	[14]
SAE TIR J2601/5_202502	Technical Information Report (TIR) setting fueling protocols for hydrogen vehicles with capacities up to 7500 L.	[15]
NFPA 2 – Hydrogen Technologies Code	Specifies the production, storage, transfer, and use of gaseous and liquid hydrogen for ground fueling operations.	[16]

Document	Purpose	Citation
NFPA 407 – Standard for Aircraft Fuel Servicing	Specifies safety requirements for aircraft fueling with liquid fuels, providing procedures and equipment protocols for safe fuel handling at airports.	[17]
NFPA 415 – Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways	Specifies requirements for airport infrastructure to minimize fire risks from fuel spills near terminal buildings.	[18]
ISO 19880-1 – Gaseous hydrogen – Fuelling stations, Part 1: General requirements	Specifies general requirements for gaseous hydrogen fueling stations, including specifications for medium and heavy-duty hydrogen vehicles	[19]
14 CFR Part 139 – Certification of Airports	Outlines the requirements for the Federal Aviation Administration (FAA) to certify airports to serve passenger aircraft public operations	[20]
AC 150/5230-4C – Aircraft Fuel Storage, Handling, and Dispensing on Airports	Provides guidance for the handling, dispensing, and storage of aviation fuel on airports and associated training protocols	[21]
AC 150/5210-20A – Ground Vehicle Operations to include Taxiing or Towing an Aircraft on Airports	Provides guidance on developing training programs for personnel operating vehicles on airports	[22]
AC 150/5360-13A – Airport Terminal Planning	Provides guidance on airport terminal planning, including requirements for airport ground vehicles and transit	[23]

Document	Purpose	Citation
ACRP Report 146 – Commercial Ground Transportation at Airports: Best Practices	Discusses best practices for designing airport infrastructure to accommodate transit to, from, and around airports and provide convenient passenger access to the terminal.	[24]

3. APPLICATION AND GAP ANALYSIS OF RELEVANT DOCUMENTS

This chapter reviews each identified document that relate to FCEB airport use, summarizes the purpose of the document and how they relate, and the gaps that may exist in the documents that could limit their application.

3.1. SAE J2601-2 - Fueling Protocols for Gaseous Hydrogen Surface Vehicles - Part 2: Heavy Duty Vehicles

SAE J2601-2, last published in 2023, outlines the requirements for hydrogen dispensing systems used for 35 MPa heavy-duty hydrogen transit buses and vehicles. SAE J2601-2 was written to fill gaps in guidance for heavy duty vehicles in SAE J2601 [25] and thus largely applies to FCEBs operating on airports. Specifically, the standard expands upon Compressed Hydrogen Storage System (CHSS) Category D (designated for hydrogen tanks greater than 10 kg or 248.6 L) by providing fueling rates, pressures, and operating conditions for these larger tank sizes, aligning with existing guidance provided in SAE J2601 for smaller, light-duty hydrogen vehicle tanks.

While the standard applies to FCEB use on airports, the lack of specificity of Category D may not provide sufficient guidance for FCEB tank sizes. Category D only provides a lower bound of tank volume of 10 kg/248.6 L, which is far smaller than many FCEB tank sizes [26]. As SAE J2601 includes lookup tables for target pressures for Category D and requires dispensers to have a fuel target pressure algorithm (Section 6.2 of the standard), greater granularity for a range of larger tank sizes could provide more precise safety guidelines for a variety of FCEB tanks.

3.2. SAE J2578 - General Fuel Cell Vehicle Safety

SAE J2578, last updated in 2023, establishes general safety requirements for fuel cell systems, hydrogen fuel storage, and high-voltage electrical systems in fuel cell vehicles. SAE J2578 has several areas that could be clarified for FCEB applications. Appendix A of the document references FMVSS 303 for post-crash criteria, which applies to vehicles under 10,000 lbs. This creates ambiguity as to whether the same

requirements should apply to heavier commercial buses, requiring clarification to ensure appropriate safety measures are in place for these larger vehicles. Additionally, the guidance for conducting discharge evaluations in enclosed spaces (the safety testing protocol for discharging the fuel cell battery to ensure the discharge process remains in safe operating parameters, detailed in Section 4.2.4 and Appendix C of the standard) uses dimensions for a light duty vehicle (4.5m x 2.6m x 2.6m). While the standard allows the enclosure to be adjusted for larger vehicles (no more than 1m longer/wider and 0.5m taller than the vehicle), more comprehensive detail for larger vehicles could be valuable if they are used at a larger scale. Additionally, the discharge rate limits (<26.7 L/minute after the initial 10 minutes for shutdown) are based on the assumption that smaller vehicles can afford brief exceedance of the 25% Lower Flammability Limit (LFL) hydrogen threshold (1 vol% hydrogen) so long as the 3-second rolling average does not exceed 25% LFL. The selection of a 3-second rolling average is based on the time until the environment in the enclosure exceeds 25% based on the discharge rate of a "standard size vehicle". It is unclear if this assumption remains valid for vehicles with large tanks such as FCEBs, which may have higher power ratings and discharge rates than a "standard size vehicle". This could be reevaluated to determine if more stringent safety measures are needed for discharge testing for FCEBs. to mitigate the risk of hydrogen accumulation in enclosed spaces.

3.3. SAE J2579 - Hydrogen Fueling System Component Standards

SAE J2579, last published in 2023, focuses on hydrogen and hydrogen handling systems onboard vehicles, specifically addressing hydrogen fuel storage and handling. The 2023 revision of the standard explicitly addresses gaps related to heavy duty vehicles that were present in the original 2018 publication by updating the storage system mounting, installation requirements, and localized fire test methods suitable for larger vehicles. With these revisions, the standard would seem applicable to FCEBs operating on airports without the need for further changes.

3.4. SAE AIR8466 - Hydrogen Fueling Standardization Guidelines for Aircraft

SAE AIR8466, last published in 2024, provides standardization guidelines for hydrogen fueling of aircraft. While not directly applicable to FCEBs, the standard applies to small aircraft, and therefore may offer insight into potential guidance for heavy duty ground vehicle airport operations and FCEB fueling infrastructure in a setting with wider hydrogen fuel usage. For example, the standard specifically mentions that gaseous hydrogen fueling flow rates should not exceed 120 g/s, “similar to hydrogen bus fueling for 35 MPa”, suggesting synergy for fueling infrastructure across different airport vehicles. The standard also provides information on liquid hydrogen (LH2) fueling connector types for aircraft (Section 8.2.3.1), including A-sLH2 and B-LH2 connector types, stating their appropriateness for heavy duty trucks, which likely extends to FCEBs. As hydrogen usage at airports increases in the future, this standard is helpful when building hydrogen fueling infrastructure for several co-located vehicle types including buses, trucks, and aircraft.

3.5. SAE TIR J2601/5_202502 - High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles

SAE TIR J2601/5_202502 is a technical information report last published in 2025 and is therefore not yet an SAE standard. It aims to establish high flow fueling protocols for medium- and heavy-duty vehicles including process limits for fueling compressed hydrogen at flowrates between 60 and 300 g/s for vehicles with storage system capacities between 248.6 and 7500 L. This standard includes lookup tables as well as formula-based fueling protocol methods for H35 (35 MPa) and H70 (70 MPa) pressure classes as well as several flow rate classes. If adopted as a standard after adequate field testing, it can provide design requirements for vehicle manufacturers and insight on fueling times for FCEBs based on vehicle flow rate class. Such information would be useful for scheduling refueling sequences during normal operations and during critical emergency service operation. Depending on

how the final published standard is written, these fueling protocol requirements may change. As written currently, they should be appropriate for FCEB use on airports.

3.6. NFPA 2 - Hydrogen Technologies Code

NFPA 2, last updated in 2023, presents fire safety guidance pertaining to the storage, transfer, and use of gaseous and liquid hydrogen. It is applicable for all vehicular infrastructure applications, and therefore applies to fueling for FCEBs. While much of the code applies without issue to FCEB use on airports, there are a few sections that could be clarified or updated:

- In Chapter 6, NFPA 2 restricts gaseous hydrogen use by building occupancy, only allowing use in industry and storage occupancies or laboratory work areas of business occupancies. Airport terminals are classified under Assembly Group A-3, which is not included in the allowed areas. Aircraft hangars and motor vehicle repair garages are classified under Storage Group S-1, which do qualify. This should not present issue for airport hydrogen fueling stations so long as the hydrogen storage location is sufficiently separated from the airport terminals by the proper setbacks detailed in NFPA 2 Chapter 7. Additionally, these classifications and their restrictions are important to consider for airport fueling station layout, siting, and operations.
- Buses may be in enclosed or semi-enclosed areas for refueling and maintenance, in which case Maximum Allowable Quantities (MAQ) and ventilation rates for maintenance facilities requirements from Chapter 6 must be followed. This may necessitate retrofitting of site facilities to accommodate these requirements.
- The setback distances for bulk outdoor storage of gaseous hydrogen included in the tables of Section 7.3.2.3 may need to be revised for the large amount of hydrogen storage necessary for a large fleet of buses, as these setback distances were derived for hydrogen storage amounts more appropriate for lighter duty vehicles. Likewise, these setback distances could be revised to account for exposures to airport-specific hazards such as aircraft.

- The maximum fueling flowrates in Section 10.5.1.5 are not specified for medium and heavy-duty hydrogen motor vehicles. The basis and assumptions behind any quantitative guidance could be re-examined for applicability to FCEB refueling.
- The maximum allowable quantity of fuel dispensed (4.2 kg of gaseous hydrogen) in Section 10.5.3.4 prohibits full refueling of FCEBs indoors. Additionally, the maximum refueling rate of 1 kg/min may result in long refueling times for the size of tanks used by hydrogen buses. These refueling limitations should be considered when deciding on layouts and siting for FCEB maintenance facilities, and when deciding on the number of dispensers needed when refueling multiple FCEBs on airports.
- The bonding and grounding requirements, electrical equipment setback distances, and emergency shutdown device locations in Chapter 10, among other requirements, are applicable to FCEBs on airports, though this may require retrofitting and installation of additional equipment. If FCEBs are adopted on airports, other regulations such as NFPA 407 and 14 CFR Part 139 should refer to NFPA 2 for these requirements.

Additionally, NFPA 2 presents guidance regarding the use of hydrogen fuel cell power systems, including fuel cell vehicles, for temporary power generation such as during an outage. Some aspects of NFPA 2 would need to be modified to allow for this application:

- When used for emergency power, FCEBs need to meet Level 2 system requirements from NFPA 110 (2-hour minimum operating time at rated load, 36-hour starting equipment maximum recharge time). Current FCEBs may not satisfy these requirements and therefore could not be used for emergency power generation [27].
- The provisions of Section 12.3.4 could be extended to FCEBs that can provide emergency backup power on airports by modifying the language so the use of fuel cell vehicles to power buildings is not limited to “small dwellings”.

3.7. NFPA 407 - Standard for Aircraft Fuel Servicing

NFPA 407, last published in 2022, only applies to fueling for aircraft requiring liquid fuel, and thus does not apply to current FCEB fueling (which uses gaseous hydrogen). However, if FCEBs adopt liquid fuel, the requirements in this standard would need to be evaluated and rewritten to encompass liquid hydrogen fuel. Nevertheless, the relevance to airport fueling offers insights into safety practices relevant to FCEBs in this setting, as aviation fueling facilities that likely already exist at airports must comply with the code, and this could inform restrictions for FCEBs operating alongside and nearby aircraft. For example, Section 4.2.11 and Chapter 5 designate setback distances from terminal buildings, hangars, service buildings, and enclosed passenger concourses other than a loading walkway. Hydrogen fueling equipment for FCEBs could ascribe to similar fueling distances in conjunction with other additional setback distance requirements from NFPA 2.

3.8. NFPA 415 - Standard on Airport Terminal Buildings

While largely not a relevant standard for transportation vehicles, NFPA 415, last published in 2022 includes requirements for drainage systems on airport aprons. Referred to as the “fueling ramp” in this standard, airport aprons are designated areas where aircraft are parked, unloaded, loaded, refueled, and maintained, and these areas are required to have drainage systems in place to mitigate liquid aircraft fuel spill accidents. Due to the gaseous fuel type and design of FCEBs, these drainage systems are less relevant, and this standard could be revised to reflect more appropriate fuel release mitigation safety systems for hydrogen releases. For example, this standard requires automated fire shutter systems which, when heat or smoke is detected, trigger the automatic closing of openings to a building. These system requirements would need to consider the risk of hydrogen fires, which may be less visible, propagate more quickly, and burn hotter than fires from traditional fuels.

The fire test guidelines for jet fuel fires for aircraft loading walkways in Chapter 6 may also require updates to address hydrogen fire risks in areas where FCEBs are in

the vicinity of walkways, potentially adapting guidance from SAE J2579. Specifically, the time-temperature curves (Section 6.4.2) and temperature limits on the walkway surfaces (Section 6.4.4) used for the fire tests may need to be adjusted to reflect the unique characteristics of hydrogen fires, such as the rapid upward diffusion of hydrogen in air, higher flame temperatures, and faster flame velocities. Additionally, the placement and design of fire suppression systems on loading walkways may need to be evaluated to ensure they are effective in mitigating hydrogen fires and protecting passengers and airport personnel.

3.9. ISO 19880-1 - Gaseous hydrogen — Fueling stations — Part 1: General requirements

International Organization for Standardization (ISO) 19880-1, last updated in 2020, is an international standard providing requirements for gaseous hydrogen fueling stations. Though some ISO standards tend to mirror SAE standards, ISO 19880-1 establishes safety and performance requirements for refueling stations themselves including station design, layout, commissioning, installation, operation, inspection and maintenance, whereas the SAE J2601 series of standards focus on vehicle fueling protocols. This standard provides useful guidance for station equipment and components as well, such as production systems, compression, buffer storage, dispensing, and fueling interface. If fueling stations are commissioned on airports, this standard may be useful to establish a safe baseline design and should be consulted alongside fueling protocols provided in standards such as SAE J2601-2. The newest revision of ISO 19880-1 includes specifications for medium- and heavy-duty hydrogen-powered vehicles, including process limits for temperature and pressure ranges, flow rate limits, and pause durations. There are no apparent gaps in the standard that prevent it from being applied to FCEBs operating on airports and can be referenced as written when developing hydrogen refueling processes.

3.10. 14 CFR Part 139 - Certification of Airports

14 CFR Part 139, last published in 2004, is the federal regulation administered by the Federal Aviation Administration (FAA) that documents the process for certifying

airports for public operation and commercial flights. The regulation is non-prescriptive but refers to FAA Advisory Circular (AC) documents for more prescriptive guidance on FAA requirements. These AC guidelines are covered in Sections 3.11 - 3.13 below.

Several sections in the regulation are pertinent to FCEBs operating on airports:

- § 139.203 requires that the airport certification manual includes elements regarding “procedures for protecting persons and property during the storing, dispensing, and handling of fuel and other hazardous substances and materials” and “procedures for controlling pedestrians and ground vehicles in movement areas and safety areas”
- § 139.321 outlines requirements for airport operators and fueling agents to establish safety procedures, training programs, and compliance measures to prevent accidents and ensure safe handling of hazardous substances, which includes gaseous hydrogen.
- § 139.329 requires airport certificate holders to separate private and public vehicle areas to avoid interference with aircraft operations, and require training for ground vehicle operators

These sections and their application to FCEBs are considered in the AC guidelines review in the following sections.

3.11. AC 150/5230-4C - Aircraft Fuel Storage, Handling, and Dispensing on Airports

AC 150/5230-4C provides specifications and guidance for the storage, handling, and dispensing of aviation fuel on airports and relates to § 139.321 of 14 CFR Part 139 discussed in Section 3.10 above. While this advisory circular focuses on aircraft fueling, it references NFPA 407 for detailed training requirements for personnel involved in aircraft fueling operations. While the AC itself does not provide specific guidance on hydrogen fueling or FCEB operations, the training requirements outlined in NFPA 407, and other requirements relevant to NFPA 407 included in

Section 3.7 of this report, could serve as a valuable starting point for developing training programs for airport personnel involved in FCEB fueling and maintenance.

3.12. AC 150/5210-20A - Ground Vehicle Operations to Include Taxiing or Towing an Aircraft on Airports

AC 150/5210-20A focuses on ground vehicle operations within the aircraft operations area (AOA) and protocols to facilitate proper training and maintaining proper restriction of movement to minimize the risk of runway incursions. This Advisory Circular relates to § 139.329 and § 139.203 of 14 CFR Part 139 discussed in Section 3.10 above. The airport apron is a part of the AOA, so this guidance applies to FCEB operations in airports assuming the FCEBs may be operating on the apron. This guidance is sufficiently general to apply to FCEB airport use as written, though the specific implementation of this guidance should be reassessed by airports if they are adjusting their ground vehicle training programs for FCEBs to ensure they still apply. For example, the introduction of hydrogen fuel cell systems could impact the ground vehicle inspection programs (Section 3.3.1) or emergency response plan (Section 4.2.2) used at a given airport.

3.13. AC 150/5360-13A - Airport Terminal Planning

AC 150/5360-13A provides guidance on the planning process for airport passenger terminals, covering various aspects of terminal design, passenger flow, and ground transportation. Chapter 8 of the document includes guidance for planning ground transportation, particularly regarding design for airport roadways and parking areas. The information in this chapter applies to FCEBs, particularly the discussion on terminal lane designation and curbside requirements, though this guidance applies identically to all buses regardless of fuel type. Section 8.7 of the document specifically discusses considerations for public transportation on airports, though it only explicitly discusses transportation modes that require significant infrastructure such as rail and automated people movers.

Chapter 9 of the document discusses guidance for sustainability considerations in terminal planning, with particular emphasis on minimizing the amount of travel required between airport locations. The provisions in this chapter are written assuming internal combustion engine vehicles and the impact of vehicle emissions. Emissions are not a sustainability concern for fuel cell electric vehicles, but using hydrogen fuel as efficiently as possible is still relevant. Therefore, language in Chapter 9 could be modified to include use of FCEBs and not just carbon-emitting vehicles.

3.14. ACRP Report 146 - Commercial Ground Transportation at Airports: Best Practices

ACRP Report 146, published in 2015 by the Airport Cooperative Research Program (ACRP), examines best practices in commercial ground transportation at airports, including transportation planning, selection of transportation options for different uses, and operational strategies. Regarding bus use, the report includes guidance on the design for bus loading/unloading zones and how to facilitate convenient access for bus passengers to the terminal. Since this applies all bus types on airports, including FCEBs, no changes should be needed.

4. SUMMARY AND CONCLUSIONS

This report reviews relevant regulations, codes, and standards pertaining to the use of hydrogen fuel cell electric buses (FCEBs) on airports. Overall, the existing regulatory framework seems largely applicable as written to apply to FCEBs operating on airports, with minor gaps and potential revisions summarized in Table 2 below. Airport authorities should consider that these regulations, codes, and standards are often written broadly to be applicable for many technologies and may not prescribe explicit guidance. Due to this, airport authorities should consider reviewing their implementation of the guidance given in these documents to ensure their internal protocols and training properly account for the unique hazards and risks of hydrogen that would be introduced by adding FCEBs into their ground vehicle fleet.

Table 2. Summary of findings from the regulations, codes, and standards reviewed for applicability to hydrogen fuel cell electric buses.

Document	Summary
SAE J2601-2 – Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	Gaps may exist in the granularity or specificity for larger bus tank sizes and the lack of a defined target pressure algorithm for dispensers.
SAE J2578 – Recommended Practice for General Fuel Cell Vehicle Safety	Post-crash criteria could be clarified for heavier vehicles. More details could be provided regarding discharge testing space dimensions and parameters for buses.
SAE J2579 – Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	Applicable as written.

Document	Summary
SAE AIR 8466 – Hydrogen Fueling Stations for Airports, in Both Gaseous and Liquid Form	Provides potential synergies for airport heavy-duty ground vehicle fueling infrastructure, including shared flow rates and potential for universal connector types with small hydrogen-fueled aircraft in the future.
SAE TIR J2601/5_202502 - High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles	Since it is a technical information report, the fueling protocols outlined are not yet applicable. After field testing and subsequent publication, the protocols should be applicable for FCEB use on airports and can provide insight into fueling times based on vehicle flow rate class.
NFPA 2 – Hydrogen Technologies Code	Building occupancy restrictions at airports should be evaluated to ensure compliance with allowable occupancy types. Setback distances could potentially be adjusted to account for larger tank sizes and aircraft exposure. Language could be added on emergency power use requirements and repair separation for FCEBs.
NFPA 407 – Standard for Aircraft Fuel Servicing	Not directly applicable, but provides relevant insights into airport fueling safety practices and setback distances that could inform hydrogen fueling layout and siting.

Document	Summary
NFPA 415 – Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways	May apply to FCEB operation on airport aprons in the event of a fuel leak. Fuel leak mitigation protocols may need to be revised for upward releases of hydrogen leaks and hydrogen flames, which burn hotter and travel faster compared to other fuels. Could be updated to consider hydrogen fire risks near terminals, fire test guidelines, and drain design.
ISO 19880-1 – Gaseous hydrogen – Fuelling stations, Part 1: General requirements	Applicable as written.
14 CFR Part 139 – Certification of Airports	Applicable as written. Broadly refers to Advisory Circulars for perspective guidance, which could be adjusted for FCEB use as given below.
AC 150/5230-4C – Aircraft Fuel Storage, Handling, and Dispensing on Airports	Focuses on aircraft fuel but points to NFPA 407 for refueling training details. Could be considered as a basis for developing FCEB fueling training programs for airport personnel.
AC 150/5210-20A – Ground Vehicle Operations in include Taxiing or Towing an Aircraft on Airports	Applies as written to FCEBs operating on the airport apron, though airports should review their specific implementation of these procedures when incorporating FCEBs.

Document	Summary
AC 150/5360-13A – Airport Terminal Planning	Guidance on ground transportation access (Chapter 8) is applicable as written. Sustainability planning guidance (Chapter 9) could be modified to remove the assumption of internal combustion vehicles and add language on electric vehicles as a potential strategy.
ACRP Report 146 – Commercial Ground Transportation at Airports: Best Practices	Applicable as written.

REFERENCES

[1] J. Kurtz, S. Sprik, C. Ainscough, G. Saur and M. Jeffers, "Fuel Cell Electric Vehicle Evaluation," 2016. [Online]. Available: https://docs.nrel.gov/docs/fy16osti/66760.pdf.

[2] K. Caesar, "California Transitioning to All-Electric Public Bus Fleet by 2040," California Air Resources Board, 2018. [Online]. Available: https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040.

[3] E. Abu-Khaled, "AC Transit's Zero-Emissions Journey: The 5x5 Study and Beyond," Mass Transit Magazine, 2025. [Online]. Available: https://www.masstransitmag.com/bus/vehicles/hybrid-hydrogen-electric-vehicles/article/55264944/ac-transits-zero-emissions-journey-the-5x5-study-and-beyond.

[4] S. King, "New Flyer Awarded Largest Hydrogen Fuel Cell-Electric Contract in Company History, 108 Buses to California's Sam Trans," New Flyer of America, Inc., 2024. [Online]. Available: https://www.newflyer.com/2024/10/nfi-subsidiary-new-flyer-awarded-

largest-hydrogen-fuel-cell-electric-contract-in-company-history-108-buses-to-californias-samtrans/.

[5] California Air Resources Board, "Fuel Cell Electric Bus Deployment in California," 2022. [Online]. Available: https://ww2.arb.ca.gov/sites/default/files/2022-10/FCEB-Deployment-Map.pdf.

[6] S. Hawks, "Metro Explores Hydrogen Fuel Cell Buses to Reduce Emissions," Metro Matters (King County Metro), 2024. [Online]. Available: https://kingcountymetro.blog/2024/06/11/metro-explores-hydrogen-fuel-cell-buses-to-reduce-emissions/.

[7] M. Jeffers, "Fuel Cell Electric Bus Evaluations," National Renewable Energy Laboratory, 2025. [Online]. Available: https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.

[8] Center for Transportation and the Environment, "Port of Portland Airport Shuttle Bus Fleet Conversion," 2025. [Online]. Available: https://cte.tv/projects/port-of-portland-airport-shuttle-bus-fleet-conversion.

[9] D. R. Stephens, S. E. Rose, S. A. Flamberg, S. M. Ricci and P. E. George II, "Failure Modes and Effects Analysis for Hydrogen Fuel Cell Vehicles - Subtask 1, DOT HS 811 075," U.S. Department of Transportation, Washington, D.C., 2009.

[10] Port of Portland, "International Arrivals," Fly PDX, 2025. [Online]. Available: https://www.flypdx.com/InternationalArrivals.

[11] Society of Automotive Engineers International, "SAE J2601-2 - Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles," Society of Automotive Engineers, Warrendale, PA, 2023.

[12] Society of Automotive Engineers International, "SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety," Society of Automotive Engineers, Warrendale, PA, 2023.

[13] Society of Automotive Engineers International, "SAE J2579 - Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles.," Society of Automotive Engineers, Warrendale, PA, 2023.

[14] Society of Automotive Engineers International, "SAE AIR8466 - Hydrogen Fueling Stations for Airports, in Both Gaseous and Liquid Form," Society of Automotive Engineers, Warrendale, PA, 2024.

[15] Society of Automotive Engineers International, "SAE J2601/5_202502 High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles," Society of Automotive Engineers, Warrendale, PA, 2025.

[16] National Fire Protection Association, "NFPA 2 - Hydrogen Technologies Code," National Fire Protection Association, Quincy, MA, 2023.

[17] National Fire Protection Association, "NFPA 407 - Standard for Aircraft Fuel Servicing," National Fire Protection Association, Quincy, MA, 2022.

[18] National Fire Protection Association, "NFPA 415 - Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways.," National Fire Protection Association, Quincy, MA, 2022.

[19] International Organization for Standardization, "ISO 19880-1:2020 - Gaseous Hydrogen - Fuelling Stations Part 1: General Requirements," International Organization for Standardization, Geneva, CH, 2020.

[20] Code of Federal Regulations, "14 CFR Part 139 - Certification of Airports," Washington, DC, 2004.

[21] U.S. Federal Aviation Administration, "AC 150/5230-4C - Aircraft Fuel Storage, Handling, and Dispensing on Airports," U.S. Federal Aviation Administration, Washington, DC, 2021.

[22] U.S. Federal Aviation Administration, "AC 150/5210-20A - Ground Vehicle Operations to Include Taxiing or Towing an Aircraft on Airports," U.S. Federal Aviation Administration, Washington, DC, 2015.

[23] U.S. Federal Aviation Administration, "AC 150/5360-13A - Airport Terminal Planning," U.S. Federal Aviation Administration, Washington, DC, 2018.

[24] National Academies of Sciences, Engineering, and Medicine, "Commercial Ground Transportation at Airports: Best Practices, ACRP 146," The National Academies Press, Washington, DC, 2015.

[25] Society of Automotive Engineers International, "SAE J2601 - Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles," Society of Automotive Engineers, Warrenville, PA, 2020.

[26] New Flyer of America, Inc., "Xcelsior Hybrid-Electric," 2025. [Online]. Available: https://www.newflyer.com/site-content/uploads/2024/08/Xcelsior-Hybrid-Electric-Brochure.pdf.

[27] National Fire Protection Association, "NFPA 110 - Standard for Emergency and Standby Power Systems," National Fire Protection Association, Quincy, MA, 2025.

DISTRIBUTION

Email—Internal

Name	Org.	Sandia Email Address
Kristin Hertz	8367	klhertz@sandia.gov
Brian Ehrhart	8854	bdehrha@sandia.gov
Chris LaFleur	8854	aclafle@sandia.gov
Marina Miletic	8854	mmileti@sandia.gov
Michael Devin	8921	mcdevin@sandia.gov
Technical Library	1911	sanddocs@sandia.gov

Email—External

Name	Company Email Address	Company Name
Andrea Caudill	andrea.caudill@portofportland.com	Port of Portland
Laura Hill	laura.hill@ee.doe.gov	Department of Energy, Hydrogen and Fuel Cell Technologies Office
Neha Rustagi	neha.rustagi@ee.doe.gov	Department of Energy, Hydrogen and Fuel Cell Technologies Office
Arun Veeramany	arun.veeramany@pnnl.gov	Pacific Northwest National Laboratory

This page left blank



Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.